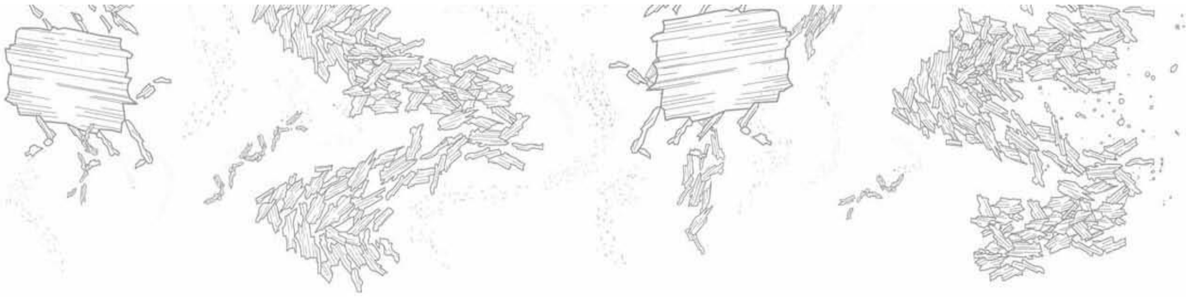

A Classification of Metamorphic Rocks

Questions to be Considered in this Chapter:

1. On what basis are metamorphic rocks classified and named?
2. What general terms are used to describe the basic textural and compositional parameters?

Like other rocks, metamorphic rocks are classified on the basis of *texture* and *composition* (either mineralogical or chemical). Although we may consider deriving a proper name for a rock as an exercise in finding the right pigeonhole, we are much better served by considering a good name as a concise way of imparting information about a rock. Unlike igneous rocks, which have been plagued by a proliferation of local and specific names, metamorphic rock names are surprisingly simple and flexible. I appreciate the flexibility in how we approach naming a metamorphic rock. In addition to a "proper" (or "root") name from the scheme that follows, we may choose some prefix-type modifiers to attach to names if we care to stress some textural or mineralogical aspects that we deem important or unusual.

The classification and textural description of metamorphic rocks are intimately related, and a proper job requires good thin section and hand specimen work. Metamorphic textures are quite varied, capable of recording a complex interplay between deformation and crystallization. In the present chapter we shall concentrate on hand-specimen description and classification, using only the textural features necessary to do so.

The IUGS-SCMR had recommended a flowchart and glossary for naming a metamorphic rock (Fettes and Desmons, 2007). Those desiring a more formalized and detailed approach are referred to that work. In what follows, I shall take a slightly simplified approach that should work for all but the most unusual specimen. Rocks that are only slightly metamorphosed and dominated by the original igneous or sedimentary textures are typically named for the protolith with the prefix "meta-" (e.g., meta-siltstone, meta-basalt). In the simplest and most general sense, for a more clearly metamorphosed rock, we approach naming it by first deciding if it is a high-strain rock or not. The decision may require thin section and/or field relationships to help us decide. High-strain rocks have their own classification scheme (Section 5). If a rock is not high strain, we must next observe whether the rock is foliated/lineated. If the rock is not high strain but is foliated, we determine the nature of the foliation and call the rock a slate, phyllite, schist, or gneiss. If the rock is non-foliated, we call it a granofels (or hornfels; the distinction is explained further below).

The foregoing simple classification would cover virtually all metamorphic rocks, but the categories are much too broad to provide a satisfactory subdivision that imparts much useful information. Knowing that a rock is a schist does not really give you an adequate picture of the nature of the rock other than that it is foliated and fairly fine grained. To improve this situation, we may want to add a few mineral and/or textural modifiers (such as "staurolite–kyanite schist," or "andalusite spotted hornfels") to convey some further information about a rock's composition or texture. When we do so, it is good to have some general guidelines. For example, is there more staurolite or more kyanite in a staurolite–kyanite schist? In what order do we place them? There must be other minerals in such a schist, why not name them all? What textural information should one include? Some of these decisions are left to our own judgment and the information that we want to convey; others have been more formalized. In addition, there are a number of metamorphic rock types that are so common that we have specific names for them. These names usually take precedence over our simple foliated versus non-foliated scheme above. For example, metamorphosed quartz sandstone and limestone are rarely foliated and are called quartzite and marble, respectively, instead of quartz granofels or calcite granofels. We would probably call them the same thing even if foliated (although we might add a modifier, such as "schistose marble"). We shall have to become familiar with these special names if we are to develop a comprehensive system for naming metamorphic rocks that conforms with common practice.

