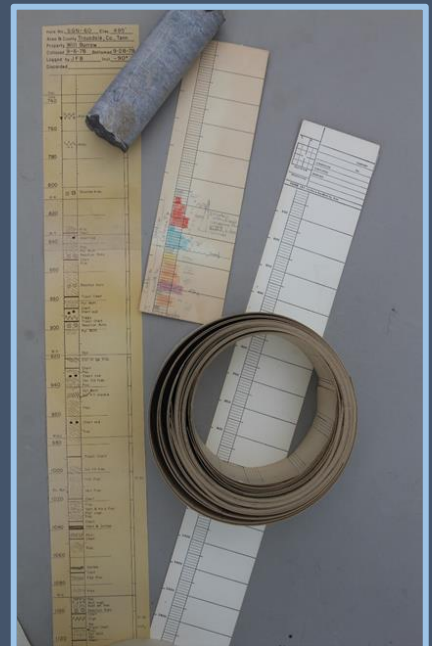


# NOTES FOR A CARBONATE CORE-LOGGING WORKSHOP

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University of Kentucky

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Geological Society of Kentucky  
and  
Kentucky Section, American  
Institute of Professional Geologists

September 21, 2018



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Popp, Richard Smath

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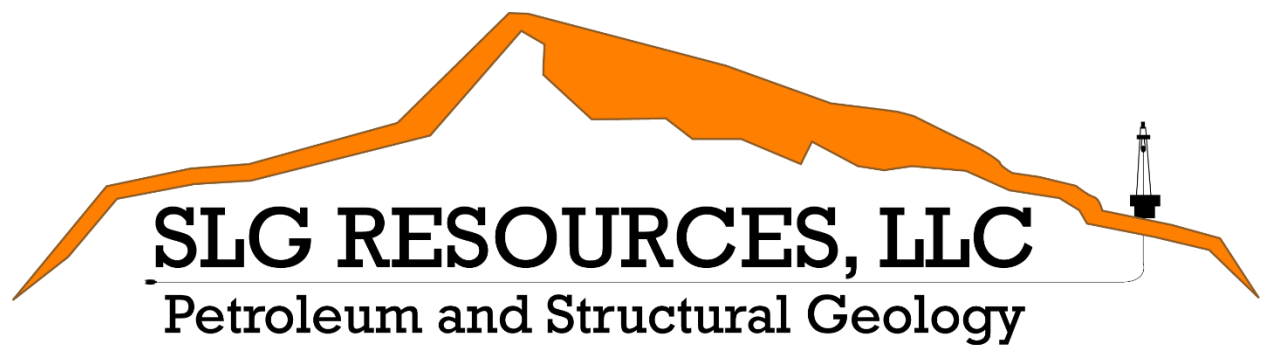
Lexington, KY

September 21, 2018

## **ACKNOWLEDGEMENTS**

We especially wish to thank our sponsors, ROGII, SLG Resources, and Resource Geosystems, who helped to make this program possible. Please see their advertisements on the next page. We are also indebted to the Kentucky Geological Survey for making the Core Library available for this workshop. Drew Andrews, Ryan Pinkston, and Ray Daniel from the Survey organized the meeting place and pulled the core that we will be examining. The University of Kentucky Department of Earth & Environmental Sciences and Morehead State University Department of Earth & Space Sciences provided the vehicles for our short field trip. Pete Idstein from the University of Kentucky and both Marshall Chapman and Charles Mason of Morehead State University arranged for the vehicles. Donald Lumm, Richard Smath, Charles Mason, and Faith Fiene provided logistical support. Clay Seckinger, Bailee Hodelka, and Erik Gudmunson, students in the Department of Earth & Environmental Sciences at the University of Kentucky, provided help with the vehicles and microscopes. Donald Lumm, Charles Mason, John Popp, and William Gilliam proofed the workshop notes, but the senior author assumes all responsibility for any remaining errors.

**We wish to thank the sponsors below for their contributions in making this workshop a success.**



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# Notes for a Carbonate Core-Logging Workshop

## The Importance of Core Logging Carbonate Rocks

Continuous rock coring is extremely important for identifying the nature, extent and thickness of rock units. Yet, because of incomplete or inconsistent core descriptions, potentially valuable information is lost or unavailable for other users. Carbonates account for approximately 55% of the exposed bedrock of Kentucky, are principal hydrocarbon targets, and are quarried in nearly 50 commercial pits in the Commonwealth. Kentucky is typically third among all states in the production of limestone, and limestone is Kentucky's most valuable non-fuel mineral (U.S.G.S, 2016). Yet, many geologists and engineers, who are tasked with describing these rocks, are unfamiliar with the bases and nomenclature of carbonate classification. Many workers unknowingly use microscopic classifications for megascopic carbonate descriptions, which are not appropriate and confusing. Others focus on dominant or unusual features, such as fossil abundance and content, weathering or dissolution (vugs), or impurities (chert). The result is that many logs cannot be easily used for unit recognition or detailed correlation because of incomplete, inconsistent or non-sequential descriptions.

The purpose of the workshop is to instruct the user how to identify and describe (log) megascopic carbonate cores in a sequential manner, with applications to hand samples, field exposures and thin-section petrography. It is our hope that this workshop will provide the needed information for better description or logging of carbonates and facilitate consistency in future logging. Many of the same principles can be used in logging other types of rocks, but that is a subject for another workshop.

Limestones vary significantly in color, texture and other characteristics, and because of the varied intentions of their users, it is important to collect all the necessary information on limestone composition, physical properties and geographic variability (King, 1985). The properties of limestones are largely controlled by two major factors: 1.) The environment in which the limestone-forming sediment was deposited, and 2.) the processes (diagenesis) that transformed the sediment into rock.

## Standard Descriptive Format

In describing carbonates, or any rocks for that matter, a definite method and sequence of descriptive criteria should be used for consistency. In any description, the most apparent or obvious descriptive criteria, ones that will truly help the logger identify the rock, should be placed at the beginning of the description. The other criteria should follow in a definite order so that they can be readily compared with other descriptions. The order and nature of these criteria, as provided here, is that used by the U.S. Geological Survey. Greater detail about this sequence and

the descriptive criteria can be found in Swanson (1981). You may decide to omit some of the descriptive criteria to simplify the log or to meet the specific needs or purpose of the data.

For brevity, log descriptions are usually **not** listed in complete sentences; rather, they are listed in a specific sequence of descriptive criteria, known as “telegraphese,” which uses single words or phrases separated by commas or semicolons. Begin your log description listing the principal type of rock (based on texture and composition in clastic and carbonate rocks; on composition alone in chemical rocks). The rock type should be followed by a comma, and in turn, listed in the order of importance, by the properties of color, texture, stratification, structures, cement and matrix, weathering and fossils. Some of these features may be included in the rock name or may not be necessary. On the other hand, if you need to add descriptive criteria that are not included in the list below, add them as appropriate. A comma follows the descriptive term where the term consists of a single adjective, such as “coarse-grained,” “friable,” and “crossbedded.” Semicolons commonly set off distinct sections of the description, especially if they contain phrases or clauses. The typical sequence of descriptive criteria is as follows:

- Lithology (rock type),**
- color,**
- texture,**
- stratification,**
- structures,**
- cement and matrix,**
- weathering,**
- fossils.**

The sample core description listed below is from the Brannon Member of the Lexington Limestone:

Lexington Limestone  
Brannon Member  
Limestone, medium light gray (N6), fine-grained (silt size), medium to thick bedded with prominent shale interbeds; flow rolls and brecciation; irregular chert nodules; brachiopod and bryozoan fossils throughout.....40 ft (12 m)

(Note: In this description, the cement is not mentioned, because, by definition, limestone will have a calcareous cement. Weathering is also not mentioned, because the description is of a core, in which weathering properties cannot typically be determined in the deeper subsurface.)

Figure 1 on the next page is an example from a U.S. Geological Survey publication (Ettensohn et al., 1984), which lists outcrop descriptions and thicknesses of several Mississippian carbonate units from eastern Kentucky.

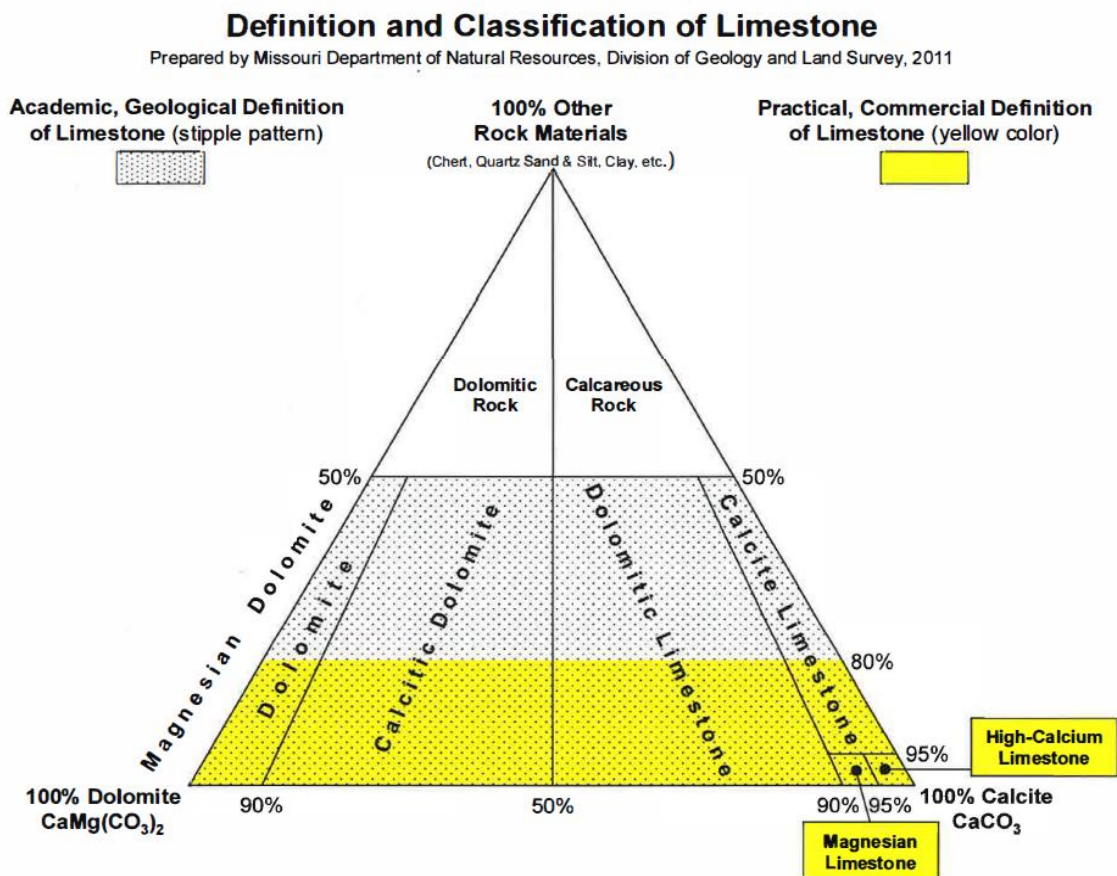
	<i>Thickness (equivalents) Meters (Feet)</i>		<i>Thickness (equivalents) Meters (Feet)</i>
Disconformity.			
Paragon Formation:			
Lower dark shale member:			
20. Shale, black to greenish-black, silty, micaceous; contains calcilutite lenses toward bottom of unit and chloritic sandstone lenses toward the top; marine fossils sparse -----	4.6	(15.1)	
Total measured thickness of Paragon Formation -----	5.9	(19.3)	
Slade Formation (Mississippian):			
Poppin Rock Member:			
19. Calcarenite, medium-dark-gray, coarse-grained, dense (very hard); very thick bedded; bioclastic -----	0.2	(0.7)	
18. Shale, brownish-black; contains abundant marine fossils -----	0.5	(1.6)	
17. Calcarenite, white to medium-dark-gray, coarse-grained, dense, thick-bedded, bioclastic -----	2.0	(6.6)	
Total thickness of Poppin Rock Member ---	2.7	(8.9)	
Maddox Branch Member:			
16. Shale, greenish-gray; contains thin lenses of calcilutite -----	1.5	(4.9)	
Ramey Creek Member:			
15. Calcarenite, white, medium-grained, thin-bedded and interbedded with greenish-gray shale; contains chert nodules -----	0.3	(1.0)	
14. Shale, greenish-gray, irregularly bedded, calcareous and highly fossiliferous; contains nodules and lenses of calcisiltite -----	2.0	(6.6)	
13. Calcarenite, white, coarse-grained, thick-bedded, locally crossbedded; crinoidal; locally contains chert nodules -----	0.6	(2.0)	
12. Calcilutite, medium-gray, fine-grained, thin-bedded and interbedded with shale; fossiliferous ---	1.8	(5.9)	
Total thickness of Ramey Creek Member ---	4.7	(15.4)	
Tygarts Creek Member type section:			
11. Calcarenite, white, coarse-grained, oolitic and skeletal; thin to thick bedded -----	1.8	(5.9)	
10. Calcarenite, white, coarse- to fine-grained, thin-bedded, interbedded with stringers of brown dolostone -	1.9	(6.2)	
Total thickness of Tygarts Creek Member ---	3.7	(12.1)	
Armstrong Hill Member:			
9. Dololutite, light-brown, fine-grained, thick-bedded -----	0.8	(2.6)	
8. Calcilutite, medium-gray, fine-grained, thin-bedded and interbedded with greenish-gray shale; fossiliferous -----	1.1	(3.6)	
Total thickness of Armstrong Hill Member -	1.9	(6.2)	
Cave Branch Bed:			
7. Shale, medium-gray, finely laminated calcareous mudstone with massive appearance -----	1.5	(4.9)	
6. Shale, greenish-gray, arenaceous, slightly calcareous; contains clasts of calcilutite from underlying Mill Knob Member; weathers rubbly ---	0.6	(2.0)	
Total thickness of Cave Branch Bed -----	2.1	(6.9)	
Disconformity.			
Mill Knob Member:			
5. Calcilutite, dark-brownish-gray, irregular thin beds; brecciated and platy with interstices filled with light-greenish-gray shale; bedding surfaces solution-pitted and brecciated; contains thin discontinuous exposure crusts, birdseyes, and rare fragments of ostracodes and gastropods -----	1.1	(3.6)	
4. Calcilutite, white to light-gray, in irregular thin to medium beds with light-greenish-gray shale partings; locally arenaceous; contains birdseyes and fragmented gastropods ---	3.3	(10.8)	
3. Shale, dark-greenish-gray, silty, sandy; contains reworked limestone clasts from unit 2 below ---	0.2	(0.7)	
2. Calcilutite and calcisiltite, interbedded; light-gray to dark-brownish-gray; in irregular thin beds; platy; brecciated with interstices filled with light-greenish-gray shale; contains thin, discontinuous exposure crusts throughout and birdseyes and "slickensides" -----	2.0	(6.6)	
Total thickness of Mill Knob Member -----	6.6	(21.7)	
Warix Run Member (incomplete):			
1. Calcarenite, white to brownish-gray, arenaceous, thin- to thick-bedded with high-angle festoon crossbeds and scours throughout; locally a thin greenish-gray bed of shale at top of unit; thin beds of white arenaceous calcilutite in upper 0.7 m (2.3 ft); prominent zone of exposure crusts 1.2 m (3.9 ft) below top of unit and thin discontinuous exposure crusts throughout upper 4.6 m (15.1 ft); contains conglomeratic lenses of chert and limestone fragments from St. Louis Limestone Member below (section measured to base of quarry) -----	10.1	(33.1)	
Total measured thickness of Slade Formation -	33.3	(109.3)	

Figure 1. Page from a U.S.G.S. publication, showing typical descriptions of stratigraphic sections for the Slade and Paragon formations in eastern Kentucky (Ettensohn et al., 1984).



