Cornwall-Type Iron Ores of Pennsylvania

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Introduction: Magnetite-apatite ore deposits are important ores of iron in many parts of the world. They can be classified into two major groups: a) high-Ti, high -P magnetite-apatite-ilmenite deposits (Nelsonites) associated with anorthosites; and b) low-Ti, variable-P magnetite +/- apatite deposits (Kiruna type ores) principally associated with volcanic rocks. The origin of the first type is generally accepted to be magmatic, with liquid immiscibility between silicate magma and iron-titanium-phosphorous-oxide magma the most commonly cited process (Philpotts, 1967; Kolker, 1982; Barton & Johnson, 1996). The origin of the Kiruna-type, however, has been a matter of controversy, with both magmatic and hydrothermal origins proposed. The Cornwall-type deposits of Pennsylvania, may be considered as an apatite-poor variety of these Kiruna-type deposits.

Many of these Kiruna-type deposits, contain originally-horizontal, laterally-extensive, stratified, iron oxide-rich units. These stratified iron oxide deposits do not appear to have formed by the same mechanism in all localities, indeed there may be a variety of mechanism that would lead to units with similar appearances. Such mechanisms might include: (1) magmatic ignimbrites, airfall ash, lavas, or sills; (2) sedimentary exhalative, lateritic, or detrital deposits, and (3) hydrothermal replacement, veins, or phreatic surface venting of hydrothermal systems. These various types of deposits should present different field relationships, textural characteristics, and trace element compositions, in accord with their mechanism of formation.

Stratified iron oxide ores have been described from El Laco, Chile

(Henríquez and Martin,1978, Nyström and Henríquez,1994); the Chilean Cretaceous Iron Belt (Travisany et al.,1995); Kiruna, Sweden (Nyström and Henríquez,1994); Cerro Mercado, Mexico (Swanson, et al., 1978; Lyons, 1988); Vergenoeg, South Africa (Crocker, 1985); and the Bafq Mining District, Iran (Förster and Jafarzadeh, 1994). In all of these localities the authors have interpreted them as pyroclastic iron ore. Similar stratiform deposits in the Missouri Iron District have been interpreted as replacement of volcanic tuff (Snyder, 1969; Ridge,1972; Panno and Hood, 1983), or as hematite tuff produced by the venting of a fumarolic system into a lake (Nold,1988; Hauck,1990). Stratified magnetite ores of the Cornwall-type are associated with a series of diabase sills in the Newark and Gettysburg Triassic rift basins. Cornwall-type deposits are characterized by laterally extensive, banded to massive magnetite ores with only traces of apatite, located adjacent to the upper contact of diabase sills. They are generally hosted in limestone or marble country rock, but locally they are hosted in the diabase sills or in clastic sediments or gneissic country rock. The Cornwall-type ores have been interpreted as hydrothermal replacement deposits (Smith, 1931; Tsusue, 1964; Lapham & Gray, 1973; Eugster & Chou, 1979).

The recent discoveries of the enormous Cu-Au-U-REE hematite breccias at Olympic Dam in Australia (Roberts & Hudson, 1983; Oreskes & Einaudi, 1990, 1992; Haynes, et al., 1995), and the giant REE iron oxide deposit at Bayan Obo, China (Argall, 1980; Wang, 1981; Wei & Shangguan, 1983; Bai & Yuan, 1983) have made iron oxide-apatite deposits of the Kiruna type of considerable economic interest for commodities other than iron. Indeed, many Kiruna type deposits are associated with near-by Cu, Au, U, or REE mineralizations (Crocker, 1985; Kisvarsanyi, 1990; Hauck, 1990; Einaudi & Oreskes, 1990; Marikos, et al., 1990; Vivallo, et al., 1993, 1994, 1995a, 1995b; Espinoza, et al., 1994; Förster and Jafarzadeh, 1994; Rojas & Henríquez, 1994; Foose & McLelland, 1995). The Cornwall type deposits are associated with minor, but recoverable amounts of Cu, Au, Ag, and Co, but no significant REE concentrations have been reported in the district.