1 FOLIATED AND LINEATED ROCKS

Foliation and **lineation** refer to planar and linear fabric elements, respectively, in a rock and have no genetic connotations. Some high-strain rocks may also be foliated, but, as mentioned above, these are treated separately. In the next chapter we shall discuss the textures in more detail, including mechanisms by which they may have been generated. For now we shall discuss the textures only to the extent that we can identify them and use them to aid in classification. Rocks with multiple foliations and/or lineations are also possible.

Minerals may exhibit a preferred orientation in two ways. **Dimensional preferred orientation (DPO)** is the more obvious, meaning that some minerals are either platy or elongated, and aligned such that one can easily see the parallelism of shapes. **Lattice preferred orientation (LPO)** is a preferred orientation of crystallographic elements (most commonly crystallographic axes). Of course when phyllosilicates are aligned so that the plates are coplanar, their c-axes are also parallel, so LPO usually accompanies DPO. Some minerals, however, rarely exhibit good crystal shapes in metamorphic rocks, yet may still have a lattice preferred orientation of crystallographic elements. Quartz and olivine are two notable examples of minerals that typically appear granular, thus lacking a dimensional orientation, yet may have a lattice-preferred orientation. Determining such a crystallographic alignment requires some tedious labor using a petrographic microscope and a universal stage. We shall restrict our present discussion to DPO and things that we can see in hand specimen.

In general, foliations in non-high-strain rocks are caused by orogeny and regional metamorphism, and the type of foliation varies with metamorphic grade. In order of increasing grade, they are:

> ***Cleavage.*** Traditionally: the property of a rock to split along a regular set of subparallel, closely spaced planes. A more general concept adopted by some geologists is to consider cleavage to be any type of foliation in which the aligned platy phyllosilicates are too fine grained to see individually with the unaided eye.
>
> ***Schistosity.*** A preferred orientation (DPO) of inequaint mineral grains or grain aggregates produced by metamorphic processes. Aligned minerals are coarse grained enough to see with the unaided eye. The orientation is generally planar, but linear orientations are not excluded.
>
> ***Gneissose structure.*** Either a poorly developed schistosity or segregation into layers by metamorphic processes. Gneissose rocks are generally coarse grained.

The rock names that follow from these textures are given below. Again, these names are listed in a sequence that generally corresponds with increasing grade:

> ***Slate.*** Figure 1a. A compact, very fine-grained, metamorphic rock with a well-developed cleavage. Freshly cleaved surfaces are dull. Slates look like shales, but have a more ceramic ring when struck with a hammer.
>
> ***Phyllite.*** Figure 1b. A rock with a schistosity in which very fine phyllosilicates (sericite/phengite and/or chlorite), although rarely coarse enough to see unaided, impart a silky sheen to the foliation surface. Phyllites with both a foliation and lineation (typically crenulated fold axes) are very common.
>
> ***Schist.*** Figure 1c. A metamorphic rock exhibiting a schistosity. By this definition, schist is a broad term, and slates and phyllites are also types of schists. The more specific terms, however, are preferable. In common usage, schists are restricted to those metamorphic rocks in which the foliated minerals are coarse enough to see easily in hand specimen.
>
> ***Gneiss.*** Figure 1d. A metamorphic rock displaying gneissose structure. Gneisses are typically layered (also called banded), generally with alternating felsic and darker mineral layers. Gneisses may also be lineated, but must also show segregations of felsic-mineral-rich and dark-mineral-rich concentrations. Gneissic layers or concentrations need not be laterally continuous.

2 NON-FOLIATED AND NON-LINEATED ROCKS

This category is simpler than the previous one. Again, this discussion and classification applies only to rocks that are not produced by high-strain metamorphism. A comprehensive term for any isotropic rock (a rock with no preferred orientation) is a **granofels**. **Granofels(ic) texture** is then a texture characterized by a lack of preferred orientation. An outdated alternative is *granulite*, but this term is now used to denote very high-grade rocks (whether foliated or not) and is not endorsed here as a synonym for granofels. A **hornfels** is a type of granofels that is typically very fine grained and compact, and it occurs in contact aureoles. Hornfelses are tough and tend to splinter or display conchoidal fracture when broken. (The SCMR allows that hornfelses may be of any grain size.)