## Naming Carbonates

There are various academic and industrial classification methods for carbonate rocks, but in order to be useful and expedient, a classification must be simple to use and convey the necessary information. In general, rocks are classified based on **composition** and **texture**. By definition, compositionally, carbonates contain greater than 50% calcite (limestones) or greater than 50% dolomite (dolostones), and most of the time these compositions will be obvious in the case of hand samples. If one needs detail about the chemical composition of carbonates, a classification like that shown in Figure 2 may be useful, but detail like this will probably require chemical analysis and is probably not very expedient.



**Figure 2.** Classification of limestones and dolostones based on the percentage of calcite and dolomite, showing the nature of academic and practical (commercial) definitions (from Missouri Department of Natural Resources, Division of Geology and Land Survey, 2011).

### *Megascopic Classification of Carbonates—*

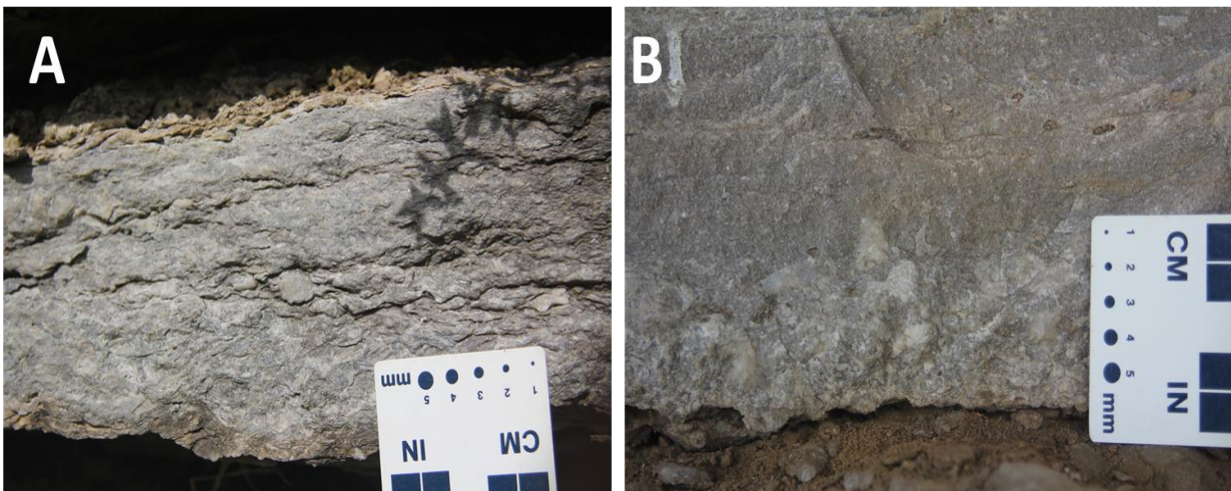
The earliest formal megascopic classification of limestones was introduced by A.W. Grabau in 1903 and 1904. His classification is based on the size of the carbonate grains composing the

limestone or dolostone. Grabau’s (1904) classification scheme uses a hybrid nomenclature, wherein the predominant carbonate mineral is used as the prefix, and the grain size is applied as a suffix. Specifically, one of the word roots for calcite (“calci-”) and dolomite (“dolo-”) composes the prefix, and the grain-size words for clay (“lutite”), silt (“siltite”), sand (“arenite”) and coarse rubble (“rudite”) comprise the suffix. A listing of these hybrid names is included in Table 1.

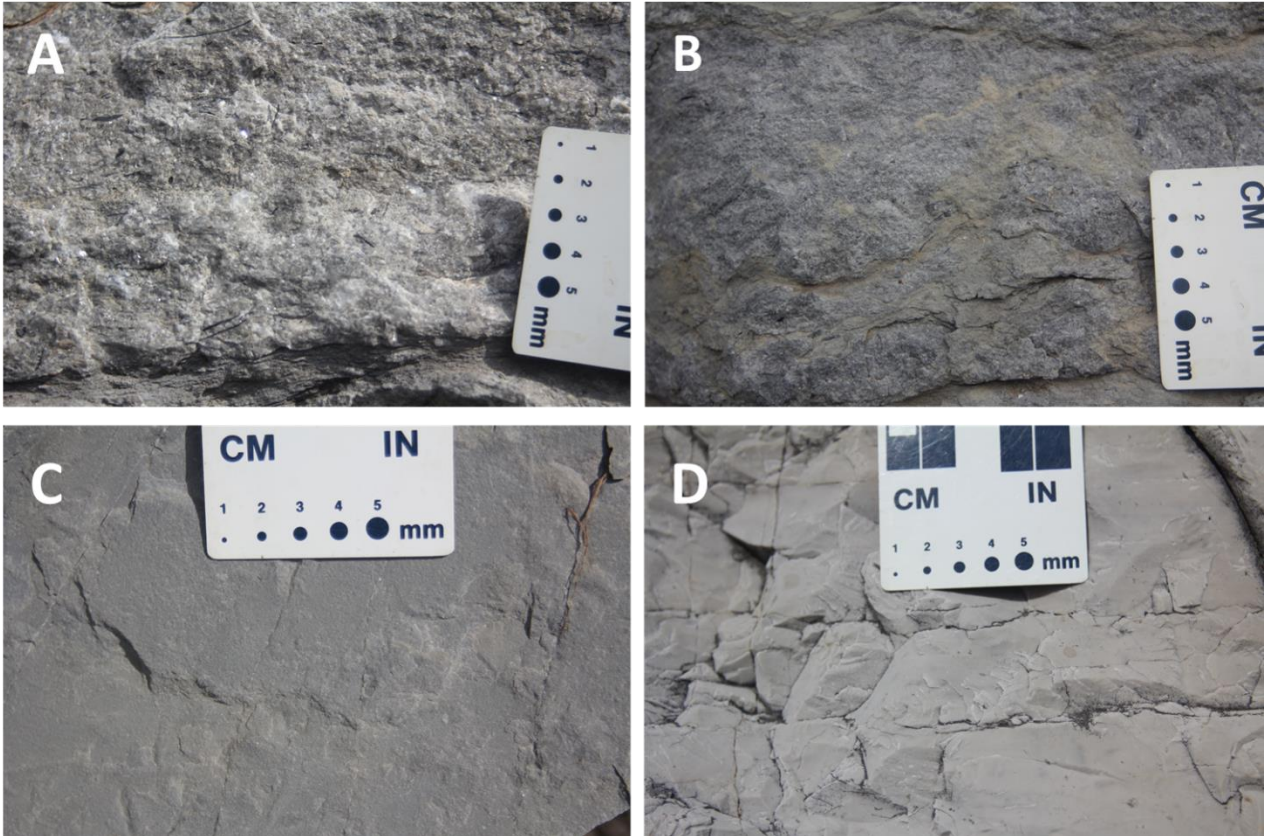
**Table 1:** List of standard grain-size designations with hybrid carbonate rock nomenclature (Grabau, 1903, 1904).

Grain size	Calcite predominates	Dolomite predominates
Clay or mud size (<1/16 mm)	calclutite	dololutite
Silt size (1/16–1/256 mm)	calcisiltite	dolosiltite
Sand size (1/16– 2 mm)	calcarenite	dolarenite
Coarser than sand (> 2 mm)	calcirudite	dolorudite

This simple classification conveys more useful information about the carbonates than the basic lithologies, limestone and dolostone and is the recommended classification for logging cores. If it is important to know the composition of the various grains, one can add adjectives to show the grain types involved, for example, fossiliferous calcarenite, bryozoan calcirudite, oolitic dolarenite or arenaceous calcarenite. Photographs of the four major types of limestone using the Grabau classification are shown below in Figures 3 and 4. Because this classification includes texture in the form of grain size, the textural part of a description may no longer be necessary (see descriptions in Figure 1).



**Figure 3.** Photographs of calcirudites from the Curdsville Member, Lexington Limestone. **A.)** Calcirudite of bryozoan, brachiopod and crinoid fragments; **B.)** Calcirudite of crinoid and bryozoan fragments at base grading upward into a calcarenite. Both examples represent poorly graded storm deposits.

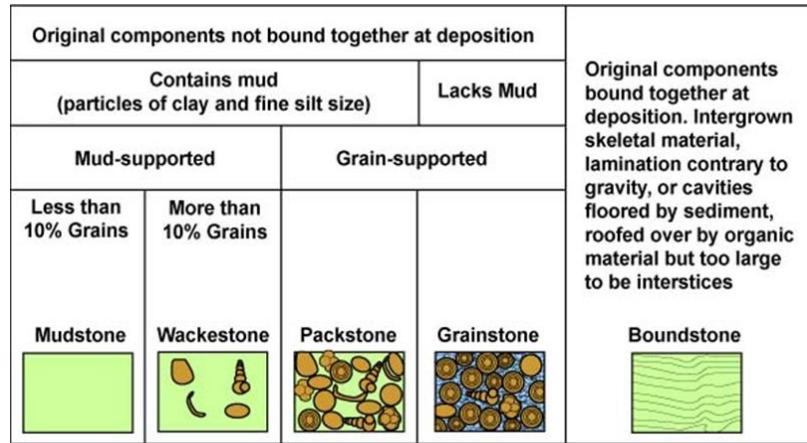


**Figure 4.** Various limestone textures. **A.)** Fossiliferous calcarenite; Tanglewood Member, Lexington Limestone; **B.)** Argillaceous (clayey) calcarenite; Grier Member, Lexington Limestone; **C.)** Calcisiltite; Clays Ferry Formation; **D.)** Calcilutite, Tyrone Formation.

*Microscopic Classifications of Carbonates—*

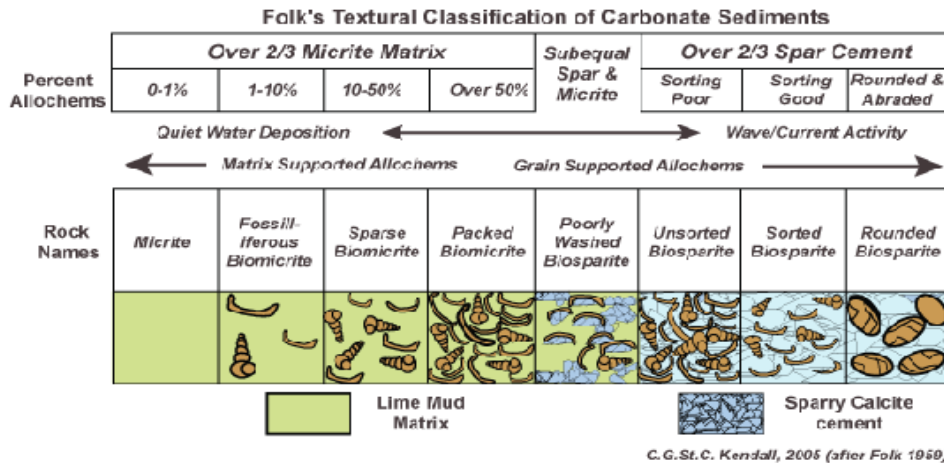
Two other commonly used carbonate classifications include the **Folk** (1959) and **Dunham** (1962) classifications. Both classifications were originally developed as microscopic classifications for use in the oil and gas industry, but have been widely adopted as megascopic classifications. Both classifications necessitate knowledge of the relationships between grains, matrices, and cements. **Grains** are the mechanically deposited particles that originate before sedimentation, and in carbonates, are either **detrital grains** from outside the basin, like quartz or feldspar grains, or **allochems**, carbonate grains that originate in the basin of deposition, like ooids or crinoid ossicles. **Matrix** is the very fine-grained, comminuted material that fills the interstices between grains, and the common carbonate matrix is **micrite** (microcrystalline calcite), also called carbonate mud or lime mud. **Cement** is the chemically precipitated mineral matter that can fill the spaces between grains and binds the grains together into a coherent mass; the most common carbonate cements are various forms of the minerals calcite and dolomite. In cores and hand specimens, it is often difficult to distinguish between matrix, cement, and fine-grained allochems. Hence, because use of the Dunham (1962) and Folk (1959) classifications requires knowledge of the relationships between the grains, matrices and cement in a sample, these relationships are best observed microscopically and require thin-section analysis. **Therefore, microscopic**

classifications should not be used in describing cores and hand samples where mainly megascopic relationships are observed. Instead, I recommend the use of a megascopic classification, like the Grabau (1903, 1904) classification, when describing cores. Figures 5 and 6 below provide brief synopses of the Dunham (1962) and Folk (1959) microscopic classifications. Thin-section photomicrographs used in the course are shown in Figures 7 and 8.



