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Studies on Ancient Rocky Shores: A Brief History and Annotated Bibliography

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ABSTRACT

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Both from an ecological and geomorphological stand point, studies on modern rocky shores are common place in the scientific literature. Published studies on ancient rocky shores through geologic time are still very rare by comparison. Review of the literature, however, shows the topic to be a fast growing discipline of potentially broad interest. The 155 research articles which comprise this annotated bibliography illustrate many different applications for data from ancient rocky shores. They include: paleogeographic mapping, bench mark for associated paleontological and sedimentological zonations, calculation of coastal uplift or subsidence rates, test for eustatic sea-level changes, comparative geomorphology of ancient rocky coasts, and development of the paleobiology and evolutionary history of rocky-shore biotas.

One of the earliest thinkers about ancient rocky shores was Benoit de Maillet, whose observations were published posthumously in 1748. During the late 18th, the 19th, and the early 20th centuries, work was refocused on the concept of geological unconformities. Major advancements were made by Antoine Lavoisier, James Hutton, John Playfair, Henry De La Beche, Andrew Ramsay, and Amadeus Grabau.

The first journal articles devoted to analysis of specific geological sites did not appear until after the turn of the 20th century. From 1905 to 1954, research papers were published sporadically at an average rate of 0.3/year. From 1955 to 1979, the flow of research quickened, with an average rate of 2.2 papers/year. The following five-year period 1980–1984 saw a doubling in rate to 4.6 papers/year. The rate doubled again to 9.4 papers/year during 1985–1989. Thus, the three consecutive half decades from 1975 to 1989 witnessed exponential growth in terms of published research. Examples of rocky shores from all geological periods in the Phanerozoic are represented by articles in the bibliography; the oldest known rocky shore from the Precambrian is 3.3–3.5 billion years old.

ADDITIONAL INDEX WORDS: *Unconformities, basal conglomerates, littoral zone, coastal terraces, wave-cut platforms.*

INTRODUCTION

The tremendous disparity between what is known about modern as opposed to ancient rocky shores may be encapsuled by the contents of two currently popular textbooks written for two very different audiences. With a long tradition beginning in 1939, the latest edition of *Between Pacific Tides* (RICKETTS *et al.*, 1985, p. 15) continues to advise young marine biologists that "From the standpoint of the field observer, the rocky tide flats of the protected outer coast are the most important of all seashore regions." Interpretation of the past through the familiarity of the present is a practice common among geologists. Young geologists, however, find little mention of rocky shores in the latest edition of *Sedimentary Environments of Facies* (READING, 1986). For that matter, no other contemporary textbook on sedimentology or stratigraphy will admit to the preservation of rocky-shore environments in the geologic record.

The pedagogic vacuum with respect to this topic in geology was not always so airtight. In one of the first great textbooks on stratigraphy, GRABAU (1913, pp. 646–651) devoted sections under the heading of "the littoral district and its deposits" to examples of "rocky cliff facies" and associated boulder beds. He later introduced the term "shantung" for a monadnock-like product of erosion drowned by sediments (GRABAU, 1940, p. 50). The name was derived from Shantung Province in China, where "rocky eminences" protrude from the flood plain of the Yellow River near its confluence with the sea. As part of his definition, GRABAU (1940, p. 50) drew clear parallels to rocky shores of Cambrian age: "Baraboo ridge of Wisconsin is an example of a 'shantung' which has now been partly re-exhumed, and Caradoc Mountain [the Longmynd] of Shropshire appears to represent another."

Other terms have been devised for ancient rocky

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shores or their biological habitat. In his study of Miocene rocky shores, RADWANSKI (1970, p. 373) used the name "lithophocoenose" for an assemblage of traces left by littoral, rock-boring organisms such as sponges, polychaets, bivalves, cirripeds, and echinoids. He also employed the name "lithophotope" to designate this special habitat. More recently, the word "paleorupicost" was coined for ancient rocky shores (JOHNSON, 1988a).

Whether they are called shantungs, lithophotopes, or paleorupicosts, the geological record of ancient rocky shores is one far more rich in examples and useful applications than generally perceived by geologists, paleontologists, physical geographers, and marine biologists. The purpose of this contribution is two fold. The following short paper is meant to outline the history of research on ancient rocky shores spanning the better part of three centuries, with emphasis on the related concept of unconformities. The appended bibliography with its annotations, is intended to illustrate the many interesting applications ancient rocky shores may be put to in solving problems in historical geology. The first brief bibliographies on this topic were given by JOHNSON (1988a,b). The present bibliography represents a significant expansion by more than 200%.

THE IMPORTANCE OF UNCONFORMITIES

The concept of the geological unconformity has a long intellectual history, notably traced by TOMKEIEFF (1962). The word owes its origin to the observation that some adjoining rock layers do not conform with one another, but show patterns of "deviating bedding." The classic angular unconformity discovered by James Hutton in 1788 at Siccar Point in Scotland with its two contrary sets of bedding, comes to mind immediately. The concept grew, of course, to become much broader. Other styles include sedimentary rocks in conjunction with igneous or metamorphic rocks, none of which necessarily exhibit signs of bedding. Some unconformities are very limited in geographic scale; others are vastly interregional (SCHLEE, 1984). What they all share in common is the dimension of a geological time gap: the ages of the rocks brought into association with one another are often substantially different.

All ancient rocky shores are represented in the geologic record by unconformities, but not all unconformities are indicative of ancient rocky shores. This means only that some unconformities form in littoral environments as the result of rocky-shore degradation, but many others form in subaerial, fresh water, or submarine environments. While the broader concept of the unconformity has to do with missing geological time, the important aspect of ecological time in the late preburial development of unconformity surfaces is easily lost sight of by geologists today. Nowhere is this aspect of ecological time more striking than with reference to rocky shores, a realization not lost on the earliest workers who pondered unconformities.

The Neptunist Tradition

A universal ocean with a secular drop in sea level was employed to account for the aqueous origin of virtually all rocks by a wide range of observers in the 18th and early 19th centuries. This neptunian tradition was given great impetus by Benoit de Maillet (1656–1738), author of a philosophical discourse called *Telliamed* (1748, 1968 translation). De Maillet had served as a French consul in Egypt and his book is filled with many references to places in the Sinai Peninsula, North Africa, and Europe. One of the main theses in the *Telliamed* is the cannibalization of older mountains to form progressively newer mountains, all in the context of coastal erosion. It was supposed by De Maillet that the oldest primitive rocks were exposed subaerially as sea level started to fall. With exposure came coastal erosion around the margins of the primary mountains. Aggradation of shelf sediments from these mountains underwent lithification. As sea level continued to fall, these secondary rocks were, in turn, exposed subaerially as mountains and submitted to coastal erosion leading to another aggradational cycle.

Expressed diagrammatically (Figure 1), this system of logic lends itself to an orderly succession of strata with naturally unconformable boundaries. As reviewed by TOMKEIEFF (1962, p. 386–387), the subsequent school of neptunists included many 18th century figures, most notably Abraham Werner in Silesia. In some cases, the descriptive language used by the early neptunists approximates the definition of an angular unconformity. In fact, it was the early 19th century neptunist Robert Jameson, a former student of Werner's at the Freiberg School of Mines and subsequently professor of geology at Edinburgh University, who coined the term "unconformity" in 1808. This was Jameson's best English equivalent for the German term "abweichende Lage-

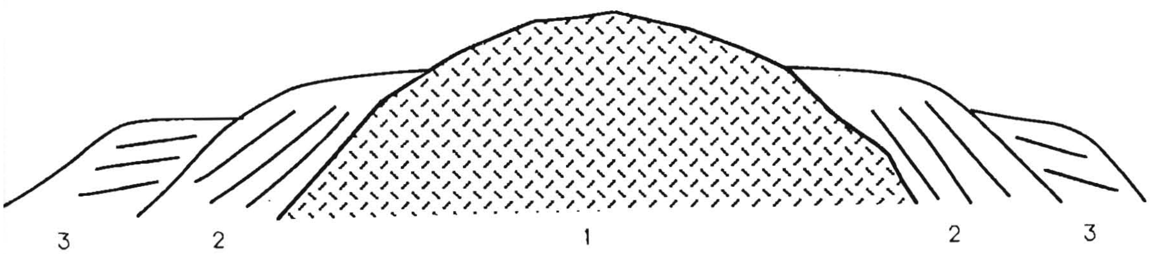

Figure 1. Neptunist concept of unconformities due to a secular fall in sea level stimulating the recycling of primary, secondary, and tertiary mountains through coastal erosion (modified from Tomkeieff, 1962, p. 388, figure 2).

rung," which literally translated means "deviating bedding" (TOMKEIEFF (1962, pp. 402–405).

De Maillet was not only one of the founders of the neptunist tradition but he also had an uncommon eye for ecological detail. He attributed step-like "amphitheaters" preserved on the flanks of mountains to the serial development rocky-shore terraces carved by retreating seas. Most intriguing of all, he clearly cited evidence for biological activity on the steep faces of such amphitheaters (DE MAILLET, 1968, p. 70) including:

> Corals which the sea had left attached there after having given birth to them and nourished them in the same places where they were petrified; and borings of sea-worms that live only in marine water, which occurred in many rocks.

It is likely that De Maillet was the earliest to observe an ancient rocky shoreline, to comprehend what he saw, and to record it. In his 1968 notes on the *Telliamed,* Albert Carozzi casts doubt on the coastal origin of some "amphitheaters" identified geographically by De Maillet. The paleontological references, however, are very creditable. De Maillet gave no hint where the corals and borings were observed but they might easily have been seen by him near Cairo (see AIGNER, 1983, under Quaternary in the appended bibliography).

