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The Rammelsberg shale-hosted Cu-Zn-Pb sulfide and barite deposit, Germany: Linking SEDEX and Kuroko-type massive sulfides

Slide presentation and explanatory notes

by Andreas G. Mueller

Version 2, June 2022

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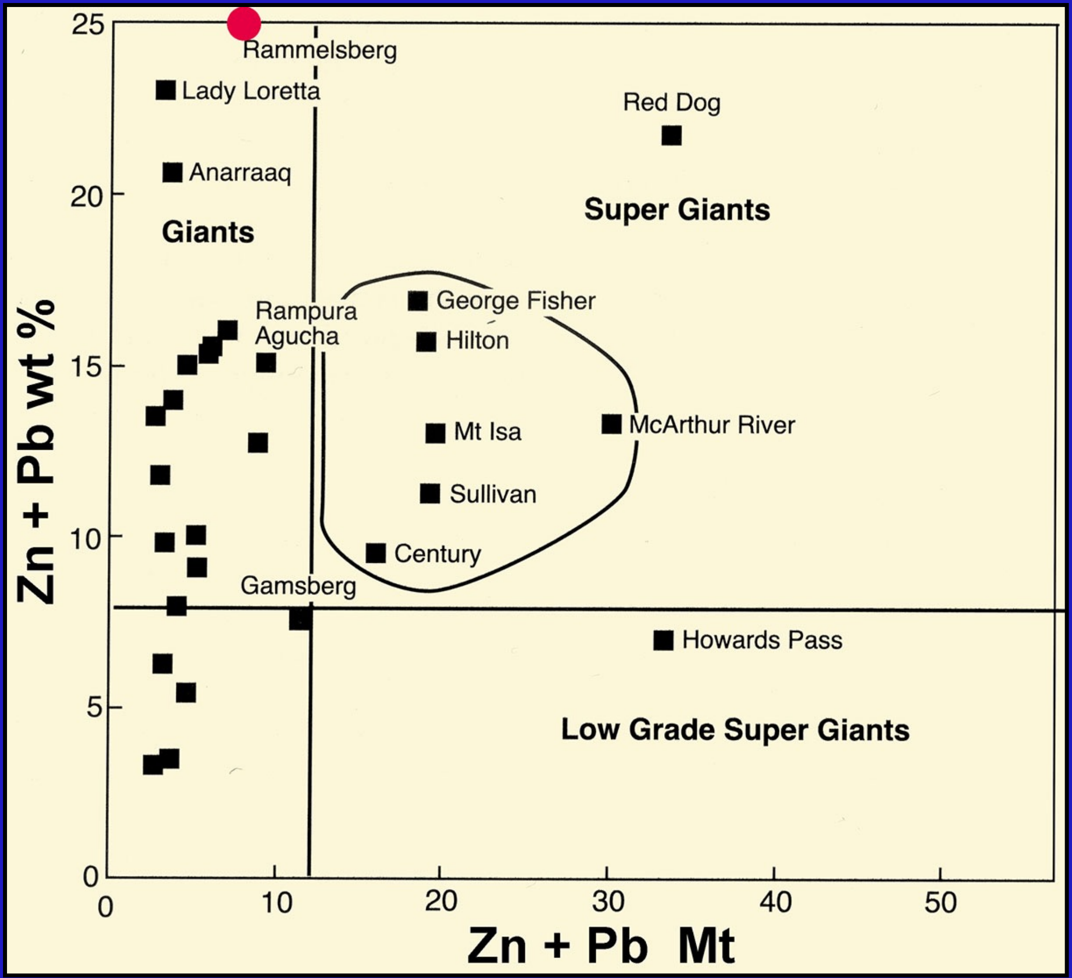
Preface

The Rammelsberg in the Harz mountains, Germany, is the highest grade SEDEX deposit ever found and a UNESCO world cultural heritage site after 1000 years of mining. This slide presentation in tablet 4:3 format is accompanied by explanatory notes, available free of charge as downloads from the SGA website (www.e-sga.org, Publications, Mineral Deposit Archive) together with a sister presentation on the Meggen SEDEX deposit. Both are designed as teaching tools for digital projection and for the study on-screen, the printed text explaining each slide. The references quoted on the slides are listed in the notes. The author's photographs are initialed AGM and dated.

Andreas G. Mueller, 12a Belgrave Street, Maylands, Western Australia, June 2022

Rammelsberg: Past production + grade

Kraume et al. (1955), diagram modified from Large et al. (2005)

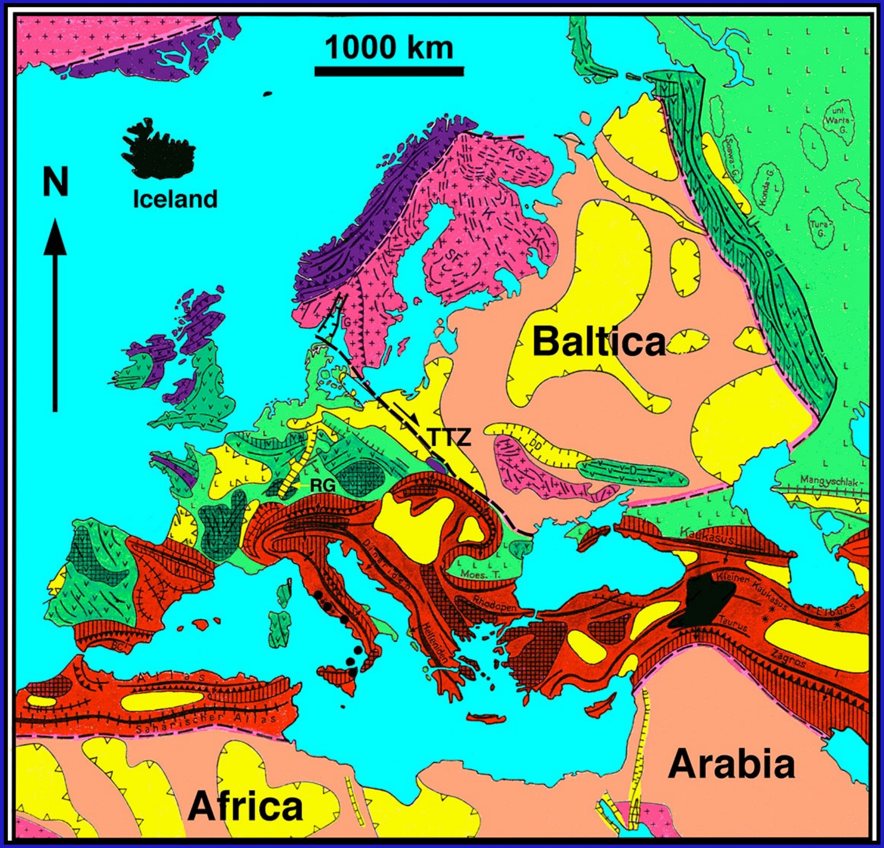


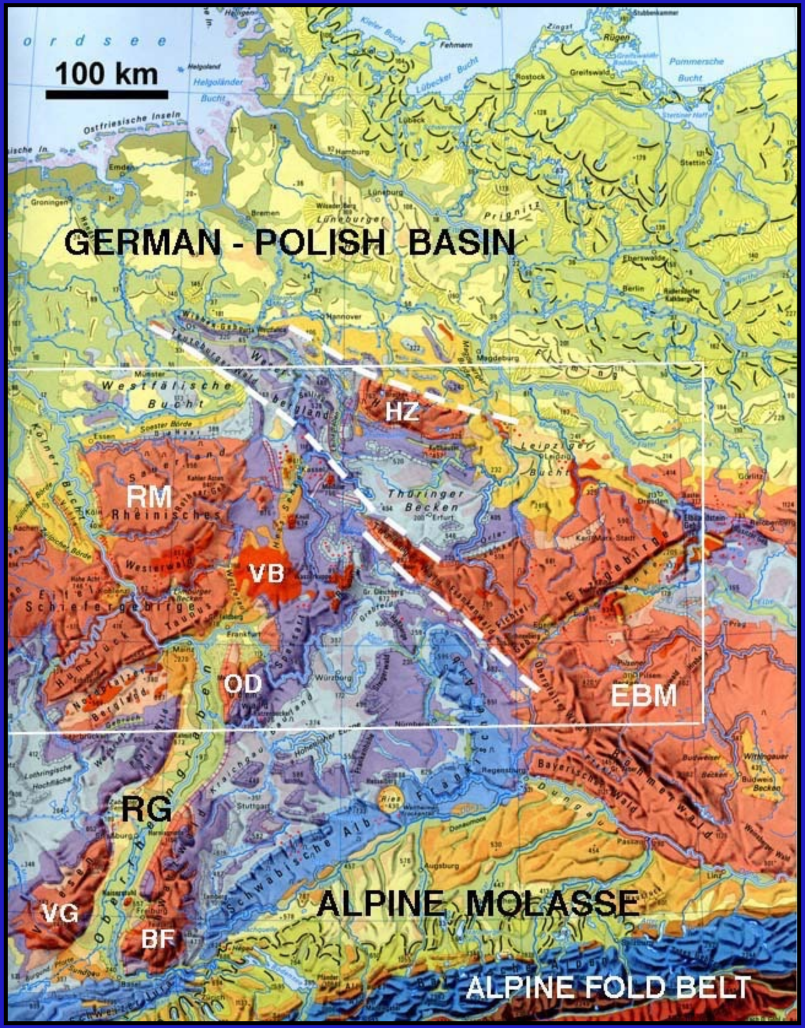
Massive sulfide ore: 27 Mt at 1% Cu + 19% Zn + 9% Pb + 160 g/t Ag + 0.5-1 g/t Au

