

Paleoclimate during the Redwall karst event, Grand Canyon National Park

By RAY KENNY

GRAND CANYON NATIONAL PARK (FIG. 1) has always been known as a Geologist's paradise (Kenny 1993). The rock formations exposed in Grand Canyon (fig. 2) range in age from the 1.7-billion-year-old Vishnu schist of the Precambrian Era (exposed in the Inner Gorge of the Grand Canyon), to the 250-million-year-old Kaibab limestone of the Paleozoic Era (exposed along the north and south canyon rims). Exposed upstream of the park in the northernmost portion of Marble Canyon is the lower part of the younger, 195-210-million-year-old Chinle Formation (late Triassic Period). At the western end of the park, 1.16-1.25-million-year-old (Late Cenozoic Era) basaltic lava flows are also prominently exposed (Hamblin 1994). Both the age and variety of rock formations, in addition to the excellent exposure of these rock formations, make Grand Canyon a spectacular area for geological research.

At first, it might seem that much of the geological research has already been accomplished at the park, but the application of new technology and instrumentation has resulted in new geologic insight. Indeed, ongoing field research has also added to the baseline geologic information about Grand Canyon (Beus 1989; Bloeser 1985). This study has combined both fieldwork and new technology and has focused on the Redwall Formation (Mississippian Period).

The Redwall Formation

The Redwall Formation has been the subject of numerous and diverse geological and paleoecological studies. The Redwall was deposited in a warm shallow sea about 330 million years ago and has many well-preserved fossils. It consists primarily of light-colored, blue-gray limestone and

Figure 1 (right). The Redwall Formation (top shown by arrow) holds many clues to the ancient climate in what is today Grand Canyon National Park, Arizona. The research focused on chemically resistant deposits, rather than fossils, within the limestone layer to provide insight into the terrestrial climate about 325 million years ago.

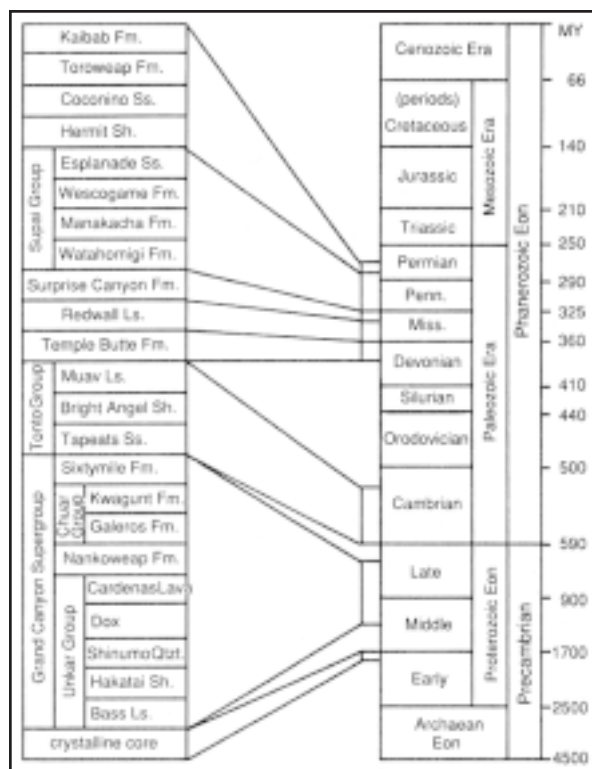


Figure 2 (left). Stratigraphic column of the major rock formations in Grand Canyon compared to the geologic timetable (after Haq and Van Eysinger 1987; in Beus and Morales 1990). The abbreviation "MY" refers to millions of years before present.

chert¹ lenses with minor dolomite. However, much of the formation has been stained red by iron oxide weathered out from the shale of the overlying Supai Formation. The ubiquitous red surface "stain" is the reason for the name "Redwall." The fossil record, extracted from previous studies of the Redwall Formation, is both extensive and well-preserved, and has yielded much qualitative information about the paleoenvironment of the ancient shallow sea (e.g., McKee and Gutschick 1969).

Scientists have derived information about the Redwall through the identification and study of foraminifera, crinoid, coral, cephalopod, brachiopod, and other fossils from this formation. Additionally, scientists have also been interested in the formation because its upper member, the Horseshoe Mesa Member, was exposed to the atmosphere

¹A hard, dense, fine-grained rock made up of silicon and oxygen. Flint is a dark-colored variety of chert.