Triassic diabase sills: At least four large diabase sills or sheets are present in the Gettysburg and Newark Basins of Pennsylvania (Figure 1).
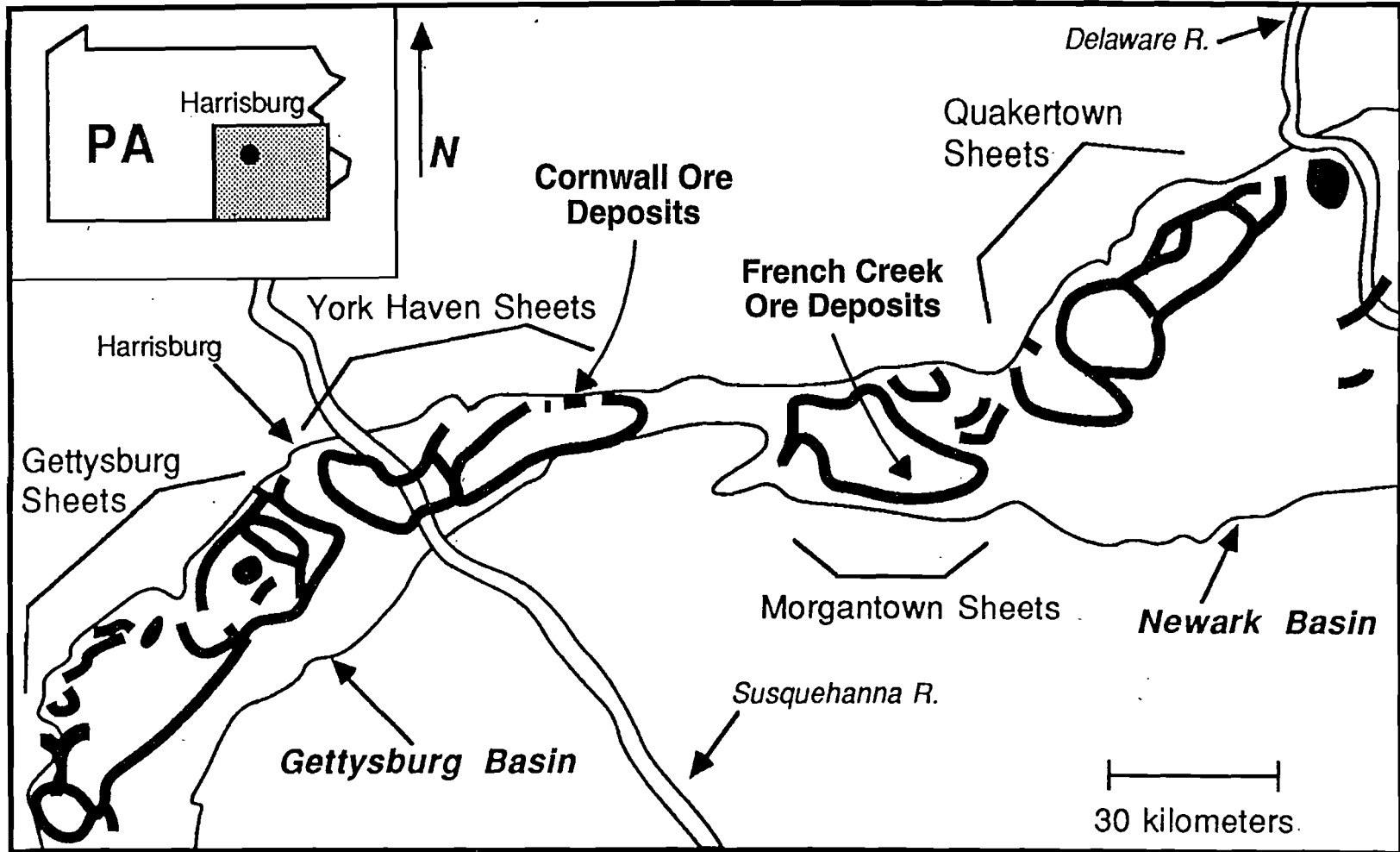
Figure 1 – Diabase sheets in the Gettysburg and Newark Basins in Pennsylvania. The locations of the Cornwall Ore Deposits and the French Creek Ore Deposits is shown. Modified from Mangan et al., 1993.

These are similar in age, bulk composition, and mode of emplacement to the more famous Palisades Sill of New York and New Jersey. The sheets outcrop as a series of rings or saucers in which the center of the sheets are covered and the inwardly dipping edges of the sheets are exposed at the surface. Iron ores of the Cornwall type are associated with all four of these major sheets in Pennsylvania. These Cornwall-type deposits were a major source of iron ore from the 1700's to the early 1900's, and played a prominent role in the Revolutionary War, the Civil War, and World Wars One and Two.

These diabase sheets range from less than 100 to over 600 meters in thickness, and are laterally extensive for 30 to 60 kms along strike. Each sheet represents the intrusion of a huge volume of tholeiitic magma in excess of 1000 km^3. They are believed to represent magma generated and intruded during the initial rifting and opening of the north Atlantic in the Mesozoic. The diabase was intruded at shallow levels (<1 km) largely within a series of rift basins filled with continental shales and sandstones. In a few cases the margins of the sills cut the bounding rift basin faults and extend into the pre-Mesozoic country rocks. Although a few of the sills, like the Palisades sill, are differentiated from a magnesium-rich diabase at their base to a more iron-rich, silica-rich granophyre in their centers, most of the sills have little compositional variation from top to bottom. The diabase is characterized by an interlocking mosaic of plagioclase, augite, and low-Ca pyroxene crystals with minor amounts of interstitial olivine, ilmenite, and/or magnetite.

Cornwall District, Pennsylvania: The Triassic magnetite deposits of Cornwall Pennsylvania produced over 140 million tons of iron ore during 230 years (1742-1972) of continuous mining (Lapham & Gray, 1973). The two main ore bodies occur as lenses or pods 30-50 m thick with over 1000 m of strike length, overlying the York Haven Triassic diabase sill. The ore occurs primarily as a replacement of limestone, and commonly interfingers with unaltered limestone along the margins of the deposit (Lapham & Gray, 1973) (Figure 2). The ore is typically finely banded or layered with alternating magnetite-rich and magnetite-poor laminae. The dominant minerals are magnetite, actinolite, chlorite, and sulfides, with only minor amounts of apatite. In places the ore replaces diabase and hornfels country rock, and in one location fills a fault

cutting the diabase. Field relations at both the Cornwall mine and the Carper mine to the west, indicate that faulting occurred after diabase solidification and before ore deposition, suggesting a time lag between the solidification of the sill and the formation of the ore bodies (Lapham & Gray, 1973). It is suggested, however, that there is an inverse correlation between the amount of granophyre in the sill and the amount of ore adjacent to (above) the sill . This would suggest that magmatic processes, perhaps degassing or late stage melt migration, are genetically related to the ore-forming process.