Shale-banded sulfide ore: 2 Mt at 0.6 % Cu + 6.5% Zn + 3.5% Pb + 60 g/t Ag

Base metal: 7-8 Mt

Variscan orogen and Alpine foreland tectonics in Europe

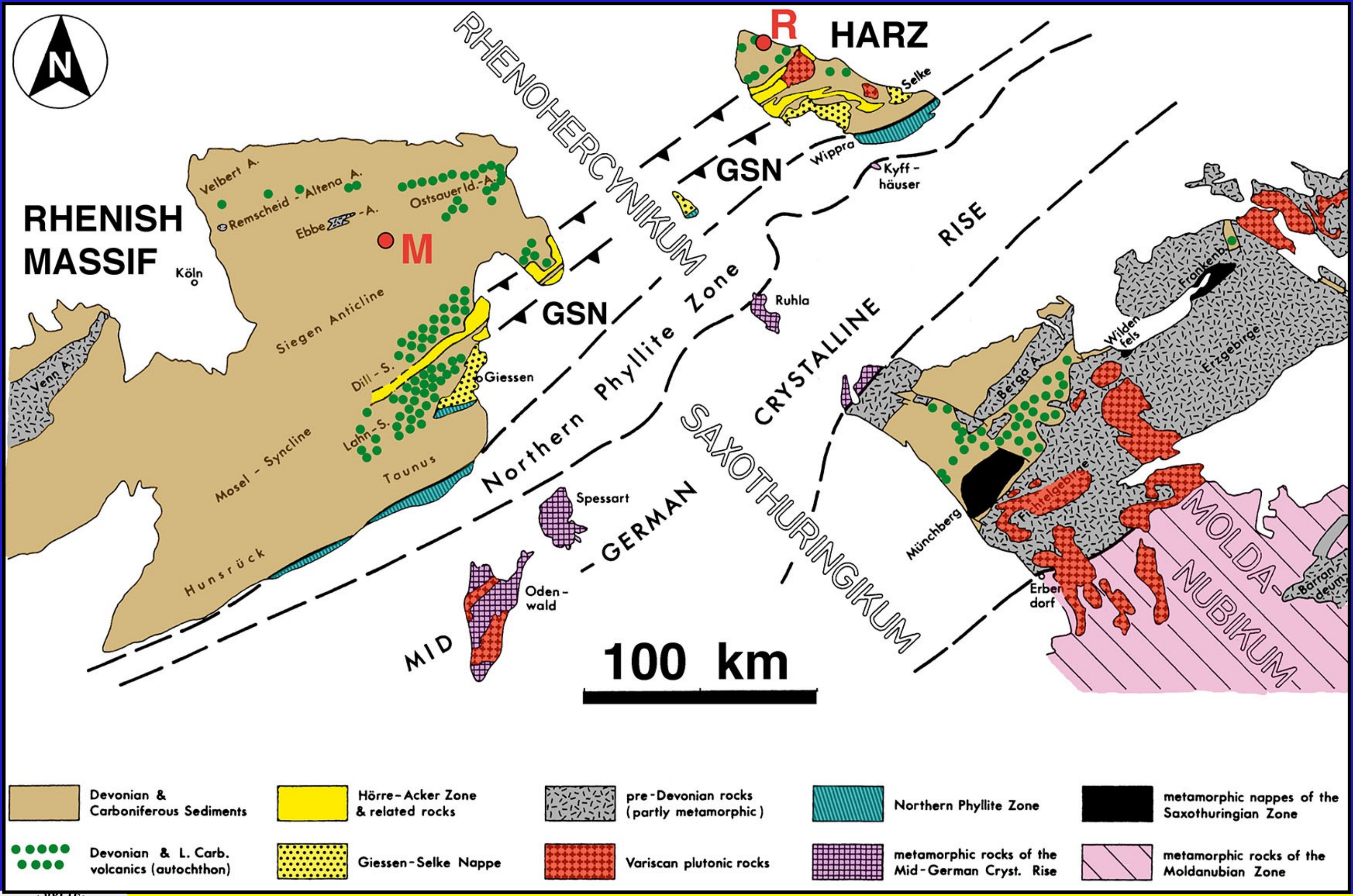




Europe, geology, modified from Meinhold (1971). Germany, landscapes, modified from Schulze (1976).

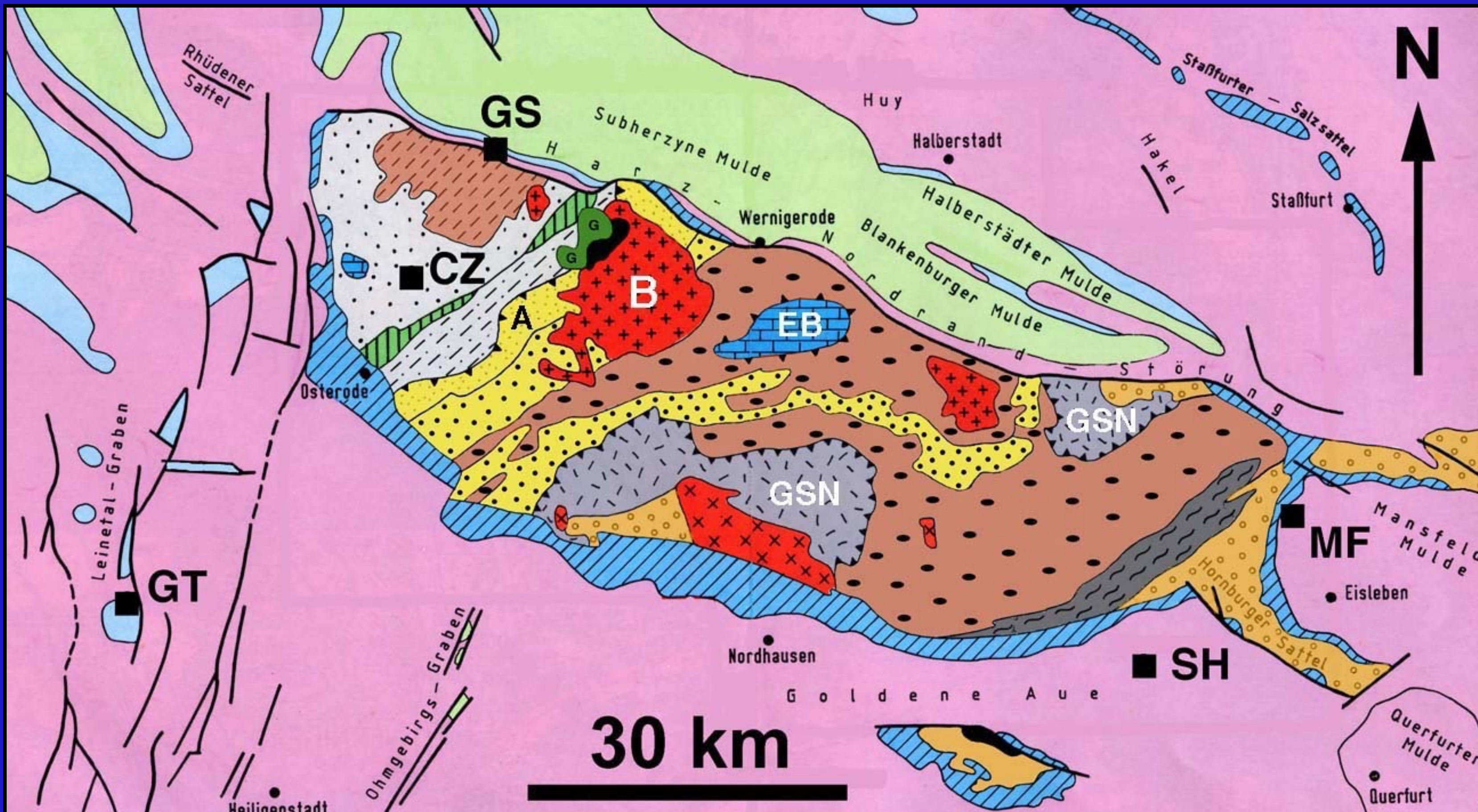
Variscan tectonic zones in Germany

Modified from Engel et al. (1983)



Harz mountains: Geologic map

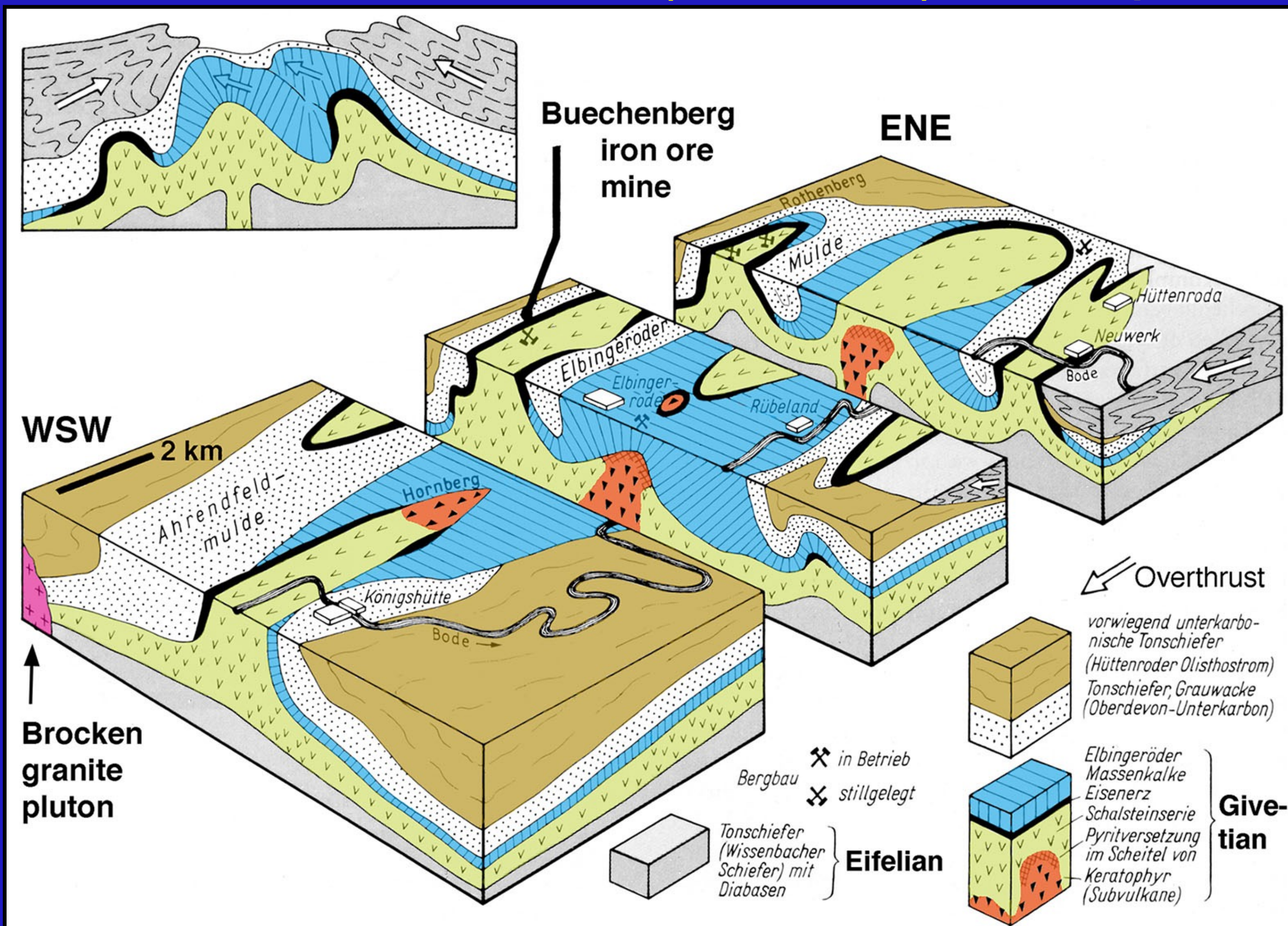
Modified from Hinze et al. (1998)



