Chapter F

A GEOENVIRONMENTAL LIFECYLE MODEL: THE AUSTINVILLE PLATFORM CARBONATE DEPOSIT, VIRGINIA

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INTRODUCTION

Ore bodies of the Austinville platform carbonate deposit make up one of the few major base-metal sulfide districts situated in Cambrian age rocks in the eastern United States, and constitute the most recently active base-metal mine in the Appalachians between Tennessee and Pennsylvania. The Austinville-Ivanhoe district is located two kilometers north of the Wythe-Carroll county line in southwestern Virginia and extends northeastward for over 11 kilometers roughly paralleling the New River (Fig. 1). The highly mineralized sphalerite, galena, and pyrite-bearing bodies are crudely pencil-shaped with lenticular cross-sections and range from tens to hundreds of meters in length.

By the time the mine closed in the early 1980's, the deposit was the most continuously mined base-metal deposit in North America. Mining operations began in 1756 with the application of surface and shallow underground techniques. Over 21,000 tons of lead ore were extracted during a period of mining that lasted until the 1860's. Much of this lead was used for ammunition for soldiers in the U.S. Civil war. Iron was mined near Austinville from surficial goethite and limonite during the years ranging from 1800 to the early 1900's and this was used in 19th century pig iron production. Mining of zinc from oxidized ores (mainly hemimorphite) was initiated during the post-Civil War years and lasted until 1902 when the New Jersey Zinc Company purchased the mine for its zinc oxide potential. During the next quarter century, the company developed reserves of sulfide ore and after the perfection of the flotation process in the 1920's, a separation plant was built and put into production. During 230 years, over 1,000,000 tons of zinc metal, and 200,000 tons of lead metal were extracted from more than 30,000,000 tons of ore mined at Austinville. In more recent years, 500,000 tons of ore averaging 3 percent zinc and 0.4 percent lead mined each year using modified open stope methods (Weinberg, 1980). The residual dolomite gangue was crushed and sold as agricultural dolomitic limestone. The lead and zinc mine ceased operation in December 1981 and was allowed to flood. In the early 1990's, a limestone quarrying operation purchased the property and produces and markets crushed limestone for the agricultural market.
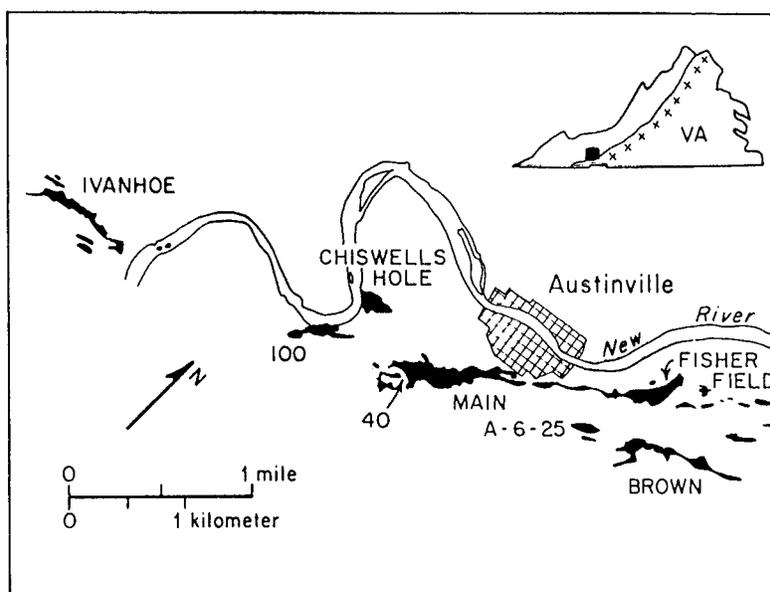

Figure 1. Locations of ore bodies that comprise the Austinville-Ivanhoe district, VA.

GEOLOGY OF THE DEPOSIT

The Austinville-Ivanhoe is deposit situated near the southeast margin of the folded and faulted Valley and Ridge province (Fig. 2). The basal stratigraphic sequence consists of Precambrian basement rocks nonconformably overlain by the Chilhowie Group of Early Cambrian age. The uppermost formation in the Chilhowie Group, the Erwin Formation, is graditionally overlain by the Early to Middle Cambrian Shade Dolomite. The Early to Middle Cambrian Rome Formation overlies the Shady and is overlain by the Early to Middle Cambrian Elbrook Formation.