As we shall see in the next chapter, many metamorphosed rocks experience more than one deformational and/or metamorphic event. Such **polymetamorphosed** rocks typically exhibit the overprinted effects of the successive events.

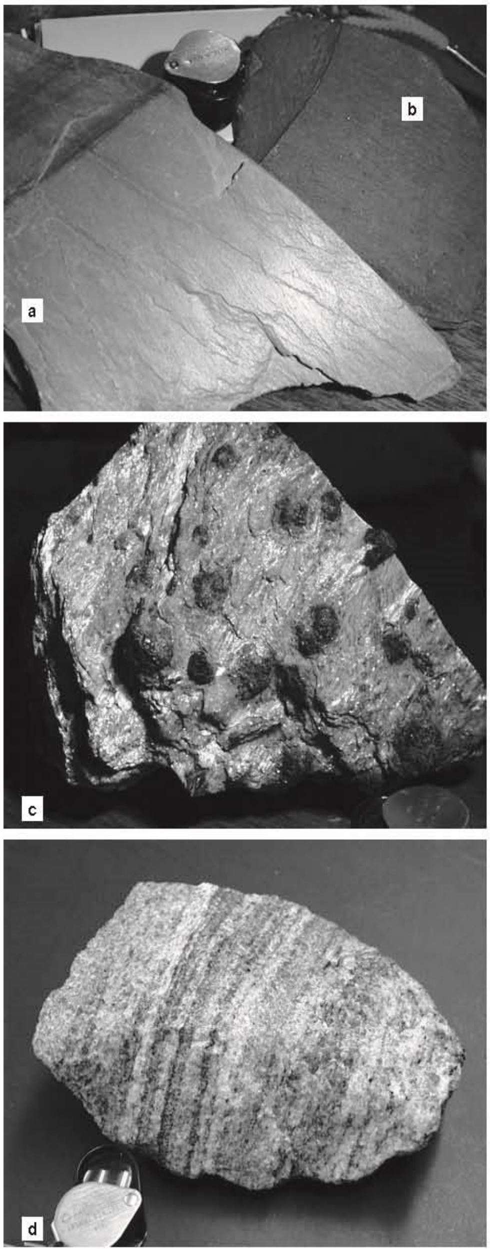

FIGURE 1 Examples of foliated metamorphic rocks. (a) Phyllite. (b) Slate. Note the difference in reflectance on the foliation surfaces between a and b: phyllite is characterized by a satiny sheen. (c) Garnet muscovite schist. Muscovite crystals are visible and silvery, garnets occur as large dark porphyroblasts. (d) Quartzo-feldspathic gneiss with obvious layering.

3 SPECIFIC METAMORPHIC ROCK TYPES

As mentioned above, some rock types are sufficiently common that they have been given special names, typically based on a common and specific protolith, but many also imply a specific range of metamorphic grade. It is also proper to name a metamorphic rock by adding the prefix meta- to a term that indicates the protolith, such as metapelite, meta-ironstone, etc.

The commonly used names that specify a particular rock type are listed below. As a rule, these names take precedence over the textural names described above:

Marble. A metamorphic rock composed predominantly of calcite or dolomite. The protolith is typically limestone or dolostone.

Quartzite. A metamorphic rock composed predominantly of quartz. The protolith is typically sandstone. Some confusion may result from the use of this term in sedimentary petrology for a pure quartz sandstone.

Greenschist/greenstone. A low-grade metamorphic rock that typically contains chlorite, actinolite, epidote, and albite. Note that the first three minerals are green, which imparts the color to the rock. Such a rock is called greenschist if foliated and greenstone if not. The protolith is either a mafic igneous rock or graywacke.

Amphibolite. A metamorphic rock dominated by hornblende + plagioclase. Amphibolites may be foliated (gneissose) or non-foliated. The protolith is either a mafic igneous rock or graywacke.

Serpentinite. An ultramafic rock metamorphosed at low grade, so that it contains mostly serpentine.