Contact metamorphism associated with the sill attained a maximum temperature of ~600 °C, while metasomatism occurred in the range of 500 to 700° C (Lapham & Gray, 1973). On the basis of experimental studies, it has been suggested (Chou & Eugster, 1977; Eugster & Chou, 1979) that the Cornwall deposit may have originated by the precipitation of Fe carried in Cl-rich hydrothermal fluids, with the cooling of the diabase sill serving as the heat source for fluid circulation. From all the available evidence, the Cornwall deposit appears to be an example of a stratified iron oxide ore formed by hydrothermal replacement. The source of the hydrothermal solution, and the source of the iron, however is not clear. The heat source for the circulation of the fluids is also not known. There is no "missing" iron in the sill, nor any rocks near the sill that appear to have lost iron. If the sill predates the ore, as some field relations suggest, than the source of heat necessary to deposit that much iron at temperatures near 500° C is not known. Even with fluids containing 30,000 ppm dissolved iron (maximum values reported in hydrothermal brines) it would require almost all of the available heat from the sill to form the amount of known iron ore.

French Creek District, Pennsylvania: A number of small magnetite deposits are associated with the Morgantown Triassic diabase sill south of Hopewell, Pennsylvania, and were the main source of ore for the Hopewell furnace active from 1771 to 1883. Deposits include: The Elizabeth and Susie mines in St. Peters Village, the Warwick mine, the Hopewell Mine, the Jones Good Luck Mine, and the Grace Mine. Ore was concentrated in pods or layers within Biotite gneiss over lying the Diabase sill (Figure 3). In places the ore
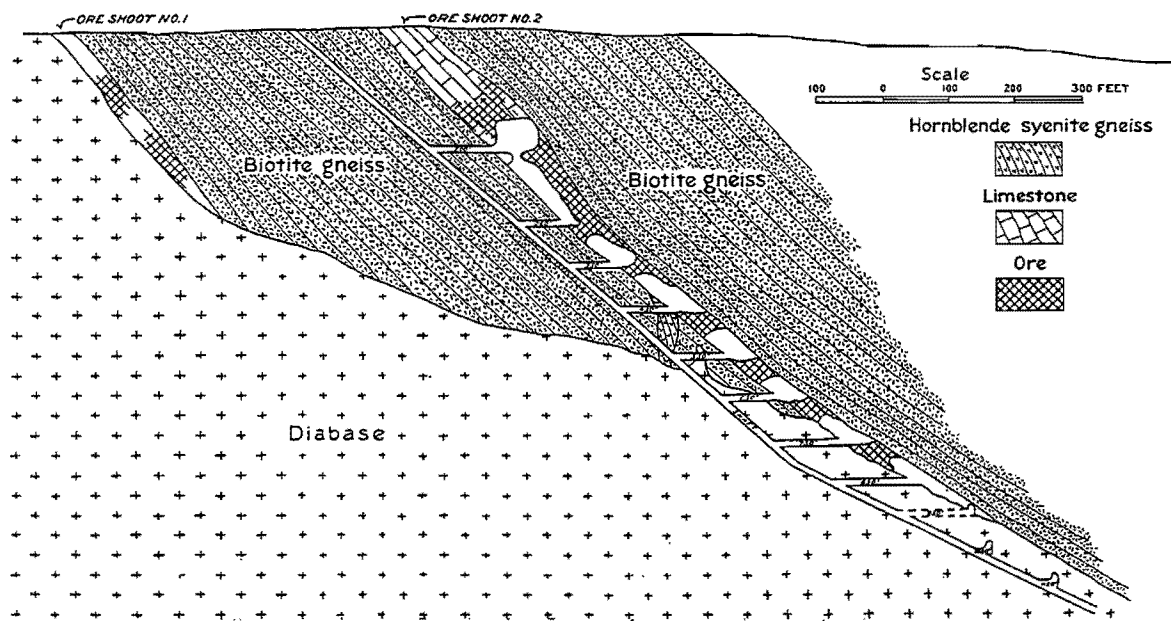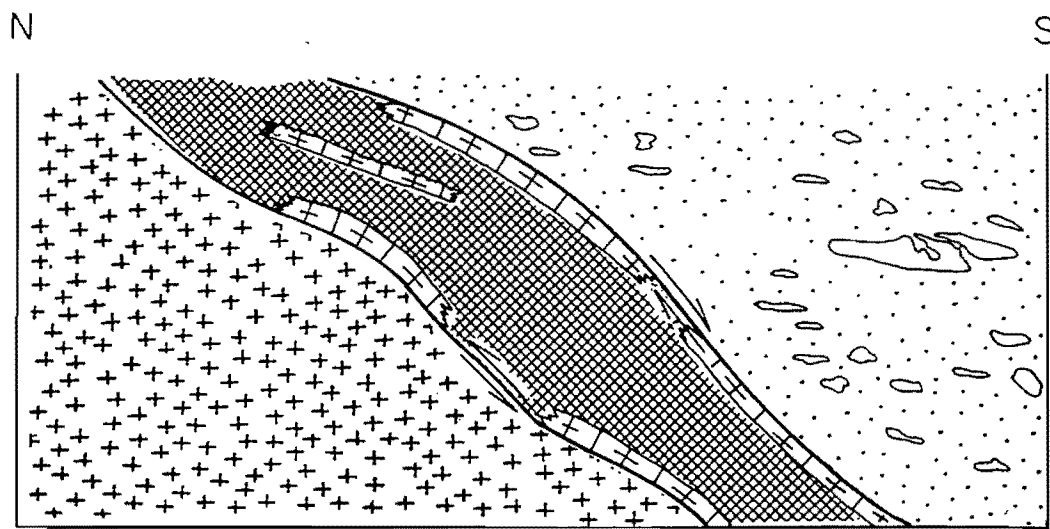
Figure 2 - Geologic cross section of the west end of the Elizabeth Mine, St. Peters, PA, French Creek District. From Smith (1931).
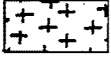