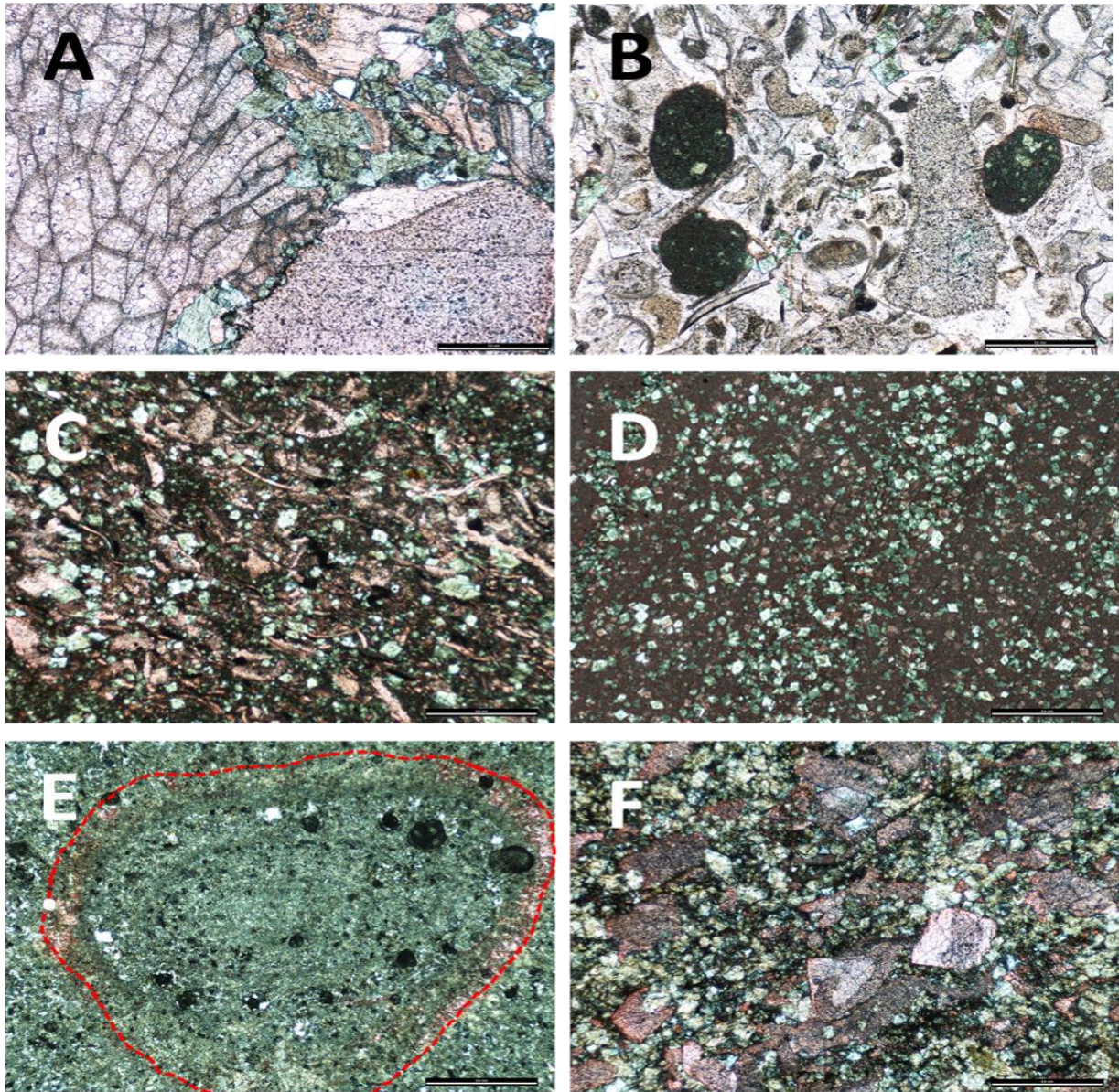
C. G. St. C. Kendall, 2005 (after Dunham, 1962, AAPG Memoir 1)

**Figure 5.** Summary of the Dunham (1962) microscopic carbonate classification.

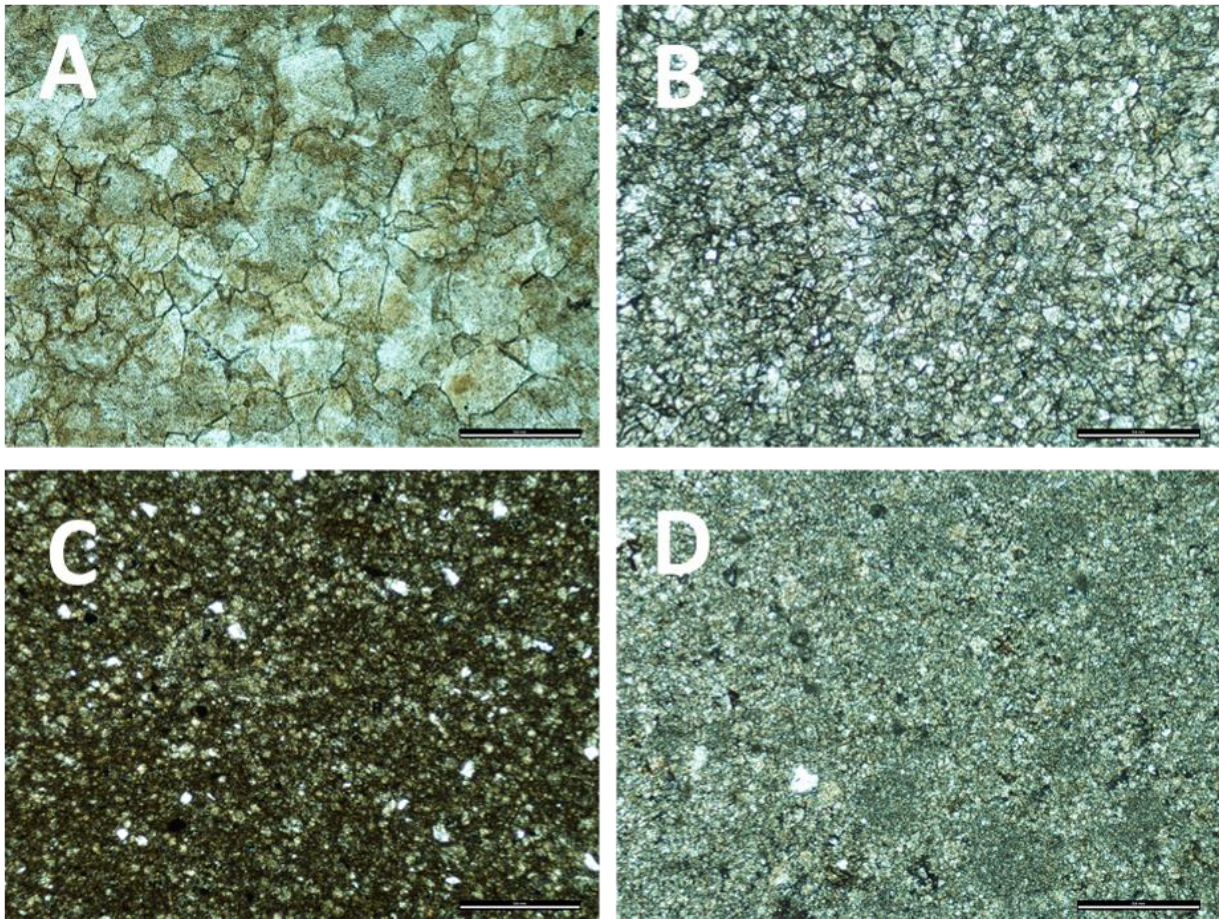


C. G. St. C. Kendall, 2005 (after Folk 1959)

**Figure 6.** Summary of the Folk (1959) microscopic carbonate classification. The Folk classification is more complex than the Dunham classification and incorporates the relative abundances of matrix, allochems and cement. Identification of allochem type (bioclasts, ooids, peloids, and intraclasts) is also critical. Both the Dunham (1962) and Folk (1959) classifications require thin-section analyses for interpretations of textures and components (Folk, 1959).



**Figure 7.** Thin sections of calcareous and dolomitic samples in plain light; all features stained pink are calcite; unstained features are dolomite; all bar scales are 0.5 mm. **A.)** Megascopic name: fossiliferous calcirudite; large bryozoan fragment to left; echinoderm fragment to lower right. Grier Mbr., Lexington Limestone. Dunham name: fossiliferous grainstone; Folk name: biosparite. **B.)** Megascopic name: fossiliferous calcarenite. Grier Mbr. Dunham name: fossiliferous grainstone; Folk name: biosparite. **C.)** Megascopic name: fossiliferous calcisiltite; unstained rhombic crystals are dolomite. Grier Mbr. Dunham name: fossiliferous packstone; Folk name: biomicrite. **D.)** Megascopic name: calcilitite; unstained rhombs are dolomite and the dark densely stained material is micrite. Dunham name: carbonate mudstone; Folk name: micrite. **E.)** Megascopic name: pisolitic dolorudite; the feature encircled with red dashes is a pisoid; Wasatch Formation. **F.)** Megascopic name: dolarenite; pink-stained areas are calcareous; Boyle Formation.

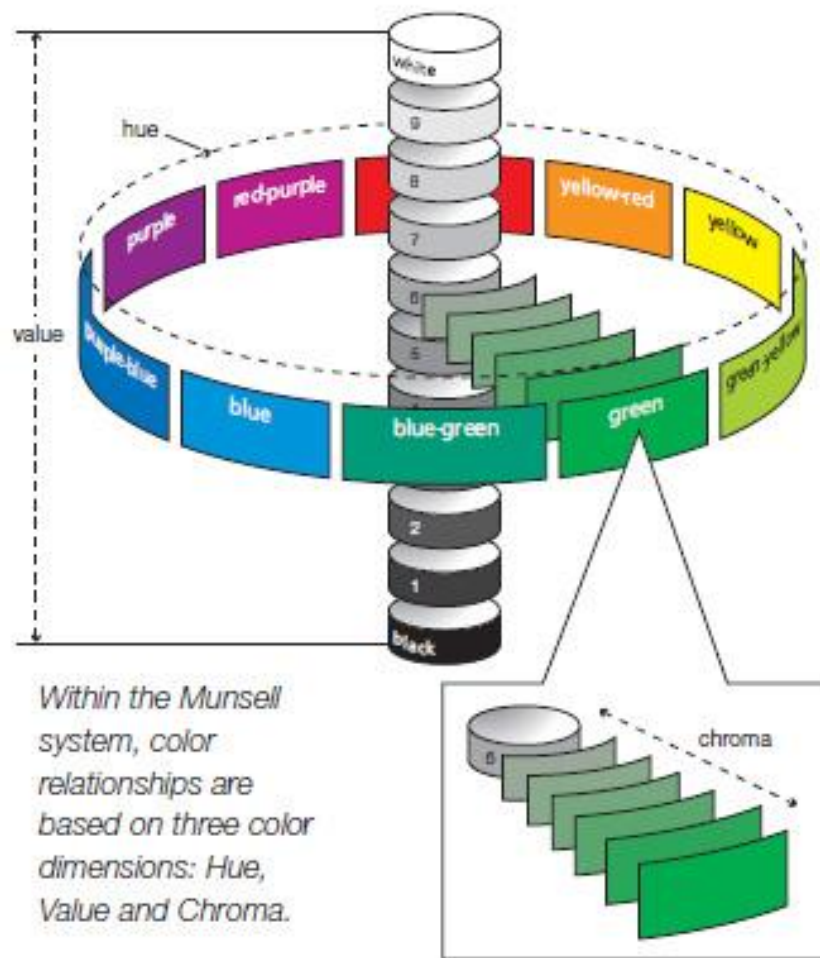


**Figure 8.** Thin sections of dolomitic samples in plain light; all sections were stained for calcite; white grains in the sections are detrital quartz; all bar scales are 0.5 mm. **A.)** Megascopic name: dolarenite; all the brown splotches are relict echinoderm grains, which have been overgrown by dolomite crystals. Dunham name: crystalline carbonate or dolomitized echinodermal grainstone; Folk name: coarsely crystalline biogenic dolomite. Livingstone Formation. **B.)** Megascopic name: dolarenite. Dunham name: crystalline carbonate; Folk name: finely crystalline dolomite. Boyle Formation. **C.)** Megascopic name: organic-rich dolosiltite; Dunham name: crystalline carbonate; Folk name: finely crystalline dolomite. Portwood Member, New Albany Shale. **D.)** Megascopic name: dololutite. Dunham name: crystalline carbonate; Folk name: finely crystalline intraclastic dolomite. Dyer Member, Chaffee Formation.

