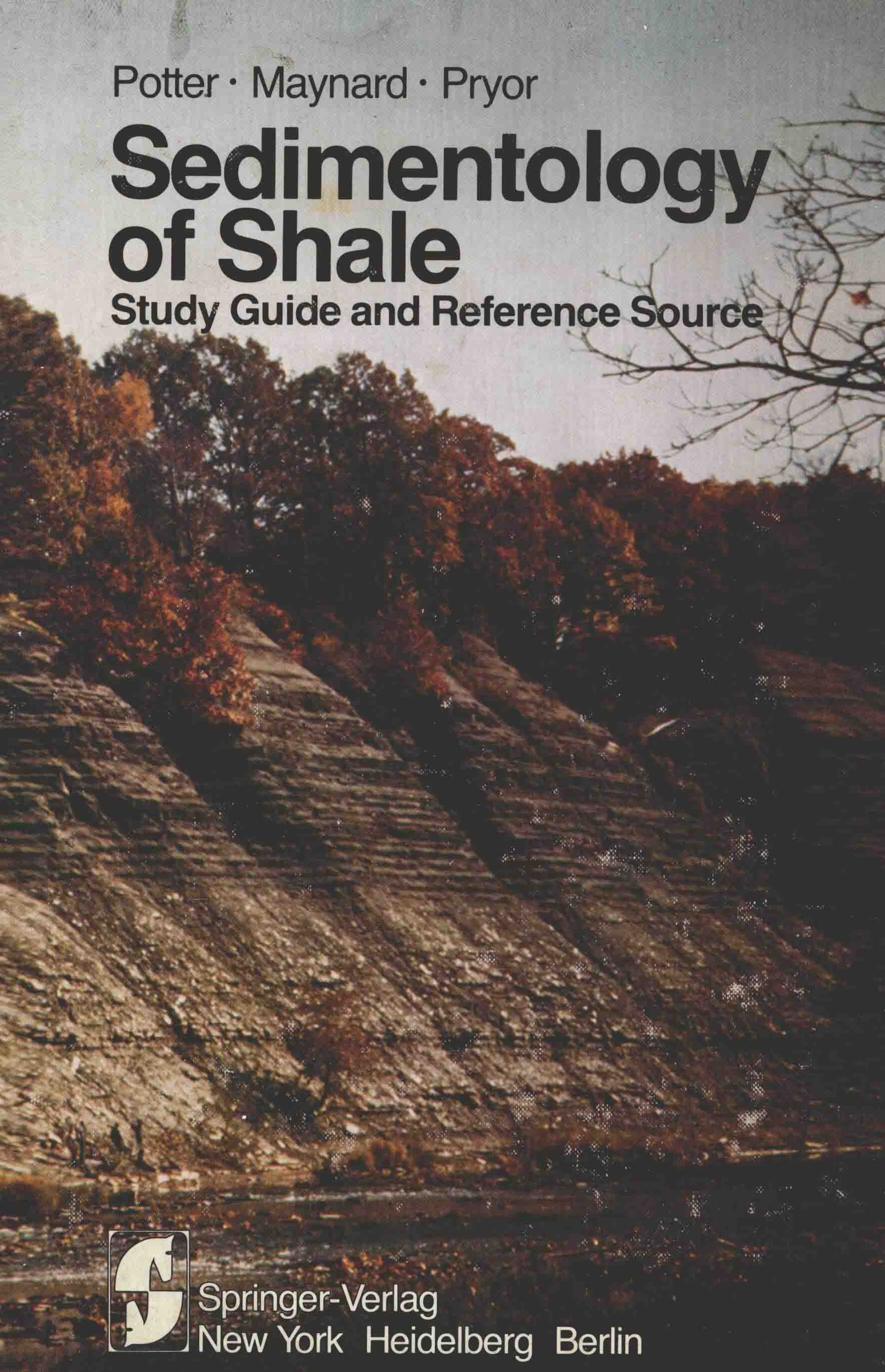
Potter · Maynard · Pryor

# Sedimentology of Shale

## Study Guide and Reference Source



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With 154 Figures and a Colored Insert