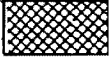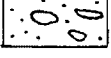Figure 3 - Cross section through the east end of main pit, No. 3 Mine, Cornwall District, Cornwall, PA. From Lapham & Gray (1973).

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occurs as a replacement of marble lenses within the Biotite gneiss. The last of the iron mines in St Peters village closed in 1928, although a diabase quarry has remained intermittently active until the present day. The Grace mine near Morgantown remained active until the 1970's.

Calcite-dolomite geothermometry from the Grace mine suggest a temperature of about 650° C for the formation of the veins adjacent to the deposit (Tsusue, 1964). Because the magnetite in the deposit is intergrown with serpentine, however, the magnetite was considered by Tsusue (1964) to have formed below 500° C which he considered to be the upper stability limit for serpentine. The magnetite in the ore at the Grace mine is associated with small amounts of chalcopyrite, marcasite, pyrite, pyrrotite, sphalerite, and galena, but the ore grades for commodities other than iron are not reported (Tsusue, 1964). The magnetite ores in the Elizabeth and Susie mines in St.Peters village are associated with ubiquitous pyrite and chalcopyrite, and although originally opened as a copper mine, very little Cu was produced except from a small near-surface supergene enrichment zone.

Formation of iron-rich melts and fluids: The origin of massive magnetite deposits and stratified iron-oxide ores is not well understood, and in fact, although they share a number of similarities, it is not likely that all of these deposits are produced by the same mechanism or mechanisms. Proposed origins include: (1) separation of an immiscible iron-rich melt from a silica-rich melt during cooling; (2) partial or complete melting of iron-rich crustal rocks; (3) contact metamorphism and/or replacement of wall rocks by iron-rich fluids; (4) hydrothermal vein or replacement deposits; and (5) sedimentary exhalative deposits. These mechanisms can be group into two major categories, magmatic and hydrothermal. Magmatic processes 1 and 2 above both involve the transport of iron as an extremely iron-rich magma; they differ primarily in how that magma was formed. Hydrothermal processes 3, 4, and 5 all involve the transport of iron as a dissolved component in a fluid, and differ mainly in how and where that fluid interacts with the surrounding rocks to release the dissolved iron. It is not necessary that the hydrothermal and magmatic processes are mutually exclusive. A magmatic iron ore at depth may produce a hydrothermal deposit near the surface as a result of degassing. Indeed, many

large "hydrothermal hematite deposits" are associated with large gravity and magnetic anomalies at depth that may represent magmatic magnetite (for example, Pilot Knob in Missouri and Olympic Dam in Australia).

Geochemical "signatures" of hydrothermal iron-oxide deposits: The formation of iron-apatite ores by hydrothermal fluids requires a system that can efficiently transport iron while limiting most other cations to low abundances. Experimental studies suggest that Fe can be transported in Cl-rich or Cl-poor hydrothermal solutions as Fe, Fe-Cl, or Fe-OH complexes (Chou & Eugster, 1977; Eugster & Chou, 1979; Whitney, et al., 1985; and Crerar, et al., 1985). Deposits formed by hydrothermal replacement should have trace element compositions that reflect the ease with which components are transported in hydrothermal solution, and the processes that result in their deposition in a specific environment. Such trace element signatures might include: low contents of immobile high-field strength cations (Zr, Nb, Ta, Th), high alkali contents (Na, K, Rb, Cs), and high contents of easily transported included elements (Ca, Mg, Mn, Cu, Zn, Pb). This will be in marked contrast to magmatic ores originating from differentiation and immiscibility which will have high P, Zr, Nb, Ta, Th, U, and REEs and low Na, K, Rb, Cs, Ca, and Mg. Experimental studies suggest that hydrothermal fluids fractionate geochemically similar elements differently than do magmatic processes, and as a result, hydrothermal fluid transport might produce unusual ratios for Cs/Rb, Pb/Ce, La/Ba, and LREEs/HREEs (You, et al., 1996) or Hf/Zr, and Y/Ho (Bau, 1996). Hydrothermal replacement deposits will also be likely to have specific elemental distribution patterns reflecting changing fluid compositions and temperatures, zoned from the center of a deposit towards the margins (Hemley, et al., 1992; Hemley & Hunt, 1992). Apatite in such deposits may be richer in Cl and OH, in contrast to the apatite in igneous systems which is generally F-rich.