### Determining Color

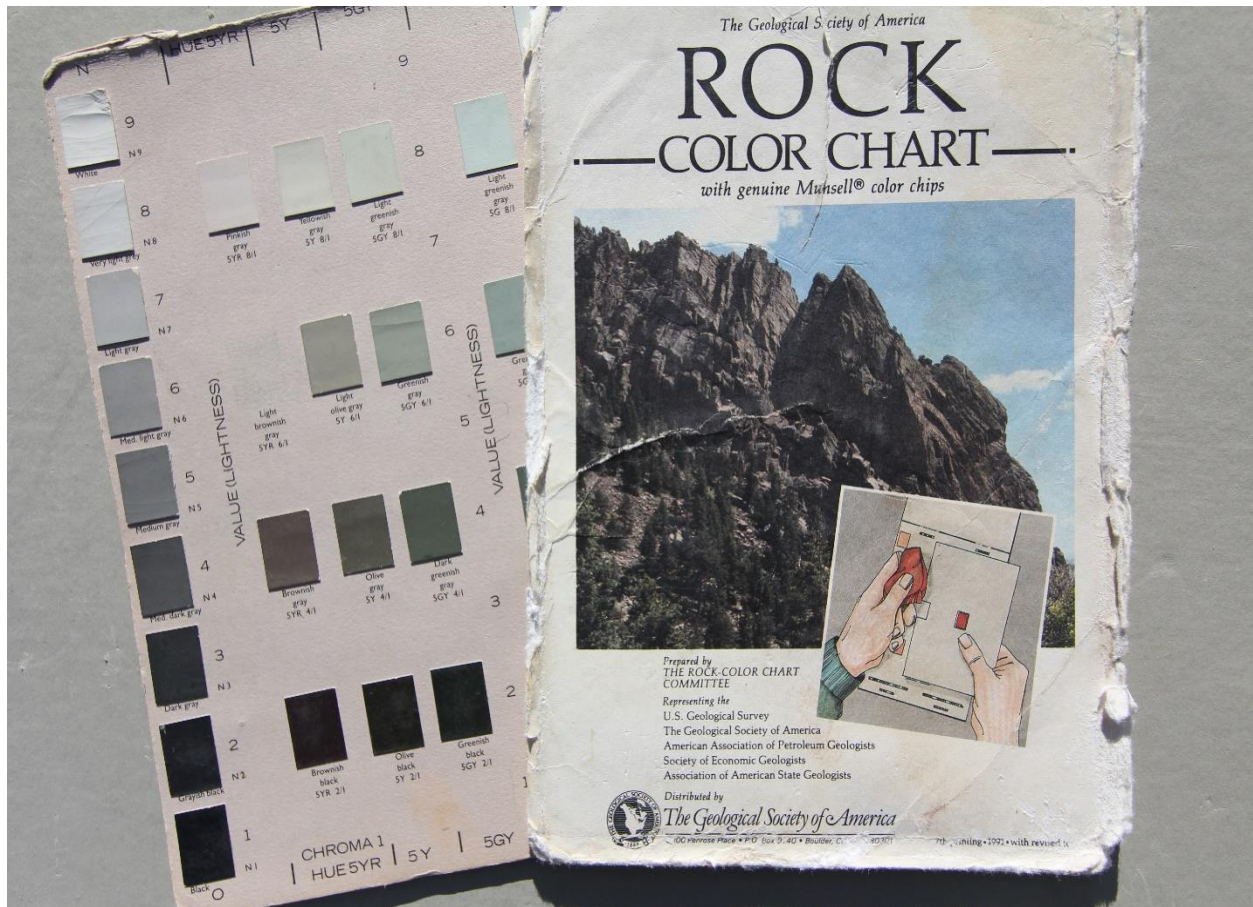
Color is one of the most obvious characteristics of a sedimentary rock and may convey information about composition, depositional setting, weathering, and oxidation state during deposition or after exposure. Color typically exemplifies some aspect of rock composition. A rock may exhibit a bulk color while also having components of different colors. The color may be derived from matrix, cement and various grains or impurities, including organic matter and clays. Therefore, carbonates may exhibit the entire spectrum of color from white to black, including

green and red hues. Hence, color is often an important characteristic in describing limestones, but a problem in describing colors arises because we all see colors differently, which can contribute to issues of consistency. To alleviate such problems where colors truly matter, rock-color charts and notations are used for uniform descriptions. Most U.S. rock-color charts use the Munsell system, which is developed from a color solid (Figure 9) that illustrates three aspects of color, **hue**, **value** and **chroma**. A typical rock color might be light-brown (5YR 5/6), wherein the “5YR” represents the hue, the “5” represents the value, and the “6” represents the chroma. Colors are shown as chips on a card with an associated color designation to which the rock color of the sample is compared (Figure 10). One can then select the closest color designation or interpolate between chips to get a more accurate designation. The user should note if the rock



**Figure 9.** Munsell color solid (a sphere) that delineates color based on **hue** around the circumference (a particular gradation of color), **value** on the vertical axis (lightness or darkness), and **chroma** on the various radii (color intensity or saturation) (<http://artquill.blogspot.com/2012/11/the-munsell-color-classification-system.html>).

is dry or wet, as wet rocks tend to be darker. The Geological Society of America (G.S.A.) produced an inexpensive field-expedient rock-color chart (The Rock-Color Chart Committee, 1991), which is now out-of-print. The only current option is a Munsell Rock Color Book (Munsell Color Company, 2009).



**Figure 10.** An undated G.S.A. rock-color chart, showing comparative color chips and Munsell color designations on one of the pages.

### Other Descriptive Criteria

Of the other descriptive criteria noted on page 6, texture and stratification are probably the most important and the most difficult to identify. Texture usually refers to grain size and sorting. In geology, grain size is measured relative to the Udden-Wentworth Size Scale, wherein the terms pebbles, sand, silt, clay (mud) refer to distinct grain-size ranges (Figure 11). For describing



carbonates with the Grabau (1903, 1904) classification, the grain size is included in the name (Table 1). If determining the textural parameters for a carbonate is difficult, many expedient field gauges and charts are available to help; examples are shown in Figure 12. Stratification usually refers to bed thickness, and bed thickness may be a critical factor in describing rock quality. The

Phi Units*	Size	Wentworth Size Class	Sediment/Rock Name
-8	256 mm	Boulders	Sediment: GRAVEL  Rock RUDITES: (conglomerates, breccias)
-6	64 mm	Cobbles	
-2	4 mm	Pebbles	
-1	2 mm	Granules	
0	1 mm	Very Coarse Sand	Sediment: SAND  Rocks: SANDSTONES (arenites, wackes)
1	1/2 mm	Coarse Sand	
2	1/4 mm	Medium Sand	
3	1/8 mm	Fine Sand	
4	1/16 mm	Very Fine Sand	
8	1/256 mm	Silt	Sediment: MUD
		Clay	Rocks: LUTITES (mudrocks)

\* Udden-Wentworth Scale

**Figure 11.** Udden-Wentworth Size Scale (Udden, 1914; Wentworth, 1922).

descriptive terms for bedding and crossbedding, as well as the thicknesses that they represent, are described in Table 2.



**Figure 12.** Illustrative guides or gauges for recognizing grain shape, grain size and sorting.

**Table 2:** Comparison of quantitative and qualitative terms used in describing layered rocks.

Terms to describe stratification		Terms to describe cross-stratification		Thickness	Terms to describe splitting properties
Very thick-bedded	Beds	Very thickly cross-bedded	Cross-beds	120 cm	Massive
Thick-bedded		Thickly cross-bedded		120 cm (~4 ft) to...	Blocky
Thin-bedded		Thinly cross-bedded		60 cm (~2 ft) to...	Slabby
Very thin-bedded		Very thinly cross-bedded		5 cm (~2 in) to...	Flaggy
Laminated	Laminae	Cross-laminated	Cross-laminae	1 cm (~1/2 in) to...	Shaly or platy
Thinly laminated		Thinly cross-laminated		0.2 cm (~0.08 in) or less	Papery

### Logging Manuals

A suggested means to expedite the logging process, especially if you are consistently logging the same lithology or rocks from the same formation, is to develop or use a published photographic

logging manual. A logging manual is a small hand-held flip book with high-quality color photographs of typical rocks encountered in cores (Figure 13). One such example is that of Ettensohn and Hendricks (2015), who identified carbonates, shales and various other sedimentary rocks from cores examining Devonian black shales throughout Kentucky. In this manual, each core photo has a scale and an alpha-numeric code to identify the rock type (Figure 13). Core samples are compared with the photos in the manual, and the alpha-numeric code of the corresponding picture is recorded across the vertical footage in the core that contains the lithology, in the place of writing a description. For a coding system to be successful, it must meet four criteria: 1.) it must be simple to use; 2.) The code must be consistent so that each position in the four-place sequence represents the same lithologic character, and each alpha-numeric descriptor means the same thing in that position; 3.) The code must be flexible enough to allow the addition of new alpha-numeric descriptors for lithologies and characters not initially coded; and 4.) the code must be capable of being computerized if needed. The coding system used in the logging manual below (Ettensohn and Hendricks, 2015) is a four-place sequence of numbers or letters, in which a digit or letter and its position in the sequence identify a specific rock type or rock property. The lithologies and corresponding pages may also be color-coded for quick access (Figure 13).

**Table 3:** Major parts of a four-part coding system for a core-logging manual. X's in the codes represent placeholders only (from Ettensohn and Hendricks, 2015).

<b>First place: Predominant lithology</b>	<b>Second place: Subordinate lithology, if present</b>
<b>1XXX</b> – Mudstone (brown) <b>2XXX</b> – Shale (black) <b>3XXX</b> – Siltstone (green) <b>4XXX</b> – Sandstone (yellow) <b>5XXX</b> – Fragmental Rocks (orange) <b>6XXX</b> – Limestone (blue) <b>7XXX</b> – Dolostone (red)	<b>Examples:</b> <b>13XX</b> – Mudstone and interbedded siltstone <b>23XX</b> – Shale with siltstone streaks <b>32XX</b> – Siltstone and interbedded shale <b>31XX</b> – Siltstone and interbedded mudstone <b>57XX</b> – Dolomitic breccia <b>61XX</b> – Limestone and interbedded mudstone
<b>Third Place: Predominant color</b>	<b>Fourth Place: Special Features</b>
<b>XX1X</b> – Black <b>XX2X</b> – Dark gray <b>XX3X</b> – Light gray <b>XX4X</b> – Green <b>XX5X</b> – Red & Green <b>XX6X</b> – Red <b>XX7X</b> – Reddish-brown <b>XX8X</b> – Light brown (tan) <b>XX9X</b> – White <b>XX0X</b> – Undetermined	<b>XXX1</b> – Fossils <b>XXX1.6</b> – Plant fragments <b>XXX1.7</b> – Crinoid fragments <b>XXX5</b> – Cross-bedding <b>XXX6</b> – Contains nodules or concretions <b>XXX6.1</b> – Chert nodules <b>XXX6.5</b> – Pyrite nodules <b>XXXD</b> – Deformation <b>XXXD.2</b> – Plastic (ball and pillow) <b>XXXB</b> – Pebble-size or larger angular clasts



**Figure 13.** Photograph of the core-logging manual of Ettensohn and Hendricks (2015). Two core samples composed largely of fragmental rocks (breccias) are featured. The page is color-coded **orange** for fragmental rocks (see Table 3, First place). The code for the core segment illustrated on the left is **578B.5**, or light-brown dolomitic rock-clast breccia. The code for the core segment illustrated on the right is **573B.5**, or light-gray dolomitic rock-clast breccia (see Table 3).

### Graphic Strip Logs

The standard method of collecting information from cores or sections in the field is to construct a graphic strip log of the section. Strip logs were originally compiled on commercially prepared light-cardboard strips, typically three-inches wide (Figure 14). Spaces at the top of the strip are available for recording the name and location of the well or section. The left side of the strip, or y-axis, represents depth or thickness from a reference point (usually ground surface). The logs are typically divided into incremental divisions of inches and tenths of inches that can be used to represent scales of tens to hundreds of feet (Figure 14). The vertical scale to use depends on the detail required, rock variability and time available. The right side of the strip log is then available for lithologies and written comments (Figure 14). There is no set format for constructing a log; the nature of the log will depend on the purpose of logging. Essential information will generally include thickness, lithology, texture (grain size), color and sedimentary structures. Each of these features will normally require its own column (Figure 15), although lithology and texture are

frequently combined (e.g., calcarenite). The horizontal scale, or x-axis, shown as the diagonal leader in the lithology/texture columns, indicates grain size (mudstone – siltstone – sandstone –

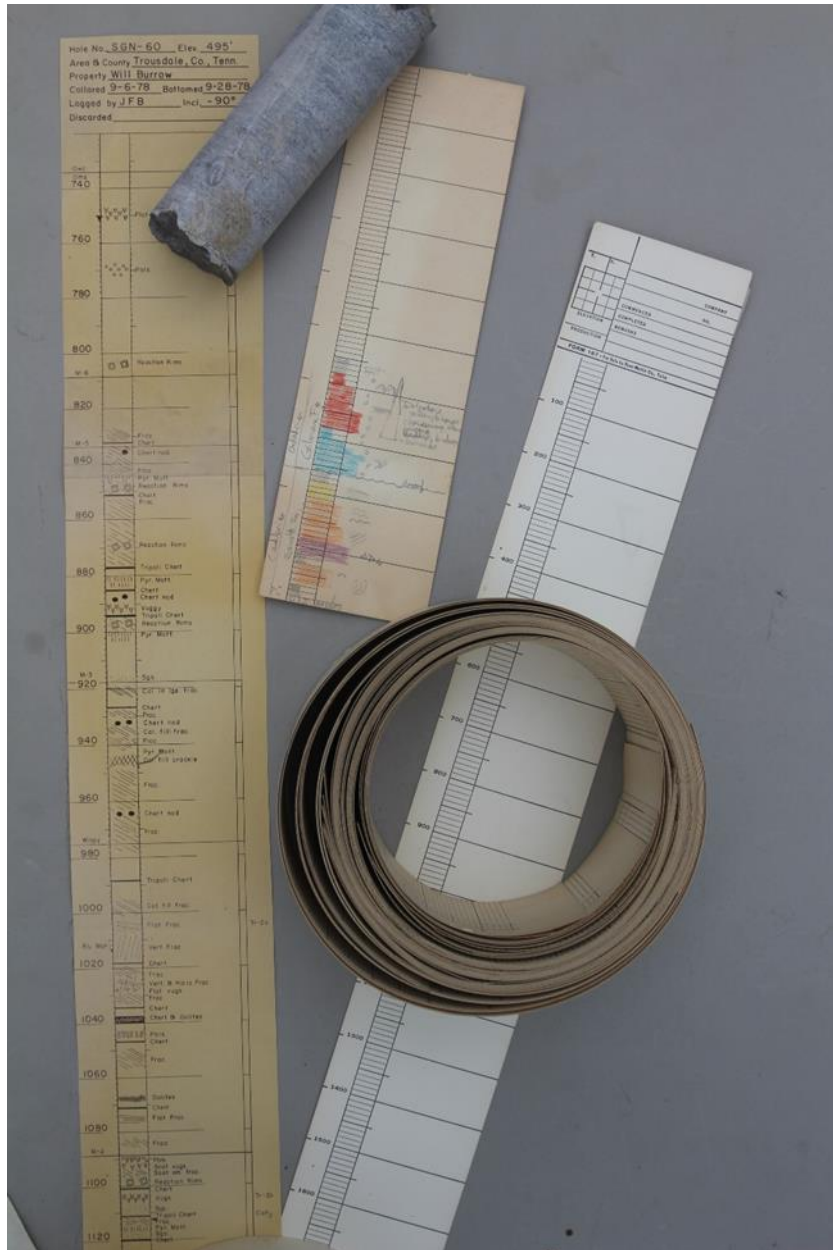
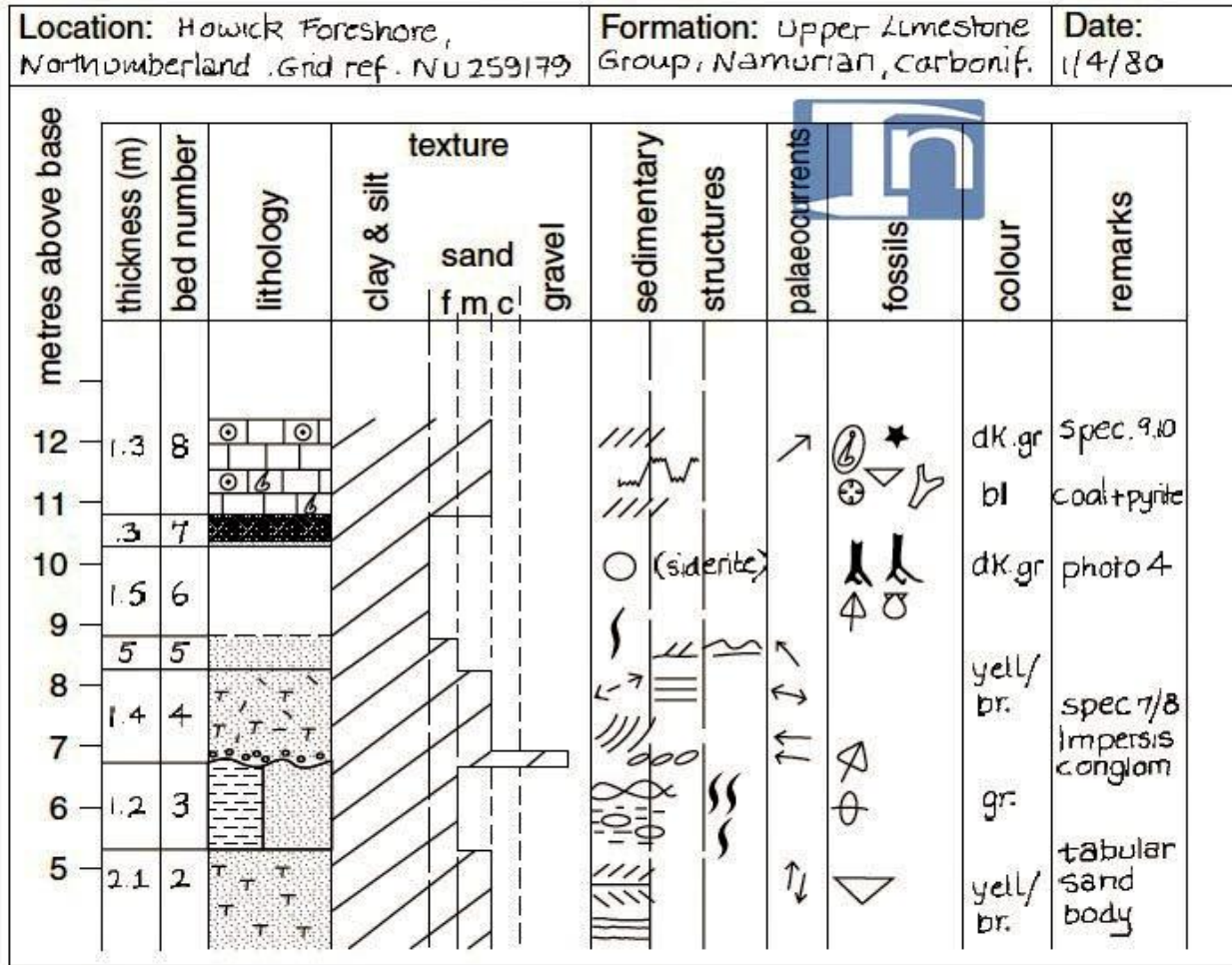


