REEE Potential of the Pea Ridge Fe-REE-Au Deposit

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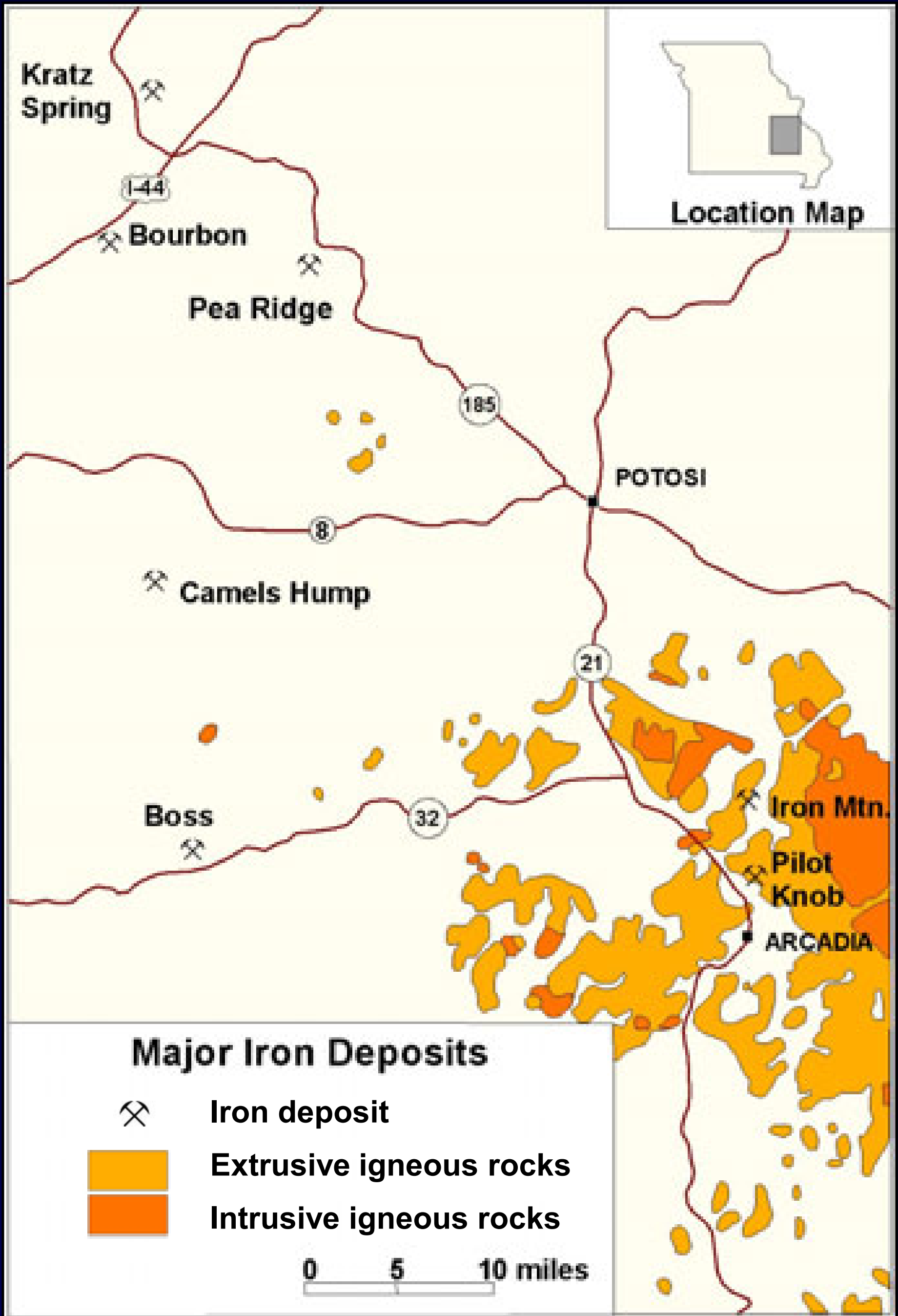
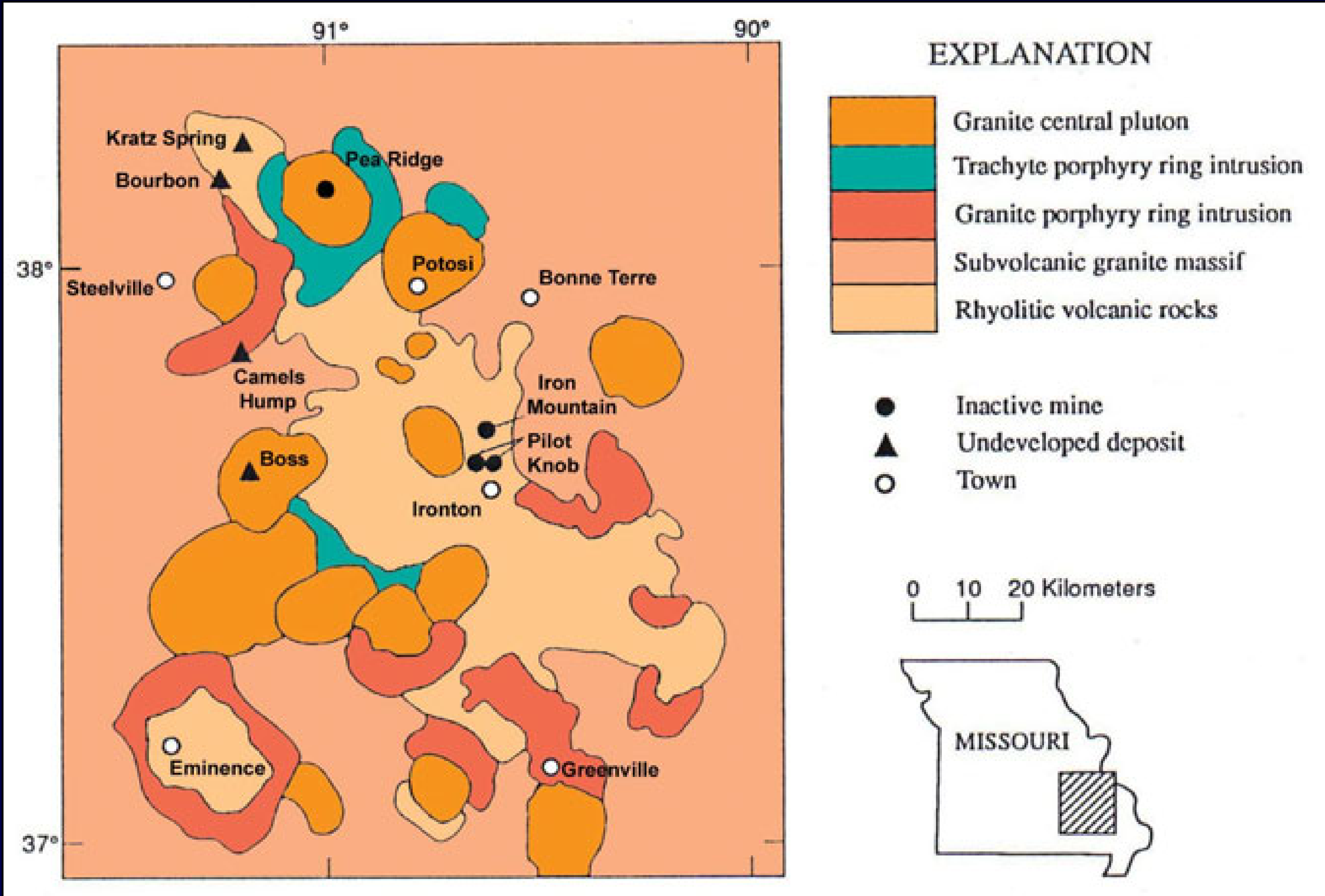