Devonian Elbingerode volcanic complex

Block diagram modified from Wagenbreth and Steiner (1990)

Givetian limestone reef (500 m thick): 100 Mt quarried to 2003

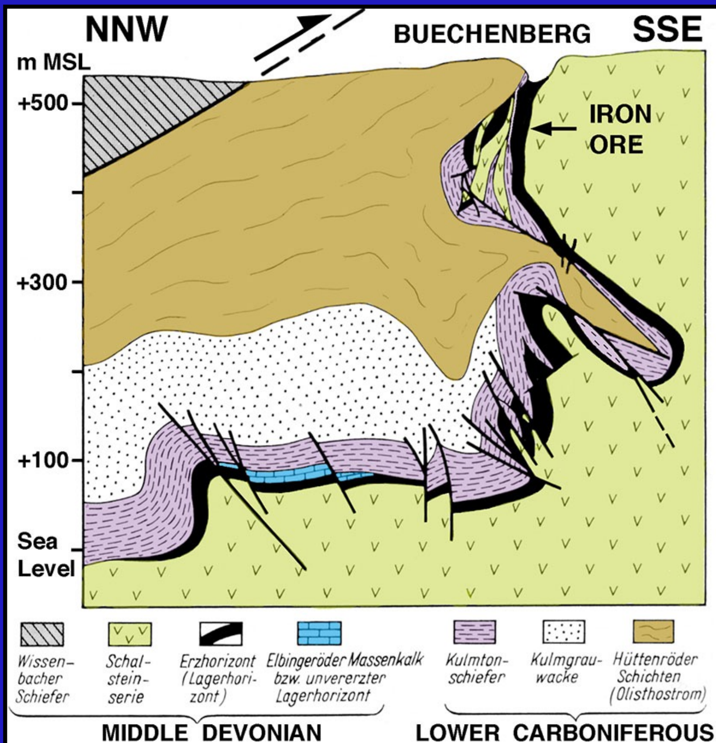


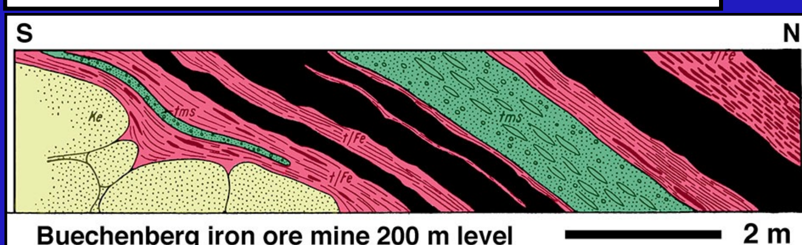
Givetian bimodal basalt - trachyte complex >700 m thick altered by seawater to spilite + kerato-phyre

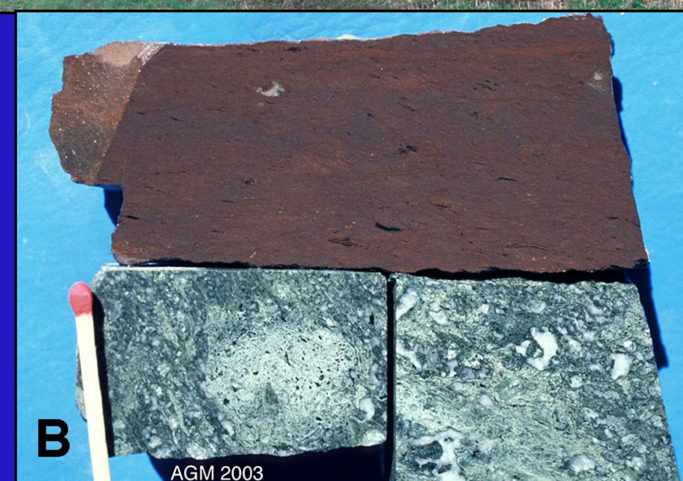
Elbingerode volcanogenic hematite ore

Production: 25 Mt at 25% Fe to 1970, reserves: 51 Mt at 23% Fe

Stedingk et al. (2002), sections modified from Reichstein (1959), Wagenbreth & Steiner (1990)

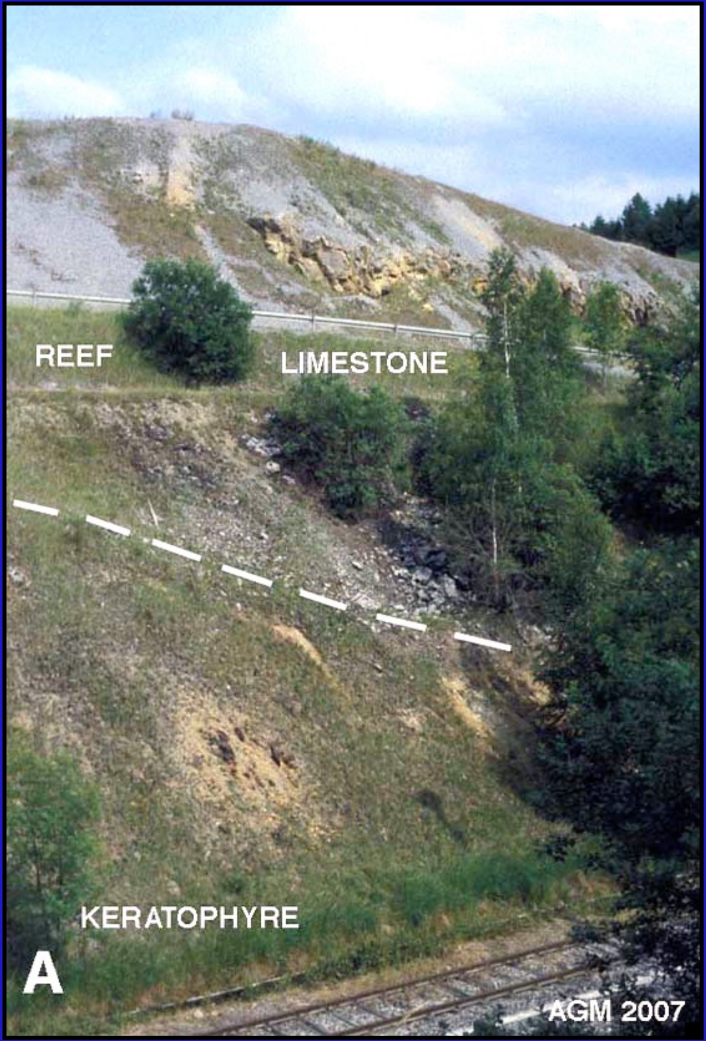


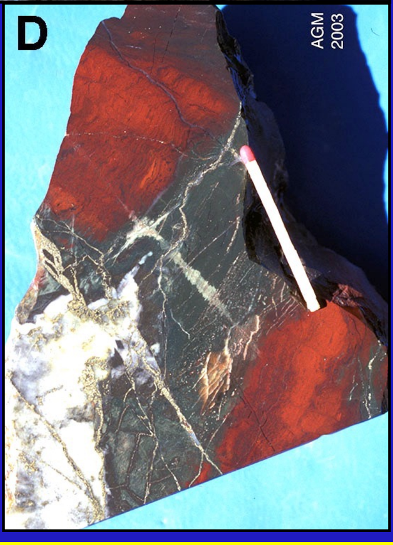




Elbingerode volcanogenic pyrite

Production: 13 Mt at 25% pyrite , Cu-Zn-Pb < 500 ppm (Scheffler 1975)





Goslar: Imperial town in 968 AD

House of the baker's guild, 1507 AD

Otto the Great (936-973) establishes imperial residence, local silver coins abundant after 968 AD.

Rammelsberg cumulative production

968-1360 AD:	2.8 million tons
1361-1648 AD:	6.2 million tons
1649-1866 AD:	8.8 million tons
1867-1988 AD:	26.3 million tons

Data: Walther (1986), Museum Rammelsberg (2008)

Otto-Adelheid silver coin ca. 985 AD

Rammelsberg mine: World heritage

Rammelsberg mine museum:
www.rammelsberg.de

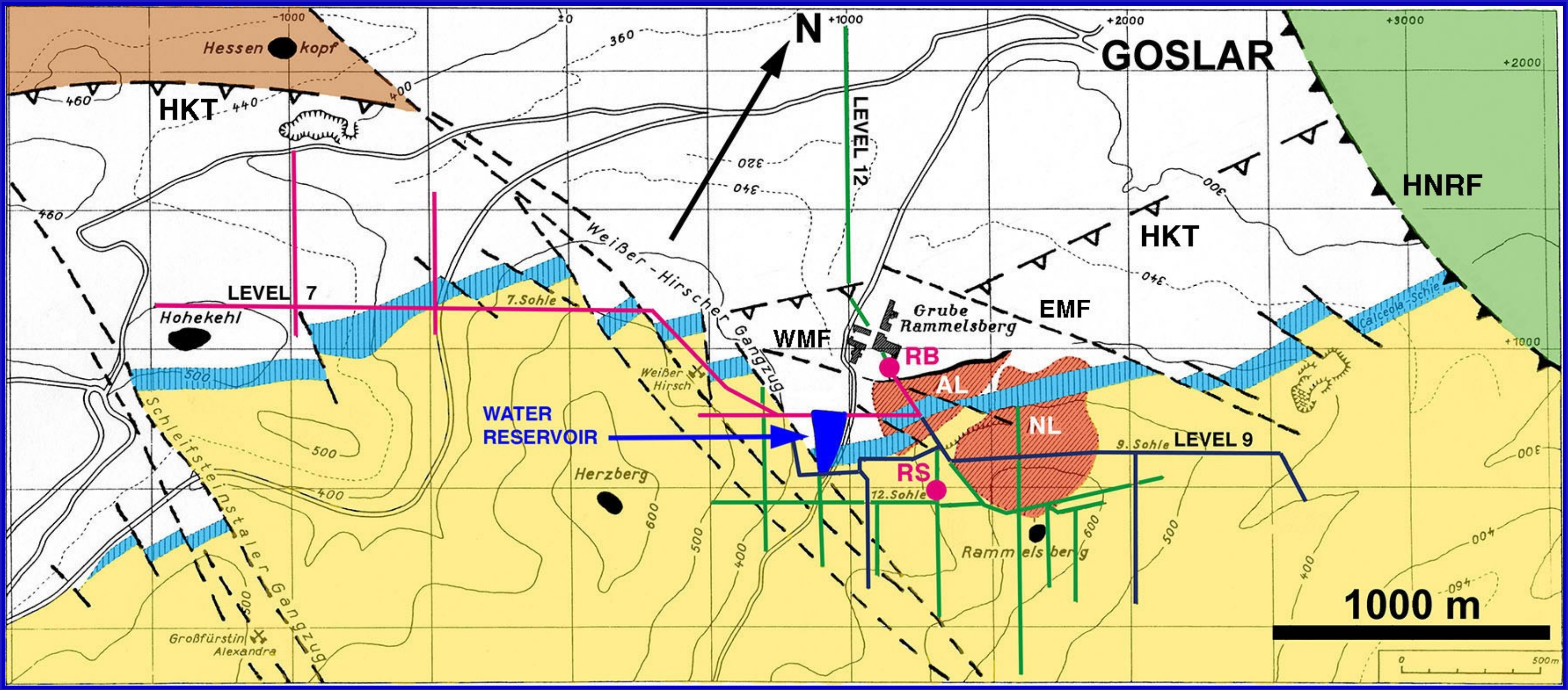
A. Shaft and flotation plant
B. Power plant
C. Altes Lager (AL) mine dumps, black slate, Harz rim