Figure 14. Photograph showing examples of strip logs. The log on the left shows graphic representations of lithologies and features in the lithology column; feature descriptions are written out to the right. The short log in the center shows lithologies with color, with sedimentary features shown graphically to the right. A strip-log template and a roll of logs are shown on the right.

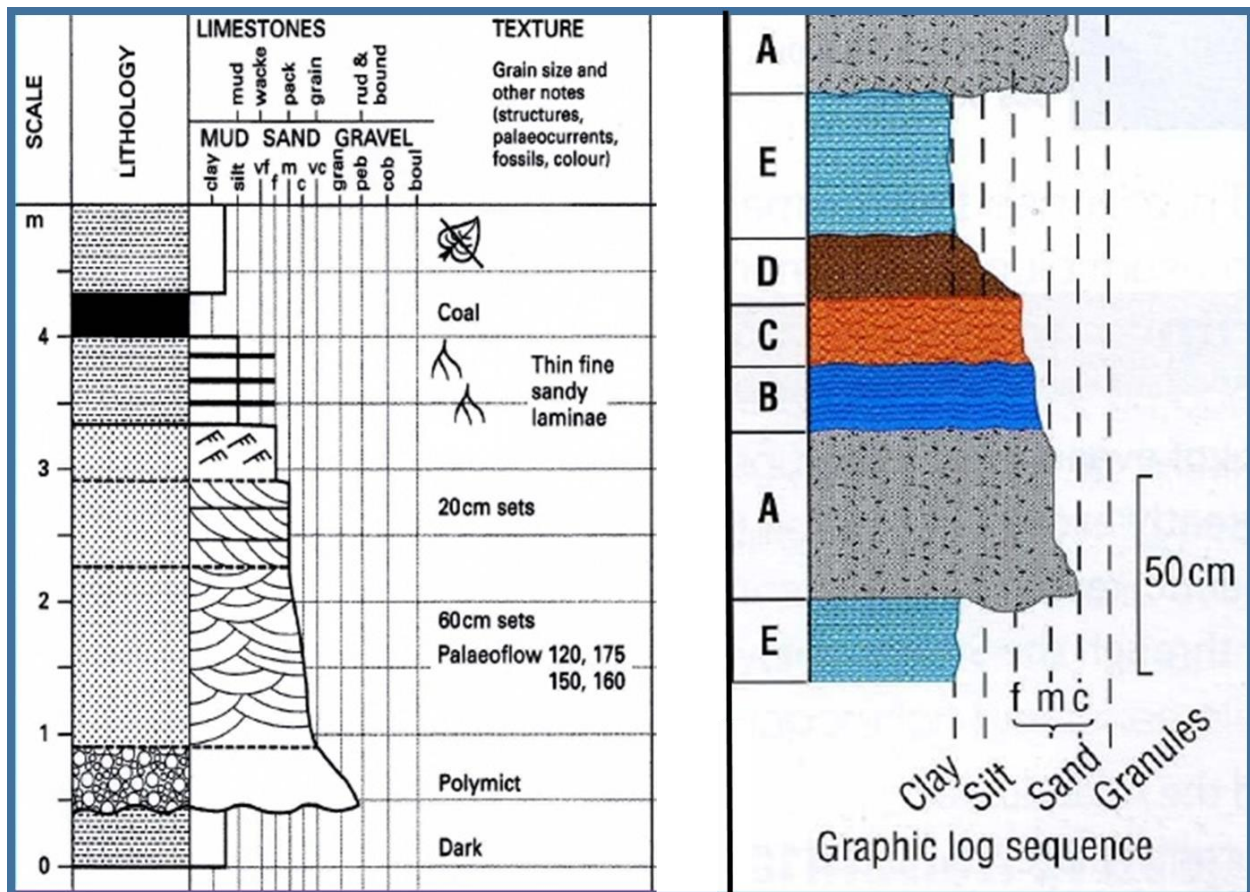


**Figure 15.** Sample strip log, showing 10 columns of various sedimentary criteria. Most commonly, logs will only have columns for thickness (or depth below the surface), lithology and texture (shown together), sedimentary structures, color and remarks (from [www.geologyin.com](http://www.geologyin.com)).

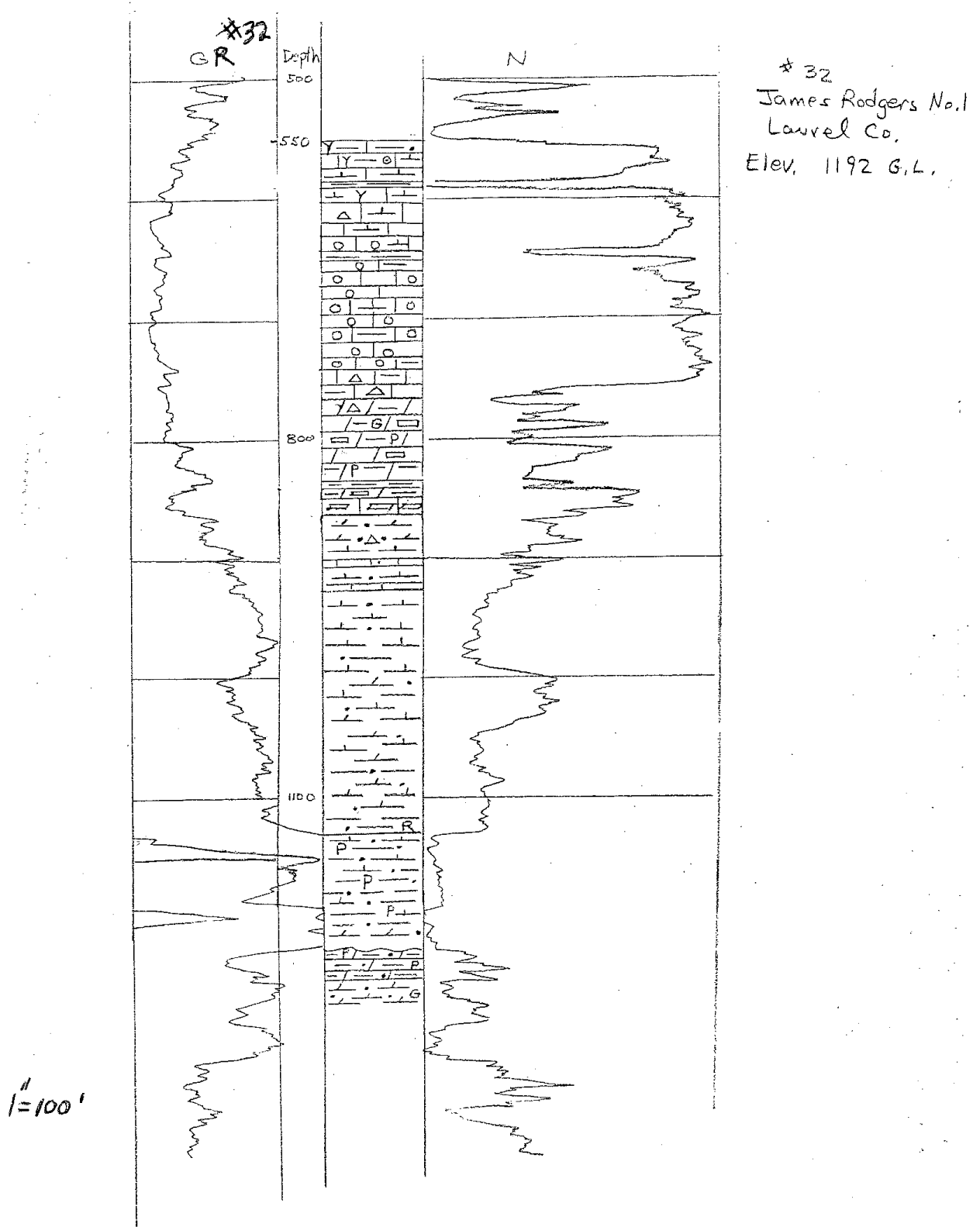
conglomerate; or clay – silt – sand – gravel), with an increase in grain size to the right. Lithology is shown using standard geologic cartoon symbols (Figures 15 and 16) or using color (Figure 14, center). A succession of thin beds, all appearing identical, can be grouped together into a single lithological unit on the log, if a large scale is being used. Where there is a frequent alternation of thin beds of different lithology (e.g., interbedded sandstones and shales), they can be treated as one unit with notes about the nature of the unit included in the remarks section. Note whether bed boundaries are sharp and planar, sharp and scoured, or gradational; each can be represented in the lithology column by a straight, wavy/irregular or dashed line respectively. Other standard lithological symbols can be found in Swanson (1981). As already indicated, texture (grain size) is shown by horizontal scales at the top and bottom of the logs (Figures 15 and 16). Sedimentary structures, fossils, color and other features may be shown in

additional columns to the right of the lithology/texture column(s). In the commercial strip columns (Figure 14), enough space remains on the right for remarks or brief descriptions of the rock units. Strip logs may also be combined with geophysical logs as in Figure 17. Of course, software that can produce strip logs is also available for computers. SciOptic, Rockware, WellSight, GeoSoft, and Golden Software, among others, sell commercial software that can produce strip logs. A standard page that is set up for strip-log format is included as Figure 18. Another style of logging form with an example of actual logging is included as Figure 19.

Strip logs give an immediate impression of the section and facilitate correlation and comparisons between sections from different areas. Repetition of facies, sedimentary cycles and general trends may become apparent, such as a systematic upward change in bed or cycle thickness or in grain-size. In addition, the visual display of a graphic log may aid in interpreting the succession.



**Figure 16.** Examples of graphic strip logs. The log on the left displays lithology and grain size in adjacent columns. The log on the right combines the lithology and grain size into one column. Both logs show an upward decrease in grain size (from [www.slideshare.com](http://www.slideshare.com)).



**Figure 17.** Example of graphic strip log (center), shown with associated gamma-ray (GR, left) and neutron (N, right) data from geophysical logs.