The Southeast Missouri Iron Metallogenic Province contains seven major iron deposits

Also numerous minor deposits

Pea Ridge has known reserves of rare earth elements



91°
90°
38°
37°
Kratz Spring
Bourbon
Pea Ridge
Potosi
Steelville
Bonne Terre
Camels Hump
Iron Mountain
Pilot Knob
Boss
Ironton
Eminence
Greenville
EXPLANATION
Granite central pluton
Trachyte porphyry ring intrusion
Granite porphyry ring intrusion
Subvolcanic granite massif
Rhyolitic volcanic rocks
Inactive mine
Undeveloped deposit
Town
0 10 20 Kilometers
MISSOURI

Pea Ridge

In production from 1964 - 2001

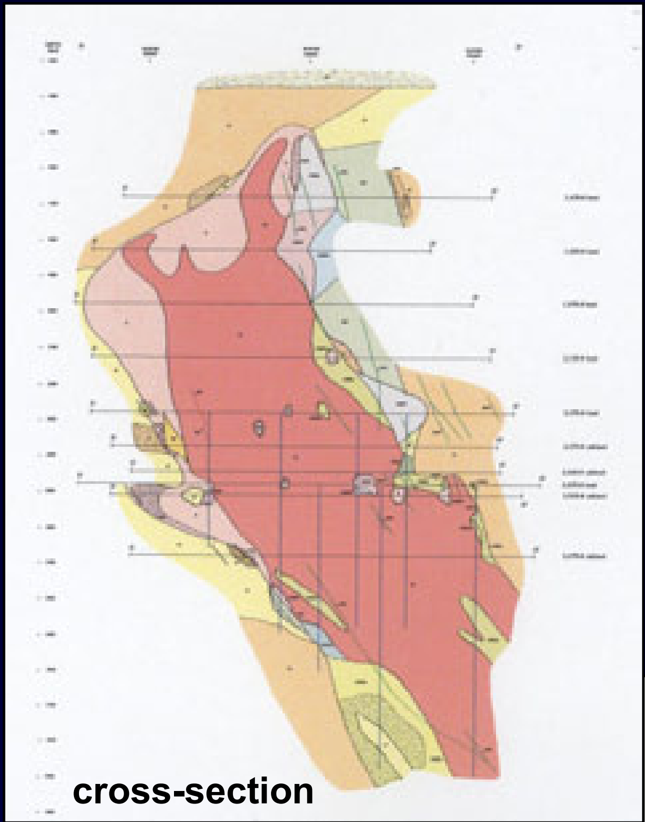
Primary product was magnetite
for steel production
also coal desulferization,
high power magnets and
iron pigments