Rammelsberg mine: Water system

Raths Tiefster drainage tunnel (1150 AD) and 18th century water-wheel pump

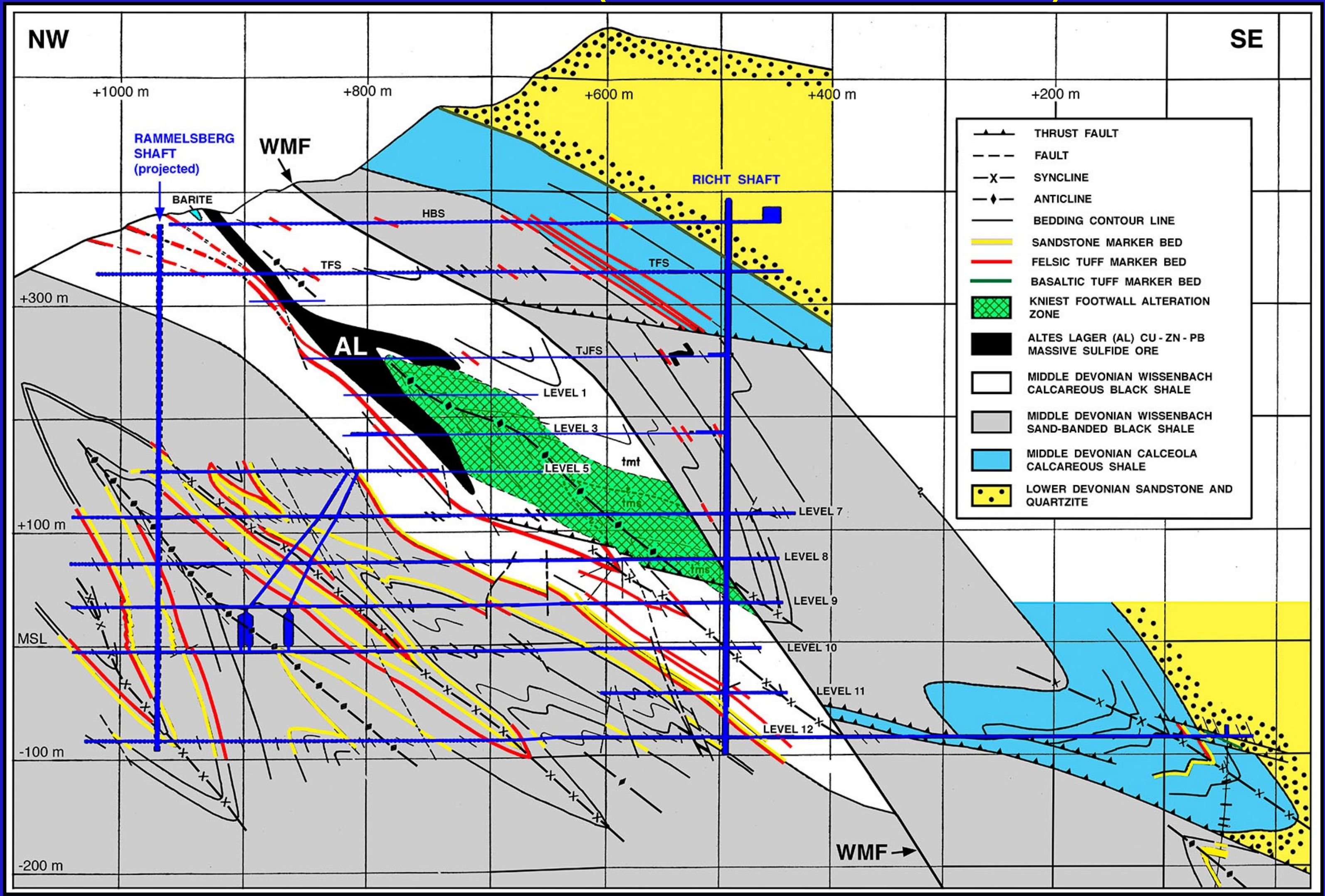
Rammelsberg district geology

Modified from Kraume (1960)

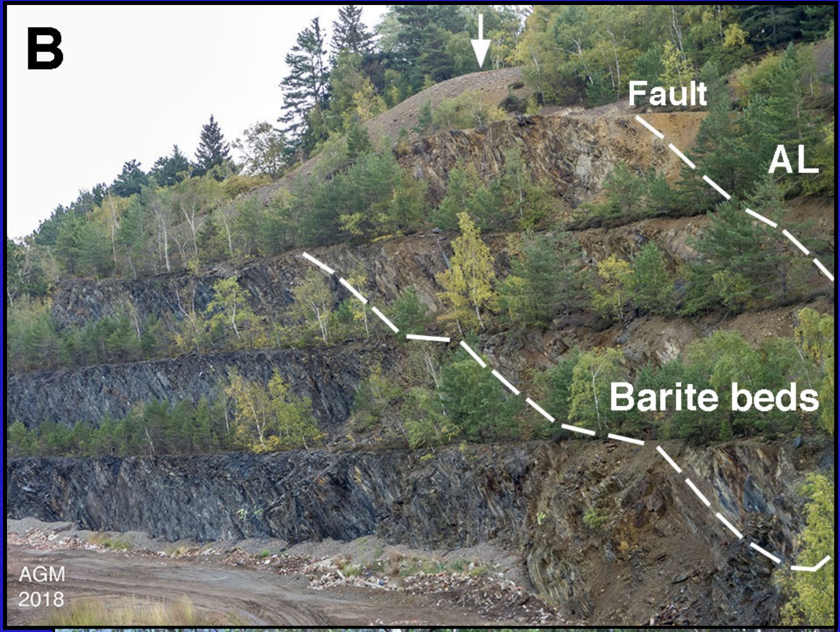


Rammelsberg: Structural cross section

Tuff marker beds (modified from Abt 1958)



Altes Lager orebody: Structural setting



Structural relationships:

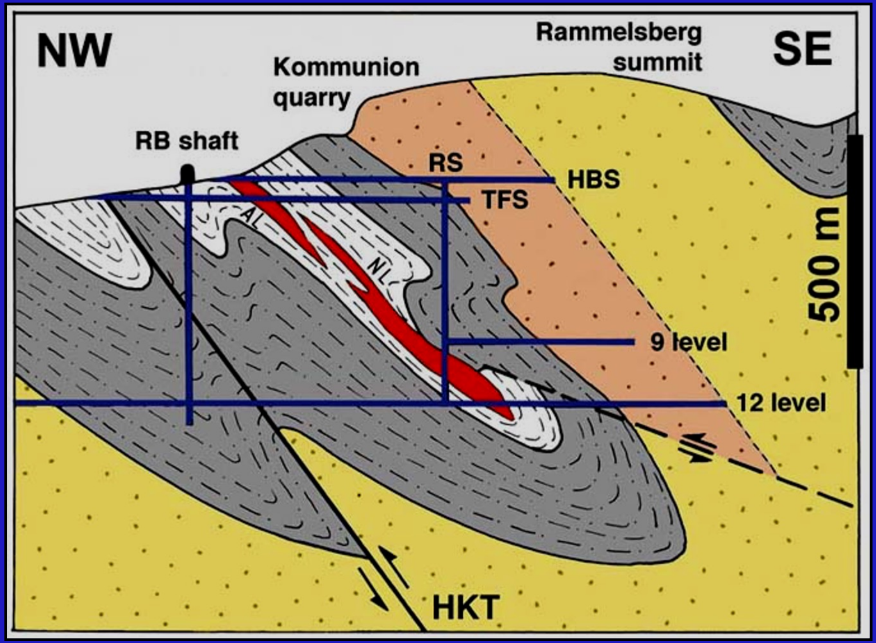
A. Backfilled open cuts

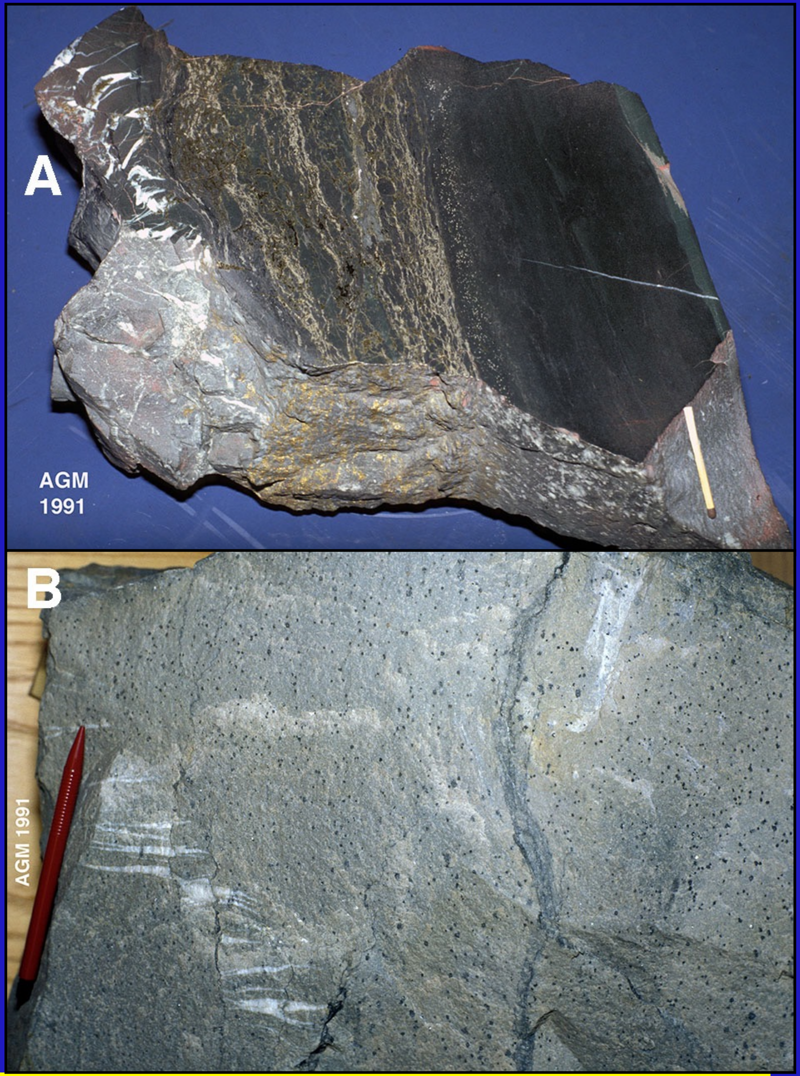
B. FW barite-bed syncline

C. Slaty cleavage in HW shale

Rammelsberg: Feeder zone Cu-Zn-Pb sulfides

Cross section modified from Hinze et al. (1998)