Associated Mineral Deposits: Recently, a new ore mineralization type has been defined, and named after the type locality at the Olympic Dam deposit in Southern Australia (Roberts & Hudson, 1983; Oreskes & Einaudi, 1990, 1992; Haynes, et al., 1995). Olympic Dam type deposits are characterized by Cu, U, Au, Ag, and/or REE mineralization associated with iron oxide-apatite

deposits. This mineralization type is accompanied by magnetic and gravity anomalies that in many of the cases are caused by magnetite–apatite deposits at depth. These deposits range from small mineralized zones to "giant" ore bodies. The type locality at Olympic Dam contains 2,000 million metric tons with an average grade of 1.6% Cu, 3.5 g/ton Au, 0.06% U_3O_8 and 0.5% REE (Oreskes & Einaudi, 1990). At Olympic Dam the Cu–U–Au–Ag mineralization is hosted principally in hematite breccias that have been interpreted as a very unusual type of sediment–hosted mineralization (Robert & Hudson, 1983), or as a hydrothermal breccia complex formed by hot saline fluids mixed with cooler meteoric waters (Oreskes & Einaudi, 1990, 1992; Hayes, et al., 1995). The Olympic Dam mineralization is characterized by iron sulfides with Cu, Co, and some Au, and Ag. The REEs and U are principally associated with apatite. Au and Ag are also present in zones of siliceous hydrothermal alteration. In the Cornwall deposit average ore grades run approximately 39.4 % Fe, 1.29% S, and 0.29% Cu. Co can be recovered from the pyrite concentrate and Cu can be recovered from the Chalcopyrite concentrate. In 1953 1700 oz of Au was recovered from approximately 1.4 million tons of ore (Lapham & Gray, 1973).

References

Argall, G.O., Jr., 1980. Three iron ore bodies of Bayan Obo, World Mining, 33, 38-41.

Bai, G., & Yuan, Z.X., 1983. On the genesis of the Bai Yun Obo ore deposit, Chinese Acad. Geol. Sci. , Inst. Mineral. Deposits. Bull. 4, 1-17.

Barton, M.D. & Johnson, D.A., 1996. Evaporitic-source model for igneous-related Fe oxide-(REE-Cu-Au-U) mineralization, Geology 24, 259-262.

Bau, M., 1996. Controls on the fractionation of isovalent trace elements in magmatic and aqueous systems: evidence from Y/Ho, Zr/Hf, and lanthanide tetrad effect. Contr. Mineral. Petrol. 123, 323-333.

Chou, I.M., & Eugster, H.P., 1977. Solubility of magnetite in supercritical chloride solutions, Am. J. Sci. 277, 1296-1314.

Crerar, D., Scott, W., & Brantley, S., 1985. Chemical controls on solubility of ore-forming minerals in hydrothermal solutions, Can. Mineral. 23, 333-352.

Crocker, I.T., 1985. Volcanogenic fluorite-hematite deposits and associated pyroclastic rock suite at Vergenoeg, Bushveld complex, Econ. Geol. 80, 1181-1200.

Einaudi, M.T., & Oreskes, N., 1990. Progress towards an occurrence model for Proterozoic iron oxide deposits - a comparison between the ore provinces of south Australia and southeast Missouri, In Pratt, W.P. & Sims, P.K., (eds.) The midcontinent of the United States - permissive terrane for an Olympic Dam-type deposit?, U.S. Geol. Sur. Bull. 1932, 58-69.

Espinoza, S., Vivallo, W., & Henríquez, F., 1994. Geología y genésis de mineralización metálica en el distrito ferrífero de Cerro Imán, Copiapó, Chile. VII Congreso Geológico Chileno Vol. II, 799-802.

Eugster, H.P., & Chou, I.M., 1979. A model for the deposition of Cornwall type magnetite deposits, Econ. Geol. 74, 763-774.

Foose, M.P., & McLelland, J.M., 1995. Proterozoic low-Ti iron-oxide deposits in New York and New Jersey: Relation to Fe-oxide (Cu-U-Au-rare earth element) deposits and tectonic implications, Geology 23, 665-668.

Förster, H., & Jafarzadeh, A., 1994. The Bafq mining district in central Iran - a highly mineralized infracambrian volcanic field, Econ. Geol. 89, 1697-1721.

Hauck, S.A., 1990, Petrogenesis and tectonic setting of middle Proterozoic iron oxide-rich ore deposits - an ore deposit model for Olympic Dam-type mineralization, In Pratt, W.P. & Sims, P.K., (eds.) The midcontinent of the United States - permissive terrane for an Olympic Dam-type deposit?, U.S. Geol. Sur. Bull. 1932, 4-39.

Haynes, D.W., Cross, K.C., Bills, R.T., and Reed, M.H., 1995. Olympic dam ore genesis: a fluid-mixing model, Econ. Geol. 90, 281-307.