Blueschist. A blue-amphibole-bearing metamorphosed mafic igneous rock or mafic graywacke. This term is so commonly applied to such rocks that it is even applied to non-schistose rocks. Glaucophane is the most common blue amphibole, and *glaucophane schist* has been commonly applied to rocks known to contain it.

Eclogite. A green and red metamorphic rock that contains clinopyroxene and garnet (omphacite + pyrope). The protolith is typically basaltic. Eclogites contain no plagioclase.

Calc-silicate rock (granofels or schist). A rock composed of various Ca-Mg-Fe-Al silicate minerals, such as grossular, epidote, tremolite, vesuvianite, etc. The protolith is typically a limestone or dolostone with silica either originally present as clastic grains or introduced metasomatically.

Skarn. A calc-silicate rock (see immediately above) formed by contact metamorphism and silica metasomatism from a pluton into an adjacent carbonate rock. **Tactite** is a synonym.

Granulite. A high-grade rock of pelitic, mafic, or quartzo-feldspathic parentage that is predominantly composed of OH-free minerals. Muscovite is absent, and plagioclase and orthopyroxene are common.

Migmatite. A composite silicate rock that is heterogeneous on the 1- to 10-cm scale, commonly having a dark gneissic matrix (melanosome) and lighter felsic portions (leucosome). Migmatites may appear layered, or the leucosomes may occur as pods or form a network of cross-cutting veins.

For a more comprehensive description of these rock types and their textures, see Chapter 2 of Shelley (1993) or several chapters and the glossary in Fettes and Desmons (2007). Any of these terms, or a term indicating the protolith, may be combined with the textural classification terms if it helps describe a rock more fully. One may choose to use either term as a modifier (e.g., *schistose amphibolite, amphibolitic schist, pelitic schist, phyllitic meta-tuff*, etc.).

4 ADDITIONAL MODIFYING TERMS

Remembering that the main purpose of naming a rock is to impart information about the nature of the rock to others, you can add modifying terms to the above list as you see fit. Aspects of a rock to consider include the mineralogy, structure, protolith, chemical composition, and metamorphic grade or conditions. For example, if you want to emphasize some structural aspect of the rock, you may add terms such as lineated, layered, banded, or folded. **Porphyroblastic** means that a metamorphic rock has one or more metamorphic minerals that grew much larger than the others. Each individual crystal is a **porphyroblast**. If you want to call attention to this texture in a sample, you may use a name such as *kyanite porphyroblast schist*. Some porphyroblasts, particularly in low-grade contact metamorphism, occur as ovoid **spots**. If such spots occur in a hornfels or a phyllite (typically as a contact metamorphic overprint over a regionally developed phyllite), the term **spotted hornfels** or **spotted phyllite** would be appropriate. Some gneisses have large eye-shaped grains (commonly feldspar) that are derived from preexisting large crystals by shear. Individual grains of this sort are called **auge** (German for *eye*), and the (German) plural is **augen**. An **augen gneiss** is a gneiss with augen structure.

Other modifying terms that we may want to add as a means of emphasizing some aspect of a rock may concern such features as grain size, color, and chemical aspects (aluminous, calcareous, mafic, felsic, etc.). As a general rule, we use these when the aspect is unusual. Obviously a *calcareous marble* or *mafic greenschist* is redundant, as is a *fine-grained slate*.

Two common prefixes that pertain to protolith are the terms ortho- and para-. **Ortho-** indicates an igneous parent, and **para-** indicates a sedimentary parent. The terms are used only when they serve to dispel doubt. For example, many quartzo-feldspathic gneisses could easily be derived from either an impure arkose or a granitoid rock. If some mineralogical, chemical, or field-derived clue permits the distinction, terms such as *orthogneiss, paragneiss,* or *orthoamphibolite* may be useful.

Although textural criteria are commonly emphasized in metamorphic rock names, it may be desirable to include some information about the mineralogy of a metamorphic rock in the name as well. The mineralogical classification of metamorphic rocks is much less formally defined than that of igneous rocks. One would include mineral-content modifiers when they are significant in terms of content or as indicators of grade (such as an index mineral). The number of minerals listed depends on the intent and emphasis of the project. If, for example, an investigator wants to distinguish metamorphosed pelitic sediments on the basis of composition, she may choose a longer list of minerals in the names. If the objective is to emphasize metamorphic grade, however, she may elect to include only the index minerals. The SCMR recommends listing all major minerals in a rock. By convention, minerals are listed in the order of *increasing* modal abundance in a rock.