Apatite produced as
phosphorous concentrate

Pyrite sold for sulfuric acid
generation

Waste rock sold as road metal

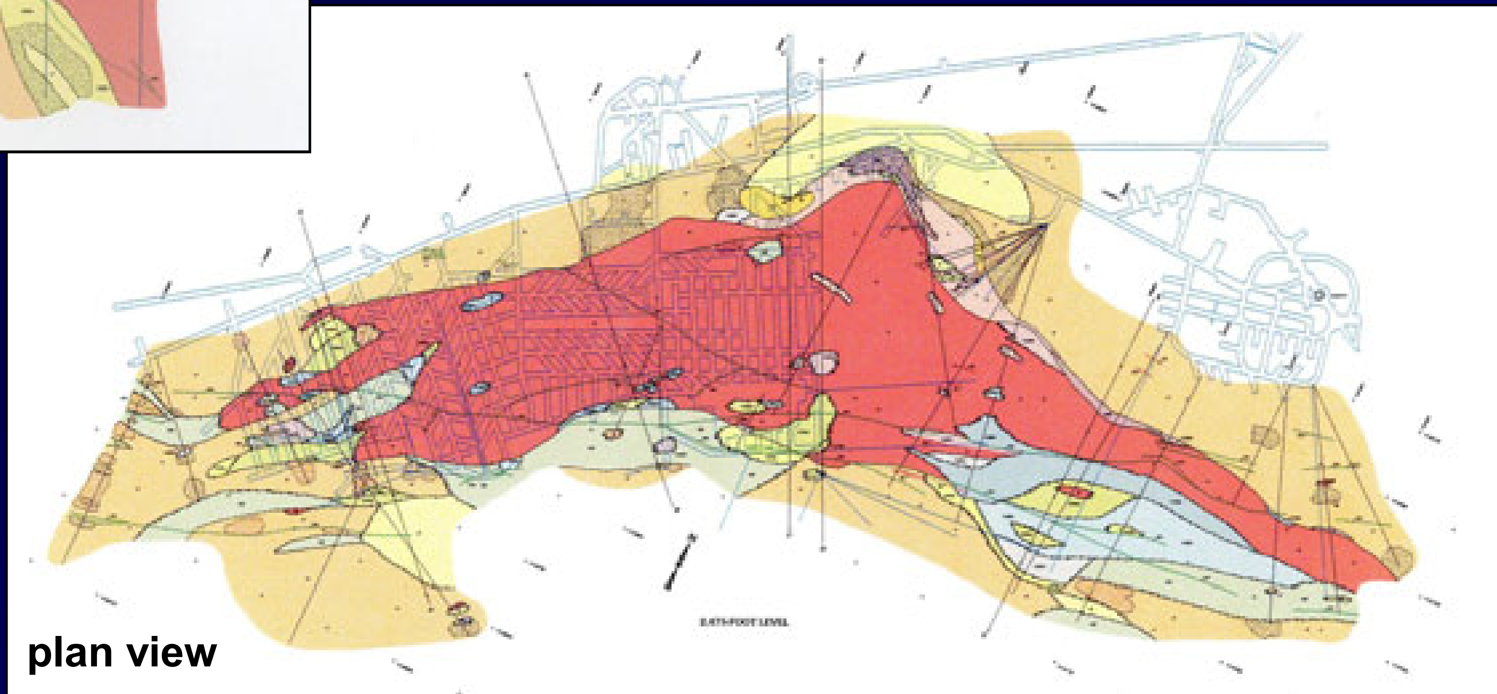
REE not produced



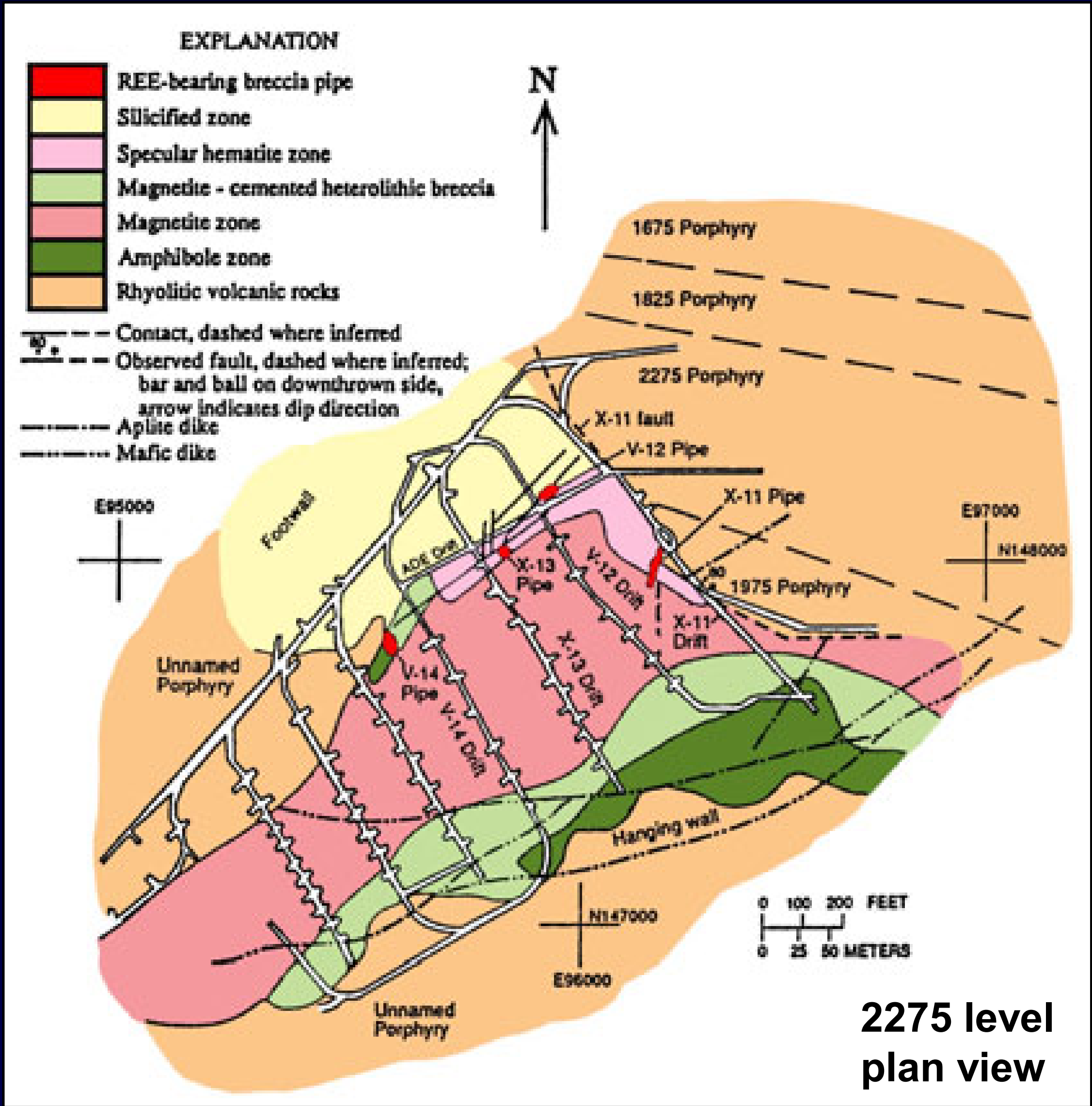
Steeply dipping, tabular discordant orebody

Mineralization hosted by a series of rhyolites and ash-flow tuffs

400m of overlying Paleozoic sedimentary cover



Map Zones



Rhyolite porphyry

Amphibole-quartz zone

Magnetite zone

Hematite zone

Silicified zone

REE- and Au-bearing breccia pipes

Zonation outward from massive magnetite core to FeOx-cemented breccias

Pea Ridge Genesis

Intrusion of Fe- and Si-rich magma into shallow subvolcanic chamber

Lowered temperature and pressure lead to liquid immiscibility

Early Fe-rich fluid altered rhyolite to actinolite and quartz

Magnetite emplacement, formation of magnetite-cemented breccias
later oxidation to hematite

Emplacement of Si-rich fluid – silicification

Breccia pipe emplacement

Breccia Pipe Genesis

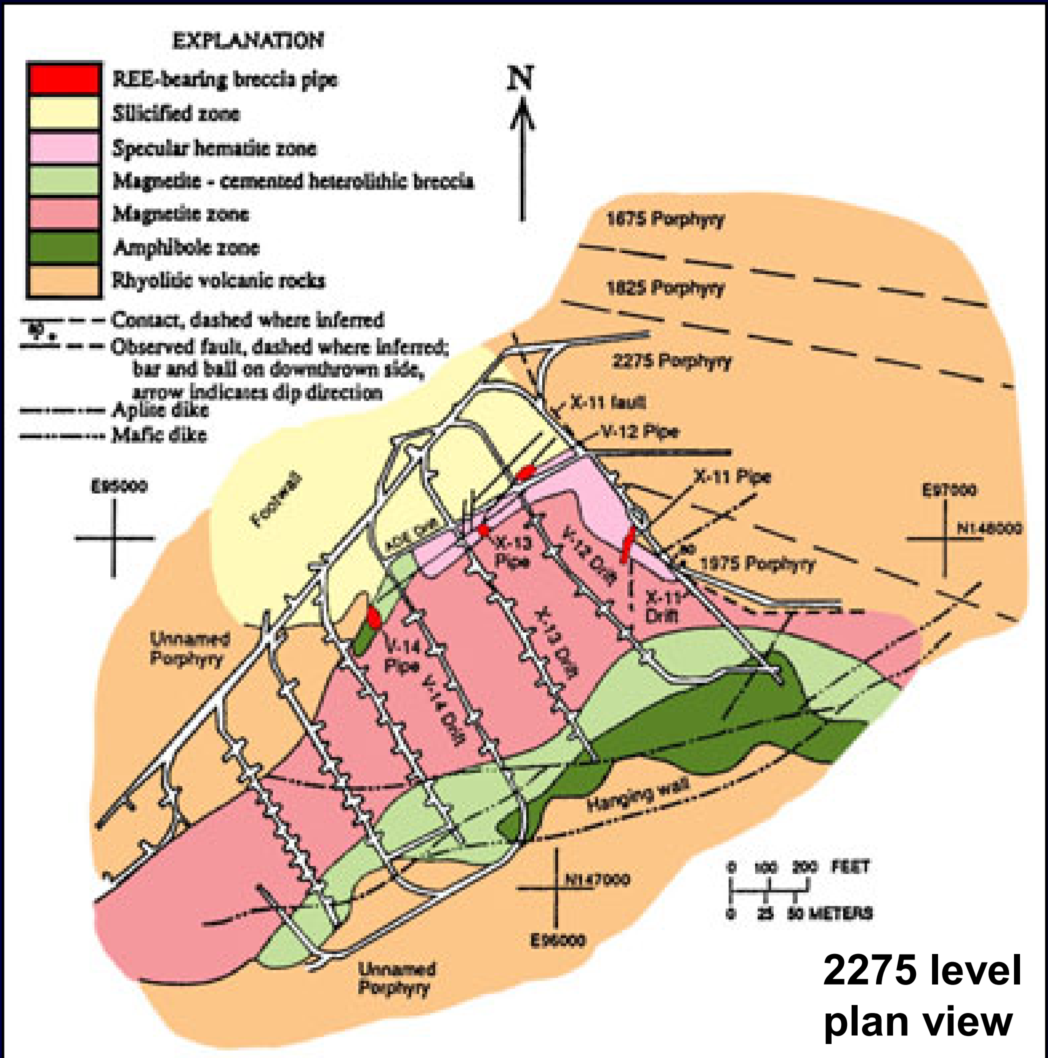
Remaining fluid in subvolcanic chamber underwent further cooling
fluid enriched in K, Ba, REE, U, Th, P, F, Cl, Au