Basal conglomerates are an important feature common to many unconformities. In theory at least, DE MAILLET (1968, p. 72) grasped the association of some conglomerate beds in the rock record with processes "performed by the sea on its coasts where it could freely roll boulders and pebbles." It was another Frenchman better known as a chemist, Antoine Lavoisier (1743–1794), who contributed important refinements in this context. LAVOISIER (1789, 1939 translation) used the term "littoral" and he clearly described the seaward fining of sediments off rocky shores. Littoral beds incorporated into the rock record were given to include "the coarsest materials, like the cobbles"; pelagic beds formed at "a rather great distance from the coast and at such a depth that the movement of the sea is almost nil" were given to include "the lightest materials, the most finely divided like clay" (LAVOISIER, 1939, p. 128). Lavoisier's original work included an idealized cross section from a modern rocky shore in Normandy, but his intention was to demonstrate how the sedimentological "order and uniformity" inherent in such a profile might be expressed in the rock record.

The Plutonist Tradition

In contrast to the neptunist tradition, many field observers during the late 18th and early 19th centuries saw a far more important role for materials of an igneous origin in the rock record. James Hutton of Scotland was the champion of this plutonist tradition and he remains best remembered today as the founding advocate of the rock cycle. The notion of a secular drop in sea level so central to the neptunist tradition, is obviated by the rock cycle, with its recurrent pattern of subaerial denudation, aqueous deposition, deformation, and uplift to renewed subaerial conditions. All rock types, whether sedimentary, igneous, or metamorphic have a role to play in this cycle. Unconformities were of fundamental importance to both the neptunist and the plutonist traditions, but the latter relied on the tremendous physical forces associated with the emplacement of igneous rocks to affect uplift and subsequent erosion.

As noted by TOMKEIEFF, (1962, p. 397), Hutton set out to discover field evidence for an unconformity in support of his *Theory of the Earth*

(1795) after he had already presented his main thesis on the rock cycle before the Royal Society of Edinburgh in 1785. It was in 1787 that he found his first unconformity on the Isle of Arran; later the same year he found another unconformity on the banks of the Tweed near Jedburgh; and in 1788 he discovered the spectacular unconformity at Siccar Point. Only the Jedburgh unconformity was illustrated in HUTTON (1795, plate III), although a drawing of the unconformity at Siccar Point executed by James Hall in 1788 was probably intended for publication (CRAIG *et al.*, 1978).

The Siccar Point locality is exposed in such a way that nearly vertical beds of graywacke [Silurian] may be observed virtually in three dimensions penetrating a thin cover of slightly dipping rocks belonging to the Old Red Sandstone [Devonian]. The truncated graywackes were not eroded flat as at Jedburgh, but retain considerable topographic relief. It was believed by Hutton that the older more deformed rocks were under attack by the sea during deposition of the younger sandstone. In describing the sandstone, he wrote (HUTTON, 1795, vol. I, pp. 459–460):

> Here we found the most distinct marks of strata of sand modified by moving water. It is no other than that which we every day observe upon the sands of our own shore, when the sea has ebbed and left them in a waved figure, which cannot be mistaken.

As we understand it today, the Old Red Sandstone was essentially fluvial in nature. Thus, Siccar Point does not represent an ancient rocky shore.

Following Hutton's death, his friend John Playfair wrote both a more accessible account of Hutton's theories as well as a biographical sketch of Hutton's life. In the *Illustrations of the Huttonian Theory of the Earth,* PLAYFAIR (1802, pp. 212–219) said no more about Siccar Point but described several new localities throughout the British Isles where angular unconformities could be observed. At least two localities in Yorkshire involve strata of flat limestone [Carboniferous] overlying vertical graywacke [Silurian]. These certainly represent a genuine marine onlap, but no flavor of ecological detail was provided by Playfair. It is in his account of Hutton's life and his description of the discovery at Siccar Point that PLAYFAIR (1805, p. 73) offered his eyewitness commentary on how giddy he felt gazing across the unconformity "so far into the abyss of time." The awe all geologists feel for unconformities as time gaps takes its cue from this famous passage.

Professionalism and Quantification

Hutton and Playfair had no time scale with which to gauge the length of time omitted by their unconformities. They did not know that the unconformable rocks at Siccar Point were Silurian and Devonian in age, because that terminology had not yet been invented. Other than a privileged few with university or mining academy posts, most thinkers on problems of natural philosophy were amateur. Development of the geological time scale was something which transpired during the transition to a professional class of geologists. The value of quantification in terms of geological mapping and other kinds of measurements was something newly demonstrated with the staffing of geological surveys under government sponsorship toward the middle of the 19th century. The role which might be played by a scholarly amateur was rapidly diminishing in importance by this period.

An odd piece of work which appeared during this time of transition was *Ancient Sea-Margins as Memorials of Changes in the Relative Level of Sea and Land,* authored by CHAMBERS (1848). A successful publisher, Robert Chambers (1802–1871), was the quintessential amateur interested in natural science. He also fully appreciated the value of systematic measurements. Much time and private expense were devoted by him to surveying and correlating terrace levels throughout many parts of the British Isles. He was convinced that terraces followed persistent elevations produced by stages in falling sea level. In effect, Chambers set out to quantify some of the neptunian concepts more vaguely treated by De Maillet with his step-like sets of "amphitheaters" a century before. A special feature of the book is a fold-out map of the Lochaber region in Scotland tracing the "shelves" or parallel roads around Glen Roy. Chambers and others, including DARWIN (1839), believed these terraces were former coastal deposits influenced by marine flooding. Much to Darwin's later embarrassment, these features were proven to be the deposits of glacial lakes, instead. Although his focus was mainly on comparatively young, unconsolidated shorelines, CHAMBERS (1848, pp. 71–73) also described what he believed were elevated rocky shores, sea arches, and sea caves carved in the Old Red Sandstone at Covesea.

The first memoir of the Geological Survey of

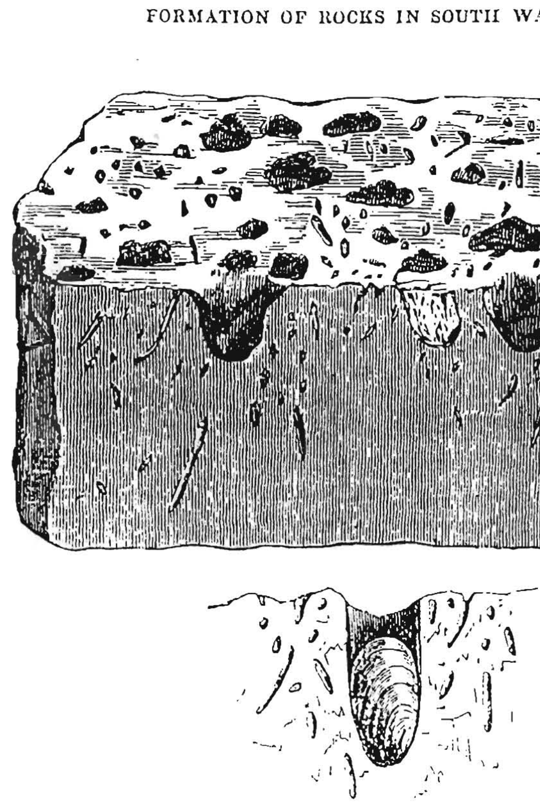

Figure 2. Reproduction of figures 43 and 44 from De la Beche (1846), showing one of the earliest illustrations of borings at an unconformity surface. The borings are of Jurassic age in Carboniferous limestone; the smaller figure shows the shell of a boring bivalve.

Great Britain was published in 1846, under the directorship of Henry T. De La Beche (1796–1855). The director belonged to the new breed of professional geologists and he initiated the memoirs to further elucidate the progress of the survey's mapping projects. The lead report from the first volume was authored by De la Beche (1846) as a summary of the geology in Wales along the Bristol Channel and the Mendip Hills of nearby England. A Jurassic-Carboniferous unconformity involving limestone on limestone is one of the most prominent features in these regions and most of the report is devoted to this subject. In some cases, considerable topographic relief is expressed by the truncated surface of inclined Carboniferous strata. The gradational accumulation of a basal Jurassic conglomerate on such a surface was described as "beach-like" by De la Beche (1846, pp. 246–247, fig. 26). Considerable attention was paid to fossils associated with the surface of unconformity, such as encrusting oysters. Among the earliest illustrations of an unconformity surface riddled by organic borings are those introduced by De la Beche (1846, p. 290, Figures 43 and 44), and here reproduced as Figure 2.