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# Preface

We wrote *Sedimentology of Shale* primarily because we lacked a handy, reasonably comprehensive source of information and ideas about shales for students in our sedimentology program. It was also our feeling that the time for shales to receive more study had finally arrived. *Sedimentology of Shale* also seems very timely because today more sedimentologists are interested in shales. Certainly in the last five years the pace of shale research has noticeably quickened because the role of shales as important sources of oil, gas, heavy metals and as a long understudied part of the earth's geologic history has been recognized. Noteworthy developments include the elucidation of the importance of trace fossils in shales, the discovery of thick sequences of overpressured shales in regions such as the Gulf Coast (which have important implications for hydrocarbon migration and faulting), the extension of the principles of metamorphic facies to the realm of low temperature diagenesis by study of the organic matter in shales, and shales as ultimate sources for mineral deposits.

Accordingly, we decided it was timely to write a book on shales. In one respect, however, ours is an unusual book. Most books in geology are produced after one or two decades of progress have been made in a field and attempt to summarize and evaluate that progress. Our book looks in the foreward direction; instead of summarizing what is well understood about shales, much of our effort has gone into identifying *approaches* to shale problems that we think will be fruitful, and in addition we have emphasized areas of uncertainty.

Chapter 1 provides an overview of the major aspects of shales; including sedimentary processes; physical, chemical and biological properties of shales; and the distribution of shales in modern and ancient basins. Chapter 2, the question set, is in effect a self-study guide, one that not only asks questions but also provides the motivation of *why* the question should be asked. In other words, Chapter 2 is a short manual on *how to study* shales. Chapter 3 is an annotated and illustrated guide to much of the literature. Thus the three chapters are study and reference guides and should provide a basis for students and professionals alike to discover the many interesting, diverse facets of shales. Ultimately, we hope *Sedimentology of Shale* will promote new models for the study of shales.

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Cincinnati, Ohio
Summer 1980

Paul Edwin Potter
J. Barry Maynard
Wayne A. Pryor

# Abbreviations of Rocks and Fossils*

| | |
|---|---|
| @ | At |
| abnt | Abundant |
| abv | Above |
| acic | Acicular |
| Alg | Algae (al) |
| amor | Amorphous |
| ang | Angular |
| anhed | Anhedral |
| anhy | Anhydrite (ic) |
| app | Appear |
| aprox | Approximate (ly) |
| arg | Argillaceous |
| argl | Argillite |
| ark | Arkose (ic) |
| asph | Asphalt (ic) |
| | |
| bar | Barite (ic) |
| bd (d) | Bed (ded) |
| bdeye | Birdseye |
| bdg | Bedding |
| bent | Bentonite (ic) |
| bf | Buff |
| biocl | Bioclastic |
| bioturb | Bioturbated |
| bit | Bitumen (inous) |
| bl | Blue (ish) |
| bldr | Boulder!(256 mm + ) |
| blk | Black |
| blky | Blocky |
| bnd | Band (ed) |
| Brac | Brachiopod |
| brgh | Branching |
| brec | Breccia (ted) |
| bri | Bright |
| brit | Brittle |
| brd | Bored |
| brn | Brown |
| bulb | Bulbous |
| bur | Burrowed |
| | |
| c | Coarse (ly) |
| calc | Calcite (areous) |
| carb | Carbonaceous |
| *Casph* | *Calcisphaera* |
| cbl | Cobble !64-256 mm) |
| Ceph | Cephalopod |
| cgl | Conglomerate |
| chal | Chalcedony |
| Chara | Charophytes |
| chit | Chitin (ous) |
| chk | Chalk (y) |
| chlor | Chlorite |
| cht (y) | Chert (y) |
| Chtz | Chitinozoa |
| cl | Clastic |
| clr | Clear |
| clus | Cluster |
| cly | Clay (ey) |
| clyst | Claystone |
| cmt | Cement (ed) |
| cncn | Concentric |
| col | Color (ed) |
| com | Common |
| conc | Concretion (ary) |
| conch | Conchoidal |
| Cono | Conodont |