Exsolution of vapor phase from fluid lead to second boiling event

Increase in volume caused rapid expulsion of fluid from chamber
expansion reopened fractures/faults

Resulted in brecciation and mixing of clasts

REE- and Au-Bearing Breccia Pipes



4 breccia pipes on footwall and eastern edge of orebody

Proven reserves of 200,000 tons REO

Associated gold

REE- and Au-Bearing Breccia Pipes

cross-section

Steeply dipping (>60°)

At contact between iron oxide and host rock

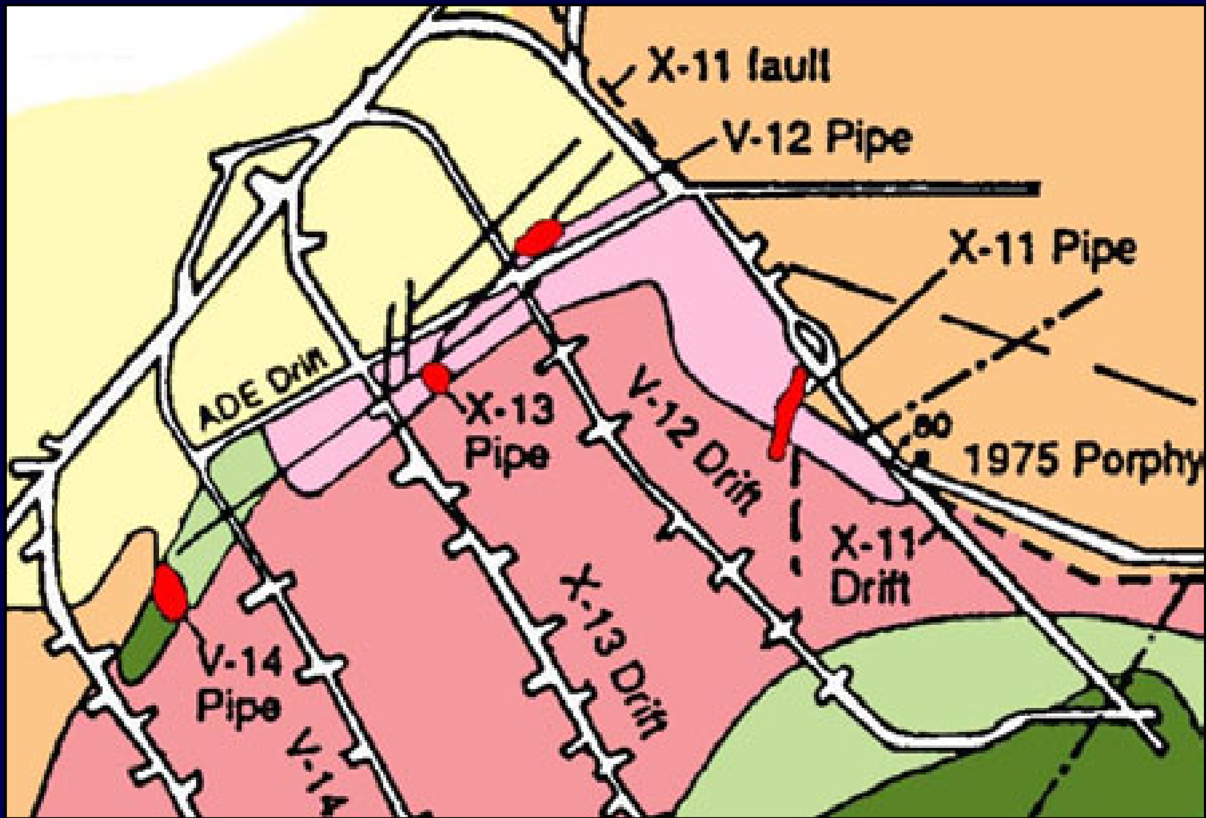
Known minimum vertical extent of 120 m

Maximum vertical extents are unknown

REE- and Au-Bearing Breccia Pipes

Elongate to ovoid in plan view

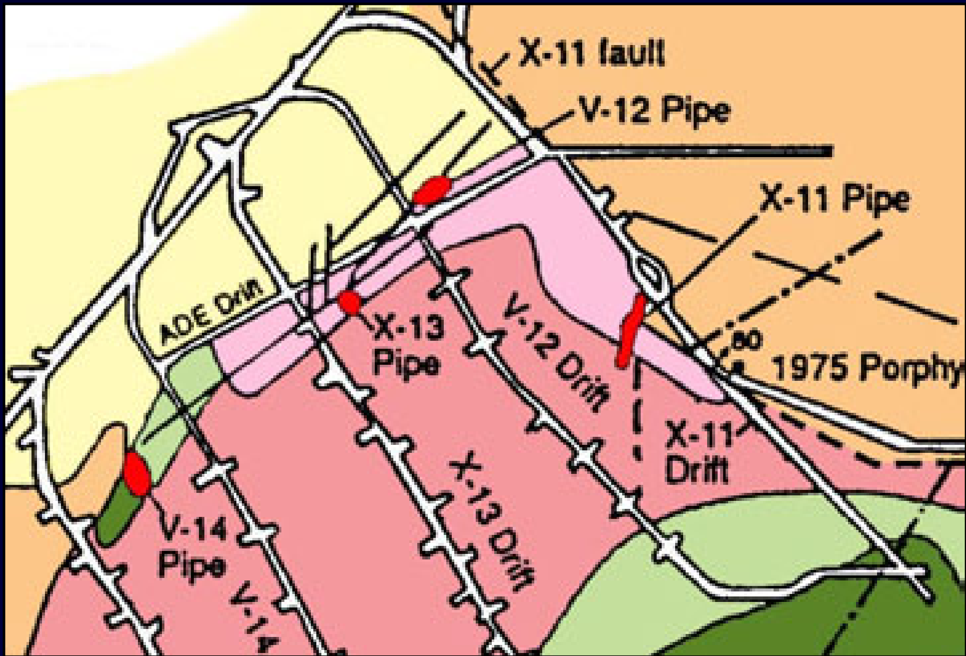
Horizontal length as much as 60 m; widths reach 15 m