5 HIGH-STRAIN ROCKS

Table 1 shows a simple scheme for classifying dynamically metamorphosed rocks associated with fault zones (including more ductile shear zones). For the moment, we shall consider the terms as purely descriptive, so that we can use Table 1 to readily identify high-strain rocks based on observed textural criteria in hand specimen and thin section. We shall discuss the processes involved in more detail in the next chapter. To name a high-strain rock, one must determine whether the rock is cohesive or whether it falls apart and then estimate the relative proportions of large clasts versus fine matrix (presumably derived mechanically from the once-larger clasts). A rock without cohesion is either a **fault breccia** or **fault gouge** (left column of Table 1). Such cohesionless rocks are typically restricted to very shallow crustal levels. Gouge is usually altered by groundwater to a clay-rich matrix.

Cohesive rocks are further distinguished by being either foliated or non-foliated, both of which are usually more fine-grained than the non-cohesive varieties. Non-foliated

TABLE 1 Classification of High-Strain Fault Zone Rocks

% fine matrix	Rocks without primary cohesion	Rocks with primary cohesion			
		Non-foliated	Foliated		Glass in matrix
	Fault breccia	Microbreccia	Protomylonite	Blastomylonite (if significantly recrystallized)	Pseudotachylite
50			Mylonite		
70	Fault gouge	Cataclasite			
90			Ultramylonite		

After Higgins (1971)

cohesive rocks are either **microbreccias** (<70% clasts) or **cataclasites** (>70% clasts). Foliated cohesive rocks are **mylonites** and are subdivided as shown in the third column of Table 1. Some geologists use the term **phyllonite** to indicate a mica-rich mylonite. As with practically any other classification, all the categories in Table 1 are gradational.

Virtually all high-strain processes involve grain size reduction. The degree of recrystallization in the matrix is not a factor unless it is very advanced (perhaps aided by a later metamorphic event). The prefix **blasto-** is then added, meaning that the mylonitic texture is still apparent but largely inherited from an earlier high-strain event. In high-strain rocks, the prefix blasto- is usually restricted to foliated rocks because a recrystallized cataclasite may be difficult to recognize without the foliation as a clue. In extreme cases of high-strain deformation, thin, commonly anastomosing seams of glassy rock, known as **pseudotachylite** (Shand, 1916), are generated. The glass is attributed to melting due to frictional heat.

Figure 2 shows the common distribution of fault-related rock types with depth. In shallow areas, the fault zone is narrower and involves more brittle behavior, resulting in anastomosing faults containing rocks that commonly lack cohesion (breccia and gouge). Below this zone, the confining pressure forces the walls of the fault together and deformation becomes more thorough and pervasive so that the constituents become finer. The rocks thus grade downward into cataclasites and microbreccias, occasionally with pseudotachylites. Deeper yet, the rocks take on a foliated character, and recrystallization accompanies deformation, producing mylonites. The processes will be discussed in more detail in the next chapter. The width of the shear zone increases with depth and becomes both more ductile and more evenly distributed throughout the rock matrix. At the greatest depths, the shear is distributed over a wide area and is not very intense at any single place. The rocks are ductile, and gneisses generally develop that are indistinguishable from gneisses of regional orogenic metamorphism.

The terminology for high-strain rocks is complicated by recent advances in our understanding of the deformation processes involved in their generation. The classification in Table 1 was developed before our modern understanding of the importance of recrystallization and the ductile processes that commonly accompany shear-zone deformation. It suffers from using terms that have genetic implications of purely brittle behavior. The term **cataclasis**, as originally conceived, refers to a process of mechanical crushing and granulation of a rock and its mineral constituents (with no accompanying recrystallization). This was once generally accepted as the predominant process operating in most fault and shear zones. **Cataclastic** is an adjective form used to describe the processes and textures resulting from cataclasis. Lapworth (1885) first used the term **mylonite** to describe a fine-grained laminated rock from the Moine Thrust of Scotland. The term was derived from the Greek word *mule*, for mill, meaning "to grind." Although cataclasis is clearly the dominant process acting in shallow brittle fault zones, resulting in broken up fault gouges and breccias, this is usually not the case at even a modest depth.