PROJECT:		LOCATION:					
DATE DRILLED: October 13, 2015		SAMPLING METHOD:					
DATE COMPLETED: October 14, 2015		SURFACE ELEVATION: 906.28' AMSL					
DRILLING METHOD: Double Core Barrel		TOTAL DEPTH: 160'					
DRILLING COMPANY: Geo-Drill		GEOLOGIST: Kevin Carey, P.G.					
ELEVATION Feet AMSL	INTERVAL DEPTH feet	GEOLOGIC DESCRIPTION	FIELD COMMENTS	GRAPHIC LOG	ROD (%)	PENE- TRATION	PERCENT RECOV.
836.28	70						
		Interbedded Limestone w/Shale Partings Limestone: Very Hard, Thin to Med. Bedded, Mod. Fossiliferous, Med. Coarse Grain, Olive/Gray Shale: Olive/Gray, Med. Grain, Slightly Fissile, Thin to Med. Bedded, Slightly Fossiliferous	50% Limestone, 50% Shale		95.2		99.2
826.28	80						
		Interbedded Limestone w/Shale Partings Limestone: Very Hard, Thin to Med. Bedded, Mod. Fossiliferous, Med. Coarse Grain, Olive/Gray Shale: Olive/Gray, Med. Grain, Slightly Fissile, Thin to Med. Bedded, Slightly Fossiliferous	50% Limestone, 50% Shale		94.6		100
816.28	90						
		Interbedded Limestone w/Shale Partings Limestone: Thin to Med. Bedded, Fossiliferous, Med. Grain, Lt. Olive/Gray, Mod. Hard Shale: Lt. Olive/Gray to Med. Olive/Gray, fine to Med. Grain, Slightly Fissile, Thin to Med. Bedded	50% Limestone, 50% Shale		99		100
806.28	100						
		Interbedded Limestone w/Shale Partings Limestone: Bluish Gray, Med. Coarse Grain, Mod. Hard, Fossiliferous, Thin to Med. Bedded Shale: Med. Olive/Gray, Fine to Med. Grain, Slightly Fissile, Partings, Med. Bedded	50% Limestone, 50% Shale Soft, Moist Shale Zones 105.3- 105.4 & 108.7-108.9'		78.6		99.2
796.28	110						
		Interbedded Limestone w/Shale Partings Limestone: Bluish Gray, Med. Coarse Grain, Mod. Hard, Fossiliferous, Thin to Med. Bedded Shale: Med. Olive/Gray, Fine to Med. Grain, Slightly Fissile, Partings, Med. Bedded, Stringers: Med. Bedded, Slightly Fossiliferous	52% Limestone, 48% Shale		91.12		98.5
786.28	120						
		Interbedded Limestone w/Shale Partings Limestone: Lt. Olive/Gray, Mod. Hard, Med. Grain, Fossiliferous, Thin to Med. Bedded Shale: Lt. Olive, Med. Grain Partings - Med. Bedded, Slightly Fissile	61% Limestone, 39% Shale		99.4		100
776.28	130						
		Interbedded Limestone & Shale Limestone: Med. Grain, Partings - Med. Bedded, Fossiliferous, Mod. Hard Shale: Fine to Med. Grain, Thin to Thick Bedded, Lt. Olive, Fissile	30% Limestone, 70% Shale	776.28' AMSL Approximate Contact between Fairview Formation and Kope Formation	96		99.4
766.28	140						

Continued Next Page

**Figure 19.** Another sample core-logging format from a core including the Kope and Fairview formations. Note that the description is performed based on 10-ft core runs, and elevation reflects depth below the surface elevation. The lower part of the log reflects the core shown in Figure 21. This example does not show a graphic log, although a place is available to put one (log provided by Kevin Carey).

## Coring and Rock-Quality Designation (RQD) (Kevin Carey and Frank Etensohn)

In many commercial and industrial applications, the competency of the rock—or the “intactness” of the rock is very important. To determine the intactness of the rock, both the “**recovery percentage**” and “**RQD**” (**rock quality designation**) need to be determined. To understand recovery percentage and RQD, one must first know that the fundamental unit of core drilling is the **core run**, which is the distance drilled from one removal of core from the barrel to the next (see Maconochie, 2013). Normally, a run will extend for the full length of the core barrel. Core barrels may range from 10 ft (~3 m) to 60 ft (~18 m) in length, but for many geotechnical uses core runs are typically 10-ft long and will fill a standard commercially manufactured core box. However, for a variety of reasons, usually because the drill bit is clogged and is not cutting the rock, the driller may terminate a core run short of the full barrel length. The materials that pass up into the core barrel may be divided into four parts:

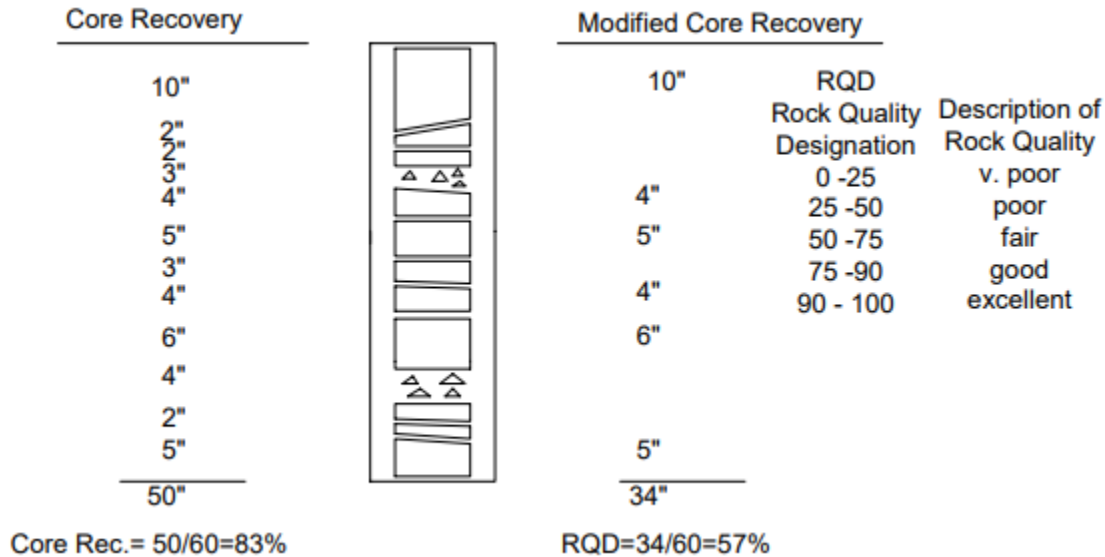
- Solid core pieces 4 inches (~100 mm) or more in length, called “**sticks**,”
- solid core less than 4 inches (<~ 100 mm) in length, called “**pieces**,” and
- **fragments** of core (i.e., not full cylindrical sides).
- Additional materials that may have been lost from previous core runs including:
  - the core “stump” left from the previous run,
  - material dropped from the core barrel during its previous withdrawal, and
  - cuttings that settled when circulation of the drilling fluid was stopped.

Core material may also have been lost by erosion of soft, friable, or intensely fractured zones, resulting in a reduction in diameter or length of the core, or both. The eroded material may be entirely removed by the flushing system as chips.

The recovery percentage is determined by the total length of the rock core recovered divided by the length of the entire core run (a “core run” is typically 10’ or 120” in length). For example, if one measures 116.5” of recovered rock core and divides that measurement by the total core run of 120”, the recovery percentage is 97.1%.

Rock Quality Designation, RQD, was introduced by Deere et al. (1967) as a way of correlating natural fracture intensity with the engineering performance of a rock mass. It was first used as a way to determine qualitatively whether or not a rock mass was good for tunneling, but its use has been extended for other purposes as well. RQD is based on a modified core-recovery procedure, which, in turn, is based indirectly on the number of fractures and amount of softening or alteration in the rock mass as observed in the rock cores from a drill hole. Instead of counting the fractures, an indirect measure is obtained by summing up the total length of core recovered but counting only those pieces of core which are 4 inches (~100 mm) in length or longer (assuming a core with a 2-inch diameter) and which are hard and sound (Figure 19). The length of individual core pieces should be assessed along the centerline of the core, so that discontinuities that happen to parallel the drill hole will not unduly penalize the RQD values of an otherwise massive rock (Brown, 1981; Maconochie, 2013).

The RQD is then determined based on core recovery. In short, the RQD is the total length of all the core pieces that are twice as long as the diameter of the core, divided by the length of the entire core run. A typical core is approximately 2 inches (50 mm) in diameter. So, if one summed up the lengths of all of the core pieces/sections obtained in the core run that are at least 4" long (which is twice the diameter) and calculates a combined total of 107", one would divide the summed total by the length of the core run:  $107"/120"=89.2\%$  RQD. Then, just compare the RQD value determined with the Deere Classification Table (Figure 20, right). The RQD value (89.2%) is classified within the "good" category.



**Figure 20.** Example of core recovery measurements (left), the graphic core (center) and modified core recovery (right) used to calculate the RQD. The entire core run was 60". The chart at the far right translates RQD into Rock Quality (modified from Deere et al., 1967).

Importantly, when determining RQD, only take into account the natural breaks in the rock core, not the mechanical breaks. The mechanical breaks are the breaks that occur during the drilling activities or when the driller needs to break the core with his hammer in order to fit it into the core box. Most commercially manufactured core boxes have five sleeves, where each sleeve of the core box is 2' long, and hence, the box holds 10' of core. Frequently, when the rock is good, long sections come out of the core barrel and the driller needs to break the long pieces to fit them into the 2' sleeve. When this occurs, the mechanical break needs to be marked with a sharpie so you know to include that as part of the portion over 4" long (see Figures 20 and 21). Additionally, mechanical breaks are fresh, so the edge of the core (at the break) will be sharper, whereas a natural break will tend to be smoother and weathered (Figures 20 and 21). More information about RQD application and standards is provided in ASTM D 6032-96 (ASTM, 2018). This standard also notes that "RQD should be logged on site when the core is retrieved because some rocks can disintegrate, due to slaking, desiccation, stress relief or swelling with time."

Much anecdotal evidence suggests that the RQD is a more sensitive and consistent indicator of general rock quality than is the gross core-recovery percentage. As simple as the procedure appears, use over the last 50 years shows that there is a reasonably good relationship between the numerical values of the RQD and the general quality of the rock for engineering purposes (see [https://www.researchgate.net/post/A few have suggested we stop using RQD](https://www.researchgate.net/post/A_few_have_suggested_we_stop_using_RQD)).



**Figure 21.** Photograph of a box of marked core from a 10-ft core run in the Kope and Fairview formations, showing mechanical breaks marked with blue-colored marker streaks. Core sticks like this would be included as portions of the core greater than 4 inches in length for determining RQD (photo provided by Kevin Carey).

Other physical aspects of cores that can be examined and evaluated qualitatively and quantitatively include fracture frequency, rock strength, soil strength, density, weathering, slaking (reaction with water or moist air), and defects (tectonic structures like sheared zones, faults, slickensides, gouge or crushed zones, intrusives, veins). In order to examine the material properties of intact rock, shear strength, or properties like slaking, cores must be examined, tested, or properly packed as soon as the core has been extruded from the core barrel, because drying, heating, or increased moisture can adversely affect some tested properties. Various standards for characterizing these features and others are provided in Maconochie (2013) and in

AusIMM (2011). A suggested field manual that describes geological, as well as engineering parameters, is AusIMM (2011).

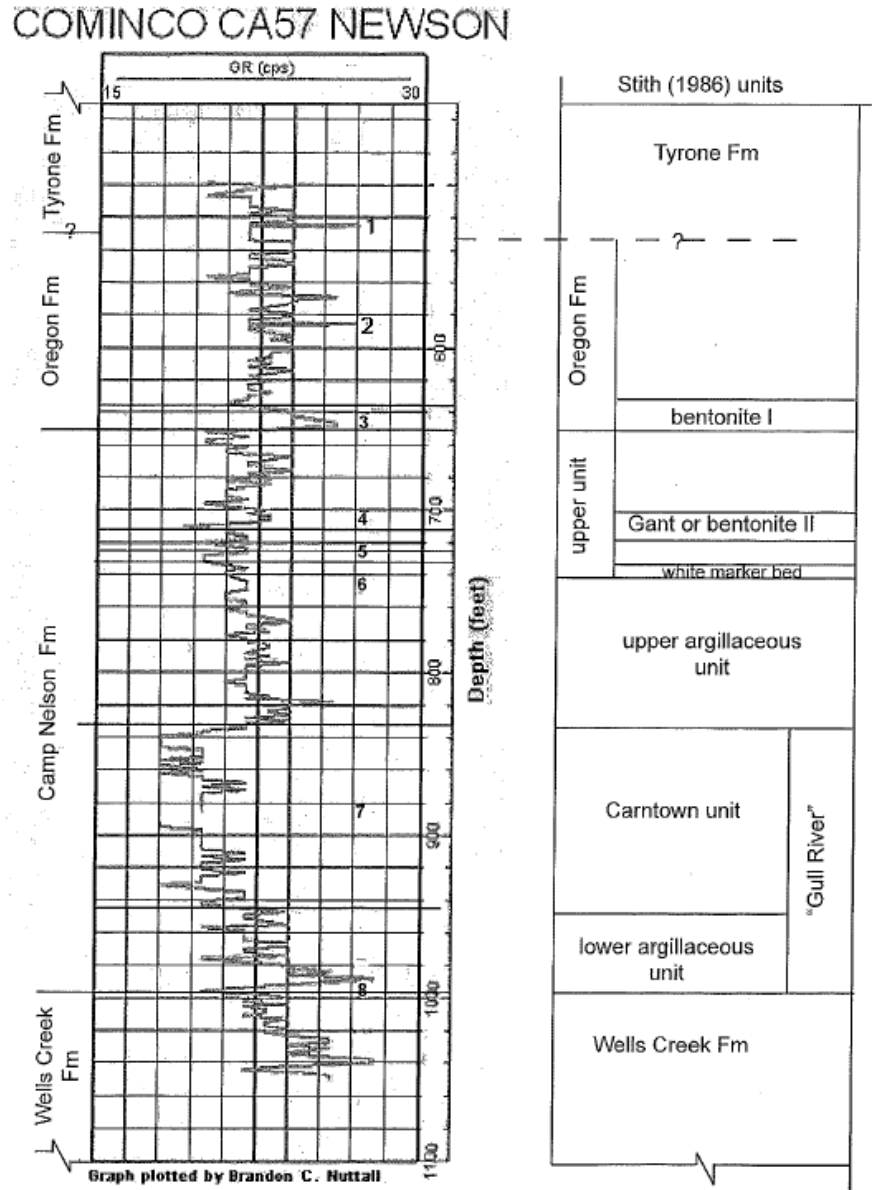
When heading out to the field or core library, it is important to have certain equipment readily available. A list of that equipment is provided below:

- Camera (label the core box and take a picture)
- Scales, color chart, and texture indicators
- Pocket knife (to determine hardness or just to look at something closer)
- Core-log sheets
- Field book (e.g., AusIMM, 2011)
- Spray bottle of water (to view the core when wet)
- Fold ruler and a regular ruler or tape (in tenths of ft to measure the core pieces)
- Hearing protection (if you are logging on site)
- Hammer
- PPE (safety glasses, high visibility vest, steel toed boots, latex gloves, especially if you are logging on site)
- Geologic dictionary/Rock & Mineral I.D. book (if needed)
- Geologic quadrangle map (if available)
- Acid bottle with dilute HCl (to verify carbonate rock)
- Small bottle of alizarin-red S to verify calcite vs dolomite
- Waterproof markers
- Small brush to clean cores