The second report in the first volume of the survey memoirs was authored by Andrew C. Ramsay (1814–1891), who eventually became the 3rd director of the British survey. In this landmark paper, the novel concept of a "plain of marine denudation" was introduced and quantified on the basis of restored geological cross sections from the survey's mapping projects in southern Wales and adjacent England. Ramsay (1846) calculated that thousands of feet of strata were stripped away in places, and argued that "the ordinary destructive action of the sea on coasts" was the major agent of denudation. Although he was criticized

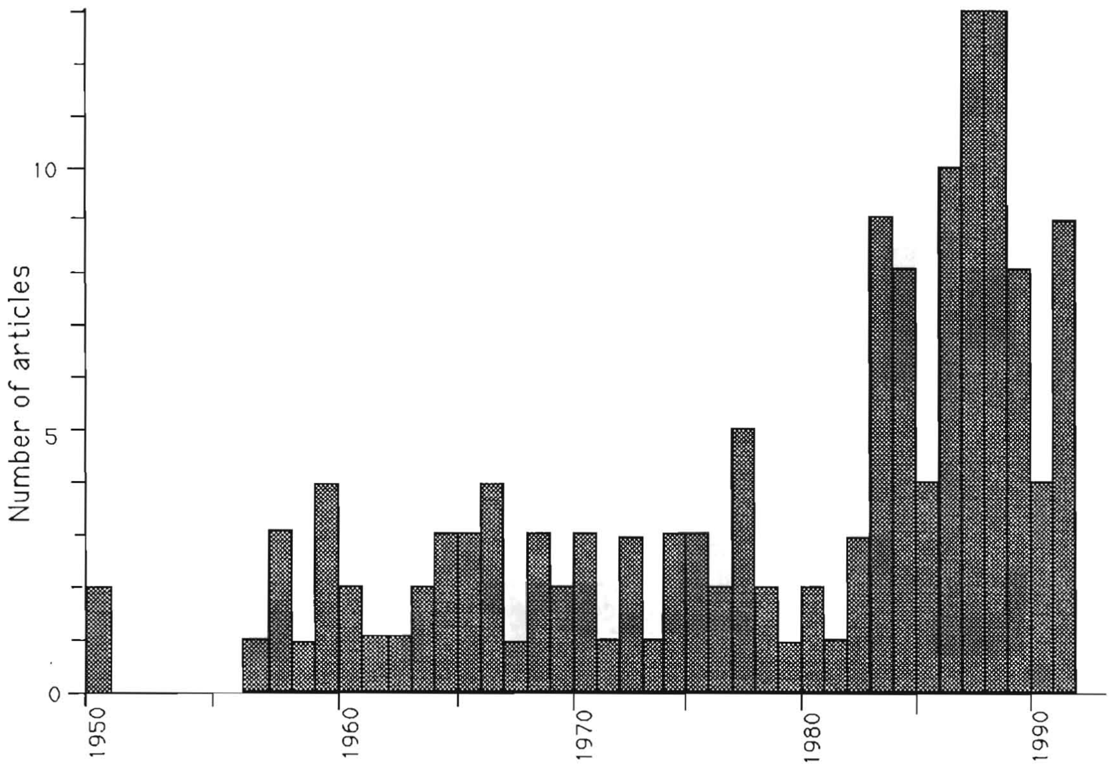

Figure 3. Histogram showing the annual number of publications on ancient rocky shores from 1950–1991.

by Charles Darwin and Charles Lyell for minimizing the effect of tectonic uplift and subaerial denudation, he knew an ancient rocky shore when he saw one. With typical aplomb, an entry in Ramsay's personal journal from 1846 reads: "Out seeing the unconformable Caradocs on the Longmynd; splendid old coast; never more charmed" (GEIKIE, 1895, p. 80).

The work of Amadeus William Grabau (1870–1946) was mentioned at the beginning of this review. Like Andrew Ramsay, he knew an ancient rocky shore when he saw one. He, too, was familiar with the Longmynd of Shropshire (GRABAU, 1940, p. 50) and many other ancient rocky shores. Much of Grabau's international career was devoted to the study of facies relationships and unconformities. While a professor at Columbia University, an important paper on patterns of "sedimentary overlap" was written by GRABAU (1906). Therein, he showed the expected diachronistic pattern of facies deposition resulting from marine regression and transgression, with the separation in time of such events by a widening hiatus. An unconformity-bound unit is the expression commonly used today for this pattern. Association with ancient rocky shores is not a necessary characteristic of unconformity-bound units, but GRABAU (1906) described several examples drawn from the relationship of Cambrian strata to basement rocks in North America. A particularly good example from eastern Newfoundland is a Cambrian rocky shore on Precambrian gneiss, the progressive burial of which is illustrated over considerable topographic relief by means of a marker bed (GRABAU, 1906, p. 572, Figure 2). Here was a "shantung" according to his later definition (GRABAU, 1940).

During the tenure of De La Beche and Ramsay, the dating of unconformities in the pursuit of regional geology began to delimit the episodic interaction of the rock cycle with respect to sea-level change. Grabau's greatest achievement during the second half of his career as a professor at Peking University in China was a massive distillation of global data on unconformities leading to the first comprehensive sea-level history for Phanerozoic time. The final summary of this work was presented in his 1940 book *The Rhythm of the Ages*. Imperfect as it was, Grabau's quantification of a 30-million-year cycle in eustatic sea-level fluctuations represents a major intellectual end point to De Maillet's 1748 *Telliamed* and the intervening body of thought on unconformities as time gaps in the geological record.

BIBLIOGRAPHIC CONSTRAINTS

After the chance discovery in 1984 and subsequent study of an unusually well preserved Ordovician rocky shore on the coast of Manitoba's Hudson Bay (JOHNSON *et al.*, 1988), I was challenged by my students to find other examples in the published literature. Thus began my interest in the bibliography of ancient rocky shores. A variety of criteria for the recognition of ancient rocky shores may be used, involving physical features such as wave-cut platforms and tidal notches or biological evidence such as the preservation of typical rough-water life forms (JOHNSON, 1988a). Basal conglomerates with rounded and graded clasts matching the same lithology or lithologies underlying an unconformity surface with some topographic relief are likely candidates for an ancient rocky-shore deposit, but not exclusively. Other superficially similar deposits may include scree-alluvial fan deposits, fluvial gorge deposits, glaciogenic boulder beds, fault-scarp breccias, intraformational conglomerates, and fan-channel conglomerates (JOHNSON, 1988a).

Aside from my own field work in Canada and Mexico, it has been my good fortune to visit and verify some of the other localities described as ancient rocky shores in Australia, England, Sweden, Germany, Czechoslovakia, Poland, and Egypt. The primary test for admission of a reference to the bibliography, however, was an interpretation of littoral conditions or some other key criteria by the original author(s). This was not automatic, as some references were rejected because other authors were able to satisfactorily dispute the original claim. Nonetheless, some of the references included in the bibliography still are controversial. Limestone ramps as unconformity surfaces, for example, are especially problematic. Sometimes the same examples are interpreted as due strictly to submarine conditions (ROSE, 1970) or "littoral abrasion platforms" (LEWY, 1985).

Although the oldest reference cited is from the

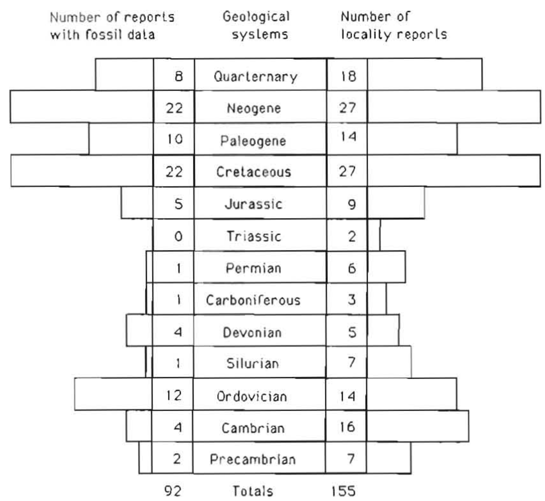

Figure 4. Histogram showing the variation in numbers of locality reports on ancient rocky shores with and without accompanying paleontological data, by geological system or period.

work of DE LA BECHE (1846), journal articles on ancient rocky shores did not appear with much regularity until after the turn of the 20th century. Between 1905 and 1954, the rate of publication was a sporadic 0.3 papers/year. From 1956 through 1991, publication has been continuous from year to year and the rate of publication has greatly increased (Figure 3). From 1955 to 1979, the average rate of publication was 2.2 papers/year. A doubling in rate to 4.6 papers/year occurred during the five year-period of 1980–1984. In the next five-year period from 1985 to 1989, the rate doubled again to 9.6 papers/year. Thus, recent years have witnessed an exponential growth in research activity on ancient rocky shores.

Out of the 155 articles in the bibliography, 59 are concerned with the Cenozoic, 38 with the Mesozoic, 51 with the Paleozoic, and 7 with the Precambrian. No geological period in the Phanerozoic is without examples of rocky shores, but the Triassic and Carboniferous are the most poorly represented (Figure 4). The best represented intervals are the Neogene and the Cretaceous periods with 27 entries each. From the Precambrian, the oldest known rocky shore dates between 3.3 and 3.5 billion years old. Over 60% of the references include paleontological data (Figure 4).

Most of the references in the bibliography are annotated to indicate a diversity of applications. Practical applications are derived from the fact that an ancient rocky shore marks the most unambiguous position of the land-sea boundary for a given point in space and time. The various authors represented have utilized ancient rocky shores for paleogeographic mapping, as bench marks for the evaluation of associated paleontological or sedimentological zonations related to hydrology, for making calculations of coastal uplift or subsidence rates, and as a test for conformity to eustatic sea-level changes. Their work also reflects an interest in the paleobiology of rocky-shore organisms and the community evolution of rocky-shore biotas through time.

CONCLUSIONS

The history of thought on the nature and significance of geological unconformities surveyed herein, shows that ancient rocky shores figured importantly in long-standing debates over the interaction of changing sea levels and the tectonics of the rock cycle. Issues written about or by De Maillet, Lavoisier, Hutton, De La Beche, Ramsay, Grabau, and others from 1748 to 1940, reflect a growing sophistication in some of the applications made of ancient rocky shores. As geologists and paleontologists take better account of the ecological time recorded by rocky-shore unconformities as opposed to the geological time lost, we stand to learn much more about the evolution of this unique environment and its biota through time.

Various excuses have been offered for the supposed poor showing of ancient rocky shore environments in the rock and fossil record. They range from the flat-out denial that sediments can accumulate in high-energy, erosive settings to the suggestion that rocky-shore biotas did not appear until a comparatively late time, to the proposal that concentration of rocky shores in tectonically active zones makes them vulnerable to eventual distruction (JOHNSON, 1988a,b). The main object of the accompanying bibliography is to indicate that ancient rocky shores are really more overlooked than rare and that much stands to be gained through their careful, systematic study.