Figure 2 indicates that purely mechanical grinding in fault zones quickly gives way with depth to processes that combine brittle deformation with recrystallization.

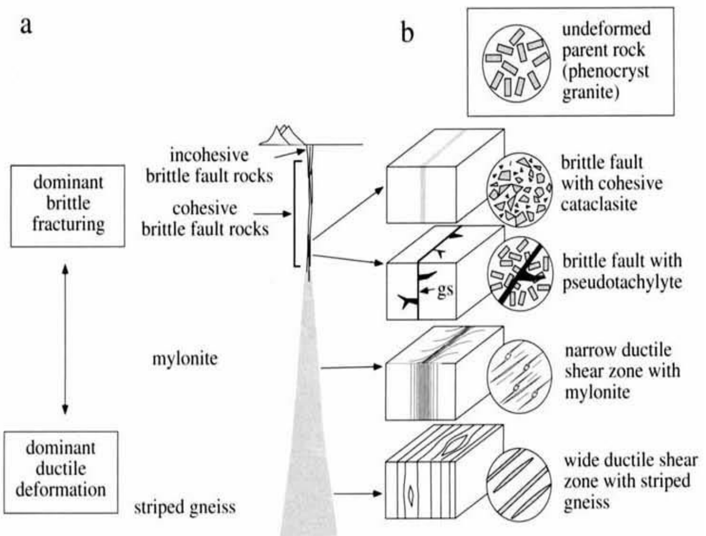

FIGURE 2 Schematic cross section through a shear zone, showing the vertical distribution of fault-related rock types, ranging from non-cohesive gouge and breccia near the surface through progressively more cohesive and foliated rocks. Note that the width of the shear zone increases with depth as the shear is distributed over a larger area and becomes more ductile. Circles on the right represent microscopic views or textures. From Passchier and Trouw (2005). Copyright © with permission from Springer-Verlag.

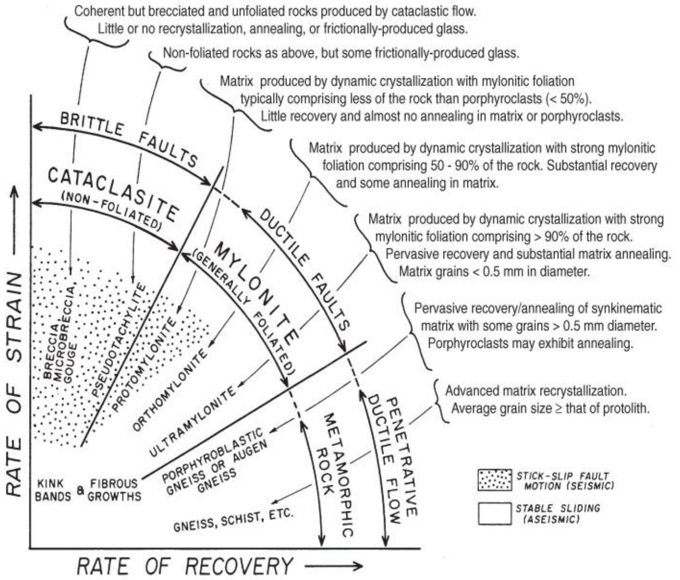

FIGURE 3 Terminology for high-strain shear-zone related rocks proposed by Wise et al. (1984). Copyright © The Geological Society of America, Inc.

Deformation increases the energy of strained crystal lattices and enhances recrystallization. Only a small amount of heat may be sufficient to permit recrystallization of the small strained grains produced by high degrees of shear. Our understanding of mylonites advanced significantly due to the work of Bell and Etheridge (1973), who demonstrated that the processes involved in the production of mylonites were ductile processes (rapid strain recovery and recrystallization), not mere brittle crushing. Although our understanding improved, our terminology did not because the roots of the terms cataclasite and mylonite had direct implications of purely cataclastic processes.