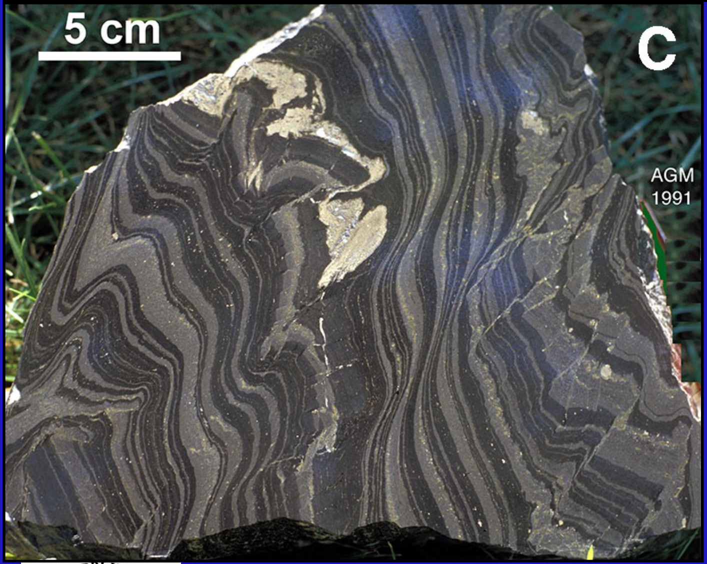


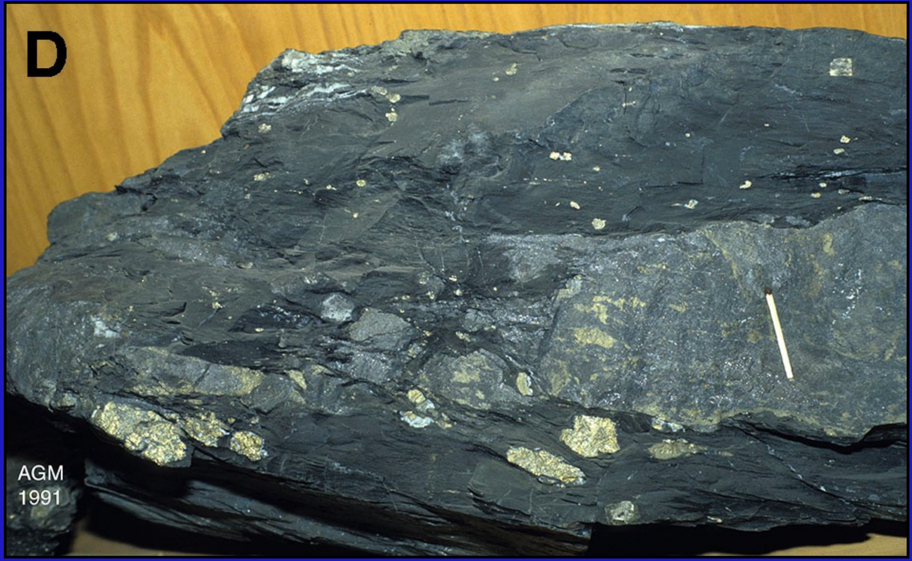
Replacement in Lower Devonian siliceous sandstone:

A. Pyrite-chalcopyrite-dolomite manto parallel to bedding

B. Disseminated sphalerite aggregates in sandstone

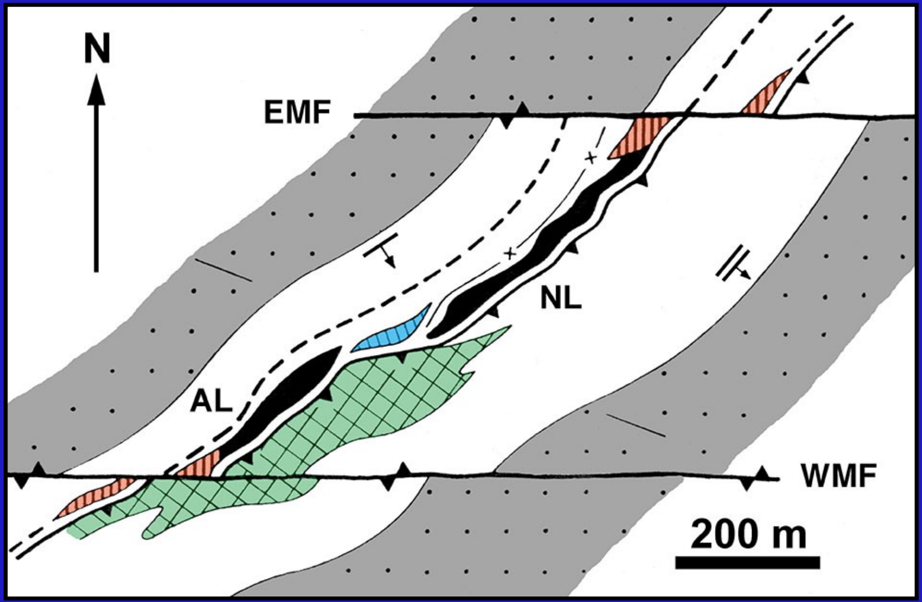
Rammelsberg: Sulfide ore in black shale

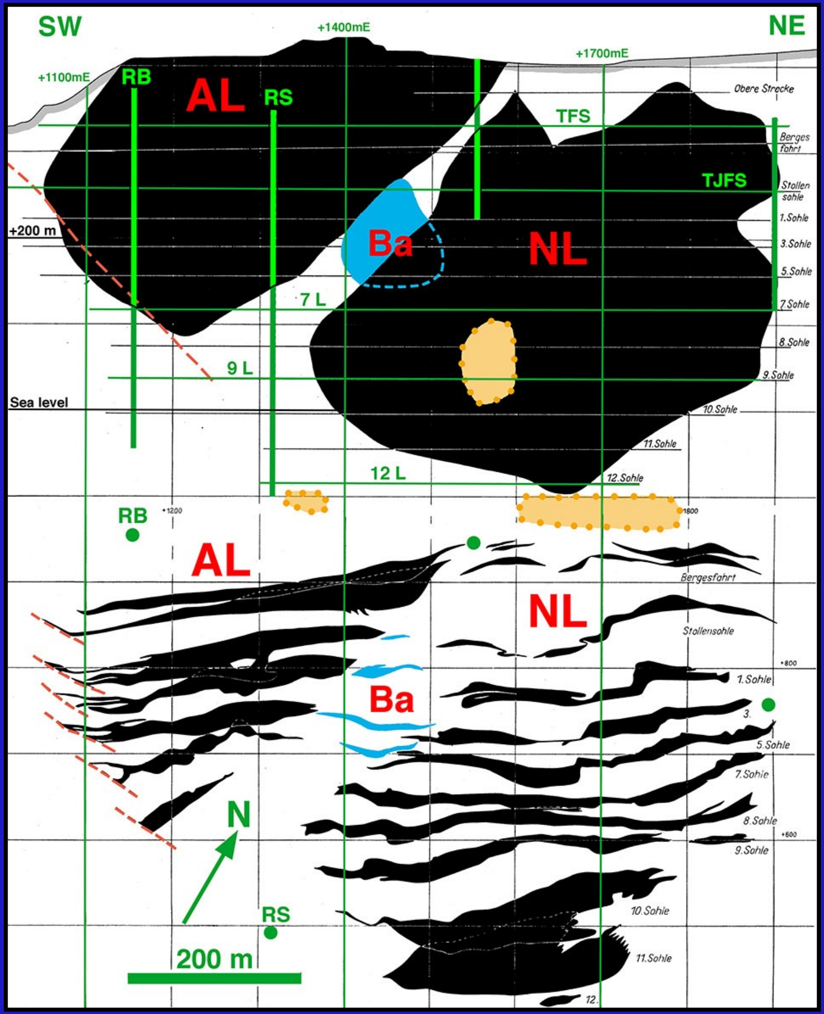




Rammelsberg: Shape of orebodies

Modified from Kraume et al. (1955) and Gunzert (1979)



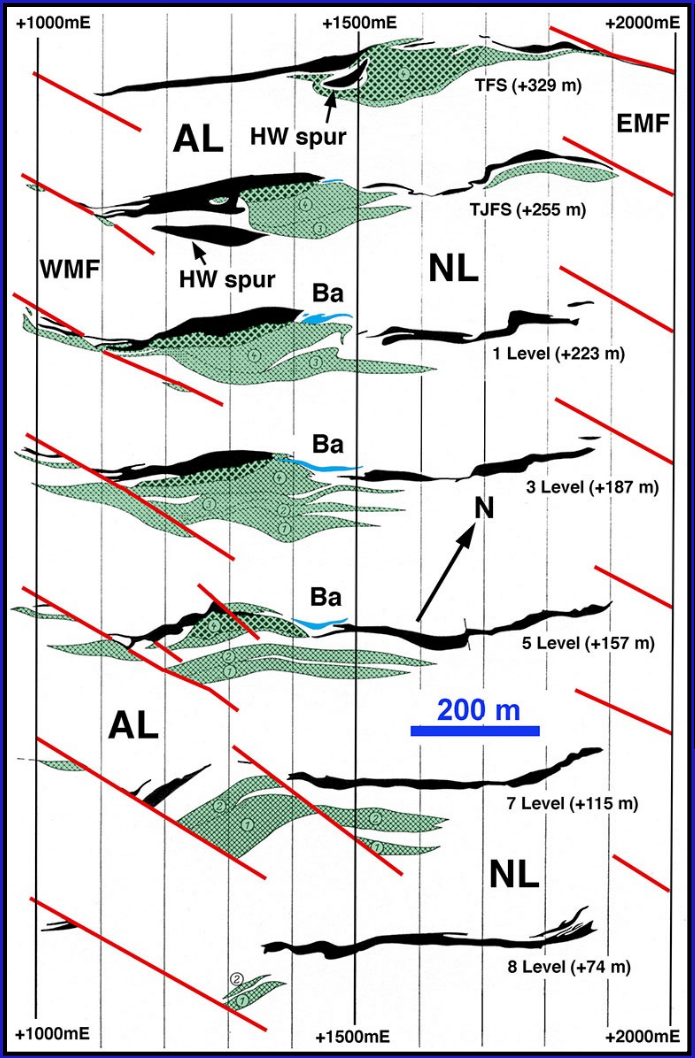


Left: Geologic map Level 3

Right: Longitudinal projection + composite level plans

Kniest footwall alteration zone

Composite level plans modified from Kraume et al. (1955)