ACKNOWLEDGEMENTS

Many individuals assisted in this project by drawing my attention to articles warranting addition to the bibliography on ancient rocky shores; among the most helpful were B. Gudveig Baarli (Williams College), Halard L. Lescinsky (University of California at Davis), Mark A. Wilson (College of Wooster), Andrzej Radwanski (Institute of Geology, Warsaw University), and Christoph Hartkopf-Fröder (Geologisches Landesamt Nordrheinwestfalen, Germany). Acknowledgement is made to the donors of the Petroleum Research Fund (American Chemical Society) for full support of this project.

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Appendix 1: Annotated Bibliography of Ancient Rocky Shores Arranged by Geologic Period

Quaternary

AIGNER, T., 1983. A Pliocene cliff-line around the Giza Pyramids Plateau, Egypt. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 42, 313–322. **Note** this shore is probably post-Pliocene in age (see Hamza, 1983).

ASHBY, J.R., KU, T.L., and MINCH, J.A., 1987. Uranium series ages of corals from the upper Pleistocene Mulege terrace, Baja California Sur, Mexico. *Geology,* 15, 139–141. **See** description of El Sombrerito—"a well-defined +12-m wave-cut terrace incised into and surrounding a small gabbroic pluton"; age determinations allow for the calculation of uplift rates of 4–5 cm/1000 yr. since terrace formation.

BAKER, G. and GILL, E.D., 1957. Pleistocene emerged marine platform, Port Campbell, Victoria. *Quaternaria,* 4, 55–68.

BOSWORTH, T.O., 1922. *Geology of the Tertiary and Quaternary periods in the northwest part of Peru.* London: MacMillan & Co., 434p. **Note** detailed descriptions of four stacked terraces or "tablazos" with well preserved sea cliffs up to 10 miles inland at 1,000 ft. above present sea level (**See** Fig. 39, p. 208); common shallow-water species include *Arca, Mytilus, Ostrea,* and *Thais* with barnacle debris often dominant (**See** Fig. 42, following p. 214).

CHAPPELL, J. and VEEH, H.H., 1978. Late Quaternary tectonic movements and sea-level changes at Timor and Atauro Island. *Geological Society of American Bulletin,* 89, 356–368. **Note** description of terrace-forming reefs built on volcanic rocks, with coarse basal conglomerates; rate of uplift estimated at 0.47 m/1,000 yr.

COLLIER, R.E.L., 1990. Eustatic and tectonic controls upon Quaternary coastal sedimentation in the Corinth Basin, Greece. *Journal of the Geological Society, London,* 147, 301–314. **See** Figs. 2 (p. 303) and 10 (p. 312) for treatment of wave-cut platforms.

GALLI, G., 1989. Storm sedimentation in a Quaternary rocky shore sequence (southern Italy). *Neues Jahrb. Geol. Palaont. Mh.,* (10), 590–602.

HAMZA, F.H., 1983. Post-Pliocene transgressive phase along the northern part of the Nile Valley, Egypt. *Neues Jahrbuch fur Geologie und Palaeontologie Monatshefte,* 6, 338–344.

KAYE, C.A., 1959. Shoreline features and Quaternary shoreline changes Puerto Rico. *Geological Survey Professional Paper 317-B,* 140p.

LUM, D. and STEARNS, H.T., 1970. Pleistocene stratigraphy and eustatic history based on cores at Waimanalo, Oahu, Hawaii. *Geological Society of America Bulletin,* 81, 1–16. **See** illustrations of a 650 foot-wide terrace with "sea-level nips" cut from the Bellows Field dune limestone (Figs. 3 and 4, p. 5); the references cite several other similar articles from other localities in the Pacific Ocean by Stearns, with primary focus on issues of eustasy.

MERRITTS, D. and BULL, W.B., 1989. Interpreting Quaternary uplift rates at the Mendocino triple junction, northern California, from uplifted marine terraces. *Geology,* 17, 1020–1024. **Note** description of 14 terraces, some with bedrock benches and pholad borings up to 300 m above present sea level; rates of uplift were as much as 1.2 m/ka during passage of the triple junction.

MONTAGGIONI, L.F. and HOANG, C.T., 1988. The last interglacial high sea level in the granitic Seychelles, Indian Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 64, 79–91. **See** photographs (Figs. 2 and 3, p. 81) showing carbonate deposits adhering to or filling joints in granitic sea cliffs.

ORTLIEB, L., 1991. Quaternary shorelines along the northeastern Gulf of California; Geochronological data and neotectonic implications. *In:* PEREZ-SEGURA, E. and JACAQUES-AYALA, C. (eds.), *Studies of Sonoran Geology. Geological Society America Special Paper,* 254, 95–120. **Note** marine platforms cut in volcanic substrates (Figs. 5a,i, m; 7a; and 9a).

RUSSELL, M.P. 1991. Modern death assemblages and Pleistocene fossil assemblages in open coast high energy environments, San Nicolas Island, California. *Palaios,* 6, 179–191.

SEMENIUK, V. and JOHNSON, D.P., 1985. Modern and Pleistocene rocky shore sequences along carbonate coastlines, south-western Australia. *Sedimentary Geology,* 44, 225–261. **See** photograph (Fig. 6a, p. 234) showing wave-cut platform and tidal notch.

VALENTINE, J.W., 1980. Camalu': A Pleistocene terrace fauna from Baja California. *Journal of Paleontology,* 54, 1310–1318. **Note** argument that preservation of intertidal faunas is enhanced when derived from terraces on the lee, or more protected flank of headlands (p. 1314); over 100 species representing the "entire intertidal zone" are represented at this locality.

VALENTINE, J.W. and LIPPS, J.H., 1963. Late Cenozoic

rocky-terrace faunas from Palos Verdes Hills, California. *Journal of Paleontology,* 37, 1292–1302.

VAN DE GRAAFF, W.J.E., Denman, P.D. and HOCKING, R.M., 1976. Emerged Pleistocene marine terraces on Cape Range, Western Australia. *Western Australia Geological Survey Annual Report,* 1975, 62–70. Note occurrence of conglomerate-filled spurs cut onto limestone platforms (Fig. 32A).

Neogene

ARANDA-MANTECA, F.J. and TELLEZ-DUARTE, M.A., 1989. Paleoecology of the San Diego Formation at La Joya, Baja California. *In:* ABBOTT, P.L. (ed.), *Geologic Studies in Baja California. The Pacific Section, Society of Economic Paleontologists and Mineralogists Los Angeles, California,* 111–113. Note description of a Pliocene rocky shore community (including *Thais* and *Ostrea* on a basaltic substrate).

BALUK, W. and RADWANSKI, A., 1977. Organic communities and facies development of the Korytnica basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica,* 27, 85–123. Note inference of the rocky intertidal kelp *Caulerpa* based on the occurrence of an associated gastropod *Berthelinia krachi* (pp. 100 and 111).

BROMLEY, R.G. and D'ALESSANDRO, A., 1987. Bioerosion of the Plio-Pleistocene transgression of southern Italy. *Rivista Italiana Paleontologia e Stratigrafia,* 93, 379–442. Note description of trace fossils from surface of vertical sea cliffs.

BUCKERIDGE, J.S., 1975. The significance of cirripedes to the paleoecology of Motutapu Island. *Tane,* 21, 121–129. Note description of a sea-stack carved from basement "graywacke" and buried by Miocene sediments including a rich barnacle fauna of "littoral fringe" origin.

BURCHETTE, T.P., 1988. Tectonic control on carbonate platform facies distribution and sequence development: Miocene, Gulf of Suez. *Sedimentary Geology,* 59, 179–204. See Fig. 8 (p. 189) for illustration of algal coatings on fracture walls in basement rock.

DONOVAN, S.K., 1989. Palaeoecology and significance of barnacles in the mid-Pliocene *Balanus* Bed of Tobago, West Indies. *Geological Journal,* 24, 239–250.

DVORAK, J., 1957. The surf relief of the Tortonian sea in the area of the Devonian of Hrance (Moravia). *Casopis pro Mineralogii a Geologii,* 2, 120–127.

FERNANDEZ, J. and RODRIGUEZ-FERNANDEZ, J., 1991. Facies evolution of nearshore marine clastic deposits during the Tortonian transgression—Granada Basin, Betic Cordilleras, Spain. *Sedimentary Geology,* 71, 5–21. Note description of an Upper Miocene basal marine facies including "bivalves, barnacles, and some red algae" in close association to a metamorphic basement penetrated by "boring lithophageous organisms" (p. 7).

HARTKOPF, C. and STAPF, K.R.G., 1983. Sedimentologie des Unteren Meeressandes (Rupelium, Tertiar) an Inselstranden im W-Teil des Mainzer Beckens (SW-Deutschland). *Mitt. Pollichia,* 71, 5–106. See photographs (Fig. 50, p. 86) of cobble-encrusting fauna.

HERM, D., 1969. Marines Pliozan und Pleistozan in Nord- und Mittel-Chile unter besonderer Berucksichtigung der Molluskenfauna. *Zitteliana,* 2, 159p.

HIGGIENS, C.G., 1960. Ohlson Ranch Formation, Pliocene, north-western Sonoma County, California. *University of California Publications in Geological Sciences,* 36, 197–232. See photograph (Pl. 20a) of bivalve borings in a rocky shore formed by Jurassic schist.

LEITHOLD, E.L. and BOURGEOIS, J., 1984. Characteristics of coarse-grained sequences deposited in nearshore, wave-dominated environments—Examples from the Miocene of southwest Oregon. *Sedimentology,* 31, 749–775.

LOCK, B.E., 1973. Tertiary limestones at Needs Camp, near East London. *Transactions Geological Society South Africa,* 76, 1–5. See also references by Wood (1908) and King (1972) under Cretaceous.

MACNEIL, F.S.; MERTIE, J.B., and PILSBRY, H.A., 1943. Marine invertebrate faunas of the buried beaches near Nome, Alaska. *Journal of Paleontology,* 17, 69–96. Note termination of buried terrace deposits by a "14 foot high old sea cliff" (p. 70).