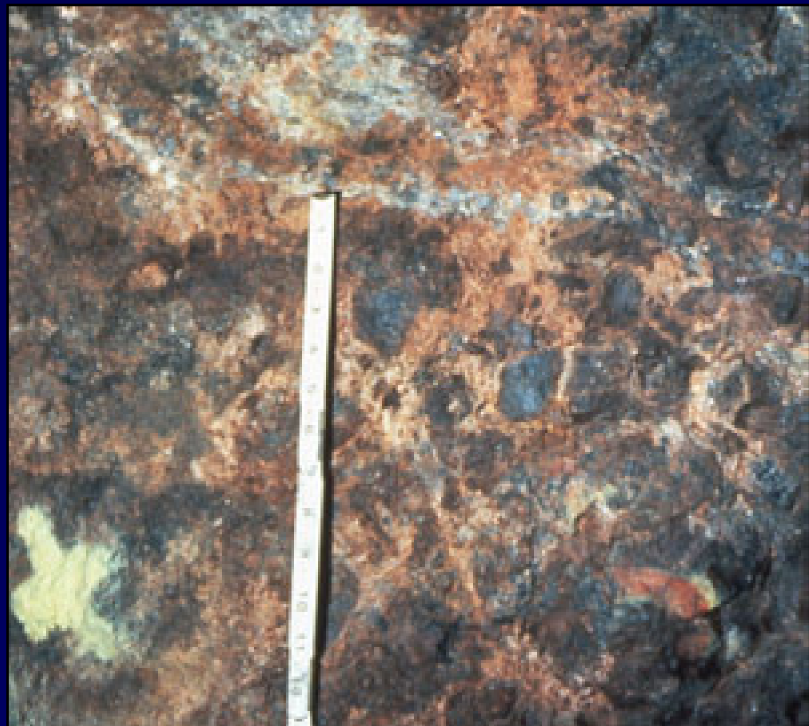
Pipes are located along faults and at faulted contacts

Suggests structural control on emplacement

REE- and Au-Bearing Breccia Pipes



Three pipes located on footwall have been rebrecciated

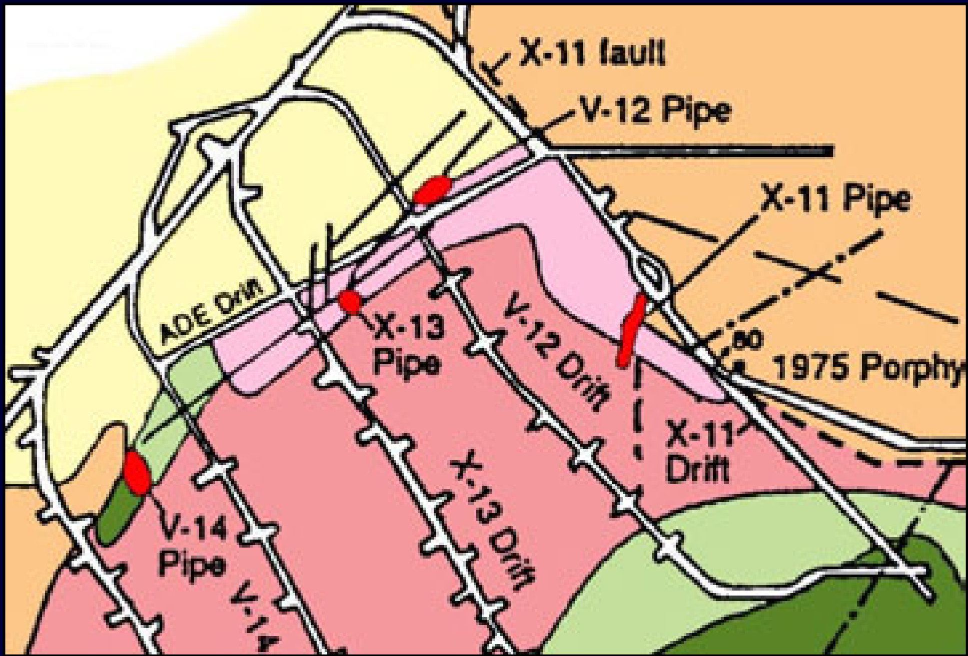


Post- breccia pipe emplacement fault movement

Friable

Light in color

REE- and Au-Bearing Breccia Pipes

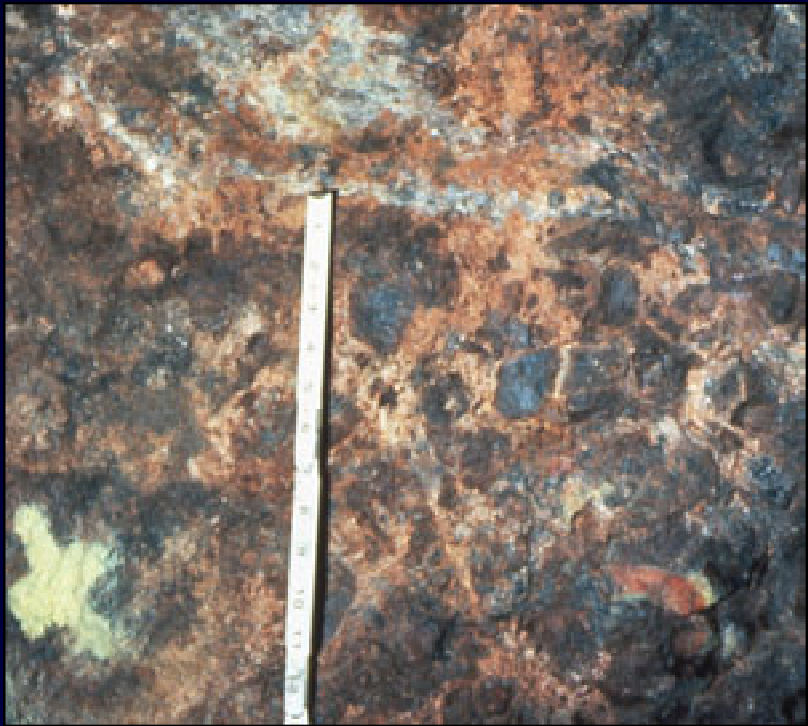


Pipe on eastern edge has not been rebrecciated

Well-indurated

Darker in color

REE- and Au-Bearing Breccia Pipes



Clasts of rhyolite, actinolite, iron oxide, silicified rock

Clasts are subrounded to rounded
< 1 mm to several meters

Matrix of rock flour, k-spar, chlorite, quartz, calcite, apatite

REE-bearing minerals

Cemented by barite, orthoclase

Breccia Pipe Indicators

Margins generally brecciated

Cemented by calcite, barite

Radioactive zones (Th, U)