Hemley, J.J., Cygan, G.L.,Fein, J.B., Robinson, G.R., & D'Angelo, W.M., 1992. Hydrothermal ore-forming processes in the light of studies in rock buffered systems I: Iron-copper-zinc-lead-sulfide solubility relations, Econ. Geol. 87,1-22.

Hemley, J.J., & Hunt, J.P., 1992. Hydrothermal ore-forming processes in the light of studies in rock buffered systems II: Some general geologic applications, Econ. Geol. 87, 23-43.

Henríquez, F., & Martin, R.F., 1978. Crystal growth textures in magnetite flows and feeder dykes, El Laco, Chile, Can. Mineral. 16, 581-589.

Kisvarsanyi, E.B., 1990, General features of the St. Francis and Spavinaw granite-rhyolite terranes and the Precambrian metallogenic region of Southeast Missouri, In Pratt, W.P. & Sims, P.K., (eds.) The midcontinent of the United States - permissive terrane for an Olympic Dam-type deposit?, U.S. Geol. Sur. Bull. 1932, 48-57.

Kolker, A., 1982. Mineralogy and geochemistry of Fe-Ti oxide and apatite (Nelsonite) deposits and evaluation of the liquid immiscibility hypothesis, Econ. Geol. 77, 1146-1158.

Lapham, D. M., & Gray, C., 1973, Geology and origin of the Triassic magnetite deposit and diabase at Cornwall, Pennsylvania, Mineral Resources Report M56, Pennsylvania Geological Survey, 343p.

Lyons, J.I., 1988. Volcanogenic iron oxide deposits, Cerro de Mercado and vicinity, Durango, Mexico, Econ. Geol. 83, 1886-1906.

Mangan, M.T., Marsh, B.D., Froelich, A.J., & Gottfried, D., 1993, Emplacement and Differentiation of the York Haven Diabase Sheet, Pennsylvania, J. of Petrol. 34, 1271-1302.

Marikos, M.A., Nuelle, L.M., & Seeger, C.M., 1990. Geologic mapping and evaluation of the Pea Ridge iron ore mine (Washington County, Missouri) for rare-earth element and precious metal potential - a progress report, In Pratt, W.P. & Sims, P.K., (eds.) The midcontinent of the United States - permissive

terrane for an Olympic Dam-type deposit?, U.S. Geol. Sur. Bull. 1932, 4-39.

Nold, J.L., 1988. The Pilot Knob hematite deposit, Iron County, Missouri - a Proterozoic volcano-sedimentary iron deposit, Geol. Soc. Am. Abstr. Progr. 20, no. 7, A141.

Nyström, J.O., & Henríquez, F.,1994. Magmatic features of iron ores of the Kiruna type in Chile and Sweden: Ore textures and magnetite geochemistry, Econ. Geol. 89, 820-839.

Oreskes, N., & Einaudi, M.T, 1990, Origin of rare earth element enriched hematite breccias at the Olympic Dam Cu-U-Au-Ag deposit, Roxby Downs, South Australia, Econ. Geol. 85, 1-28.

Oreskes, N., & Einaudi, M.T, 1992, Origin of hydrothermal fluids at Olympic Dam: preliminary result from fluid inclusions and stable isotopes, Econ. Geol. 87, 64-90.

Panno, S.V. & Hood, W.C.,1983. Volcanic stratigraphy of the Pilot Knob iron deposits, Iron County, Missouri, Econ. Geol. 78, 972-982.

Parák, t., 1975. Kiruna iron ores are not "intrusive magmatic ores of the Kiruna type", Econ. Geol. 70, 1242-1258.

Philpotts, A.R., 1967. Origin of certain iron-titanium oxide and apatite rocks, Econ. Geol. 62, 303-315.

Ridge, J.D., 1972. Annotated bibliographies of mineral deposits in the Western Hemisphere, Geol. Soc. Am. Memoir 131, 1-681.

Roberts, D.E., & Hudson, G.R.T., 1983. The Olympic Dam copper-uranium-gold deposit, Roxby Downs, South Australia, Econ. Geol. 78, 799-822.

Rojas, M.G., & Henríquez, F., 1994. Contento y distribución de terras raras en apatitas del yacimiento de hierro El Algorrobo, III region, VII Congreso Geológico Chileno Vol. II, 1177-1178.

Smith, L.L., 1931, Magnetite deposits of French Creek, Pennsylvania, Bulletin M14, Fourth Series, Pennsylvania Geological Survey, 52p.

Snyder, F.G., 1969. Precambrian iron deposits in Missouri, In Wilson, H>D>B>, (ed.), Magmatic ore deposits - a symposium, Econ. Geol. Monograph 4, 231-238.

Swanson, E.R., Keizer, R.P., Lyons, J.I., & Clabaugh, S.E., 1978. Tertiary volcanism and caldera development near Durango City, Sierra Madre Occidental, Mexico, Geol. Soc. Am. Bull 89, 1000-1012.

Travisany, V., Henríquez, F., & Nyström, 1995. Magnetite lava flows in the Pleito-melon district of the Chilean iron belt, Econ. Geol. 90, 438-444.

Tsusue, A., 1964, Mineral aspects of the Grace Mine magnetite deposit, Mineral Resources Report M49, Pennsylvania Geological Survey, 10p.