MARTINELL, J. and DOMENECH, R., 1986. Activida bioerosiva en el Plioceno marino del Emporda (Catalunya). *Paleontologia i Evolucio,* 20, 247–251.

MASUDA, K., 1968. Sandpipes penetrating igneous rocks in the environs of Sendai, Japan. *Transactions Proceedings Palaeontological Society Japan, N.S.,* 72, 351–361. Note first report of bivalve borings (p. 353) in igneous rock (Takadate Andesite of Miocene age); cracks and cavities also contain encrusting worm tubes (p. 354).

NEUFFER, F.O.; ROTHAUSEN, K., and SONNE, V., 1978. Fossilfuhrende Rinnenfullung im Unteren Meeressand an einer Insel-Steilkuste des Mitteloligozan-Meeres (Steigerberg bei Eckelsheim Mainzer Becken). 1. Aufschluss, Makro- und Mikrofauna. *Mainzer Geowiss. Mitt.,* 6, 99–120.

PETERS, J.M.; TROELSTRA, S.R., and VAN HARTEN, D., 1985. Late Neogene and Quaternary vertical movements in eastern Crete and their regional significance. *Quarterly Journal Geological Society of London,* 142, 501–513. See Figs. 3 & 4 on p. 505 illustrating early Pliocene marls drapping near vertical sea cliffs with associated *Lithophaga* borings.

RADWANSKI, A., 1964. Boring animals in Miocene littoral environments of southern Poland. *Bulletin Polish Academy of Science, Serie des science geology et geography,* 12, 57–62.

RADWANSKI, A., 1968. Tortonian cliff deposits at Zahorska Bystrica near Bratislava (Southern Slovakia). *Bulletin Polish of Academy Science, Serie des science geology et geography,* 16, 97–102.

RADWANSKI, A., 1970. Dependence of rock-borers and burrowers on the environmental conditions within the Tortonian littoral zone of southern Poland. *In:* T.P. CRIMES and J.C. HARPER (eds.), Trace fossils. Liverpool: Letterpress Limited, pp. 371–390. Note this reference records one of the most diverse rocky-shore biotas yet known.

RICKETTS, B.D.; BALLANCE, P.F.; HAYWARD, B.W., and MAYER, W., 1989. Basal Waitemata Group lithofacies: rapid subsidence in an early Miocene interarc basin, New Zealand. Sedimentology, 36, 559–580. Note sea stacks and rocky headlands (Fig. 16, p. 577) are interpreted to have subsided from the intertidal to bathyal depths of 1,000–2,000m.

SMITH, J.T., 1986. Middle tertiary rocky substrate mollusks from Baja California Sur, Mexico. American Malacological Bulletin, 4(1), 1–12. Note the age of these rocky substrates is Middle Miocene.

SMITH, J.T., 1991. Cenozoic Marine Mollusks and Paleogeography of the Gulf of California. *In:* DAUPHIN, J.P. and SIMONEIT, B.R.T. (eds.), *The Gulf and Peninsular Province of the Californias, American Association of Petroleum Geologists,* 47, 637–666.

SPILLMANN, F., 1959. Die sirenen aus dem Oligozan des Linzer Beckens (Oberosterrich), mit ausfuhrunger uber "osteoklerose" und "pachyostose." *Denkschriften Osterreichische Akademie der Wissenschaften Mathematische-Naturwissenschaftiche Klasse,* 110(3), 68. See Fig. 5 (p. 10), showing the skeleton of an Oligocene sea cow near a cobble beach overlying a gneisic rocky shore.

WATKINS, R., 1990. Paleoecology of a Pliocene rocky shoreline, Salton Trough region, California. *Palaios,* 5, 167–175. Note many components belonging to the *Typanites* ichnofacies are well illustrated.

ZULLO, V.A. and GURUSWAMI-NAIDU, R.B., 1982. Late Miocene balanid cirripedia from the basal Wilson Ranch Beds ("Mercid" Formation), Sonoma County, northern California. *Proceedings of the California Academy of Sciences,* 42, 525–535. Note that "The petrology and fauna of the basal conglomerate suggest the barnacles inhabited a rocky intertidal or immediately subtidal environment exposed to moderate or heavy surf" (p. 527).

Paleogene

BOSEL, C.A. and COOMBS, D.S., 1984. Foveaux Formation: A warm-water strandline deposit of Landon-Pareora age at Bluff Hill, Southland, New Zealand. *New Zealand Journal of Geology and Geophysics,* 27, 221–223. Note description of Late Oligocene-Early Miocene deposits accumulated at the foot of a sea cliff cut in massive gabbrorite.

BUCHBINDER, B.; MAGARITZ, M., and BUCHBINDER, L., 1983. Turonian to Neogene palaeokarst in Israel. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 43, 329–350.

CROWELL, J.C. and SUSUKI, T., 1959. Eocene stratigraphy and paleontology, Orocopia Mountains, southeastern California. *Geological Society American Bulletin,* 70, 581–592. Note reference to sea cliffs and sea stacks (p. 590). See also stratigraphic column (Fig. 3, p. 585).

EFFINGER, W.L., 1938. The Gries Ranch Fauna (Oligocene) of western Washington. *Journal of Paleontology,* 12, 355–390. Note description of a "near-shore or littoral" fauna from the "upper conglomeratic zone" above a local unconformity (p. 360).

HECKER, R.F., 1965. *Introduction to Paleoecology.* New York: American Elsevier Publishing Co., 166p. See field sketches in Fig. 31 (p. 95) illustrating a Paleogene rocky shore with lithophag borings and encrusting oysters, located near Ura-Tyube in the Tadzhik S.S.R.

LEE, D.E.; CARTER, R.M.; KING, R.P., and COOPER, A.F., 1983. An Oligocene rocky shore community from Mt Luxmore, Fiordland. *New Zealand Journal of Geology and Geophysics,* 26, 123–126. Note spectacular uplift of a rocky shore 1,300 m above sea level since middle-late Oligocene time (p. 125).

LINDBERG, D.R. and HICKMAN, C.S., 1986. A new anomalous giant limpet from the Oregon Eocene (Mollusca: Petellida). *Journal of Paleontology,* 60, 661–668.

LINDBERG, D.R. and SQUIRES, R.L., 1990. Patellogastropods (Mollusca) from the Eocene Tejon Formation of southern California. *Journal of Paleontology,* 64, 578–587.

MARKER, M.E., 1984. Marine benches of the eastern Cape, South Africa. *Transactions Geological Society South Africa, 87, 11–18.* Note this reference covers a series of nine benches spanning the Cenozoic, the oldest being Paleocene in age and elevated highest above present sea level (200 m).

MILLER, P.R. and ORR, W.N., 1986. The Scotts Mills Formation: Mid-Tertiary geologic history and paleogeography of the central Western Cascade Range, Oregon. *Oregon Geology,* 48, 139–151. Note description of "exhumed wave-cut platforms and sea stacks developed on the Little Butte basalt" of late Oligocene-early Miocene age.

MILLER, P.R. and ORR, W.N., 1988. Mid-Tertiary transgressive rocky coast sedimentation: Central, Western Cascade Range, Oregon. *Journal of Sedimentary Petrology,* 58, 959–968. See discussion of the Marquam Member (pp. 960–962) for description of fossil debris along basaltic rocky shores.

POMONI-PAPAIOANNOU, F. and SOLAKIUS, N., 1991. Phosphatic hardgrounds and stromatolites from the limestone/shale boundary section at Prossilion (Maastrichtian-Paleocene) in the Parnassus-Ghiona Zone, Central Greece. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 86, 243–254. Note evidence that the area "seems to correspond to a paleotopographic high which emerged at the end of the Maastrichtian."

SHROBA, C.S. and ORR, W.N., 1991. Paleontology of a middle Tertiary regressive sequence, Willamette Valley and Western Cascades, West-central Oregon. *Geological Society of America Abstracts with Programs,* 23(5), A403. Note description of Oligocene rocky shore with associated barnacle and brachiopod bearing sandstones.

WOODS, A.J.C. and SAUL, L.R., 1986. New Neritadae from south-western North America. *Journal of Paleontology,* 60, 636–655.

Cretaceous

ARNAUD-VANNEAU, A. and ARNAUD, H., 1985. Mise en evidence d'un paleokarst Turonien date par des bryozoaires dans le vercors septentrional (France SE). *Geobios,* 18, 617–619.

BOSE, P.K. and DAS, N.G., 1986. A transgressive storm- and fair-weather wave dominated shelf sequence: Cretaceous Nimar Formation, Chakrud, Madhya Pradesh, India. *Sedimentary Geology,* 46, 147–167.

CRAMPTON, J.S., 1988. A late Cretaceous near-shore rocky substrate macrofauna from northern Hawkes Bay, New Zealand. *New Zealand Geological Survey Record,* 35, 21–24.

GONZALEZ-DONOSO, J.M.; LINARES, D.; MARTIN-ALGARRA, A.; REBOLLO, M.; SERRANO, F., and VERA, J.A., 1983. Discontinuidades estratigraficas durante el Cretacico en el penibetico (Cordillera Betica). *Estudios geol.,* 39, 71–116. Note occurrence of stromatolites colonizing a karst surface during an Aptian transgression.

HARRIS, P.M. and FROST, S.H., 1984. Middle Cretaceous carbonate reservoirs, Fahud Field and Northwestern Oman. *American Association of Petroleum Geologists Bulletin,* 68, 649–658. See Fig. 9 (p. 657) depicting subaerially eroded limestone ruble deposited in wave-swept shoals on the flanks of fault-block islands.

HERCOGOVA, J. and KRIZ, J., 1983. New Hemisphaerammin인ae (Foraminifers) from the Bohemian Cretaceous Basin (Cenomanian). *Vestnik Ustredniho ustavu geologickeho,* 58, 205–216. Note description of fauna associated with debris eroded from silicite monadnocks formed from Precambrian silicite.