Stringers of pipe material in host rock

REE-Bearing Minerals

Primary:

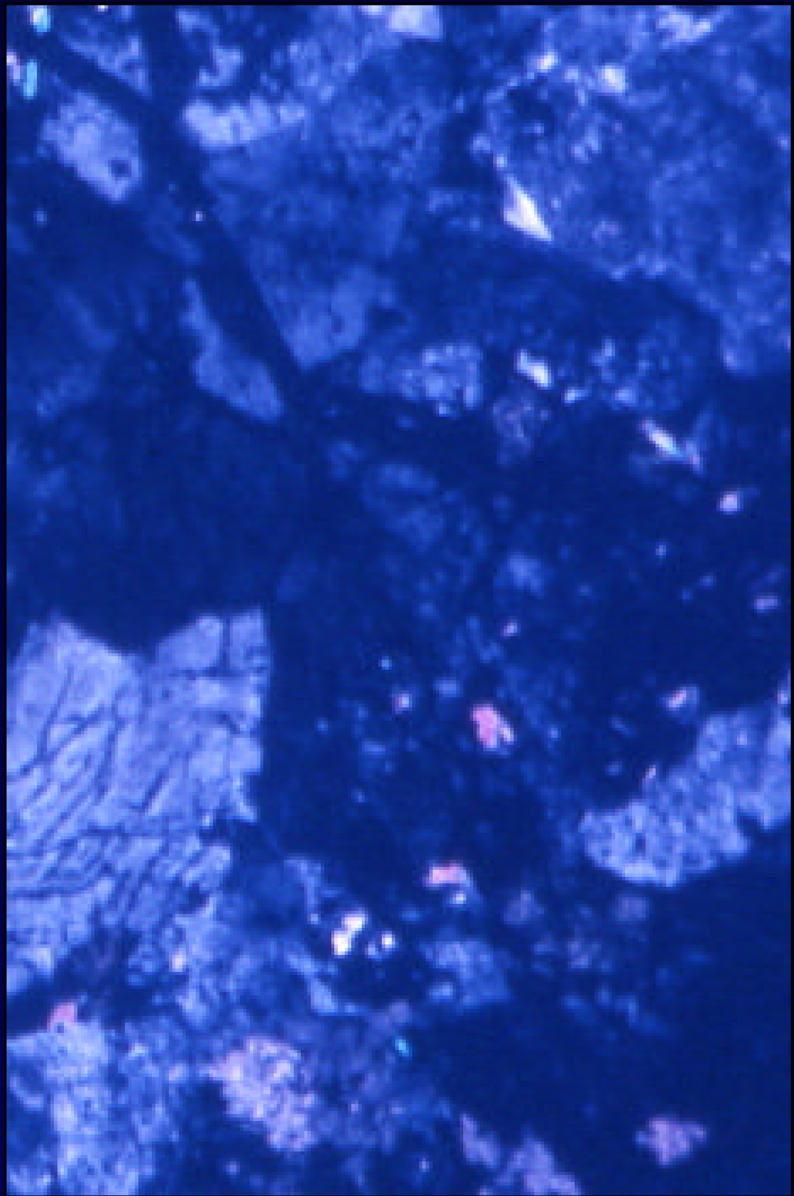
- monazite $(Ce,La,Nd,Th)PO_4$
- xenotime YPO_4

Rare:

- bastnaesite $(Ce,La)CO_3(OH,F)$
- britholite $(Ca,Ce)_5(SiO_4,PO_4)_3(OH,F)$
- allanite $[Ca(Ce,La,Y)](Al_2Fe^{2+})O(OH)(SiO_4)(Si_2O_7)$

Tentative:

- tengerite $(CaY_3(CO_3)_4(OH)_3\cdot 3H_2O$
- synchisite $(Y,Ce)Ca(CO_3)F_2$



REE-bearing Minerals Occurrence

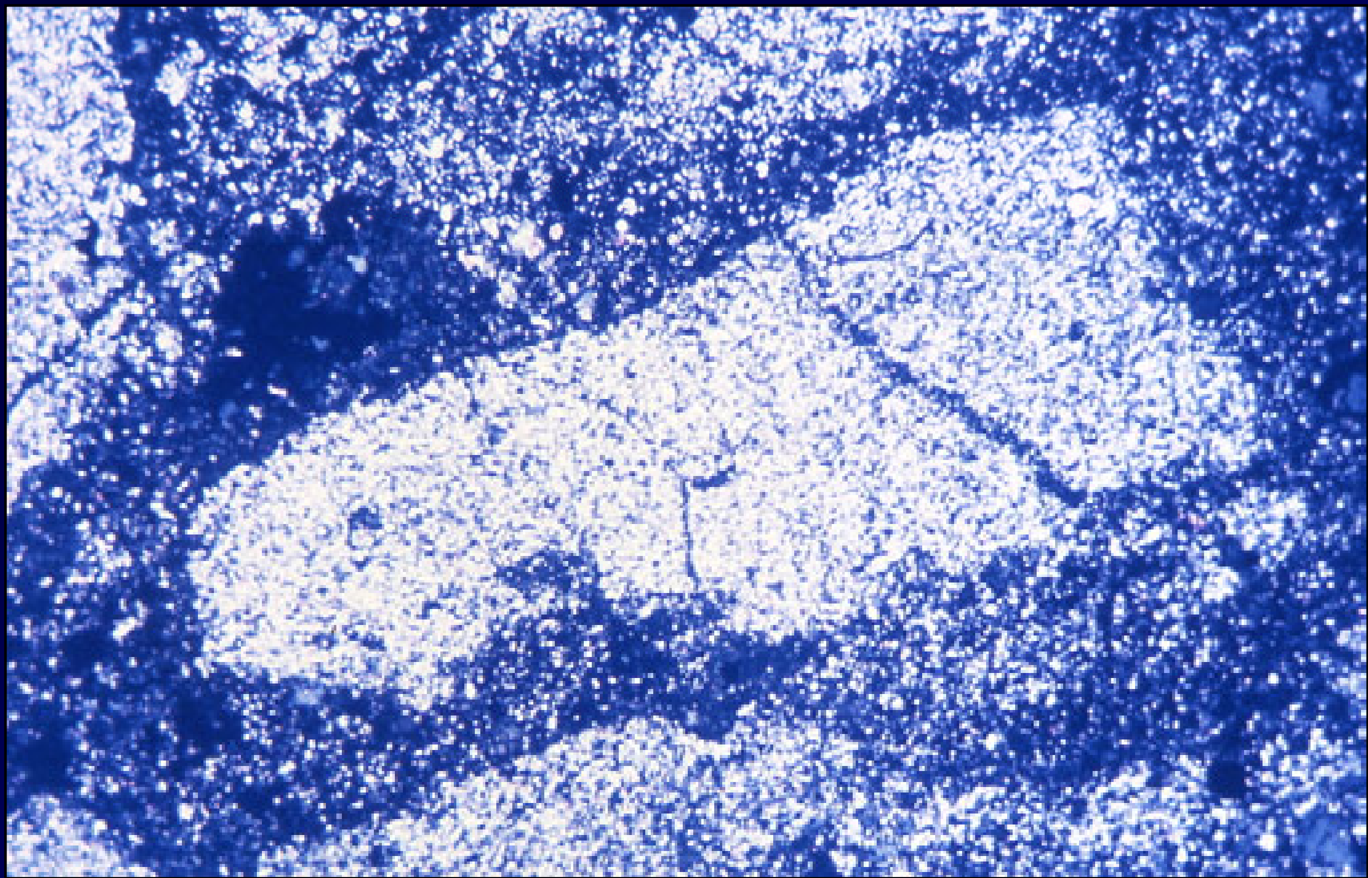
<0.5-4.0 mm crystals

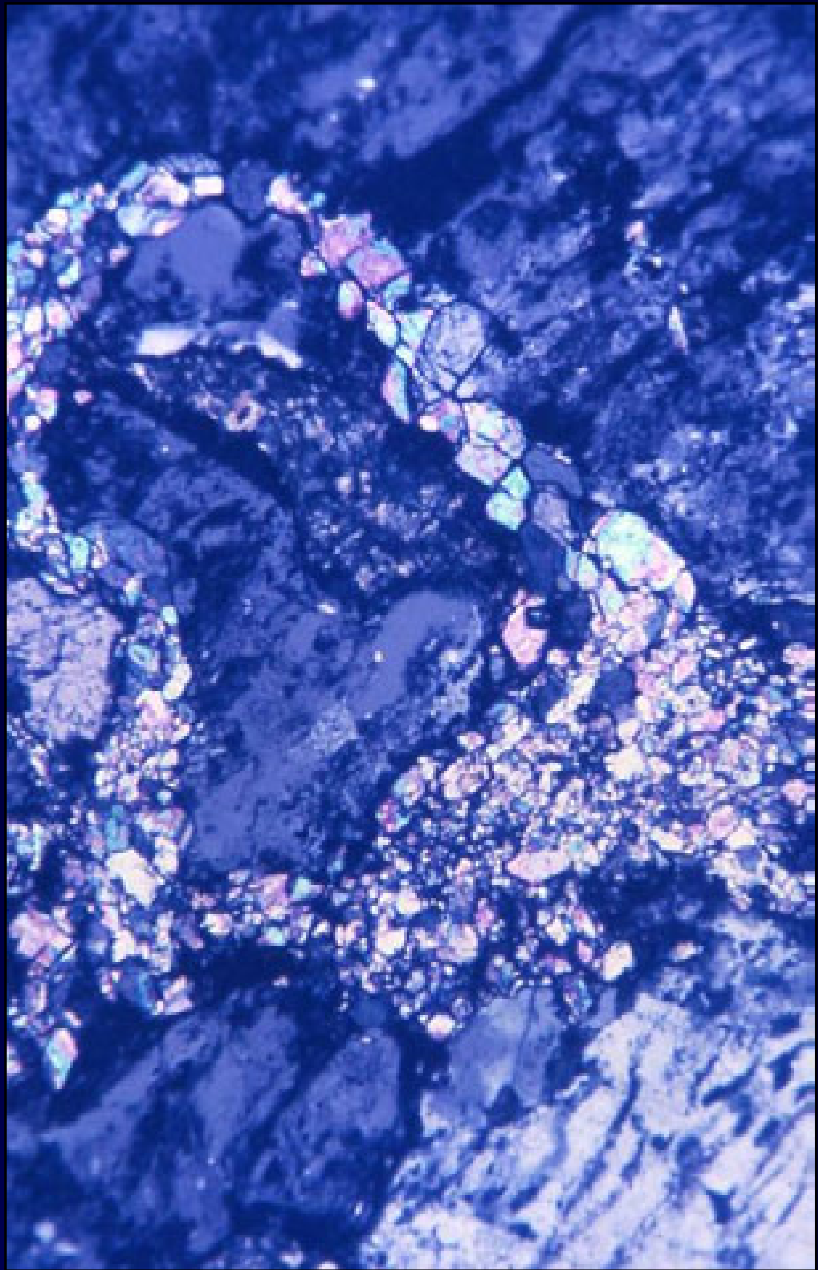
Granular texture
some euhedral crystals

Discrete grains
disseminated in matrix

Occurrence

Monazite crystals replacing wallrock fragments
- disseminated to nearly total replacement
- also replace matrix



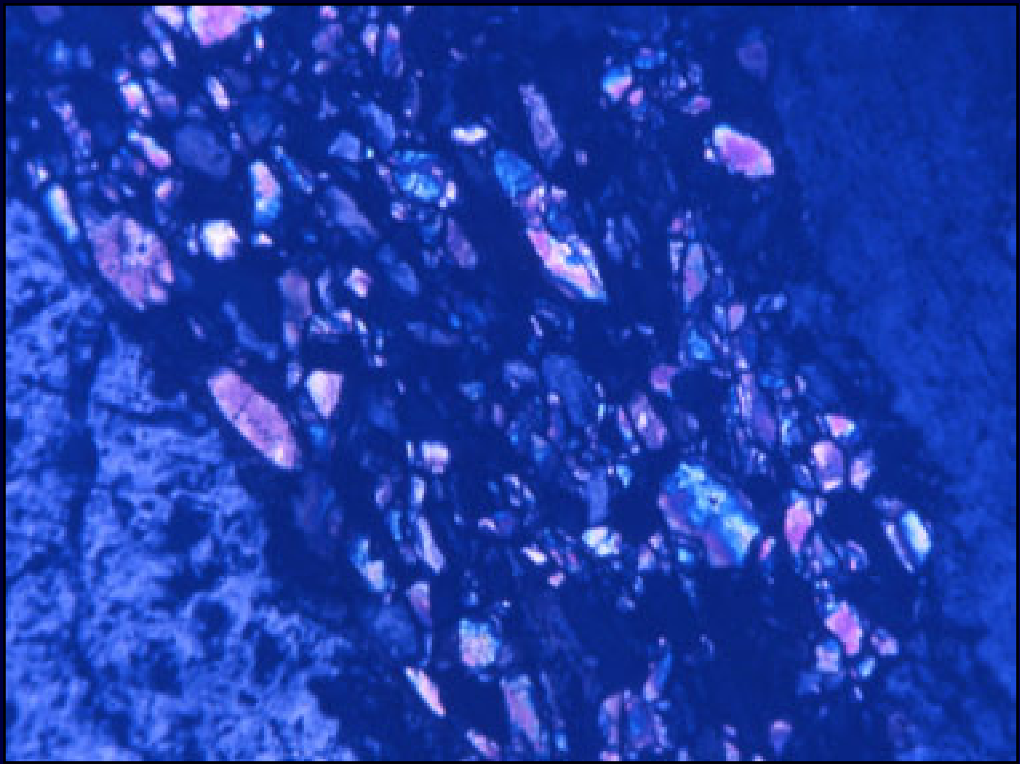


Occurrence

Monazite and xenotime as fracture fill in brecciated barite and feldspar crystals