### **Radioactive Characterization**

Geophysical logs may provide additional information about the nature of the core you are examining, and sometimes, such logs will be available, but logs like this are an additional expense and are commonly not run for smaller projects. However, it is very easy to generate artificial gamma-ray logs from cores with a hand-held scintillometer. Carbonate cores typically generate rather monotonous gamma-ray logs, and might not be very useful, but prominent shales and bentonites in the carbonates will stand out and might be very useful for correlation or trying to find your location in a monotonous carbonate section (Figure 22). Gamma-ray logs reflect the presence of radioactive elements (uranium, thorium and potassium) that decay and generate gamma rays in the process. These elements are typically attracted to clays and organic matter, which are more abundant in shales and mudstones. Hence, gamma-ray logs can be used to distinguish prominent shale intervals or argillaceous (shaly) carbonates. The artificial gamma-ray log in Figure 22 was generated, using a hand-held scintillometer from the High Bridge core in the core boxes that are stationed around our workshop room. The further to the right the curve migrates (positive deviation), the more argillaceous material there is in the core. Prominent shales and bentonites are shown at numbers 1, 2 and 3 on the log. These could be important marker horizons in a carbonate section and aid in locating where you are in a monotonous carbonate section. As the curve moves to the left (negative deviation) the amount of argillaceous

material in the carbonates decreases. Hence, looking at Figure 22, the Oregon and Wells Creek formations contain more argillaceous material than the Camp Nelson Formation, but the upper part of the Camp Nelson is more argillaceous than the lower part (Carntown unit). If I were looking for the most calcium-rich parts of the Camp Nelson Formation, I would immediately choose the Carntown unit as it has the most negative



**Figure 22.** Artificial gamma-ray log made from the Cominco core in Mason County, KY, showing lithostratigraphic units compared with Stith's (1986) informal units for the Camp Nelson. The recording interval for readings was one foot (from Ettensohn and Smath, 2007).

deviation. Most carbonates also contain dolomite, but dolomite can be a serious detractor. Because argillaceous material is known to provide Mg and Fe ions that could enhance dolomite

formation, I would also want to choose the Carntown unit because the low levels of argillaceous material mean that presence of abundant dolomite will be less likely.

Producing an artificial gamma-ray log such as the one included in Figure 22 is relatively easy. Based on the length of the core, determine the reading interval, or how frequently the gamma-ray readings will be taken. For short cores, the reading interval may be one-foot increments, but for longer cores, the reading intervals may range from two feet to ten feet. Readings are taken by placing the detecting part of the scintillometer on the core at every interval (Figure 23). The readings in counts per second (cps) are read from the appropriate scale on the instrument. Repeat this process at every interval along the core until finished. Record the readings and intervals and plot them with a graphic strip log or on a graph with the radioactivity (cps) on the horizontal or x-axis versus depth on the vertical or y-axis. The same procedures can be used to



**Figure 23.** Student scanning core from the Ohio Shale on Pine Mountain in Letcher County, KY, using a hand-held scintillometer.



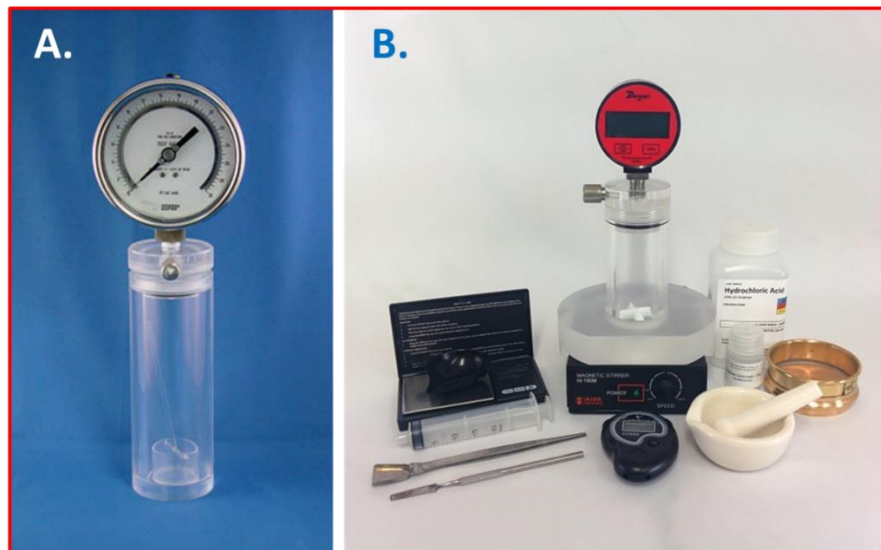
develop logs for outcrops, except that weathered portions must be removed to get true readings. All the procedures for developing artificial gamma-ray logs are outlined in Ettensohn et al. (1979).

### Measuring $\text{CaCO}_3$ and $\text{CaMg}(\text{CO}_3)_2$ Content in Cores

One potential use of cores is for determination of the amount of calcite and dolomite in the cored material. Deposits of sufficiently high chemical purity may be required to meet specifications for a number of metallurgical, chemical and special industrial uses. The cored material may also indicate potential sources of scaling ( $\text{CaCO}_3$  accumulation in the well bore or pipe). Lab-based chemical testing of core material is one way to acquire this kind of data. Lab testing can also indicate the presence of various contaminants, such as aluminum oxide, iron oxide, magnesium carbonate, silicon dioxide, phosphorus, and sulfur, which might preclude uses for certain purposes. The Kentucky Geological Survey and other state agencies have published several reports on chemical analyses of the Ordovician, Silurian and Mississippian carbonates most commonly quarried in the Commonwealth (e.g., Dever and McGrain, 1969; IMMR, 1984, 1985; Dever, 1990). Lab testing, however, can be more expensive and time-consuming. Calcimetry and x-ray fluorescence provide more expedient testing of core material.

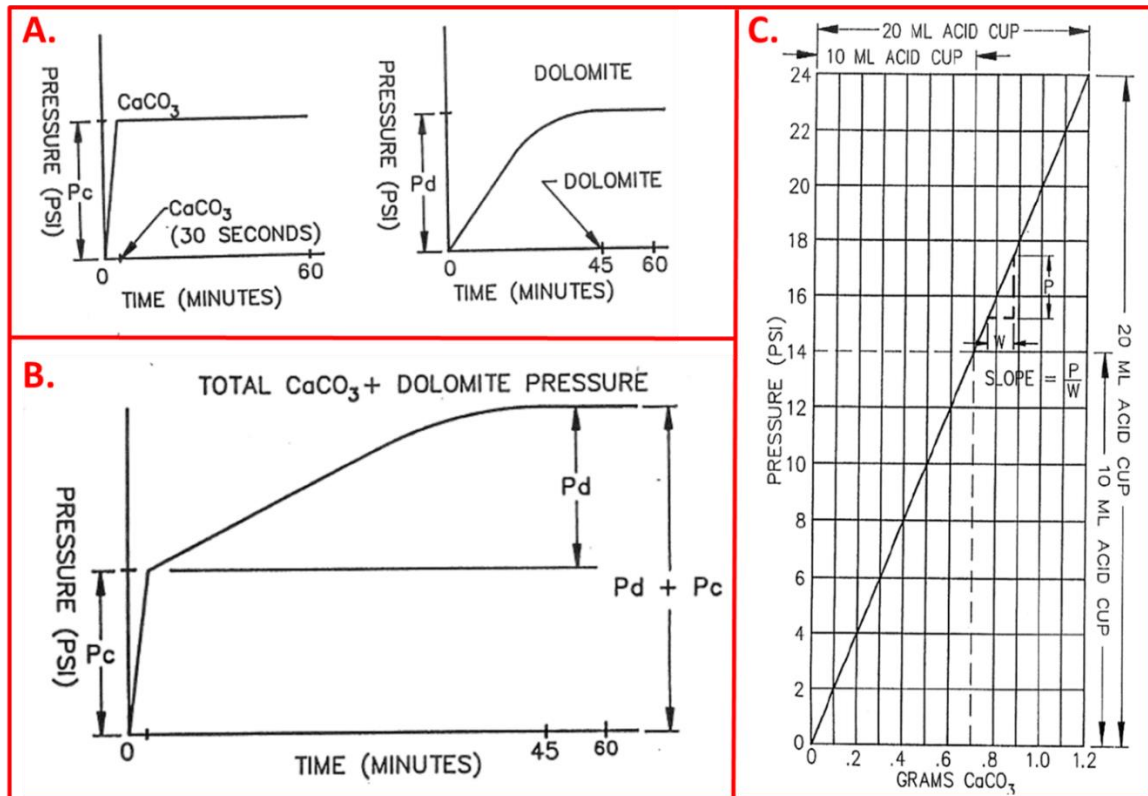
#### *Calcimetry—*

Calcimetry is a method for providing fast, reliable measurements of the amount of calcite ( $\text{CaCO}_3$ ) and dolomite [ $\text{CaMg}(\text{CO}_3)_2$ ] in samples from cores, cuttings and soils. The typical calcimeter is an enclosed reaction chamber with a pressure gauge (Figure 24). A simple gauge-type calcimeter



**Figure 24.** Calcimeters. **A.)** Simple gauge-type calcimeter; **B.)** Digital calcimeter with needed assessor equipment.

Is shown in Figure 24A, and a digital model on a magnetic mixer is shown in Figure 24B. Automated and computer-based models are also available. In using a calcimeter, the sample is washed free of any contaminants and thoroughly dried. It is then ground to 100 mesh or finer in a mortar and pestle and put through a 100-mesh sieve (Figure 24B). A small sample (0.5–0.7 gr) is weighed to the nearest 0.001 mg and placed in the bottom of the reaction chamber. Ten ml of 10% HCl are then placed in the acid cup and gently lowered into the reaction chamber. Tighten the cell cap with its gauge, and the gently shake or swirl the chamber and its contents so that the acid reacts with the powdered sample. Record the pressure after 30 seconds; this is the  $\text{CaCO}_3$  pressure. Swirl the reaction cell again to allow the reaction to go to completion, which should happen in 30–45 minutes, after pressure has stopped increasing. This final value of pressure is the total  $\text{CaCO}_3$  plus dolomite pressure. To obtain the pressure due to the dolomite, subtract the calcium carbonate pressure (30 second reading) from the total reading (30-45 minute reading). Pressures can then be converted into grams of  $\text{CaCO}_3$  using the calibrated pressure-recorder charts shown in Figure 25 (see FIC, 2009). Many users now consider that calcimetry may not provide sufficiently accurate results and have switched to portable x-ray fluorescence spectroscopy (Figure 26).



**Figure 25. A.)** Pressure-versus-time graphs for calcite (left) and dolomite (right), showing that pressure from dissolution of calcite ( $P_c$ ) is generated within the first 30 seconds, whereas generating full pressure from dolomite dissolution ( $P_d$ ) may take 30–45 minutes. **B.)** Pressure versus time for total calcite and dolomite. **C.)** Table for converting pressure from calcite ( $P_c$ ) into grams calcite; grams dolomite can be calculated by subtracting grams calcite from the total (from FIC, 2009).

*X-ray fluorescence spectroscopy (Mike McGlue)—*

X-ray fluorescence (XRF) has become a widely used tool for rapid and nondestructive chemical analysis of heterogeneous geological materials like fine-grained sedimentary rocks, soils, or ceramics. The basic principle of the technique is that atoms will emit characteristic colors (or unique fluorescence energy) from their inner-shell electrons when they absorb high-energy photons (in this case, delivered to the sample from the XRF) that exceed electron binding energy. When this occurs, the inner electron is driven off the atom and an outer-shell electron “falls back” to fill the vacancy. In this process of “falling back,” the energy differences between the shells is released as an x-ray photon exactly equal to the energy difference. The XRF’s detector intercepts and analyzes this photon, and can diagnose which element it came from based on its energy. In practice, the XRF will provide major- and trace-element data to the analyst, which are often interpreted from the perspective of mineralogy. Such insights can be valuable for thinking about



**Figure 26.** Handheld x-ray fluorescence spectrometer analyzing a vertebrate fossil (<https://illuminatingfossils.wordpress.com/2011/01/04/x-ray-fluorescence-spectroscopy/>).

paleoenvironmental conditions, depositional processes, provenance, and diagenesis. In practice, hand-held XRF tools like the Bruker Tracer IV©, which will be demonstrated in the workshop, have many limitations. They are not a panacea, but when used correctly they can provide an abundance of information rapidly and at low cost relative to other techniques used to determine sediment chemistry or mineralogy (e.g., inductively coupled plasma mass spectrometry or ICP-

MS; instrumental neutron activation analysis or INAA; x-ray diffraction or XRD; etc.). Though tempting to use the XRF to analyze unknowns only, it is preferable to track the performance of the device and its matrix calibration using a standard whose chemical composition is reasonably well known. For mudstones, SARM-41 is a commonly used standard; SARM-41 is South African in origin, and certified values of major elements like Al, Si, and Ca are readily available. At UK, we analyze SARM-41 periodically within a batch of unknowns (e.g., measurement of 1 standard for every 20 unknowns), and retain a long-term database on how our XRF-derived chemical data compare to certified values. XRF spot sizes constrain the effectiveness of the analysis, and powdering samples that are coarse grained (i.e., non-uniform) can be necessary to obtain reliable results. Pore space and pore fluids may also influence results; samples must be infinitely thick relative to the range of emitted photons for each element of interest. XRF cannot measure certain elements (C, O and H), and most instruments have difficulty with elements that emit low-energy electrons like Na and Mg. The chemical data provided by the XRF are best crosschecked with other methods, most specifically x-ray diffraction and carbonate coulometry. Used in conjunction, the analyst can ascertain if a true proxy relationship exists between elemental abundance derived from XRF and the abundance of certain minerals.

### **Overview of the Commercial and Industrial Use of Aggregates** (Donald Lumm and John Popp)

The commercial and industrial production and use of limestone and dolomite has a significant impact on the economy of Kentucky and other Midwestern states. The information listed in this section is a brief overview of the properties, uses, testing, and sales of limestone and dolomite, which are commonly referred to as aggregates or crushed stone by the industry (see Hack and Ryan, 2006; NSSGA, 2013).

#### *What are Aggregates?*

Aggregates are simply any collection of rocks. In the aggregates industry, these rocks are classified as crushed stone, sand, gravel, and slag. Crushed stone typically includes limestone ( $\text{CaCO}_3$ ) and dolomite [ $\text{CaMg}(\text{CO}_3)_2$ ].