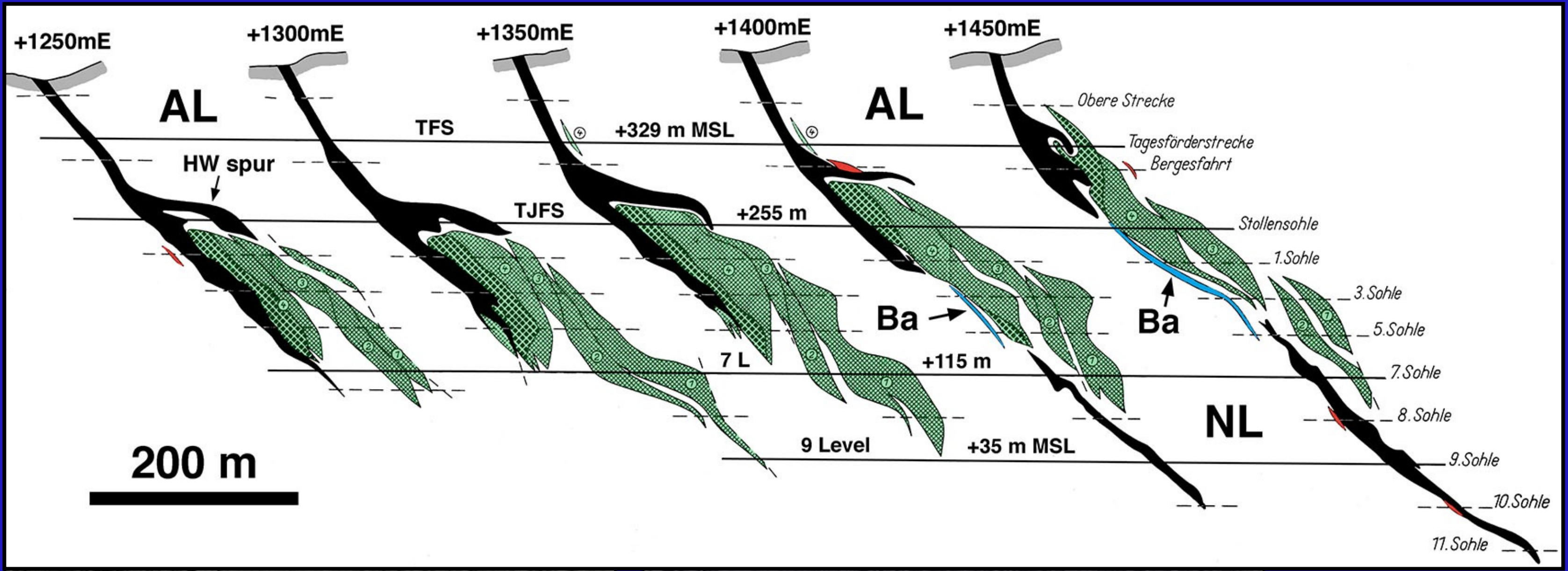


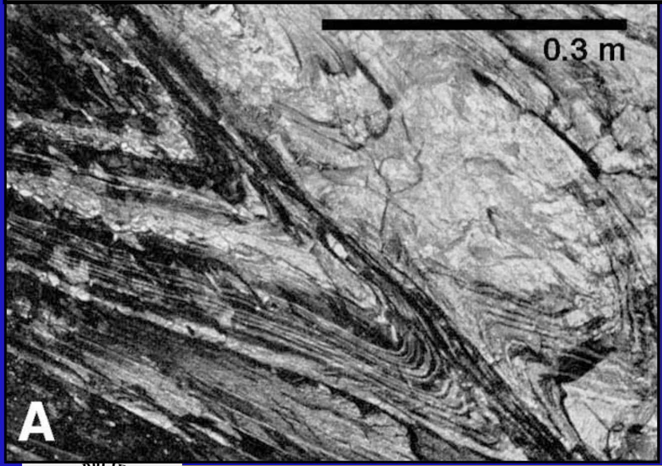
Kniest = Quartz ± Fe-chlorite ± ankerite replacement of black shale

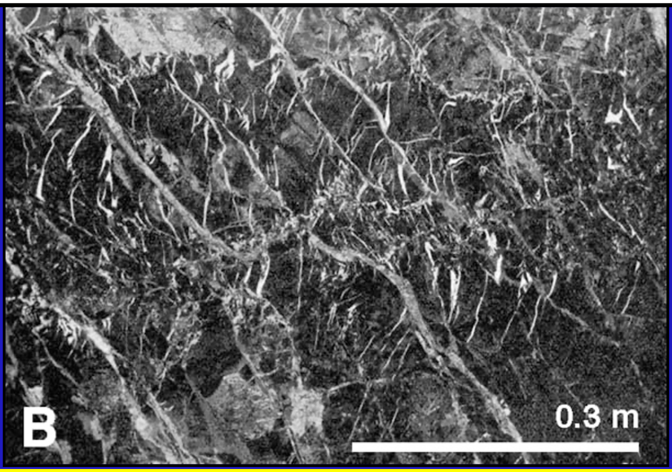
Sulfide-veined Kniest: 2.5 Mt at 1.3% Cu + 3.0% Zn + 1.4% Pb + 28 g/t Ag

Structure of the Altes Lager and Kniest

Modified from Kraume et al. (1955)





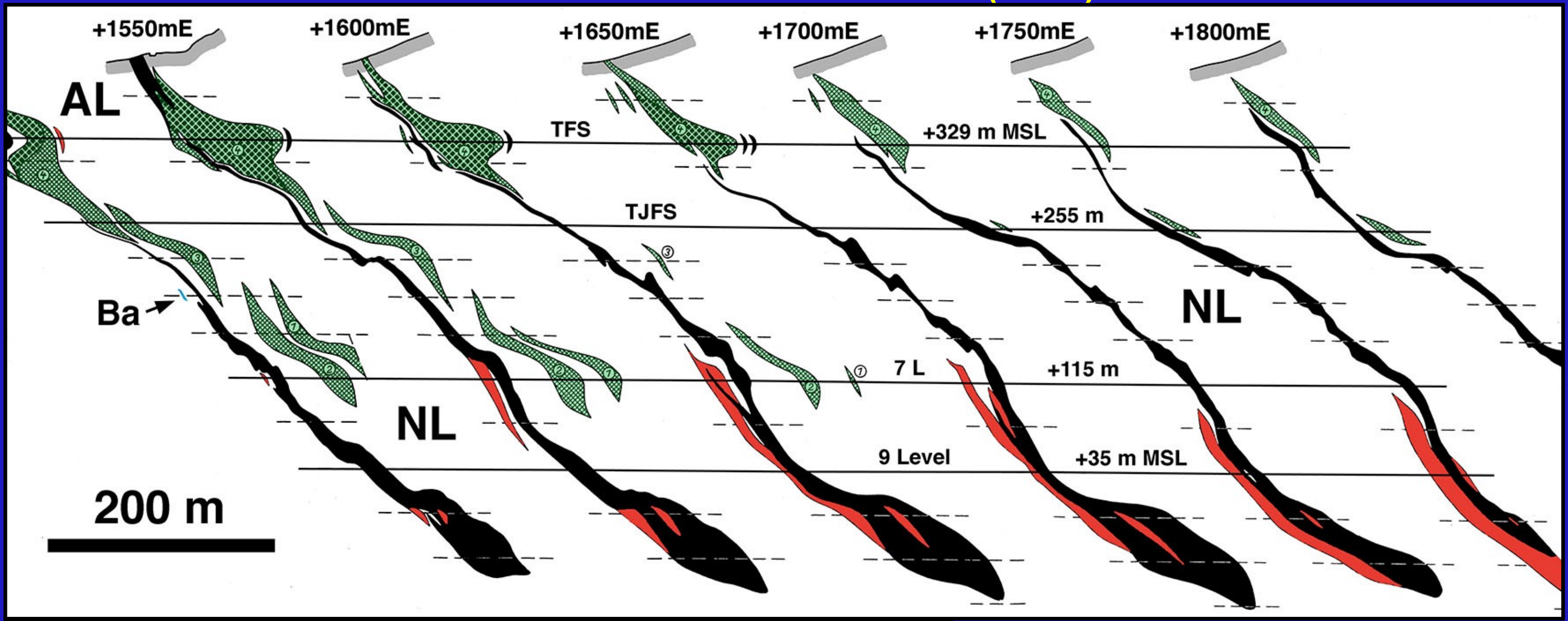


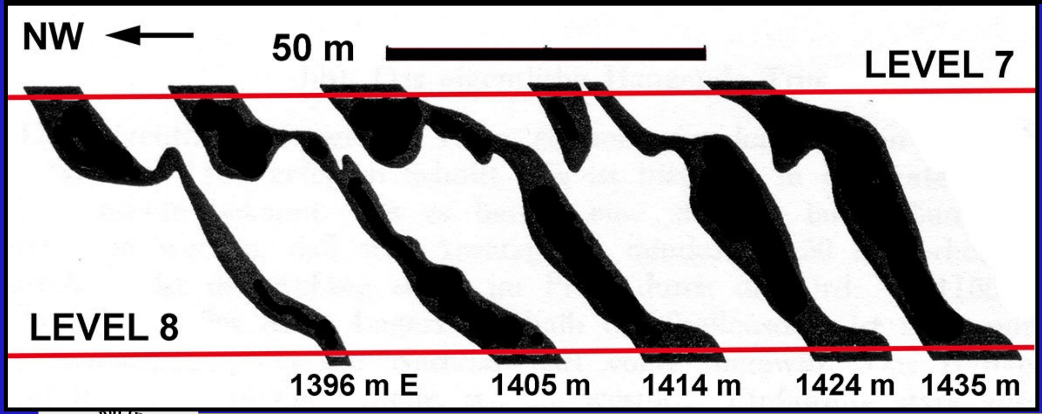
A. Altes Lager ore

B. Veined Kniest

Structure of the Neues Lager and Kniest

Modified from Kraume et al. (1955)