*Slightly condensed from a list of the American/Canadian Stratigraphic Company (Denver, Colorado and Calgary, Alberta) and published by their kind permission.

| | |
|---|---|
| coq | Coquina |
| Cor | Coral |
| crbnt | Carbonate |
| Crin | Crinoid (al) |
| crpxl | Cryptocrystalline |
| ctd | Coated |
| ctc | Contact |
| cvg | Cavings |
| deb | Debris |
| decr | Decrease (ing) |
| dend | Dendrite (ic) |
| dess | Desiccation |
| dism | Disseminated |
| dk | Dark (er) |
| dns | Dense (er) |
| dol | Dolomite (ic) |
| dolst | Dolostone |
| drsy | Druse (y) |
| dtrl | Detrital (us) |
| | |
| Ech | Echinoid |
| elg | Elongate |
| *Endo* | *Endothyra* |
| euhed | Euhedral |
| | |
| f | Fine (ly) |
| fau | Fauna |
| Fe | Iron-Ferruginous |
| Fe-mag | Ferro-magnesian |
| Fe-st | Ironstone |
| fib | Fibrous |
| fis | Fissile |
| fld | Feldspar (thic) |
| flk | Flake (y) |
| flor | Fluorescence |
| flt | Fault (ed) |
| ltg | Floating |
| fnt | Faint (ly) |
| Foram | Foraminifera |
| fos | Fossil (iferous) |
| fr | Fair |
| frac | Fracture (ed) |
| frag | Fragment (al) |
| fri | Friable |
| frmwk | Framework |
| fros | Frosted |
| Fus | Fusulinid |
| | |
| g | Good |
| Gast | Gastropod |
| gil | Gilsonite |
| gl | Glass (y) |
| glau | Glauconite (ic) |
| *Glob* | *Globigerina* |
| glos | Gloss (y) |
| gn | Green |
| gr | Grain (ed) |
| gran | Granular |
| Grap | Graptolite |
| grd | Grade (ed) |
| grdg | Grading |
| grnl | Granule |
| grnt | Granite |
| grnt.w | Granite wash |
| gsy | Greasy |
| gy | Gray |
| gyp | Gypsum (iferous) |
| gywk | Graywacke |
| | |
| hd | Hard |
| hem | Hematite (ic) |
| hex | Hexagonal |
| hrtl | Horizontal |
| hvy | Heavy |
| hydc | Hydrocarbon |
| | |
| ig | igneous |
| imbd | Imbedded |
| imp | Impression |
| incl | Included (sion) |
| incr | increase (ing) |
| ind | Indurated |
| indst | Indistinct |
| intbd | Interbedded |
| intcl | Intraclast (s) |
| intfrag | Interfragmental |
| intgran | Intergranular |
| intgwn | Intergrown |
| intlam | Interlaminated |
| intpt | Interpretation |
| intstl | Interstitial |
| intv | Interval |
| intxl | Intercrystalline |
| ireg | Irregular |
| irid | Iridescent |
| | |
| kao | Kaolin |
| | |
| lam | Laminated |
| lchd | Leached |

| | |
|---|---|
| len | Lentil (cular) |
| lig | Lignite (ic) |
| lith | Lithographic |
| lmn | Limonite (ic) |
| lmpy | Lumpy |
| lmy | Limy |
| lrg | Large (er) |
| ls | Limestone |
| lstr | Lustre |
| lt | Light (er) |
| | |
| m | Medium |
| magn | Magnetic |
| magnt | Magnetite |
| mar | Maroon |
| mas | Massive |
| mat | Material, matter |
| meta | Metamorphic |
| mica | Mica (eous) |
| mic | Micro |
| mnr | Minor |
| mnrl | Mineral (ized) |
| mnut | Minute |
| Mol | Mollusca |
| mot | Mottled |
| mrlst | Marlstone |
| mrly | Marly |
| msm | Metasomatic |
| mtx | Matrix |
| musc | Muscovite |
| | |
| n | No, none |
| nod | Nodule |
| num | Numerous |
| | |
| o | Oil |
| och | Ochre |
| od | Odor |
| olvn | Olivine |
| onc | Oncolites |
| ooc | Oocast (ic) |
| ool | Oolite (ic) |
| oom | Oomold (ic) |
| op | Opaque |
| org | Organic |
| orng | Orange |
| orth | Orthoclase |
| Ost | Ostracod |
| ovgth | Overgrowth |
| ox | Oxidized |