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for an extended period of time (approximately 325 million years ago) before the deposition of the overlying Supai Formation sediment. During the time the Redwall Formation was exposed to the atmosphere (subaerially exposed), the limestone was severely altered by chemical dissolution and reprecipitation and developed a recognizable karst (limestone) topography replete with caves, caverns, sinkholes, chert-lag breccias, red-residual soil, and related solution features. Detailed and ongoing research on karst features (Kenny 1989) has produced new insights into information about the ancient terrestrial climate (Kenny in press).

New karst features

During the Redwall karst event, chemical dissolution of the chert-rich limestone produced numerous large- and small-scale features. In many areas of northern Arizona (outside and south of Grand Canyon National Park), much of the limestone was completely dissolved away, leaving behind a heap of more chemically resistant, partially weathered, and cemented chert breccias or “lag” deposits. In some areas, these residual chert-lag deposits are quite extensively developed (fig. 3). In other areas, such as in the park study area, the residual deposits are not as well developed. In all cases, the chert-lag deposits are held together by

silica (quartz) “cement,” and locally contain preserved soil features. These residual deposits were cemented together by silica that formed at or near the time of the Redwall karst event, at or near the Earth’s surface.

The cement that holds together the residual heaps of partially weathered chert, also called secondary silica (Kenny and

ment is also chemically distinct. It is the chemical distinction that has been used to provide insight into the ancient terrestrial climate, about 325 million years ago.

The ancient climate

Samples of the secondary silica cement were chemically analyzed for oxygen and hydrogen isotopic values. Each element

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Knauth 1992), formed under very different environmental conditions than the chert. The chert formed under marine conditions at approximately the same time as the limestone was forming. The secondary silica cement formed under terrestrial conditions much later than the already solidified chert. The secondary silica cement also has forms and features that are distinct from the chert, owing, in part, to its formation under very different environmental conditions. Figure 4 illustrates some of these unique forms of silica. Both macroscopic and microscopic studies reveal the presence of microlaminated, fibrous, botryoidal (like bunches of grapes), and other forms of silica cement. These distinctive forms of silica may have formed under subaerial, terrestrial conditions (as shown by Kenny and Knauth 1992). In addition, the secondary silica ce-

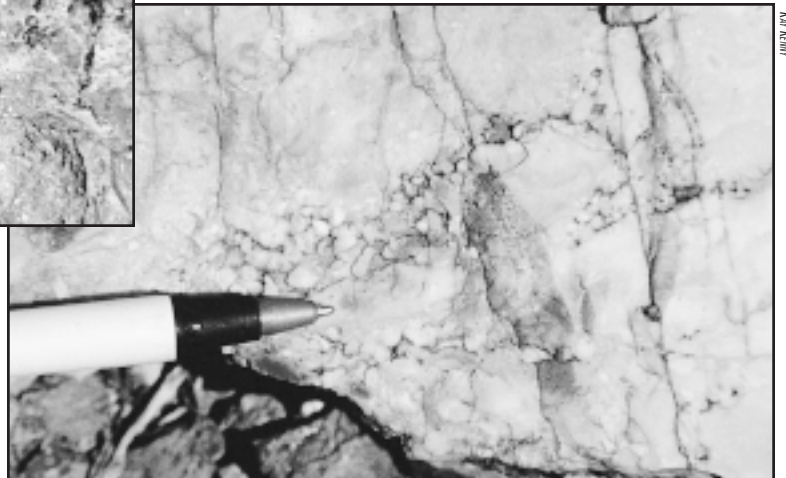
that makes up the basic chemistry of the silica has its own distinct isotopic value. These values will remain relatively unaltered in silica until the mineral is either destroyed by weathering or altered by relatively high temperature and pressure. Since the secondary silica cement was formed (or precipitated) in the presence of fresh water (on land), it is chemically (isotopically) distinct from the chert (also quartz) that actually precipitated in the presence of seawater. This isotopic difference, dictated by the environment in which the mineral formed, can be clearly and unambiguously determined. The isotopic value for the silica cement can then be used to determine the temperature at which the substance formed because the isotopic value is also determined, in part, by the temperature at the time of precipitation (see Knauth and Epstein 1976; Kenny and Knauth 1992).

Using this information, we determined that the near-surface temperature at which the cement formed was a balmy 27-28°C (81-82°F). These preliminary temperature estimates are geologically reasonable values and are in agreement with the range of temperature or climate needed to produce



Figure 3A (above). Secondary silica deposit at the top of the Redwall Formation (Bass Canyon). The chemistry of the secondary silica was used to determine the ancient terrestrial temperature range.