The Shady Formation, the ore host, is approximately 640 meters thick in the Austinville area, where is has three conformable members (Fig. 2). The Patterson member is a 300-meter thick sequence of ribbon-laminated limestones and dolomites. The Austinville member consists of a 300-meter thick sequence of stromatolitic and massive dolomite that has minor quartzose grainstones and black shaly carbonate tongues. The Ivanhoe member consists of a thick-bedded stromatolitic limestone with minor dolomite and shale and is up to 43 meter in thickness (Pfiel and Read, 1980). The mineralized zones lie within a 400-meter stratigraphic interval that straddles the contact between the Patterson and Austinville members of the Shady Formation. Pfiel and Read (1980) have suggested that the Austinville region represents a Cambrian platform to platform margin, foreslope, and slope facies transition.
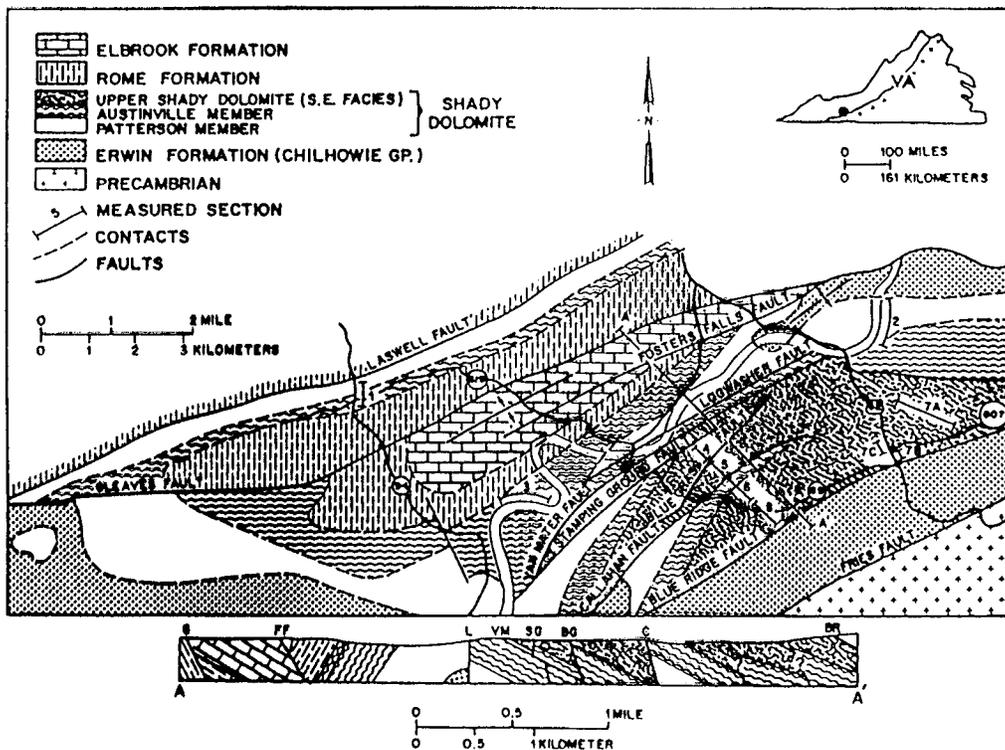

Figure 2. Geology of the Austinville-Ivanhoe region showing distribution of the Shady Dolomite, which contains the zinc and lead ore bodies

ORE TEXTURES, MINERALOGY, AND PARAGENESIS

The ore minerals occur within a 400-meter stratigraphic interval defined by marker beds in the Austinville and Patterson members of the Shady Formation. Ore bodies are separated from each other by faults and areas of sub-economic mineralization. The ore occurs as ribbon and disseminated replacements and as open-space fillings. Ribbon and disseminated replacements of dolomite by sphalerite, galena, and pyrite are usually accompanied by total recrystallization of the surrounding dolomite. The mineralized zones at Austinville contain sphalerite, galena, pyrite, and traces of marcasite, chalcopyrite, and arsenopyrite intergrown with at least three generations of dolomite gangue; minor amounts of quartz, fluorite, barite, gypsum, anhydrite, and calcite are also present. Alteration minerals occur in near-surface parts of the ore lenses and, locally, at depth near faults; these include smithsonite, cerussite, anglesite, iron-oxides, hydrozincite, plumbo-aragonite, and hemimorphite.