HOUSA, V., 1974. Traces of boring of organisms and attached epifauna on the surface of the Stramberk and Olivetska hora limestones in Stamberk. *Casopis pro Mineralogii a Geologii,* 19, 403–414.

KING, L., 1972. Geomorphic significance of the Late Cretaceous limestones at Needs Camp, near East London. *Transactions Geological Society South Africa,* 75, 1–3. Note two quarry sites are both assigned a Cretaceous age herein, but the age of strata in the upper quarry is contested as Tertiary by Lock (1973); see also Woods (1908) under Cretaceous.

LEDESMA-VASQUEZ, J. and JOHNSON, M.E., 1991, Late Cretaceous rocky shorelines in Baja California, Mexico. *Geological Society of America Abstracts with Programs,* 23(5), A193–A194. Note arguments for a rise in sea-level of 320 m over a 9 m.y. period on the basis of Cretaceous shorelines flanking the Peninsular Ranges batholith.

LESCINSKY, H.L.; LEDESMA-VASQUEZ, J., and JOHNSON, M.E., 1991. Dynamics of Late Cretaceous rocky shores (Rosario Formation) from Baja California, Mexico. *Palaios,* 6, 126–141.

LEWY, Z., 1985. Paleoecological significance of Cretaceous bivalve borings from Israel. *Journal of Paleontology,* 59, 643–648. Note observations on "flat, marine abrasion-platforms within the intertidal zone" (p. 646).

MAEJIMA, W., 1983. Prograding gravelly shoreline deposits in the Early Cretaceous Yuasa Formation, western Kii Peninsula, southwestern Japan. *Journal of the Geological Society of Japan,* 89, 645–660.

NEKVASILOVA, O., 1982. Craniidae (Brachiopoda, Inarticulata) from the Lower Cretaceous of Stramberk (Czechoslovakia). *Casopis pro mineralogii a geologii,* 27, 127–137.

NEKVASILOVA, O. and ZITT, J., 1988. Upper Cretaceous epibionts cemented to gneiss boulders (Bohemian Cretaceous Basin, Czechoslovakia). *Casopis pro mineralogii a geologii,* 33, 251–270. Note documented clustering and zonation of epibionts.

PERKINS, B.F. and STEWART, C.L., 1971. Whitestone quarry. *In:* PERKINS, B.F. (ed.), Trace fossils: A guide to selected localities in Pennsylvanian, Perman, Cretaceous and Tertiary rocks of Texas. *Louisiana State University School of Geosciences Miscellaneous Publications,* 71-1, 17–22. Note ongoing dispute unsettled by the authors regarding submarine vs. subaerial lithification prior to extensive boring at the top of the Whitestone Limestone Member of the Walnut Formation (Cretaceous); Lewy (1985, p. 646) argues "This example from Texas is interpreted to be a typical abrasion-platform within the intertidal zone after its lithification, most probably, in the supratidal zone."

PIANOVSKAYA, I.A. and HECKER, R.T., 1966. Rocky shores and hard ground of the Cretaceous and Palaeogene seas in central Kizil-Kum and their inhabitants. *In: Organisms and environment in the geological past—A symposium.* Moscow: Nauka, pp. 222–245 (in Russian). See Plates 2 and 3 for photographic views of rocky shores exposed in three-dimensional relief under present desert conditions.

PIETZSCH, K., 1962. *Geologie von Sachsen.* Berlin, Veb Deutscher Verlag Der Wissenschaften, 870p. See pp. 386–391 giving a detailed description of a rich Turonian-Campanian rocky-shore fauna (including many encrusters) associated with a coarse conglomerate derived from a porphyritic island coast.

RODDA, R.U., 1989. A fossiliferous rocky shore environment in the Lower Cretaceous (Albian) of northern California. *Geological Society of America Abstracts with Programs,* 21(5), 135–136.

SHURR, G.W., 1981. Cretaceous sea cliffs and structural blocks on the flanks of the Sioux Ridge, South Dakota and Minnesota. *In:* BRENNER, R.L. *et al.* (eds.), Cretaceous stratigraphy and sedimentation in northwest Iowa, northeast Nebraska, and southeast South Dakota. *Iowa Geological Survey Guidebook Series,* 4, 25–41. Note stepped paleotopography (Fig. 8, p. 38) used to calculate changes in the rate of sea-level rise.

SILVER, L.T.; STEHLI, F.G., and ALLEN, C.R., 1963. Lower Cretaceous pre-batholithic rocks of northern Baja California, Mexico. *American Association of Petroleum Geologists Bulletin,* 47, 2054–2059. Note mention of "exhumed Late Cretaceous sea-cliffs and shorelines" cut into plutonic rock (p. 2059).

SLOAN, R.E., 1964. The Cretaceous System in Minnesota. *Minnesota Geological Survey Report of Investigation,* 5, 64p. Note description of fossiliferous "boulder beach conglomerates" (pp. 15–16).

SURLYK, F. and CHRISTENSEN, W.K., 1974. Epifaunal zonation on an Upper Cretaceous rocky coast. *Geology,* 2, 529–534. See drawing (Fig. 10, p. 534) illustrating well developed zonation of encrusting, rocky-shore organisms.

WOODS, H., 1908. Echinoidea, Brachiopoda, and Lamellibranchia from the Upper Cretaceous Limestone of Needs Camp, Buffalo River. *Annuals of the South African Museum,* 7, 13–20. Note appended locality description by A.W. Rogers (p. 19): "The areas where the deposits occur are completely enclosed by dolerite: they may be described as two level ten-acre lots surrounded by boulders; and were, I presume, old shore-basins or lagoons, walled in by the igneous dyke." See more recent references by King (1972) under Cretaceous and Lock (1973) under Neogene.

ZITT, J. and NEKVASILOVA', O., 1987. Epibionts cemented to rocky bottom and clasts in the Upper Cretaceous of Zelezne Hory Mts. (Czechoslovakia). *Casopis Narodniho Muzea,* 156, 17–35.

ZITT, J. and NEKVASILOVA', O., 1990. Upper Cretaceous rocky coast with cemented epibionts (locality Knezivka, Bohemian Cretaceous Basin, Czechoslovakia). *Casopis pro mineralogii a geologii,* 35, 261–276.

ZITT, J. and NEKVASILOVA', O., 1991. New occurrences of phosphorites and phosphatized organic remains in the Upper Cretaceous of Bohemia (Czechoslovakia). *Vestnik Ustredniho ustavu geologickeho,* 66, 251–256. Note these occurrences are attributed to the "so-called surf facies."

ZULLO, V.A.; RUSSELL, E.E., and MELLEN, F.F., 1987. *Brachylepas* Woodward and *Virgiscalpellus* Withers (Cirripedia) from the Upper Cretaceous of Arkansas. *Journal of Paleontology,* 61, 101–111. Note oldest recorded example of fossil barnacles associated with a rocky shore.

Jurassic

AGER, D., 1986. A reinterpretation of the basal "Littoral Lias" of the Vale of Glamorgan. *Proceedings of the Geological Association,* 97, 29–35. Note modification of observations by Trueman (1922), which differs by proposing a storm-mode of origin for basal conglomerates instead of slow, *in situ* accumulation as littoral debris; the existence of a former rocky shore is verified by the occurrence of rock-encrusting ? worm tubes (Fig. 1A, p. 31) and lithophagid borings (Fig. 3, p. 34).

COX, A.H. and TRUMAN, A.E., 1936. The Geological History of Glamorgan. *In: Glamorgan County History, Vol. I, Natural History.* Cardiff: W. Lewis, p. 19–59. Note description of terraces formed by successive wave-cut platforms carved in Carboniferous limestone during Jurassic time (p. 55–56).

DE LA BECHE, H.T., 1846. On the formation of the rocks of south Wales and south western England. *Memoirs of the Geological Survey of Great Britain,* 1, 1–296. See especially Figs. 45 and 46 (p. 290) representing some of the earliest illustrations of lithophag and other borings associated with unconformity surfaces.

DZULYNSKI, S., 1950. Littoral deposits of the Middle Jurassic south of Krzeszowice. *Annales de la Societe Geologique de Polongne,* 19, 387–400. Note description of a porphyry sea cliff with attached gastropods.

FLETCHER, C.J.N.; DAVIES, J.R.; WILSON, D., and SMITH, M., 1986. The depositional environment of the basal "Littoral Lias" in the Vale of Glamorgan—A discussion of the reinterpretation by Ager (1986). *Proceedings of the Geological Association,* 97, 383–384.

FLETCHER, C.J.N., 1988. Tidal erosion, solution cavities and exhalative mineralization associated with the Jurassic unconformity at Ogmore, South Glamorgan. *Proceedings of the Geological Association,* 99, 1–14.

RADWANSKI, A., 1959. Littoral structures (cliff, clastic dikes and veins, and borings of *Potamilla*) in the high-tatric Lias. *Acta Geologica Polonica,* 9, 270–280. Note physical evidence for a wave-cut notch and the occurrence of polychaete borings.

RICHARDSON, L., 1907. The Inferior Oolite and contiguous deposits of the Bath-Doulting District. *Quarterly Journal Geological Society of London,* 63, 383–423. Note the fauna described includes *Lithophaga* borings (p. 400).

TRUEMAN, A.E., 1922. The Liassic rocks of Glamorgan. *Proceedings of the Geological Association,* 33, 245–284.

Triassic

GLAZEK, J.; DABROWSKI, T., and GRADZINSKI, R., 1972. Karst of Poland. *In:* HERAK, M. and STRINGFIELD, V.T. (eds.), *Karst, Important Karst Regions of the Northern Hemisphere.* Amsterdam: Elsevier Publishing Co., pp. 327–340. See Fig. 4 (p. 332) showing a schematic cross-section through the Triassic shore cave earlier discussed by Lis and Wojcik (1960).