| | |
|---|---|
| p | Poor (ly) |
| pbl | Pebble |
| pel | Pellet |
| perm | Permeability |
| pet | Petroleum (iferous) |
| phos | Phosphate (ic) |
| piso | Pisolite (ic) |
| pit | Pitted |
| pk | Pink |
| plas | Plastic |
| Plcy | Pelecypod |
| pl | Plant |
| pity | Platy |
| pol | Polish (ed) |
| por | Porous (sity) |
| pos | Possible (ility) |
| p-p | Pin point |
| pred | Predominant (ly) |
| pres | Preserved (ation) |
| prim | Primary |
| pris | Prism (atic) |
| prly | Pearly |
| prob | Probable (ly) |
| prom | prominent (ly) |
| psdo | Pseudo |
| pt | Part (ly) |
| ptch | Patch (es) |
| ptg | Parting |
| pyr | Pyrite (ic (ized) |
| pyrbit | Pyrobitumen |
| | |
| qtz (c) | Quartz (itic) |
| qtzs | Quartzose |
| qtzt | Quartzite |
| | |
| rad | Radiate (ing) |
| rd | Round (ed) |
| repl | Replaced (ing) (ment) |
| resd | Residue (al) |
| rexl | Recrystallize (ation) |
| rhmb | Rhomb (ic) |
| rmn | Remains (nant) |
| rr | Rare |
| rsns | Resinous |
| rthy | Earthy |
| | |
| s | Small |
| sa | Salt |
| sa-c | Salt cast (ic) |
| S | Sulphur |

| | |
|---|---|
| sat | Saturated |
| sb | Sub |
| sc | Scales |
| scat | Scattered |
| sch | Schist |
| sd | Sand (1/16-2 mm) |
| sdy | Sandy |
| sec | Secondary |
| sed | Sediment (ary) |
| sel | Selenite |
| sept | Septate |
| sft | Soft |
| sh | Shale |
| shy | Shaly |
| sid | Siderite (ic) |
| sil | Silica (eous) |
| sks | Slickensided |
| sl | Slight (ly) |
| sln | Solution |
| slky | Silky |
| slt | Silt |
| sltst | Siltstone |
| slty | Silty |
| sm | Smooth |
| sol | Solitary |
| sp | Spot (ted) (ty) |
| spec | Speck (led) |
| Spg | Sponge |
| sph | Spherules |
| sphal | Sphalerite |
| spic | Spicule (ar) |
| spl | Sample |
| splty | Splintery |
| Spr | Spore |
| srt | Sort (ed) (ing) |
| ss | Sandstone |
| stmg | Streaming |
| stn | Stain (ed) (ing) |
| str | Streak |
| strg | Stringer |
| stri | Striated |
| Strom | Stromatoporoid |
| stromlt | Stromatolite |
| struc | Structure |
| styl | Stylolite (ic) |
| *Stylio* | *Styliolina* |
| suc | Sucrosic |
| sug | Sugary |
| surf | Surface |
| sy-Ca | Sparry calcite |
| sz | Size |
| tab | Tabular |
| *Tas* | *Tasmanites* |
| *Tent* | *Tentaculites* |
| tex | Texture |
| thk | Thick |
| thn | Thin |
| thru | Throughout |
| tr | Trace |
| trip | Tripoli (ic) |
| trnsl | Translucent |
| trnsp | Transparent |
| tt | Tight (ly) |
| tub | Tubular |
| tuf | Tuffaceous |
| uncons | Unconsolidated |
| unident | Unidentifiable |
| v | Very |
| var | Variable |
| vcol | Varicolored |
| ves | Vesicular |
| vgt | Varigated |
| vit | Vitreous |
| vn | Vein |
| volc | Volcanics |
| vrtl | Vertical |
| vrvd | Varved |
| vug | Vug (gy) (ular) |
| / | With |
| w | Well |
| wh | White |
| wk | Weak |
| wthrd | Weathered |
| wtr | Water |
| wvy | Wavy |
| wxy | Waxy |
| xbd | Cross-bedded (-bedding) |
| xl | Crystal (line) |
| xlam | Cross-laminated |
| yel | Yellow |
| zeo | Zeolite |
| zn | Zone |