The open-space filling ore consists of symmetrically and asymmetrically banded coatings and rosettes on brecciated dolomite fragments (Fig.3). Polycrystalline aggregates of pyrite, admixed with minor marcasite and galena, encrust the dolomite fragments. Three generations of crustiform pyrite, sphalerite, and galena exist in the open-space filling ore. Earlier galena and sphalerite is partially replaced by dolomite. Low grade metamorphism and deformation resulted in minor recrystallization and microfaulting of all generations of ore minerals.
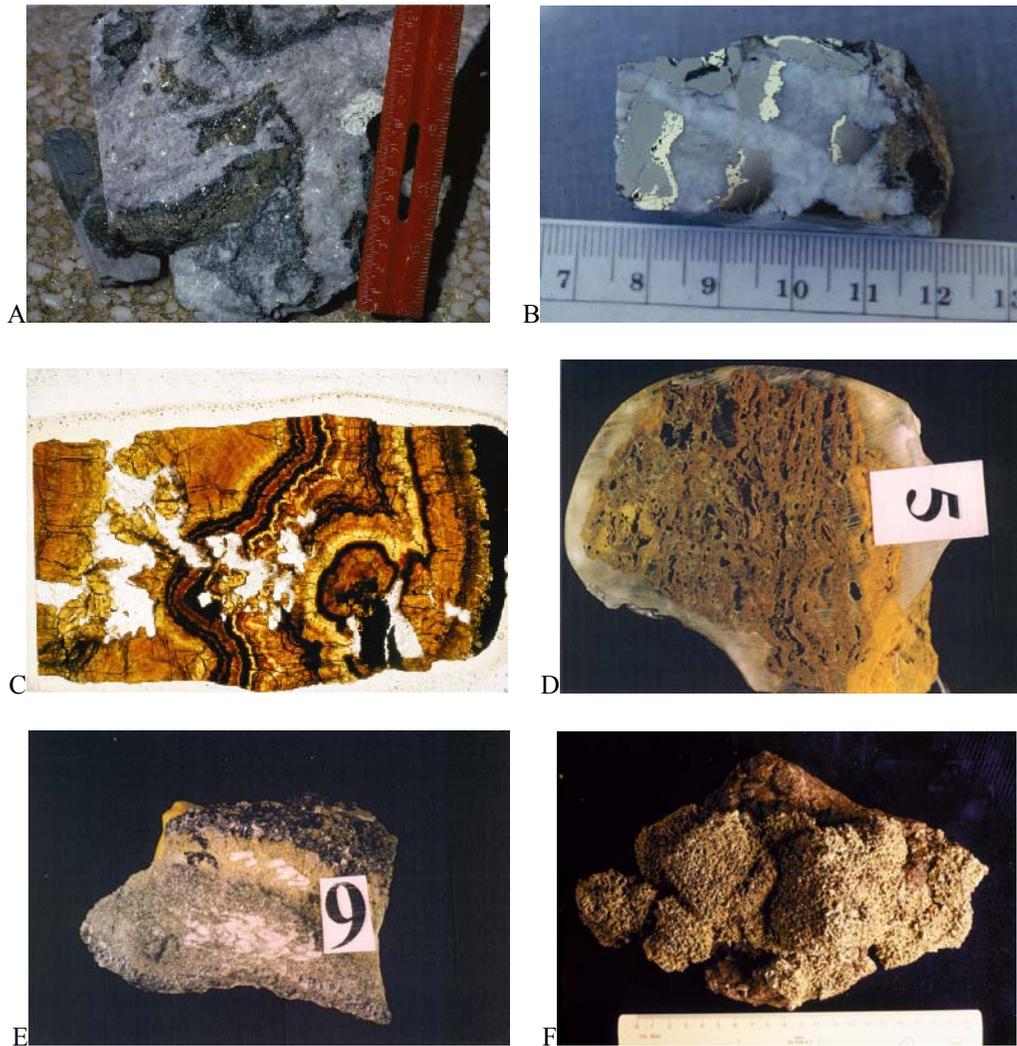

Figure 3. Primary and secondary ore textures typical of platform carbonate deposits: A. Carbonate breccia with ribbon ore fragments; B. Polished samples showing ribbon texture of dolomitic carbonate and sphalerite coated by pyrite, cut by later recrystallized dolomitic gangue; C. Polished thin section showing delicate growth banding in sphalerite (pale yellow to red-brown); D. Iron oxide minerals (primarily goethite) forming box-work patterns on quartzite waste rock; E. Layered altered iron-oxide, zinc and lead-bearing carbonate crusts; F. Massive iron oxide gossan that occurs as filling vugs within some ore bodies.