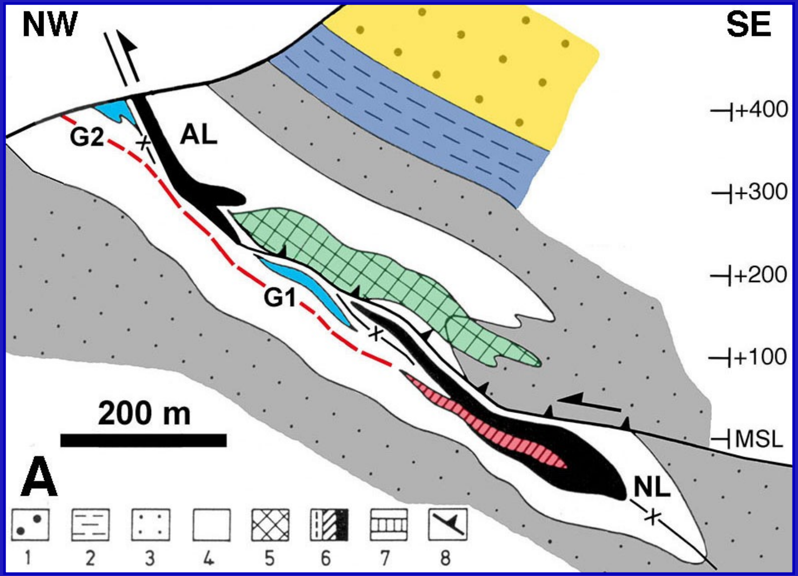


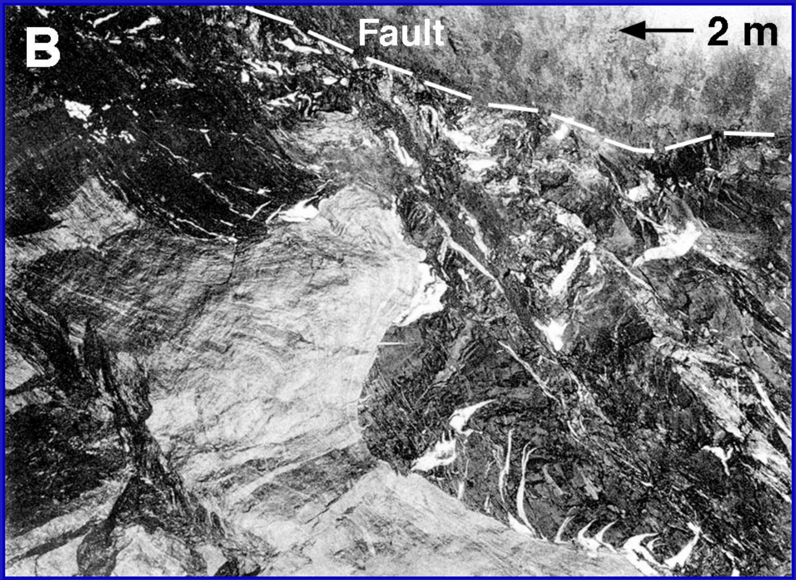


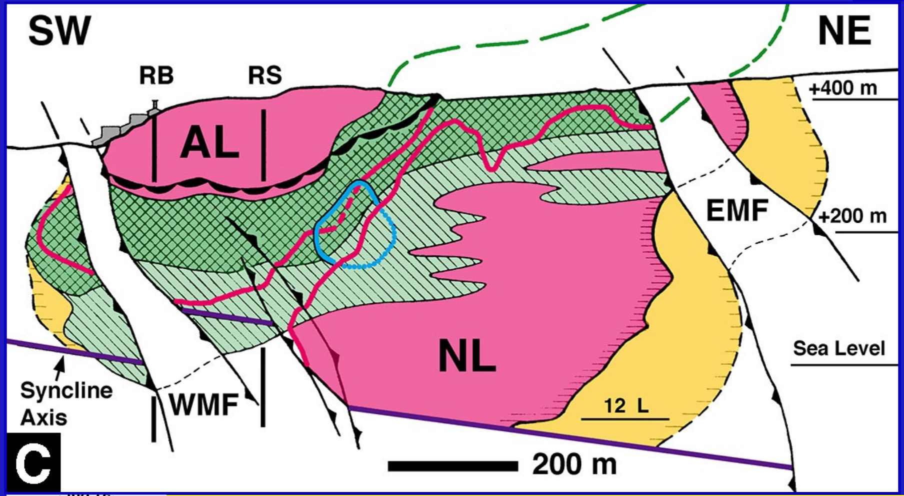
Left: Drag folds In NL massive sulfide, reverse movement

Deformation during reverse faulting

Modified from Wolff (1913), Gunzert (1969), Gunzert (1979)





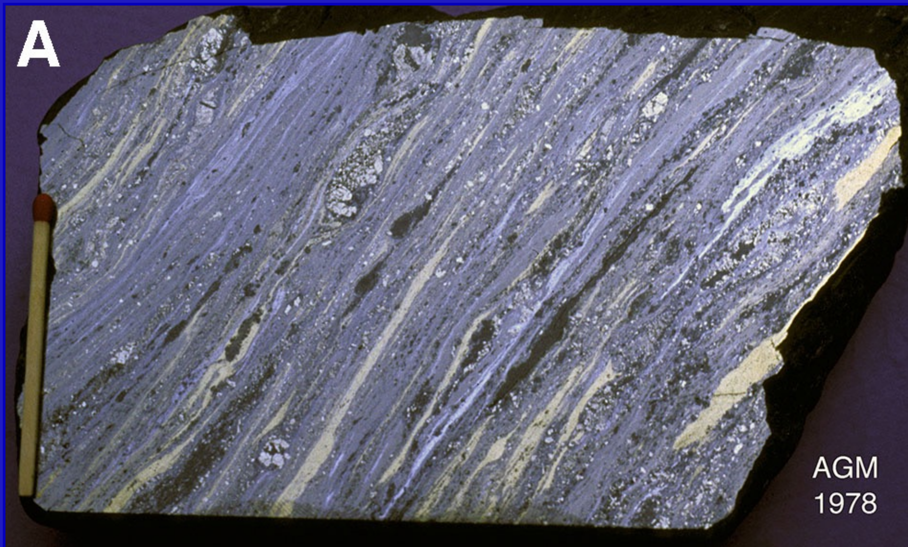


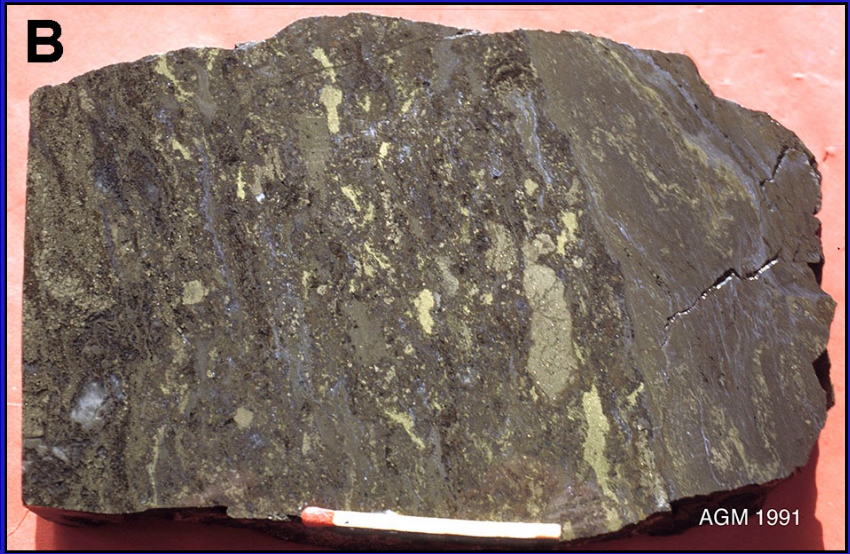
A. Cross section

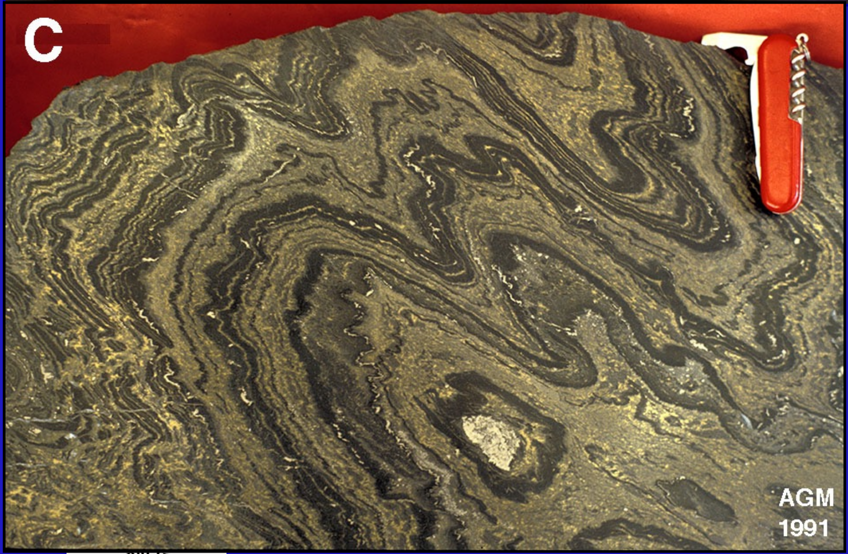
B. Drag fold in Neues Lager massive sulfide