# Contents

Possibly many may think that the deposition and consolidation of fine-grained mud must be a very simple matter, and the results of little interest. However, when carefully studied . . . it is soon found to be so complex a question, and the results dependent on so many variable conditions, that one might feel inclined to abandon the inquiry, were it not that so much of the history of our rocks appears to be written in this language.

H.C. Sorby

*On the Application of Quantitative Methods to the Study of the Structure and History of Rocks*, 1908, pp. 190–191.

# CHAPTER 1
# OVERVIEW

To see the whole of any subject is to see its future.

## INTRODUCTION

The study of shale—and we use shale as the generally accepted class name for all fine-grained argillaceous sediment, including mud, clay, and mudstone—can be approached from many points of view (Fig. 1.1), but most of the emphasis has generally been placed upon mineralogy and geochemistry, a possible exception being the study of microfauna in Tertiary and Mesozoic shales. As a consequence, much more is known about sandstones and carbonates and even evaporites than shales. As sedimentologists we have long had an interest in shales and are acutely aware of how far their study lags behind that of most other sediments. All too commonly shale has been the "interbedded" and "taken for granted" matrix between lithologies of greater scientific or economic interest, in spite of the fact that shale forms more than 60% of the world's sediments.

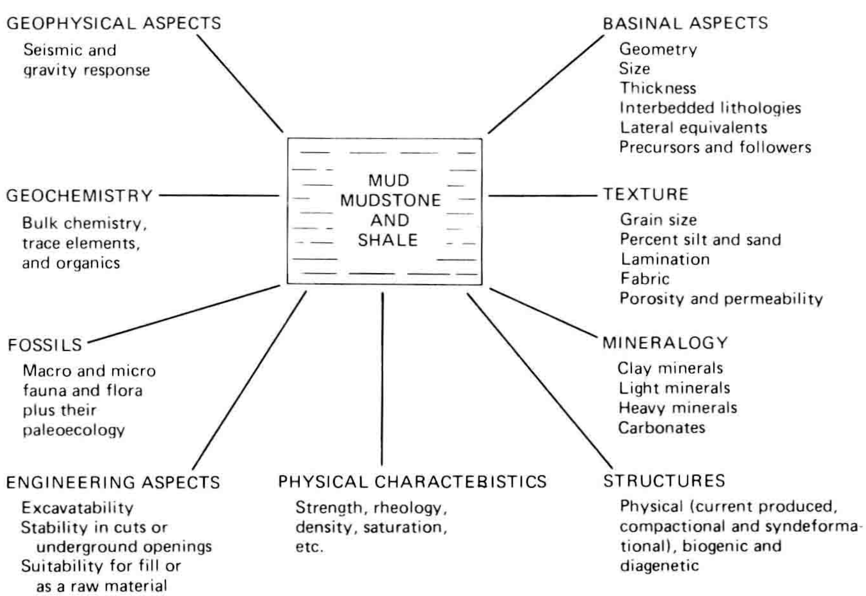


**Figure 1.1** Contributors to the study of shale.

The present attitude of many sedimentologists toward shales is well expressed by their typical representation of shales in vertical profiles which give much detail about the bedding type and thickness, directional structures, grain size, and fossil content of sandstone and carbonates but show mudstones and shales as *solid black*—a structureless, uninteresting, "matrix" interbedded and interlaminated between much more informative lithologies. It has been the experience of many sedimentologists that shales are hard to work with: they are very fine grained and lack the well-known sedimentary structures that are so useful in sandstones. Therefore many feel that work with shale has a low reward/investment ratio. However, is this because of the nature of shale, or is it because we lack readily applicable tools and models to study them? We and, indeed, an increasing number of sedimentologists believe that shales deserve much more attention and, when properly studied, can yield valuable additional insight into the origin of many sedimentary basins.