Sphalerite is the most abundant of the primary ore minerals, followed by pyrite, galena, marcasite, and chalcopyrite. Pyrite and marcasite comprise about 5% of the total sulfide content, although they are very abundant locally, as in the Pyrite ore body. Pyrite was the first mineral to form and it is ubiquitous. It occurs as polycrystiform crustiform overgrowths 100 micrometers to 3 millimeters in thickness on dolomite fragments, as layers in banded sphalerite, and as cubes scattered in sphalerite, dolomite, and most of the late stage minerals. The pyrite overgrowths contain thin layers of dolomite and sphalerite, interstitial galena and, rarely laths of marcasite and arsenopyrite. Galena was the last sulfide mineral to form in major proportions. Galena crystals include fragments of pyrite, sphalerite, and dolomite. Silver contents of up to 0.7 ounces per ton of ore are reported (Foley and Craig, 1989) although the average is slightly less than 0.5 ounces of silver per ton of lead ore (~17 ppm). During the later stages of mineralization, fluorite, quartz, barite, gypsum, and anhydrite were deposited locally in vugs and veins. Gypsum and anhydrite usually contain scattered cubes of pyrite and feather-like aggregates of marcasite. Barite contains pyrite cubes aligned along growth zones. Secondary carbonate minerals, smithsonite (Zn), hydrozincite (Zn carbonate hydroxide), cerussite (Pb), and plumbo-aragonite, formed within the zone of oxidation of the sulfide ore under conditions of high carbonate activity. Metals contained in these mineral phases are available for release to the ground water during breakdown of the carbonate minerals. Where minerals oxidized to form metal-sulfate and metal-oxide minerals such as anglesite, which occurs within and rimming galena and hemimorphite (Zn silicate hydroxide) and goethite, which form coatings on fragments of zinc and iron-bearing ore.

SOIL AND SEDIMENT SIGNATURES

Many MVT deposits are thought to have essentially no geochemical signature outside of the zone of wall rock alteration because of limited primary dispersion of ore related elements into the surrounding carbonate rocks (Lavery and others, 1994), except along structures that acted as fluid conduits. In the Austinville-Ivanhoe district background carbonate rocks typically contain about 20-ppm zinc and 9-ppm lead. However, extensive volumes of rock containing dolomite cement are widely peripheral to mineralized zones (for example throughout most of Wythe County, Virginia). Replacement dolomite and late calcite in these rocks have considerably elevated abundances of trace metals associated with of deposits, including as much as 9,300 ppm iron, 200 ppm strontium, 1,500 ppm lead, 1,000 ppm manganese, and 10,000 ppm zinc (Barnaby, 1989).

Although MVT deposits are hosted by carbonate rocks, residual soil overlying some deposits can be acidic. The soils can have moderate to high permeability, medium to high erosion potential, and moderate to high water capacity. These factors can influence the mobility of metals into the environment. Soils in the immediate vicinity of the zinc mines and smelter (now a state park) at Austinville had elevated Pb and zinc contents which related directly to the mining and smelter processes which required removal and regrading of the site. In Wythe County, Va., soil is moderately to very strongly acidic (pH 5.6 to <4.5) although as much as 30 percent of the surface may consist of dolomitic limestone outcrops; the soil has moderate permeability, medium to high erosion potential, and moderate water capacity. Much of the soil is deemed suitable for cultivated crops (legumes), hay, or pasture and much is prime farmland (corn, vegetables, small grain, and strawberries) (U.S. Department of Agriculture, 1992). No soils containing elevated lead or zinc were found in farm fields during preliminary regional sampling. In contrast, bed sediments of the New River (Fig. 1) do contain elevated Zn and Cd.