Figure 3B (right). A chert-lag deposit at the top of the Redwall Formation (Bass Canyon). Chert is more chemically resistant to erosion and dissolution than the limestone matrix and is considered evidence for surficial weathering.



an extensive karst event. The paleotemperature estimates are probably a long-term climatic average. The paleotemperature estimates are significant because, until recently, quantifying terrestrial paleoclimate conditions has been extremely difficult, if not impossible.

Benefits of climate research

Modern global climate change is very much on the minds of resource managers, scientists, and the public. By studying the rocks and minerals, geologists have shown that global climate change is a natural phenomenon that has occurred countless times in the geologic past. To understand modern climate change and associated resource concerns, we first need to quantify the conditions and features of ancient, naturally occurring climate shifts. The research at Grand Canyon will provide scientists and resource managers with new information about ancient climate changes. Information from this research can be used in a management and education program designed to inform the public about ancient climates (which were very different from our modern climate) and address public questions about modern global climate change. Resource managers may also find the research useful in terms of describing the importance of the preservation of biological and geological resources—resources that may hold the key to a vast amount of information that has yet to be tapped and used by our modern society.

Finally, the research at Grand Canyon can be used at other national parks and monuments (e.g., Death Valley and Glacier National Parks) to quantify past climate and climate change. But more work remains at Grand Canyon! The 250-million-year-old Kaibab Limestone (the rock formation that makes up the rim of the Grand Canyon) has also been subaerially exposed and

karsted. The Kaibab limestone may also provide us with information about ancient climate change from yet another interval of time. In the meantime, the research at Grand Canyon is providing us with greater insight into the climate of the geologic past—a climate that helped produce the stunning array of rocks exposed in Grand Canyon National Park. **P₅**

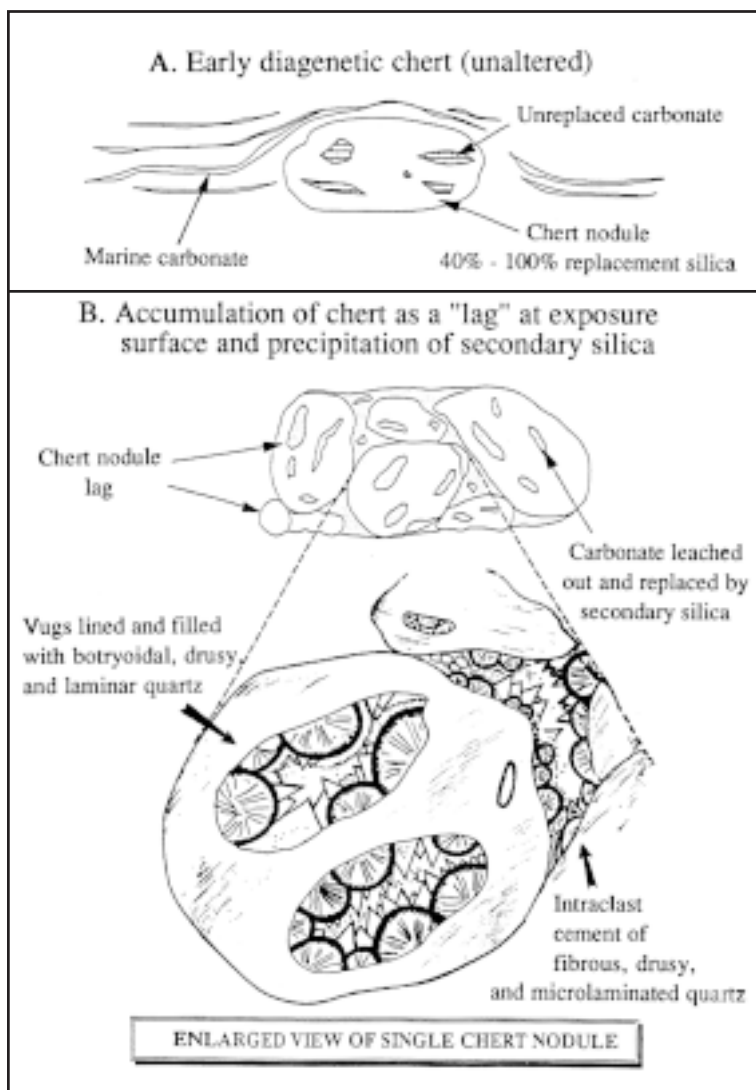


Figure 4. Some of the distinct forms and features of the secondary silica cement that precipitated during the Redwall karst event approximately 325 million years ago: (A, above) early marine chert; and (B, below) examples of secondary silica.

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