The natural question to ask is *why* the study of shales has lagged behind that of sandstones, carbonates, and even evaporites, coal, and sedimentary iron formation. Certainly the foremost reason is that shales, as a rule, are of lesser immediate economic interest. Beyond this practical reason, however, are at least four others:

1. Until very recently, it was almost impossible to identify and study *single particles* in most shales, especially the clay minerals, which predominate.
2. Many of these single particles that can now be defined by the scanning election microscope (SEM) have, unlike most quartz or skeletal carbonate grains, a complex history that to some degree reflects source area, possibly the depositional environment, and very probably postdepositional burial.
3. We are only beginning to recognize and interpret the equivalent of the "vertical environmental profile" that has been so spectacularly successful in the study of sandstones and carbonates in the last 10 years.
4. We rarely have an idea of the paleocurrent or paleocirculation systems that have existed during the deposition of most shales.

Of the above four factors that have retarded the study of shales, we believe our inability to *isolate, study, and write the history of single particles,* as has been done so well for most of the framework grains of sandstones and carbonates, is by far the most important. In other words, the complete history of a sedimentary deposit is far better based on the *summation of the histories of its individual particles than on measurement of bulk properties, such as chemical composition and clay* mineralogy. Such measurements average not only the different compositions of many different particles of diverse origins but also combine the effects of source area, depositional environment, and postdepositional change. In short, if sandstones and carbonates could only be studied by a listing of their bulk mineralogy and chemistry, it is clear that we would know little about them. However, assume for a moment that we could, indeed, obtain a "particle history" for shales. What would be the second task? Surely it would be finding an analog to the vertical profile, which for carbonates and sandstones integrates many diverse features into a coherent, useful environmental interpretation, based on bedding, texture, mineralogy, bioturbation, and fossils, and possibly even some geochemical parameters. The equivalent profile for shales will be based primarily on bedding (types, thickness, and degree of perfection), on bioturbation (kinds and abundance), on fossil content (kinds and abundance), and finally on the amount and type of organic matter. It seems to us that these four, along with supplementary evidence from associated lithologies, shale body geometry, bounding contacts, and position in the basin, are essential in developing a better environmental perception of shales. We suggest bedding, bioturbation, fossils, and organic geochemistry as the most useful because they most closely reflect the primary depositional processes of mud deposition. To this we would add information about paleocirculation based on evidence from directional structures of the minor sandstones and carbonates that are commonly associated with most shales or possibly from the orientation of silt, fragments of wood, and/or elongate fossils, such as graptolites, as was done very early by Ruedemann (1897) for the Ordovician Utica Shale of New York.

## SOURCES OF MUD

Terrigenous mud consisting of clay minerals as well as fine quartz and feldspar and detrital micas is mostly generated at the earth's surface by the erosion of preexisting muds, mudstones, and shales. We feel this is so, because shale alone forms 60% of the sedimentary section; moreover, sedimentary rocks themselves cover most of the earth's surface (Way 1973, p. 75). The ultimate source is the weathering of silicates formed at high pressures and temperatures and therefore mostly unstable at the earth's crust (Fig. 1.2). Another probable source, at least during the earth's major periods of glaciation, is abrasion by continental ice sheets and production of rock flour. Other sources include volcanic dust (perhaps a major source during the earth's earliest days) and dust from the deflation of continental deserts. Organisms that pulverize and ingest sediment are a very minor source of terrigenous mud.

Clay minerals form from the weathering of primary minerals in the following general way:

$$H^+ + \text{primary mineral} \rightarrow \text{intermediate clay mineral weathering products} + \text{solutions} \rightarrow \text{gibbsite} + \text{solutions}$$

For instance:

$$H^+ + \text{potash feldspar} \rightarrow \text{(sericite)} \rightarrow \text{montmorillonite} \rightarrow \text{kaolinite} \rightarrow \text{gibbsite}$$