DRAINAGE SIGNATURES

Metal mobility away from platform-carbonate deposits typically is limited by the abundance of carbonate rock associated with these deposits; carbonate rock consumes acid mine drainage and inhibits aqueous metal mobility. In southwestern Virginia, acidic rain from the Northeast affect surface conditions in the region. The presence of Pb-sulfate in some of the ore at Austinville, indicates that some Pb is sequestered in an insoluble sulfate form, however, Pb contained within cerussite and other carbonate minerals is available to groundwater and soils. Near-neutral waters having elevated concentrations of dissolved Zn (as high as 100 mg/l) and Pb and Cd have been reported in mine workings with high iron sulfide contents (Plumlee and others, 1995). Near-neutral zinc-bearing river waters also occur near Austinville. In this case, others factors besides iron sulfide contents may control zinc contents of mine drainage waters because the deposits are low in pyrite and marcasite.
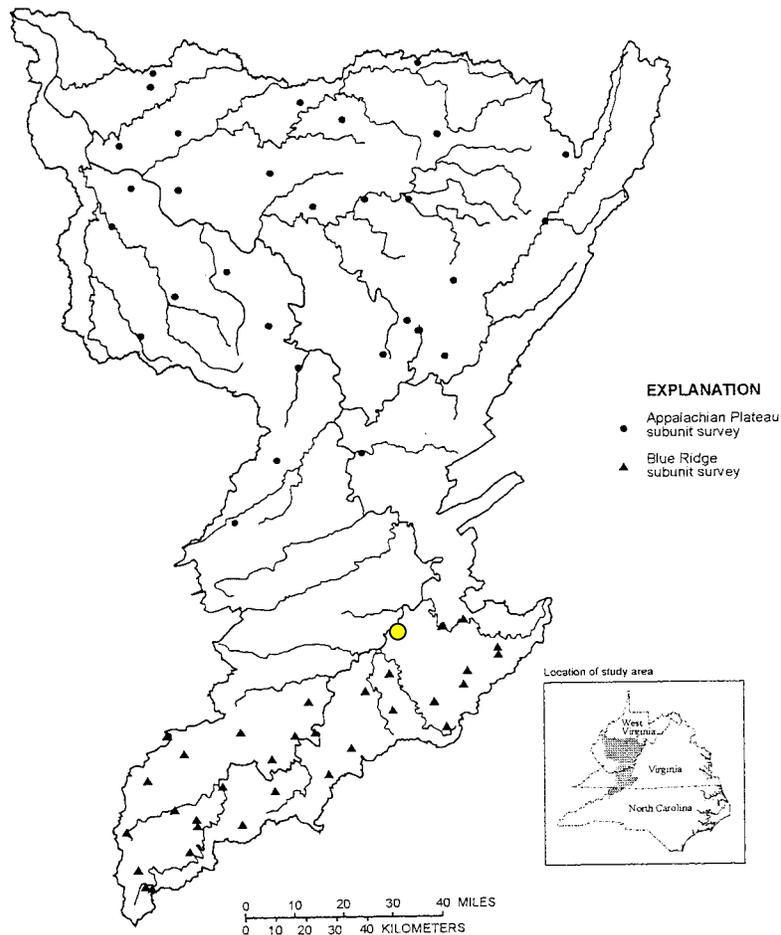
Figure 4. The outline of the Kanawha-New River Basin showing the location of Austinville mines.