LIS, J. and WOJCIK, Z., 1960. Triassic bone breccia and karst forms in Stare Gliny Quarry near Olkusz (Cracow region). *Kwartalnik Geologiczny,* 4, 55–74. Note description of a small island composed of Devonian dolomites which experienced a marine transgression in Rhae-Rothic times; dolomitic shore rubble and worn bone fragments were found mixed together in a karst cave.

Permian

HERRMANN, A., 1956. Der Zechstein am sudwestlichen Harzrand. *Geologisches Jahrbuch,* 72, 1–72. See paleogeographic maps (Figs. 7a–g, p. 18–19) and rocky-shore profile with encrusting bryozoan reef (Fig. 8, p. 27).

HOCKING, R.M.; MOORS, H.T., and VAN DE GRAAFF, J.E., 1987. Geology of the Carnarvon Basin Western Australia. *Geological Survey of Western Australia Bulletin,* 133, 289p. See illustrations of exhumed coastal karst towers up to 8 m high with corridors up to 20 m wide (Figs. 54 and 55, p. 79).

HUNTOON, J. and CHAN, M.A., 1987. Marine origin of paleotopographic relief on eolian White Rim Sandstone (Permian), Elaterite Basin, Utah. *American Association of Petroleum Geologists Bulletin,* 71, 1035–1045. Note interpretation (Fig. 14, p. 1044) of stepped topography cut in partly indurated eolian dunes, also used to calculate changes in rate of sea-level rise.

RADWANSKI, A. and RONIEWICZ, P., 1972. Permian (Zechstein) littoral structures in the Holy Cross Mts. *Acta Geologica Polonica,* 22, 17–24. See map (Fig. 2) showing the direction of a long-shore "littoral current" based on the orientation of flat pebbles.

RUNNEGAR, B., 1979. Ecology of *Eurydesma* and the *Eurydesma* fauna, Permian of eastern Australia. *Alcheringa,* 3, 261–285. Note description of the associated fauna from deposits formed "on or near rocky shorelines."

STONE, P. and STEVENS, C.H., 1988. An angular unconformity in the Permian section of east-central California. *Geological Society of America Bulletin,* 100, 547–551. See a photo of the unconformity (Fig. 4, p. 549); three paleotopographic highs with well over 35 m of relief are represented.

Carboniferous

DIX, G.R. and JAMES, N.P., 1987. Late Mississippian bryozoan/microbial build-ups on a drowned karst terrain: Port au Port Peninsula, western Newfoundland. *Sedimentology,* 34, 779–793. Note one of the few examples of a rocky shore preserved by a progradation following marine regression.

DIX, G.R. and JAMES, N.P., 1989. Stratigraphy and depositional environments of the Upper Mississippian

Codroy Group: Port au Port Peninsula, western Newfoundland. *Canadian Journal Earth Sciences,* 26, 1089–1100. **Note** "Carbonate buildups and associated intermound clastics and carbonates accumulated preferentially within high-relief topographic, paleokarst depressions developed on the carbonate autochthon." **See** Fig. 9., p. 1099.

VEEVERS, J.J. and ROBERTS, J., 1966. Littoral talus breccia and probable beach rock from the Visean of the Bonaparte Gulf Basin. *Journal Geological Society Australia,* 13, 387–403.

Devonian

FANNIN, N.G.T., 1969. Stromatolites from the middle Old Red Sandstone of western Orkney. *Geological Magazine,* 106, 77–88. **See** drawing (Fig. 5, p. 82) illustrating a gneiss cobble coated with stromatolitic limestone from the fringe of a "basement island."

KOBLUK, D.R.; PEMBERTON, G.S.; KAROLYI, M., and RISK, M.J., 1977. The Silurian-Devonian disconformity in southern Ontario. *Canadian Petroleum Geology Bulletin,* 25, 1157–1189. **See** drawing (Fig. 23, p. 1183) illustrating a dolomitic rocky shore with solution-widened joints.

PEMBERTON, S.G.; KOBLUK, D.R.; YEO, R.K., and RISK, M.J., 1980. The boring *Trypanites* at the Silurian-Devonian disconformity in southern Ontario. *Journal of Paleontology,* 54, 1258–1266.

PLAYFORD, P.E. and LOWRY, D.C., 1966. Devonian reef complexes of the Canning Basin, Western Australia. *Bulletin Geological Survey Western Australia,* 118, 150p. **See** photograph (Fig. 43, p. 114) showing reefal limestone fringing islands of Precambrian quartzite exposed in three-dimensional relief under present desert conditions.

WOLF, K.H., 1965. Littoral environment indicated by open-space structures in algal limestones. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 1, 183–223. **Note** description of "erosional remnants of lava flows which are occasionally surrounded and transgressed by algal bioherms" under criteria suggestive of intertidal conditions (p. 191).

Silurian

BRIDGES, P.H., 1975. The transgression of a hard substrate shelf: The Llandovery (Lower Silurian) of the Welsh Borderland. *Journal Sedimentary Petrology,* 45, 79–94. **Note** this is an updated version of the work by Whittard (1932).

BROOKS, M. and DRUCE, E.C., 1965. A Llandovery conglomeratic limestone in Gullet Quarry, Malvern Hills, and its conodont fauna. *Geological Magazine,* 102, 370–382. **See** field sketches (Fig. 1, p. 371) showing the basal boulder bed of early Silurian age at the Gullet Quarry; a defense of Reading and Poole (1961).

CHERNS, L., 1982. Palaeokarst, tidal erosion surfaces and stromatolites in the Silurian Eke Formation of Gotland, Sweden. *Sedimentology,* 29, 819–833.

KOBLUK, D.R., 1984. Coastal paleokarst near the Ordovician-Silurian boundary, Manitoulin Island, Ontario. *Canadian Petroleum Geology Bulletin,* 32, 398–407.

READING, H.G. and POOLE, A.B., 1961. A Llandovery shoreline from the southern Malverns. *Geological Magazine,* 98, 295–300.

WHITTARD, W.F., 1932. The stratigraphy of the Valentian rocks of Shropshire: The Longmynd-Shelve and Breidden outcrops. *Quarterly Journal Geological Society of London,* 88, 859–902. **Note** maps (Plates 59 and 62, II) illustrating a prominent seastack at the base of Wooler's Batch.

ZIEGLER, A.M., 1964. The Malvern line. *Geological Magazine,* 101, 467–469. A defense of the earlier paper by Reading & Poole (1961).

Ordovician

BERGSTROM, S.M., 1988. On Pander's Ordovician conodonts: Distribution and significance of the *Prioniodus elegans* fauna in Baltoscandia. *Senckenbergiana lethaea,* 69, 217–251. **Note** "The basal portion of the Talubacken succession can be interpreted as an example of an Ordovician rocky shore deposit." p. 229. **See** also text-figure 4, p. 228.

BROOKFIELD, M.E. and BRETT, C.E., 1988. Palaeoenvironments of the Mid-Ordovician (Upper Caradocian) Trenton limestones of southern Ontario, Canada: Storm sedimentation on a shoal-basin shelf model. *Sedimentary Geology,* 57, 75–105. **See** photographs in Fig. 16 (p. 95) showing islands formed of Precambrian granite; **note** also implications of an encrusting biota.

DESROCHERS, A. and JAMES, N.P., 1988. Early Paleozoic surface and subsurface paleokarst: Middle Ordovician carbonates, Mingan Islands, Quebec. *In:* JAMES, N.P. and CHOQUETTE, P.W. (eds.), *Paleokarst.* New York: Springer-Verlag, pp. 183–210. **See** photographs in Fig. 9.7A & B showing *Trypanites* borings on a karst surface.

DONOVAN, R.N. and RAFALOWSKI, M.B., 1984. The anatomy of an early Ordovician shell bank in the Honey Creek Formation, southwestern Oklahoma. *Geological Society of America Abstracts with Programs,* 16(2), 82. **Note** wave sorting of brachiopod shells on "a small pocket beach on a rocky shoreline."

HARLAND, T.L. and PICKERILL, R.F., 1984. Ordovician rocky shoreline deposits—the basal Trenton Group around Quebec City, Canada. *Geological Journal,* 19, 271–298. **See** photograph (Fig. 3, p. 275) of a fossil tidal pool infilled by gravel-forming algae.

JOHNSON, M.E. and BAARLI, B.G., 1987. Encrusting corals on a latest Ordovician to earliest Silurian rocky shore, south-west Hudson Bay, Manitoba, Canada. *Geology,* 15, 15–17. **See** photographs (Fig. 3a–c, p. 16) illustrating the oldest known boulder-encrusting corals.

JOHNSON, M.E.; SKINNER, D.F., and MACLEOD, K.G., 1988. Ecological zonation during the carbonate transgression of a Late Ordovician rocky shore (Northeastern Manitoba, Hudson Bay, Canada). *Palaeogeography, Palaeoclimatology, Palaeoecology,* 65, 93–114. **See** fold-out map in Fig. 7 (p. 101–105) tracking the linear arrangement of several offshore biological zones.

JOHNSON, M.E. and RONG, J.-Y., 1989. Middle to Late Ordovician rocky bottoms and rocky shores from the Manitoulin Island area, Ontario. *Canadian Journal of Earth Sciences,* 26, 642–653.

JONES, O.T. and PUGH, W.J., 1950. An early Ordovician shore-line in Radnorshire, near Builth Wells. *Quarterly Journal of the Geological Society of London*, 105, 65–99. See Fig. 3 (p. 79) depicting sea cliffs and stacks eroded from the basaltic Builth Volcanic Series in Wales.

MERGL, M., 1983. Rocky-bottom fauna of Ordovician age in Bohemia (Arenigian; Prague Basin, Barrandian area). *Vestnik Ustredniho ustavu geologickeho*, 58, 333–339. Note oldest known occurrence of a rocky-shore fauna.