Vivallo, W., Henríquez, F., & Espinoza, S., 1993. Hydrothermal alteration and related mineralization at El Laco mining district, northern Chile. Low temperature Metamorphism, processes, Products and Economic Significance, Symposium IGCP Proyect 294, 142-146.

Vivallo, W., Espinoza, S., & Henríquez, F., 1994. Significado de la distribución del oro en menas y rocas de caja en los depósitos de hierro de los distritos Cerro Negro Norte y Cerro Imán, Chile. VII Congreso Geológico Chileno Vol. II, 926-930.

Vivallo, W., Espinoza, S., & Henríquez, F., 1995a. Metasomatismo y alteración hidrotermal en el Distrito Ferrífero Cerro Negro Norte, Copiapó, Chile. Revista Geológica de Chile 22, N° 1, 75-88.

Vivallo, W., Espinoza, S., & Henríquez, F., 1995b. Los depósitos de hierro del tipo magnetita-apatita: geoquímica de las rocas volcánicas asociadas y potencialidad de la mena de hierro como fuente de mineralización de oro. Revista geológica de Chile 22, N° 2, 159-175.

Wang, K.Y., 1981. Distribution characteristics of the rare earth elements in Bayanobo iron deposit, Scientia Geologica Sinica 4, 360-367.

Wei, J.Y., & Shangguan, Z.G., 1983. Oxygen isotope composition of magnetite and hematite in Baiyun Ebo iron deposit, Inner Mongolia, Scientia Geologica Sinica 3, 218-224.

Whitney, J.A., Hemley, J.J., & Simon, F.O., 1985. The concentration of iron in chloride solutions equilibrated with synthetic granite compositions: the sulfur-free system, Econ. Geol. 80, 444-460.

You, C.F., Castillo, P.R., Gieskes, J.M., Chan, L.H., & Spivack, A.J., 1996. Trace element behavior in hydrothermal experiments: Implications for fluid processes at shallow depths in subduction zones, Earth. Planet. Sci. Lett. 140, 41-52.

B3 - Roadlog

Mileage is broken up into three parts: (1) Binghamton to the Village of St. Peters, Pennsylvania; (2) St. Peters to Cornwall, Pennsylvania; and (3) Cornwall, Pennsylvania to Binghamton, New York.

Binghamton, New York to St. Peters, Pennsylvania:

0.0   Leave from the Parking lot at Binghamton University, turn right and proceed out the main campus entrance.

0.4   Turn Right on Vestal Parkway, Rt. 434

3.4   Follow the road as it turns left over the Susquehanna River and get into the right lane.

3.6   Turn right onto Rt. 363 following signs for Interstate 81.

5.3   Turn right onto Interstate 81 south. Watch the merge lane onto 81 South, traffic enters from the left.

17.9   Pennsylvania State Line

37.9   Pennsylvanian aged Cross bedded Sandstone on left.

40.3   Pennsylvanian aged Red Beds on Right.

58.7   Clark's Summit, Pennsylvania. Turn right onto Pennsylvania Turnpike (Interstate 476).

118.8 Lehigh Tunnel. Note the Valley and Ridge topography.

133.1 Take exit 33 to Routes 78, 22, and 309. Follow signs to 22 east and take the first exit onto 309 south.

136.5 Turn right South on Route 222.

140.7 Turn left, South on Route 100.

146.8 Junction with Route 29 south, continue on Route 100.

160.8 Triassic Red Beds on left.

165.2 Triassic Red Beds on Right.

172.1 Turn right on Route 23 west.

175.6 Turn right on St Peters road.

176.1 Turn right into parking lot across from St. Peters Inn.

St Peters, Pennsylvania to Cornwall, Pennsylvania:

Mileage for part 2 begins in the Parking lot across from St. Peters Inn on St. Peters Road in the Village of St Peters, Pennsylvania.

0.0 **Stop 1** - Pennsylvania Granite Corporation Quarry. Diabase is exposed in the parking lot and along the road to the south. The main point of this stop is to see the diabase that is associated with the ore deposits. Two of the largest ore bodies in this district are located 1 mile to the north of this spot. Note how unaltered and unfractured the diabase is at this location. In fact, its fresh, unfractured character is the reason there is a building stone quarry here. If the iron ores were formed from a hydrothermal system associated with the cooling of the sill, it does not appear to have affected the underlying diabase.

0.5 Turn right onto Route 23 west.

2.7 This stretch of 23 west travels on top of the diabase sill. Note the diabase stone fence on right.

3.1 Turn right on Warwick road.

3.7 Turn right on 345 north.

3.8 Turn left onto Laurel road.

4.6 Continue on gravel road.

4.8 **Stop 2** - Turn right and park cars. This is state game land open to hunters. Not a good spot to visit during deer hunting season. Proceed on foot through gate on "emergency road". Turn left at every road junction. Note the "blue conglomerate" in the float along the road. This Ordovician sediment forms the cap rock above the Cornwall deposit. Its relationship to the ore body here is not known. After about 10 minutes you will come to an open field. Follow the road to the left under the power lines. At the far edge of the trees follow the road to the left back into the woods. This is the Hopewell iron mine. Dumps are on the right, the open pit is on the left. Exposed in the walls of the pit is a quartz-feldspar pegmatite that predates the ore body, but cross cuts the host gneiss. A similar pegmatite is present in the Ore body in St. Peters village to the east. The relationship of these pegmatites to the diabase sill is not clear. In the dumps you should be able to find all the ore

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textures present in the deposit.