#### *Aggregate Properties*

- A. Physical Properties  
Absorption (Porosity and Permeability), Surface Texture, Strength and Elasticity, Density and Specific Gravity, Hardness
- B. Chemical Properties  
Mineralogical Composition, Reactions with Asphalt and Cement

#### *Limestone and Dolomite Uses*

Limestone and dolomite are used most commonly as a crushed and sized construction material,

base rock, and concrete. Limestone combined with some clay and or gypsum yields Portland cement (“Quikrete”). Limestone is highly preferred in building materials because:

- Limestone can be easily shaped into blocks or bricks
- Limestone has a relatively high density and high strength
- Limestone blocks are relatively resistant to corrosion
- Limestone has high durability

*Other important uses of limestone are many and include (see Figure 27):*

- Lime production: for use in food processing, water treatment, sulfur dioxide pollution control, neutralization of waste
- Agriculture: for use in soil amendment, animal-feed supplement, poultry grit
- Chemical and industrial processing: for use in glass, paper and pulp production, flux stone/iron ore reduction
- Industrial filler: for use in paint, rubber, plastics, cleansers, paper, putty and calking compounds, alkalizers, digestion acids
- Other uses: coal mine dust, architecture and dimension stone

*Permitting and Mining Aggregates in Kentucky*

Limestone, dolomite, and all other aggregate operations in Kentucky are permitted by the Non-Coal Review Branch of the Division of Mine Reclamation and Enforcement (DMRE). In 2016, 47 operating limestone mines were operating in 40 Kentucky counties.

*Laboratory Testing of Aggregates*

Physical testing is far more common for aggregates than chemical testing because of the great variety of uses and physical requirements for civil engineering, construction and industrial applications. The most important and commonly applied tests are:

#### **Los Angeles (L.A.) Abrasion Test (ASTM C131-14)**

The Los Angeles (L.A.) abrasion test measures the degradation of an aggregate sample due to abrasion and impact from other aggregate particles and steel spheres. Once the testing is complete, a sieve analysis is performed on the aggregate sample, and the mass that is broken into smaller pieces is determined. This is represented as a percentage of the total mass of the aggregate sample. The L.A. Abrasion value indicates the resistance to breaking due to impact and abrasion; therefore, low percent loss values indicate a tougher aggregate. Typical loss values for dolomite and limestone range from 18 to 30 percent by weight.

### **Specific Gravity and Absorption Test (ASTM C127-15)**

Relative density or specific gravity is defined as the ratio of mass of an aggregate to the mass of a volume of water equal to the volume of the aggregate particles. The density of dolomite and limestone can vary from 2.3 to 2.9. A higher density is preferred for aggregate use in hot-mix asphalt.

The absorption rate is an indication of the porosity of the aggregate in question. The generally accepted absorption rate for use in a hot-mix asphalt design would be less than one percent by mass.

### **Sodium Sulfate Soundness Test (ASTM C88-13)**

The sodium sulfate soundness test is used to determine the resistance to disintegration of an aggregate sample. The test involves submerging an aggregate sample repeatedly in a solution of sodium sulfate. This process causes the formation of salt crystals in the pores of the aggregate similar to ice crystal formation, creating internal forces in the aggregate pores that tend to break the aggregate. A sieve analysis is performed to determine the percent loss of the aggregate sample.

### *Crushed Stone Sizes, Local Cash Prices, and Common Uses*

The crushed stone industry classifies limestone and dolomite products and sales into size classes for its customers. A list of sizes, diameters, local prices per ton<sup>(1)</sup>, and uses are listed below:

<b><u>Size</u></b>	<b><u>Diameter</u></b>	<b><u>\$/Ton</u></b>	<b><u>Uses</u></b>
RR	7" to 14"	20.00	Riprap; culvert, stream bank, channel lining
#1	1.5" to 3.5"	20.00	Culvert lining
#2	1.5" to 2.5"	N/A	Portland cement, asphalt, filler material
#3	1" to 2"	N/A	Drainage, railroad ballast
#4	0.75" to 1.5"	N/A	Road base
#5	1" to fine particles	17.50	Road and paver base
#57	1" to 0.19"	17.50	Concrete, asphalt mix, driveways, landscaping, drains
#67 (DGA)	1" to fine particles	12.95	Fill, road, paver base, slab base, driveways
#8	0.375" to 0.09"	N/A	Concrete and asphalt mix, walkways
#9	0.375" to 0.125"	20.00	Paver base, walkways
#10	screenings or dust	11.50	Fab for concrete blocks and pavers
#411	mix of stone dust and #57	N/A	Driveways, roads, retaining wall, base material
Waste		10.50	Various fill material

<sup>1</sup>Size class price/ton data provided by Vulcan Materials, Lexington Quarry, and reflect non-contract, non-volume sales.

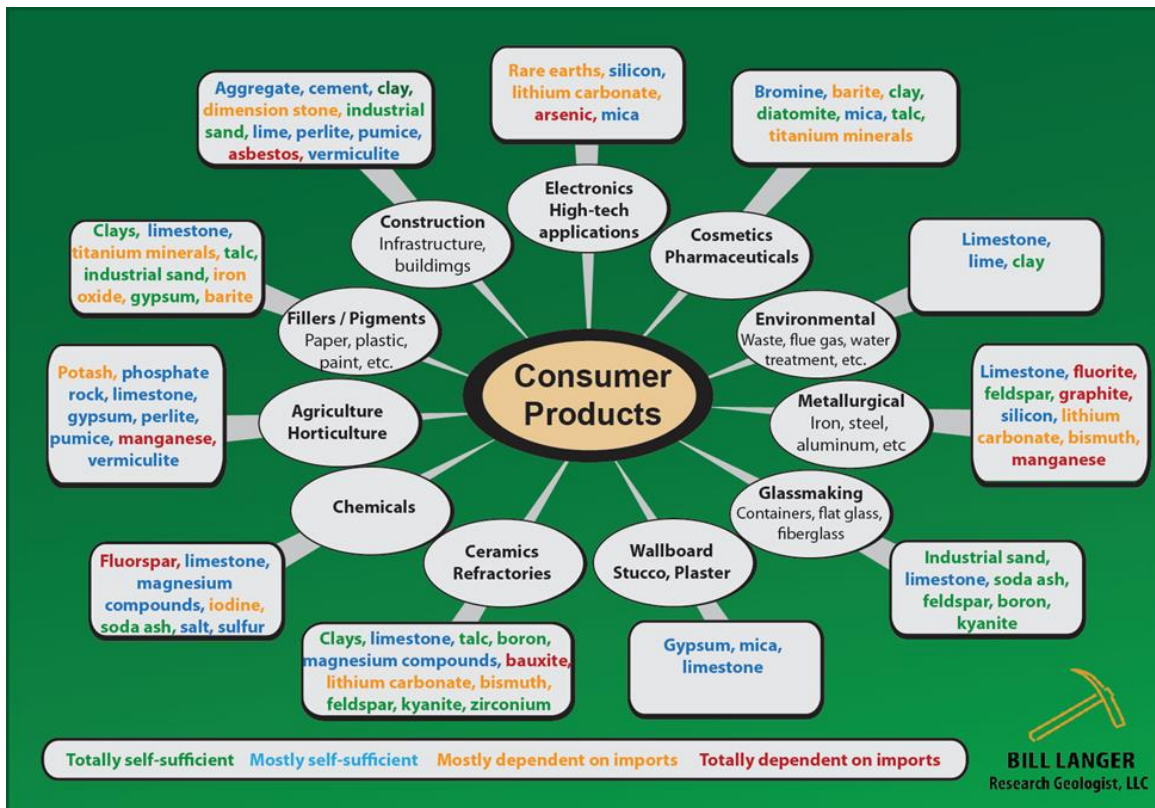


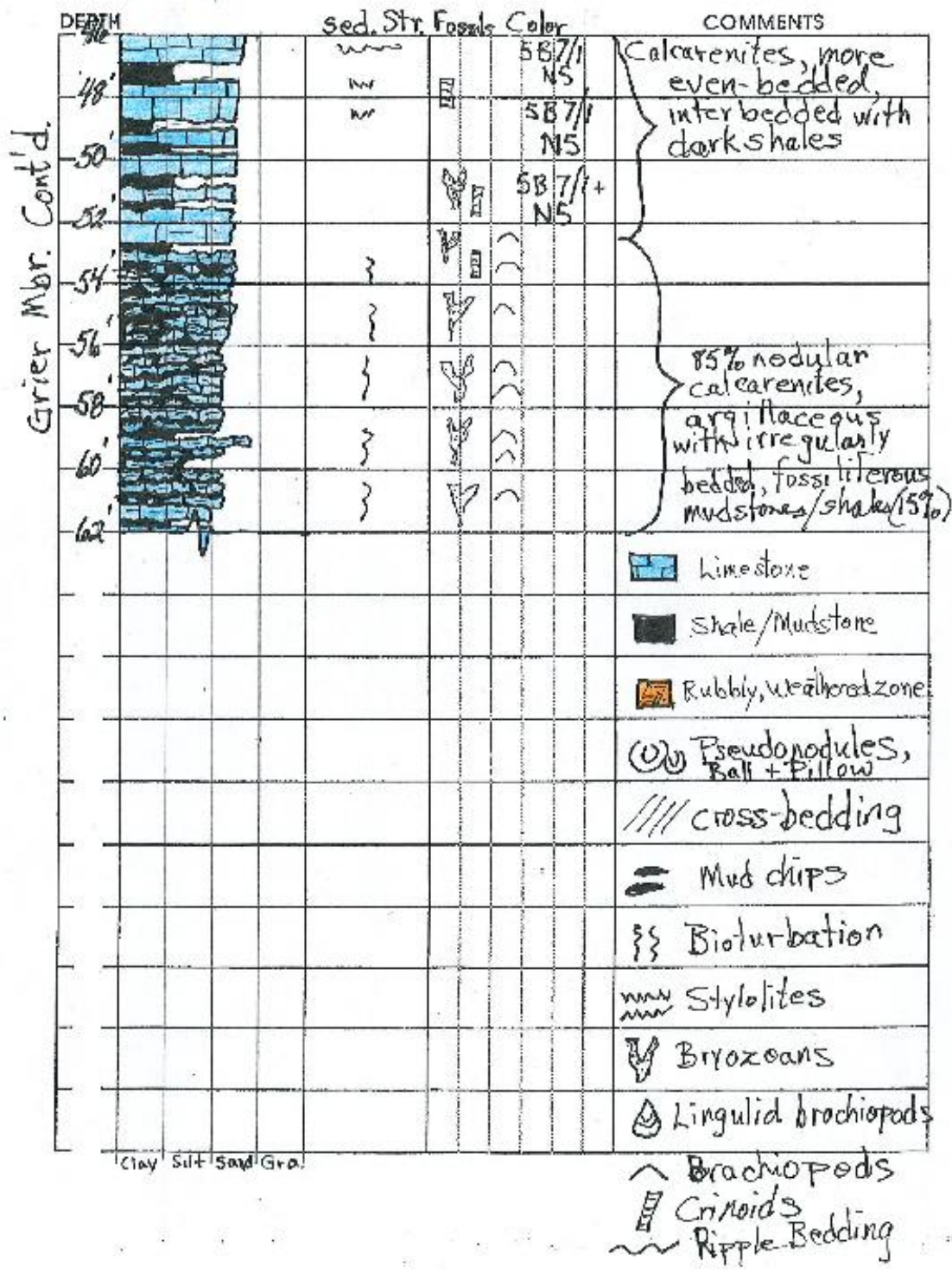
Figure 27. Carbonate uses and sources for the U.S. (from Langer, 2013).

## General carbonate Distribution and Uses (John Popp)

General Carbonate Distribution and Uses in KY			
Rock Unit	Sub units	Geographic Distribution	Primary uses
Kinkaid Ls	upper member	mostly absent in KY	Not exploited
Kinkaid Ls	middle member	mostly absent in KY	Not exploited
Kinkaid Ls	lower member	WKY	Construction agg.
Glen Dean and Haney Ls		WKY	Construction agg.
Girkin Formation and correlative Ls's		SKY	Construction & agriculture; oolitic zone is hi cal (95% or more CaCO <sub>3</sub> )
Reelsville Ls		Central KY	Const. & agri.
Beaver Bend Ls		Central KY	Const. & agri.
Paoli Ls		Central KY	Const. & agri.
Paint Creek Ls		WKY	Const. & agri.
Renault Ls		WKY	Const. & agri.
Ste. Genevieve Ls		WKY	Const. & agri.; also dimension stone; oolitic zone is high cal for industrial uses
Ste. Genevieve Ls	Levias Ls	WKY - Caldwell, Crittenden, and Livingston Cos	
Ste. Genevieve Ls	Rosiclare Ss	WKY - Caldwell, Crittenden, and Livingston Cos	
Ste. Genevieve Ls	Fredonia Ls	WKY - Caldwell, Crittenden, and Livingston Cos	
Salem, Warsaw, and Harrodsburg Ls		West-central to South-central KY	Const. & agri.
Warsaw Ls of WKY		WKY	Const. & agri.; also, scrubber stone; riprap, filter stone.
Fort Payne Fm		WKY	Const.; also skid-resistant agg., railroad ballast, riprap, filter stone.
Louisville Ls and Laurel Dolomite		West-central and NKY, and south-central KY	Const. & agri.; also dimension stone.
Grant Lake Ls		East-central and west-central KY	Const. stone in the upper Ls in Fleming County
Lexington Ls		Central KY	Const. & agri.
High Bridge Group	Tyrone Ls	Central & NKY	Const., agric., & industrial; also dimension stone
	Oregon Fm	Central & NKY	Const., agric., & industrial; also dimension stone
	Camp Nelson Ls	Central & NKY	Const., agric., & industrial; high-carbonate (CaCO <sub>3</sub> + MgCO <sub>3</sub> ) in NKY
Bangor and Monteagle Ls's and Slade Fm	Bangor	South-central KY	Const. & agri., or it is wasted because it can be difficult to crush.
	Monteagle	South-central KY	Const. & agri.
	Slade	East-central and northeastern KY	Const. & agri.
Newman Ls	upper member	Southeastern KY	Not being exploited
Newman Ls	lower member	Southeastern KY	Const. & agri.; also hi cal, low silica.
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