The Austinville mine is contained within the Kanawha-New River basin (Fig. 4). The rivers of the catchment drain across three physiographic provinces: the Blue Ridge, Valley and Ridge and, finally, the Appalachian plateaus. The New River begins in North Carolina at the confluence of the North and South Forks and flows generally north for 250 miles to Gauley Bridge, West Virginia where it joins with the Gauley River to form the Kanawha River. Upriver from the Austinville mine site, the New River traverses crystalline rocks of the Blue Ridge Province and carbonate rocks of the Valley and Ridge Province. Groundwater occurs primarily in fractures in the sedimentary and crystalline rocks of the basin and in the pore spaces of unconsolidated sediments and regolith. Elevated concentrations of cadmiun, zinc, nickel, mercury and selenium were found in bed sediments and fish tissues at some sites downriver from the mines, however, coal mining activities in the Appalachian plateau may contribute considerable metals to the groundwater and bed sediments (Paybins and others, 2000). Near Austinville, zinc, copper, lead, iron occurs at only slightly elevated levels in the near-neutral river waters (Fig. 5).
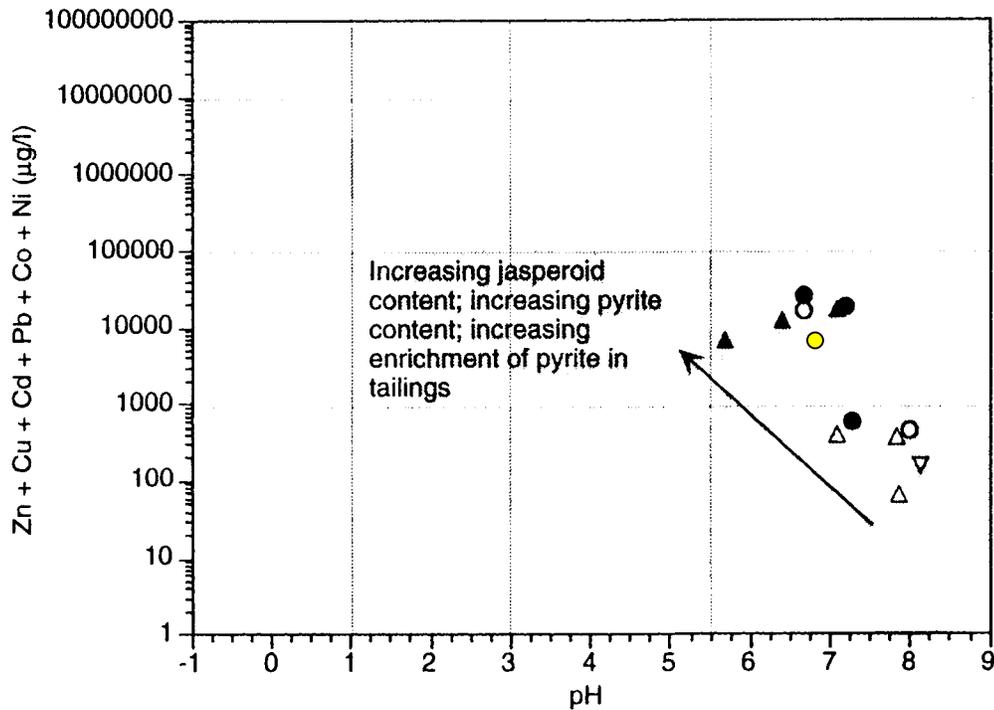
Figure 5. Ficklin plot for platform carbonate deposits showing data for Austinville, compared to data for other platform carbonate deposits.

CLIMATIC EFFECTS

Climate is extremely critical in assessing the environmental concerns associated with the platform carbonate deposit type. Current climatic setting can be as varied as Sahara conditions in North African deposits to permafrost conditions at the Polaris mine (Leach and others, 1995). Many North American deposits occur in humid temperate, and dry temperate regimes (e.g., Bailey, 1983). Potential acid-mine drainage problems related to MVT deposits in relatively dry climate settings are much less than those of deposits in warm, wet climates. Acid-rain aggravates potential environmental problems in the mid-Atlantic and northeastern United States, especially the Appalachian region.

POTENTIAL ENVIRONMENTAL CONCERNS

Small MVT deposits are present throughout the Appalachians in Cambrian to Mississippian carbonate rock sequences (for example, Shady Dolomite and Knox Dolomite). The Austinville-Ivanhoe, Va., deposit is a prime example of how climatic conditions and soil properties may interact to increase the potential for local environmental problems. Most of the area is in the drainage basin of the New River, which has water quality problems including excessive concentrations of trace metals such as zinc, copper, lead, iron, and locally acidification caused by mining activities (Virginia Water Control Board, 1990a,b). Prime farmlands of the valley and ridges within and adjacent to the historic lead and zinc mines may have be locally affected by metal contamination attributable to past releases of lead and zinc into soil and ground water as a result of environmental conditions specific to the region. Currently, the closure of the mines and clean-up of area adjacent to the mines, smelter, and the development of workings related to limestone quarrying has mitigated any long-term consequences of the lead and zinc mining operations. The development of the limestone quarrying operation, which produces crushed limestone for the agricultural market, demonstrates an important facet of platform carbonate deposit models. Geoenvironmental models of this deposit type (any many others) should be expanded to consider the effects of mining industrial minerals in this geologic setting.

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