MERGL, M., 1984. *Marcusodictyon*, an encrusting bryozoan from the Lower Ordovician (Tremadocian) of Bohemia. *Vestnik Ustredniho ustavu geologickeho*, 59, 171–172. Note that the bryozoan affinity of this organism is now disclaimed.

READ, J.F. and GROVER, G.A., JR., 1977. Scalloped and planar erosion surfaces, Middle Ordovician limestones, Virginia: Analogues of Holocene exposed karst or tidal rock platforms. *Journal Sedimentary Petrology*, 47, 956–972. See photograph (Fig. 3B, p. 959) showing a cross-section through rocky-shore encrusting algae.

RIVA, J. and PICKERILL, R.K., 1987. The late mid-Ordovician transgressive sequence and the Montmorency Fault at the Montmorency Falls, Quebec. *Geological Society of America Centennial Field Guide—Northeastern Section*, 5, 357–362.

SKINNER, D.F. and JOHNSON, M.E., 1987. Nautiloid debris oriented by long-shore currents along a late Ordovician-Early Silurian rocky shore. *Lethaia*, 20, 157–164. See hydrodynamic map (Fig. 3, p. 161).

Cambrian

ANDERSON, M.M., 1987. Stratigraphy of Cambrian rocks at Bacon Cove, Duffs, and Manuels River, Conception Bay, Avalon Peninsula, eastern Newfoundland. *In:* ROY, D.C. (ed.), *Geological Society of America Centennial Field Guide—Northeastern Section*, 5, 467–472. Note descriptions of two different Early Cambrian rocky-shores, one at Bacon Cove featuring an angular unconformity and the other at Duffs involving a nonconformity; also see Edhorn and Anderson (1977).

BAARS, B.L. and SEE, P.D., 1968. Pre-Pennsylvanian stratigraphy and paleotectonics of the San Juan Mountains, southwestern Colorado. *Geological Society of America Bulletin*, 79, 333–350. Note under depositional environment (p. 340) that "Local topography, which resulted from fault escarpments, caused irregularities of the coastline and supplied coarse debris to the sea; the coarsest sediments [Cambrian Ignacio Formation] accumulated near the fault-formed islands and peninsulas, while the finer clastics and some carbonate sediments were deposited in deeper waters."

COBBOLD, E.S., 1927. The stratigraphy and geological structure of the Cambrian area of Comley (Shropshire). *Quarterly Journal Geological Society of London*, 83, 551–573. Note stratigraphic cross-section (Fig. 9, p. 569) illustrating rocky shores and conglomeratic deposits.

DAKE, C.L. and BRIDGE, J., 1932. Buried and resurrected hills of central Ozarks. *American Association of Petroleum Geologists Bulletin*, 16, 629–652.

DALZIEL, I.W.D. and DOTT, R.H., JR., 1970. Geology of the Baraboo District, Wisconsin. *Wisconsin Geological and Natural History Survey, Information Circular*, 14, 164p. Numerous excellent maps and diagrams; Note especially Fig. 13 (p. 53) depicting the paleogeography of the quartzitic Baraboo islands during late Cambrian (Franconian) time and Plate 6 mapping the offshore size-distribution of quartzite clasts. See also Dott (1974).

DONOVAN, R.N.; RAGLAND, D.; RAFALOWSKI, M.; MCCONNELL, D.; BEAUCHAMP, W.; MARCINI, W.R., and SANDERSON, D.J., 1988. Pennsylvanian deformation and Cambro-Ordovician sedimentation in the Blue Creek Canyon, Slick Hills, southwestern Oklahoma. *In:* HAYWARD, O.T. (ed.), *Geological Society of America Centennial Field Guide—South-Central Section*, 4, 127–134. Note Fig. 4 (p. 130) showing cross bedded Cambrian carbonates on a wave-cut platform cut into rhyolite.

DOTT, R.H., JR., 1974. Cambrian tropical storm waves in Wisconsin. *Geology*, 2, 243–246. See rocky-shore profile (Fig. 2, p. 244) and paleogeographic map (Fig. 3, p. 244).

DUNBAR, C.O. and RODGERS, J., 1957. *Principles of Stratigraphy*. New York: John Wiley & Sons, Inc., 356p. See description of a basaltic rocky shore at Taylors Falls, Minnesota (pp. 170–171 and Fig. 85) attributed to late Cambrian coastal erosion; an 1897 reference by C.P. Berkey on the same locality is cited, but the conclusions therein are not as specific.

EDHORN, A.-ST. and ANDERSON, M.M., 1977. Algal remains in the Lower Cambrian Bonavista Formation, Conception Bay, Southeastern Newfoundland: *In:* FLUGEL, E. (ed.), *Fossil Algae*. New York: Springer-Verlag, pp. 113–123. Note description of fossil algae occupying "pockets, hollows, and irregularities in the late Precambrian erosion surface" (p. 113); also see Anderson (1987).

HOWE, W.B., 1966. Digitate algal stromatolite structures from the Cambrian and Ordovician of Missouri. *Journal of Paleontology*, 40, 64–77. See related article by Stinchcomb (1975).

KISVARSANYI, E.B. and HEBRANK, A.W., 1987. Taum Sauk Power Plant section: Buried and exhumed hills of Precambrian rhyolite, the St. Francois Mountains, Missouri. *In:* BIGGS, D.L. (ed.), *Geological Society of America Centennial Field Guide—North-Central Section*, 3, 167–168.

MILLER, W.J., 1913. The geological history of New York State. *New York State Museum Bulletin*, 168, 1–130. Note description of a Cambrian shoreline along the fringes of the Adirondack Precambrian in Saratoga County (Fig. 15 on p. 43): boulders of a coarse conglomerate (from 1–3 feet across) "were torn off the Adirondack cliffs by the waves of the Potsdam sea and were deposited near shore in local depressions of the old rock surface."

REDDEN, J.A., 1987. Early Proterozoic and Precambrian-Cambrian unconformities of the Nemo area, Black Hills, South Dakota. *In:* HILL, M.L. (ed.), *Geological Society of America Centennial Field Guide—Rocky Mountain Section*, 1, 219–225. See sketch in Fig. 4 (p. 225) depicting an accumulation of boulder conglomerate on the lee side of a quartzitic island.

SHARP, R.P., 1940a. Ep-archean and ep-algonkian erosion surfaces, Grand Canyon, Arizona. *Geological Society of America Bulletin,* 51, 1235–1270. See Fig. 8 (p. 1263) illustrating a buried monadnock modified by marine erosion.

SHARP, R.P., 1940b. A Cambrian slide breccia, Grand Canyon, Arizona. *American Journal of Science,* 238, 668–672. Note that slide eminates from a monadnock, "the slopes of which had been undercut and oversteepened by marine erosion" (p. 668).

STINCHCOMB, B.L., 1975. Paleoecology of two new species of late Cambrian *Hypseloconus* (Monoplacophora) from Missouri. *Journal of Paleontology,* 49, 416–421. Note the monoplacophorans described herein are associated with "stromatolites peripheral to a topographic high of igneous rock which was probably exposed as a small island" (p. 416); see also Howe (1966).

Precambrian

BJORLYKKE, K. 1967. The Eocambrian "Reusch Moraine" at Bigganjargga and the geology around Varangerfjord; northern Norway. *In:* Studies on the latest Precambrian and Eocambrian rocks in Norway, *Norges Geologiske Undersøkelse,* 251, 18–44. See map (Fig. 2, p. 21) and aerial photograph (Fig. 13, p. 33) of Precambrian "monadnocs" penetrating the Karlbotn Quartzite.

BYERLY, G.R.; LOWE, D.R., and WALSH, M.M., 1986. Stromatolites from the 3,300–3,500-Myr Swaziland Supergroup, Barberton Mountain Land, South Africa. *Nature,* 319, 489–491. See well developed stromatolites (Fig. 2) directly overlying the brecciated surface of an Archean lava flow.

GLAESSNER, M.F. and PARKIN, L.W. (eds), 1958. The Geology of South Australia: Chapter 1, The Mt. Lofty-Olary Region and Kangaroo Island. *Journal Geological Society Australia,* 5, 3–27. Note description of a transgressive, late Precambrian conglomerate belonging to the Aldgate Formation which rests "with violent unconformity on Archaean crystalline basement" indicating "encroachement on a sinking land surface" by "residual shore deposits" (p. 11, Plates 1B and 9).

GUNATILAKA, A., 1977. Environmental significance of Upper Proterozoic algal stromatolites from Zambia. *In:* FLUGEL, E. (ed.), *Fossil Algae.* New York: Springer-Verlag, 74–79. Note description of stromatolitic build-up following the topographic highs of older basement rock.

KERANS, C. and DONALDSON, J.A., 1988. Proterozoic paleokarst profile, Dismal Lakes Grup, N.W.T., Canada. *In:* JAMES, N.P. and CHOQUETTE, P.W. (eds.), *Paleokarst.* New York: Springer-Verlag, 167–182. See arrow in Fig. 8.3 (p. 170) marking the part of the stratigraphic column where a karst surface punctuates "peritidal" conditions.

LAWSON, D.E., 1976. Sandstone-boulder conglomerates and a Torridonian cliffed shoreline between Gairloch and Stoer, northwest Scotland. *Scottish Journal of Geology,* 12, 67–88. See diagram (Fig. 5, p. 81) depicting stepped surface of an unconformity with overlying conglomerates exposed on the coast at Rubha Reidh and following schematic reconstruction (Fig. 9, p. 85).

SIGMOND, E.M.O., 1986. *Berggrunnen i Norge.* Trondheim: Tapir Forlag, 32 p. plus map. See back cover with photograph of a Precambrian beach conglomerate emplaced on basement gneiss in the eastern part of the Hardangervidda (Norway).