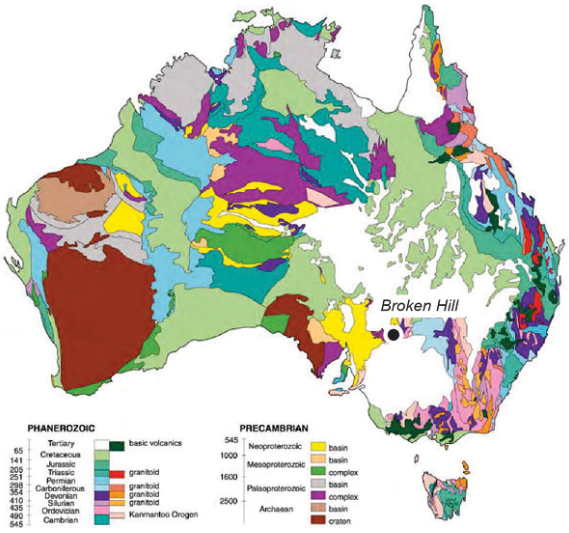
Earth & Space Sciences 345: Economic Geology

Introductory example – the Broken Hill Ag-Pb-Zn deposit:

To introduce the class with some basic ideas, unusual geology, and strange words, here's a brief history of the Broken Hill deposit (see also: http://en.wikipedia.org/wiki/Broken_Hill_ore_deposit and http://en.wikipedia.org/wiki/BHP_Billiton (section on the history of Broken Hill Proprietary Co):

Remote location in far western New South Wales, Australia



Nondescript black hill first staked by Charles Rasp (a boundary rider on a sheep station).

Originally prospected as a tin deposit (though interest in silver had been aroused by earlier finds and mining at Silverton nearby). What Rasp found was a ***gossan***, a surficial mass of iron-oxide that can form when reactive sulfide minerals are exposed to oxygen and water. Some gossans conceal underlying metal sulfide deposits. Others are uninteresting (e.g. formed at the expense of ***pyrite***, or mafic silicate minerals).

Initial ***assay*** revealed no tin, some Pb, and a trace of Ag.

Rasp and his partners persisted, staked the whole of the exposed hill, and eventually reached rich deposits of Ag, Pb and Zn which turned out to be wildly profitable.

The mineralogy of the upper ***oxidized zone*** of the deposit is interesting. Silver occurred as the native metal, various metal alloys (*e.g.* dyscrasite Ag_3Sb) and in halides such as chlorargyrite AgCl and bromargyrite AgBr. Lead and zinc occurred in a variety of oxide, carbonate, sulfate and phosphate minerals. The deposit was enriched in other unusual elements such as Mn and Ba, which we now recognize as a clue to its origin.

Previous photo: Pyromorphite $Pb_5(PO_4)_3Cl$. This photo: Native silver. Both from the oxidized ore at Broken Hill.

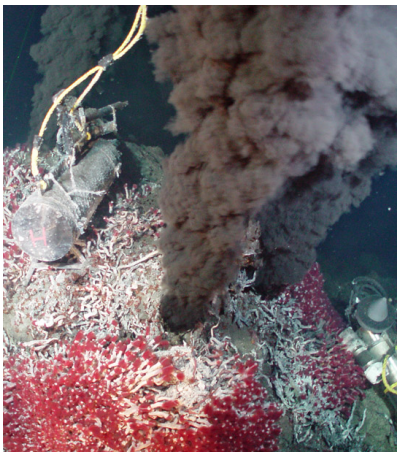
Silver enrichment in the oxidized zone made the mine highly profitable, and provided capital for the Broken Hill Proprietary Company (BHP) to diversify into steel-making, coal, iron-ore and other resources. BHP quit the field in the 1930s having mined much of the oxidized ore. Other companies continued mining the deep extensions of the deposit to the north and south. These held much higher overall tonnages of Pb and Zn, but required more expensive underground mining, and more complicated ***metallurgical*** procedures to concentrate metals from the primary ***sulfide*** ore.

What to learn from all this?

(i) Geological/mineralogical oddities of the Broken Hill deposit are clues to its origin:

- It is a stratiform body, highly folded and metamorphosed, but distinctively layered.
- Metal contents and Pb/Zn ratio change gradationally along the length of the deposit, and through the stratigraphic section.
- Unusual enrichment in Mn and Ba.
- Deposit is comparatively low in pyrite (Fe) and arsenopyrite (note - low As content also increases the value of the ore).
- Comparatively low in Cu. Little ***chalcopyrite*** accompanying ***galena*** and ***sphalerite***.

The Broken Hill deposit is a ***volcanogenic massive sulfide (VMS)*** or ***SEDEX (sedimentary exhalative)*** ore body, likely formed as a sediment of sufide minerals in a Proterozoic marine basin. Until the 1970s, we did not know that sedimentary sulfides are deposited on the seafloor by volcanic hydrothermal systems that vent along the mid-ocean ridges:



Black smokers are vents to vigorous submarine hydrothermal systems. Intrusion of hot basalt magma into the upper oceanic crust sets up convective cooling cells. Circulating fluids extract metals from the rock they pass through. Oxidation and cooling when expelled ***brines*** mix with seawater precipitates metal sulfides, barite, Fe sulfides and oxides.

- Seafloor sediments are commonly enriched in Mn, and may contain ***Mn nodules***. Manganese enrichment is commonly accompanied by Cu, Ni and Co.

· Ba enrichment probably originated from cooler “white smoker” fluids.

· Cooler fluid temperatures may also account for the low Cu content of the ore. Hotter submarine vent fluids tend to have higher Cu/Zn ratios.

· Clues to the sedimentary origin of the deposit have been well disguised by high grade (granulite facies) metamorphism. The deposit is tightly folded across its length, plunges north and south of the original outcrop, and both sulfide and silicate minerals in the deposit are coarsely recrystallized.

The ***Sullivan Pb/Zn (Ag/Sn) Mine*** in southeastern British Columbia, which closed in 2001 after nearly 100 years of production, is another example of a VMS deposit.

· The high metal grades (especially Ag) of the oxidized Broken Hill ore resulted from tens of millions of years of sub-aerial weathering and ***supergene enrichment***. Soluble ***gangue*** components of the ore and host rock weathered away, and primary sulfides reacted with rain- and groundwater to form insoluble oxides, hydroxides and halides, enriching metal grades.

Sullivan Mine, Kimberley, BC

Cerussite ($PbCO_3$), oxidized zone, Broken Hill