4.8   Return to cars and retrace route out Laurel Road.

5.8   Turn right onto 345 south.
[3.3 miles north of this point is the Hopewell Furnace National Historic Site. Open daily 9 to 5, except national holidays. If you are with a student group and call in advance you can take a self guided tour of the old furnace for free. Otherwise it is $4. Hopewell Furnace National Historic Site, 2 Mark Bird Lane, Elverson, PA 19520. ph. 610-582-8773. If you want to show students about iron making in the 19th century, this is a better site than the Cornwall Furnace Historic Site]

5.9   Turn right at the intersection with Warwick road and continue on 345 south.

6.0   Continue to the left around the curve on 345 south. The house on right is constructed of locally quarried diabase "Pennsylvania Black granite".

6.3   Turn right onto Route 23 west.

8.6   Continue straight on Route 23 west.
[Chestnut Street (Route 82 north) in Elverson. Several of the older homes in Elverson are constructed out of "Pennsylvania Black Granite". The Jones Luck Iron Mine is located approximately 2 miles north of this point at the intersection of Route 82 and Red Hill Road. The mine is a good example of reclamation. The open pit is now a swimming lake north and east of the intersection. The only sign of the mine are some tailings piles on the north side of Red Hill Road (south side of the lake) just past the intersection.]

11.7   Turn right on Cherry Lane (Route 10) in Morgantown.

12.6   Turn right onto Route 76 west.
[About 0.5 miles north of here is the now inactive Grace Iron Mine where calcite-dolomite geothermometry in veins adjacent to the ore body suggests temperatures in excess of 650 degree C. The ore body is located at the upper contact of a diabase sheet, and is composed of magnetite and serpentine.]

17.6   Good diabase outcrops on the right.

35.0   Exit 20 to Lebanon.

35.4   Turn left on Route 72 north.

38.6   Turn right on Route 419 north.

39.5   Turn right onto Alden street, (Route 419 turns to the left) big church on your left after you turn.

39.8   Go under viaduct on Burd Coleman Road.

40.0   **Stop 3.** - Mine dump on the left. This is from the main pit of the No. 3 mine.

40.1   Turn around and continue back on Burd Coleman Road. Turn right just before the underpass on Rexmont Road.

40.6   Cornwall Iron Furnace Historic Site on the right.

40.7   Go through intersection and veer to the right on Rexmont road.

41.4   **Stop 4** - After crossing a small bridge park on the right. Return to bridge on foot and climb down into railroad cut at the south east side of the bridge (the corner closest to where you parked). Rail road cut through the diabase sill below the ore body. Outcrops of the diabase are just north of the bridge (to your right as you climb down). Outcrops of altered sediments below the diabase sill can be reached by walking south along the railroad right of way for about 200 meters.

41.7   **Stop 5** - Driveway on right. "No dumping of Refuse Allowed" Park and walk back along old railroad right of way. Slag from the iron furnace has been dumped along either side of the road. Near where you park, most of it is covered by later piles of concrete and asphalt. About 30 meters back on the right are some good chunks of furnace slag.

42.1   Turn left at intersection.

42.4   **Stop 6** - Turn into driveway on left watching for traffic. If you are in a big van it is best to back in so you will be able to see when pulling out. This is the upper part of the No. 3 mine. The contact between the ore body and the diabase is preserved on the slope to the left of the talus pile. Be careful of the talus pile, it is unstable so it is best not to climb on it. Most of this talus is probably from the underground Elizabeth mine at the to of the hill. Walk south along the road to diabase out crops across from the Historic Marker. Note how fresh it is for a rock associated with a major hydrothermal system. Walk across the street to the overlook beside the historic marker for a good view of the pit.

42.9   Turn around at the baseball diamond and head back the way you came. The main point of this detour was to drive through the old Cornwall

mining village. There are old tailings piles from the No. 4 mine behind first base if you haven't had enough of mine tailings by this point, or if you have been scared off by no trespassing signs at earlier stops.

43.7   Turn left at intersection onto Rexmont Road.

43.8   **Stop 7** - Turn left into Cornwall Iron Furnace Historic Site. Tuesday-Saturday 10-4; Sunday 12 -4; closed Monday.

Cornwall, Pennsylvania to Binghamton, New York:

Mileage for part 3 begins in the Parking lot of the Cornwall Iron Furnace Historic site in Cornwall, Pennsylvania.

0.0   Turn left on Rexmont Road at the entrance to the Cornwall Iron Furnace Historic Site.

0.5   Turn right on Burd Coleman Road and go under the Railroad Viaduct.

0.9   Turn left on Route 419.

1.8   Turn right on Route 72 north.

5.9   Limestone exposed along sidewalk in Lebanon. A similar limestone was the host rock for the Cornwall deposit.

16.9   Turn onto Interstate 81 north.

172.9 Stay in left lane on Route 17 west.

176.9 Turn right onto 201 south.

177.9 Take first right at circle and cross the Susquehanna River. Follow signs to route 434 east and SUNY.

178.9 Turn right into SUNY campus.

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