Attempts to remedy this situation and avoid using terms in ways contrary to their original intent have thus far traded one problem for another. Figure 3 is a classification proposed by Wise et al. (1984). These workers clearly recognized that deformation in shear zones commonly involves coeval deformation and recovery–recrystallization processes, and they attempt to relate these processes in a clear fashion by comparing the rate of strain versus the rate of recovery. Although I can appreciate the attempt to understand the processes involved and relate them to the products, it is very difficult to infer the rates of strain versus recovery from a rock in hand specimen. We have thus traded a classification that we can easily use for one that we can't easily use, but is based on a better understanding of the processes and involves less misuse of terms. I prefer to have a classification that is easy to use, so I choose Table 1 for naming a shear-related rock and refer to Figure 3 for an understanding of how the processes of deformation and recovery relate to the continuous spectrum of rock types from truly cataclastic fault breccias to well-recrystallized schists. Several of the terms used in the figure are discussed in the next chapter, so it may be a more useful reference for you after you have read further and return to when addressing hand specimens.

Perhaps we can use Table 1 and discuss the rock types and processes if we use the terms *cataclasite* and *mylonite* in a purely descriptive sense. Bell and Etheridge (1973), among others, have advocated that we redefine the term *mylonite* to strip it of any genetic implications. Remembering the root of the term, this makes it a bit of a

FIGURE 4 Shatter cones in limestone from the Haughton Structure, Northwest Territories. Sample is ~9 cm across. Photograph courtesy of Richard Grieve © Natural Resources Canada.

misnomer, but I think it is a fair compromise. Sixty-one participants at a 1981 Penrose Conference on mylonitic rocks generally agreed, although not unanimously, that mylonites should occur in a relatively narrow zone (< a few tens of kilometers wide), involve grain-size reduction, and have a distinct foliation and/or lineation (Tullis et al., 1982). Purely brittle behavior was no longer required. Likewise, a cataclasite may have some accompanying recrystallization and may thus not be purely cataclastic.

Impact rocks are a separate category of high-strain rocks and do not really lend themselves to classification using Table 1. Impacts are catastrophic events, producing shock waves and raising the temperature at impact to thousands of degrees, melting (and even vaporizing) some minerals. The rocks can all be called **impactites**. All impactites are breccias and have characteristic field settings (impact crater and ejecta blanket, if preserved) and textural features, such as shocked crystals (highly deformed lattices, commonly with multiple sets of planar deformation features), and amorphous glassy phases. High-pressure silica polymorphs, such as coesite and stishovite, may be present. Impact areas may have macroscopic nested cone-like structures called shatter cones (Figure 4). See Hibbard (1995) and IUGS-SCMR (Fettes and Desmons, 2007, which had a subcommittee working on a classification of impact-related rocks) for descriptions.

Summary

Assigning a name to a metamorphic rock involves the following steps:

1. Is the rock only slightly metamorphosed and dominated by the original igneous or sedimentary textures? If so, name if after the protolith, with the prefix "meta-" (e.g., meta-conglomerate). If not, proceed.
2. Is the rock a high-strain rock? If so, use Table 1. If not, proceed.
3. Is the rock foliated? If so, name it a slate, phyllite, schist, or gneiss, based on the nature of the foliation. Add appropriate mineral constituents (in order of increasing abundance). If not, proceed.
4. Non-foliated rocks are granofelses (or hornfelses), also with appropriate mineral names.
5. Would one of the more specific terms in Section 3 be more appropriate or informative?
6. Is there any other information that would be useful or that you would like to emphasize, based on mineralogy, structure, protolith, chemical composition, and metamorphic grade or conditions?

Key Terms

Metamorphic rock names
Dimensional preferred orientation (DPO)
Lattice preferred orientation (LPO)
Cleavage
Schistosity
Gneissose structure
Porphyroblast/spot
Augen
Ortho-/para-

Review Questions

Review Questions are located on the author's web page at the following address: **http://www.prenhall.com/winter**

Important "First Principle" Concept

- Metamorphic rock names are not as rigidly prescribed as are igneous names. Remember, you are trying to convey information about the rock, so a good name is one that describes the rock well.

Suggested Further Readings

Fettes, D., and J. Desmons (eds.). (2007). *Metamorphic Rocks: A Classification and Glossary of Terms. Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks.* Cambridge University Press. Cambridge, UK.

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