- **irregular grains**
- **some grains abraded**
- **larger grains**

Potential Ore Concentrations



total REO concentrations:

grab samples -
4.9 to 37.8 weight %
avg of 20.3 weight %

U.S. Bureau of Mines bulk samples -
7 to 25 weight %
avg 12 weight %

Proven reserves: 200,000 tons REO
72,000 tons REO in X-11 pipe
(600,000 tons 12% REO)

Pipes are open at depth

Potential Ore Concentrations

Cerium, lanthanum, and yttrium present in recoverable quantities

42 samples averaged 15.21% REO

6.2% Ce

3.6% La

0.92% Y

4.5% other REE

Pea Ridge Company Data
8% REO grade cutoff

Significant amounts of Nd, Sm, Gd, Dy

USGS data

Accessory and By-Product Mineralization

Th and U present in minor quantities

Concentration in grab samples

- Th ~3,320 ppm
  - thorite
  - inclusions in REE minerals
  - disseminated grains in pipes
- U ~190 ppm

Gold is erratically distributed

Concentrations seldom > 1 ppm

- individual assays as high as 371 ppm

But...

Recoverable if recovering REE

Other sources – REE

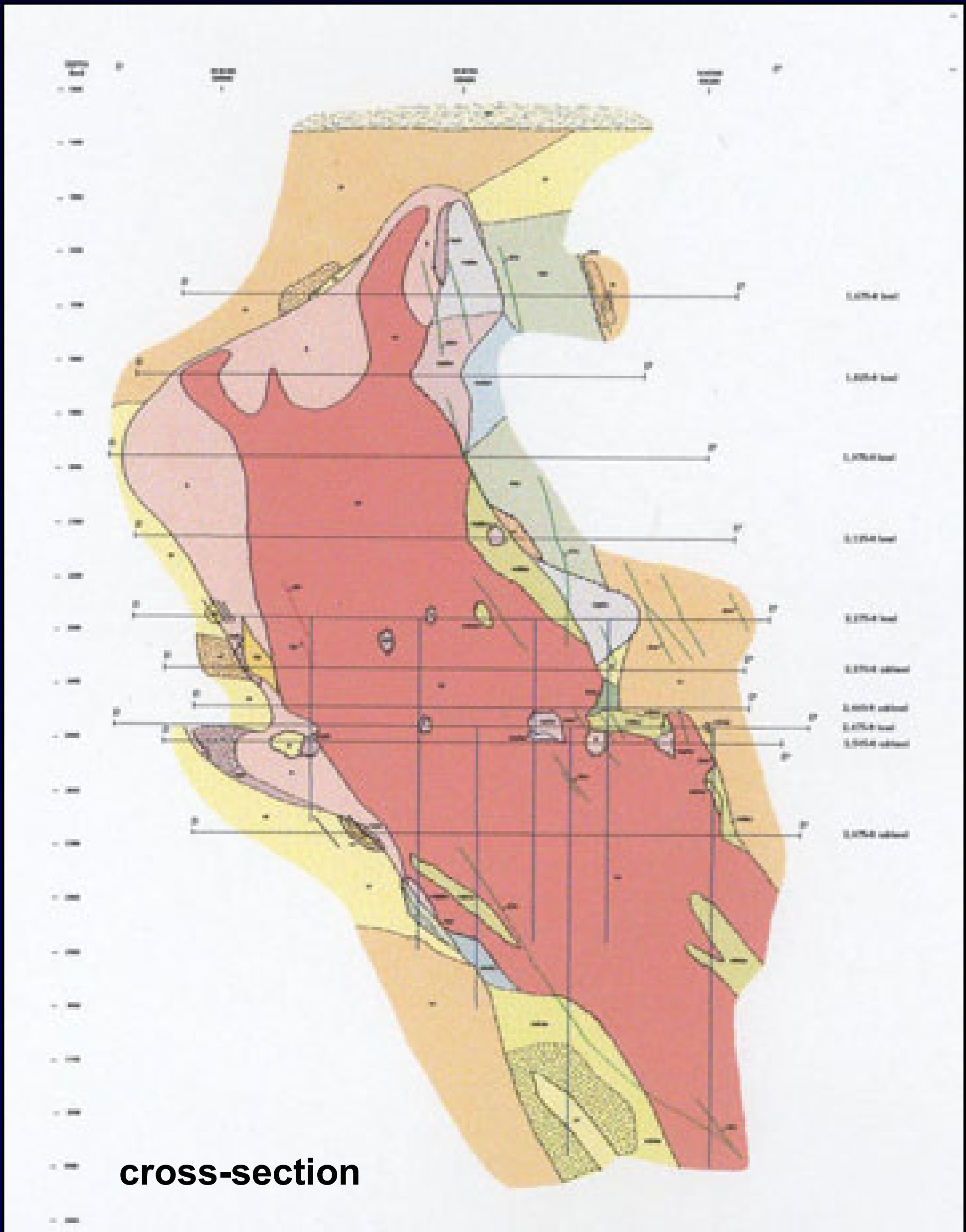
Abundant inclusions of monazite, xenotime and possible britholite in interstitial apatite

Photo courtesy of Kevin Conroy

Apatite recovered during magnetite beneficiation

USGS photo

Other sources – REE



cross-section

At higher levels in mine, have inclusion-free apatite and discrete grains of monazite interstitial to iron oxide

Inclusions of monazite in apatite common at greater depths in mine

Suggest grains formed by exsolution

Other sources - REE

Mine Tailings

USBM testing on reprocessing of mine tailings

Flotation of phosphate minerals in tailings
primarily apatite
monazite, xenotime, britholite

Resulted in 70%+ recovery of available phosphate minerals

Up to 95% recovery of rare earth-bearing minerals from concentrate
gravity separation
average size REE grains - 10 µ

Significant Dy, Sm, Nd

USBM data

Summary

Pea Ridge operated as iron mine

Rare earth elements and gold are potential by-product

Primary reserves in breccia pipes
Monazite, Xenotime
Ce, La, Y

Potential reserves in inclusions in apatite or as interstitial grains exsolved from apatite

Apatite removed as part of magnetite beneficiation

Potential resource in mine tailings

Possible reserves of Sm, Nd, Dy