C. Longitudinal projection

Brittle-ductile sulfide deformation





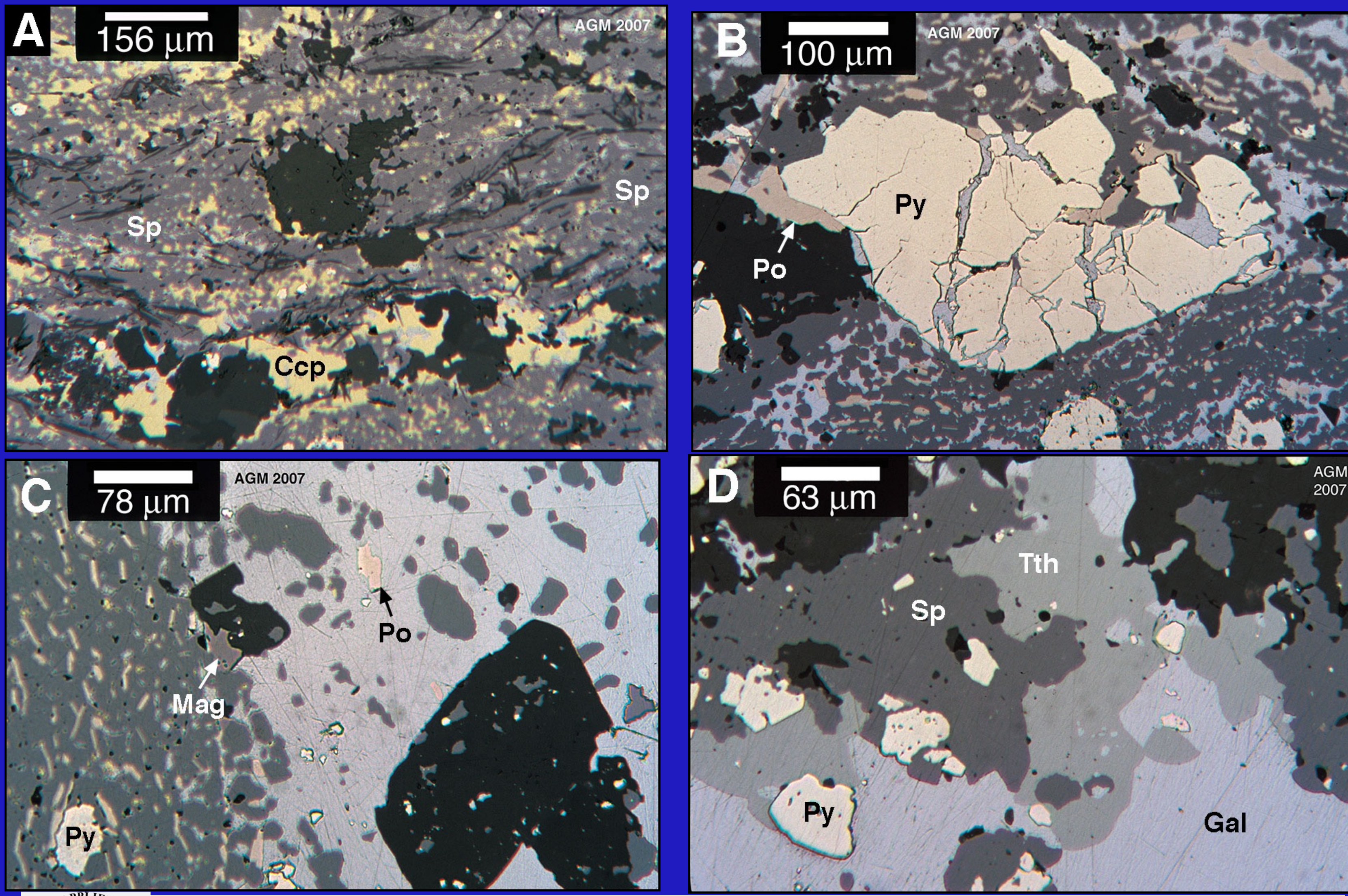


A. Sheared sulfide ore, rolled pyrite nodules

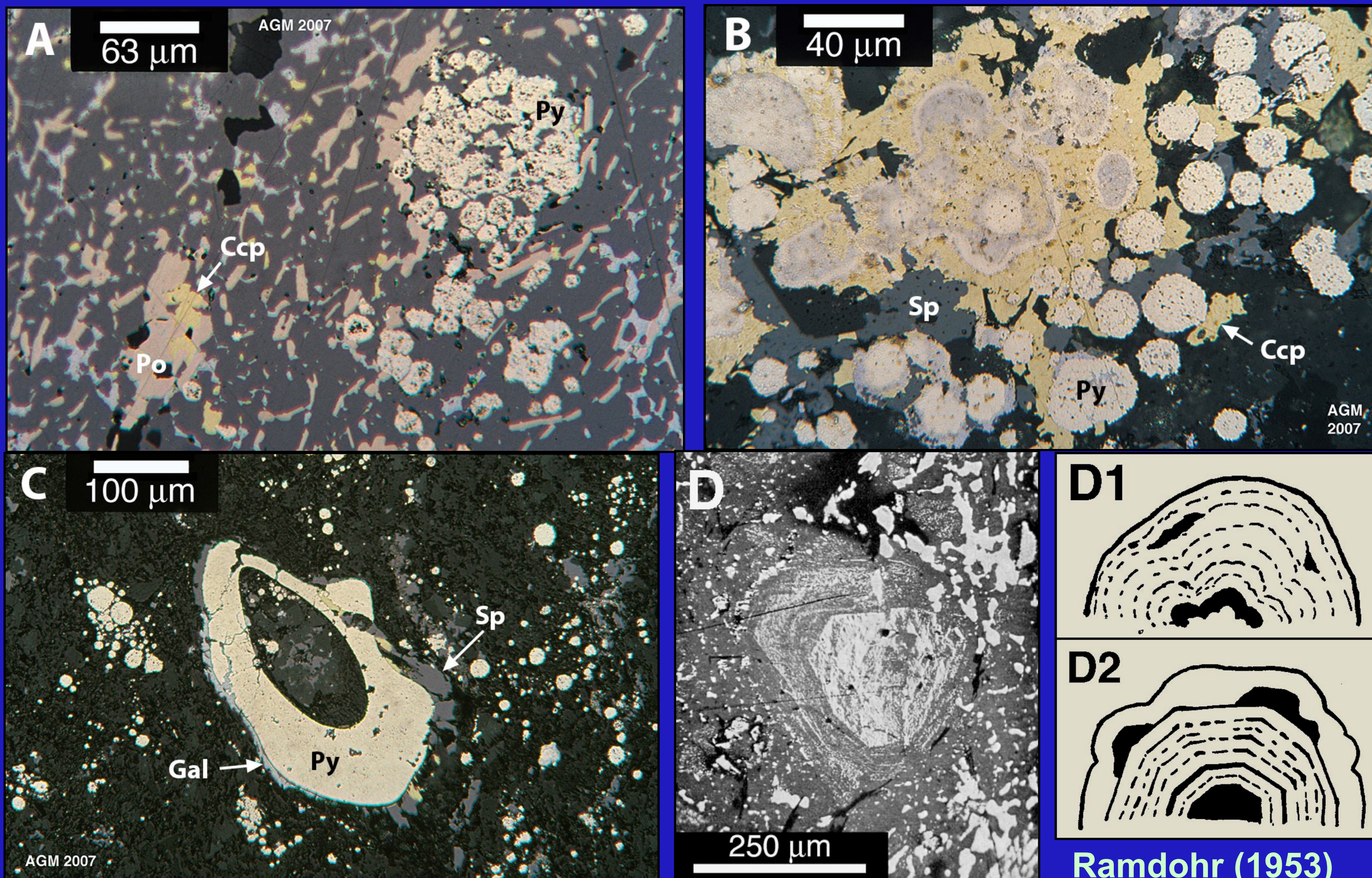
B. Breccia ore, pyrite fragments in sphalerite

C. Folds in shale-banded sulfide ore

Rammelsberg: Sulfide textures



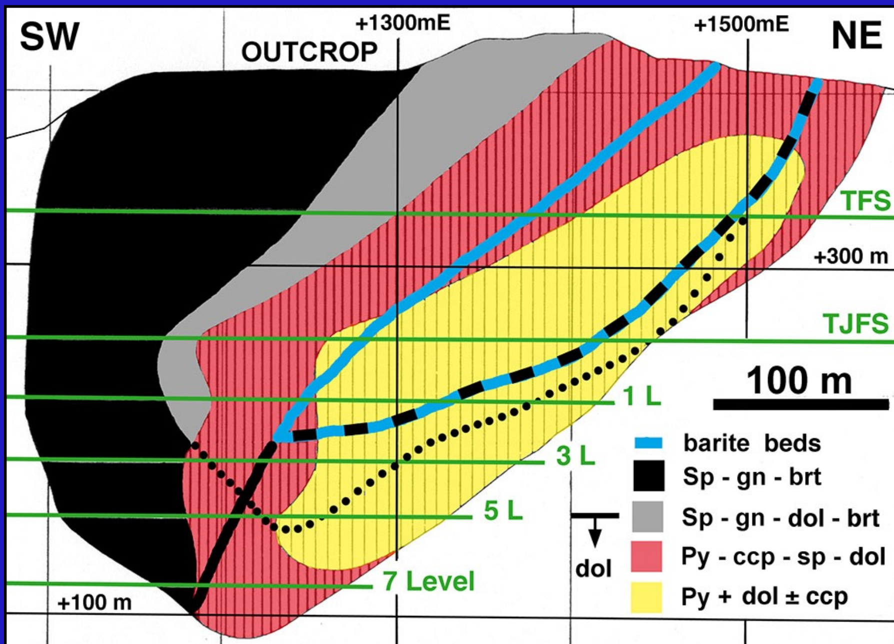
Rammelsberg: Sulfide textures



Ramdohr (1953)

Altes Lager: Zoned massive sulfide

Longitudinal projection modified from Kraume et al. (1955)



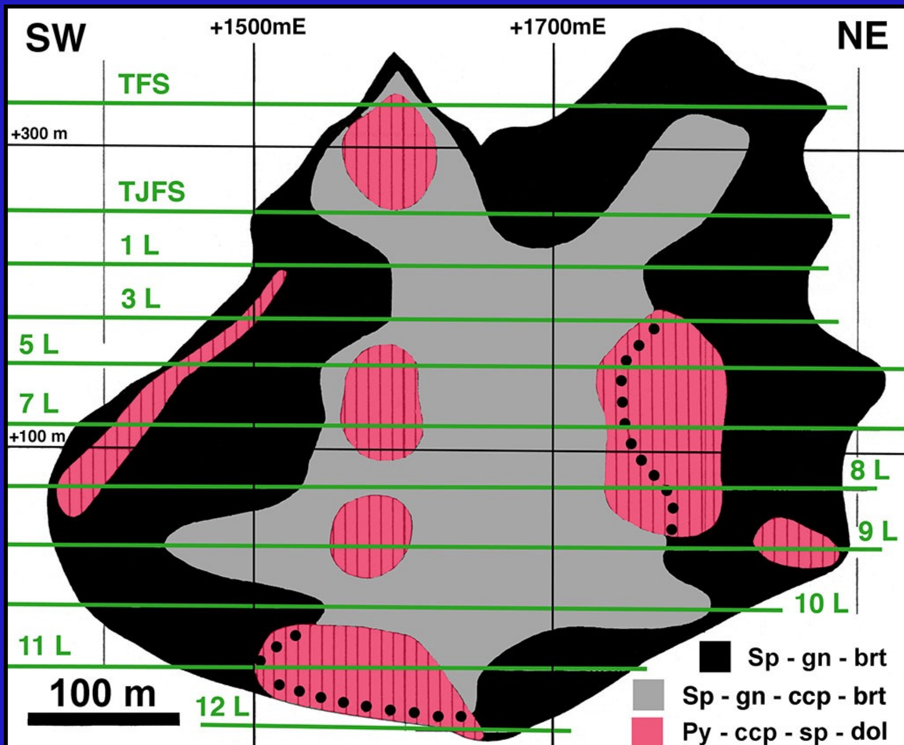
8 million metric tons

A. Massive pyrite, yellow in the projection above

B. Sphalerite (grey) and chalcopyrite ore (red)

Neues Lager: Zoned massive sulfide

Longitudinal projection modified from Kraume et al. (1955)



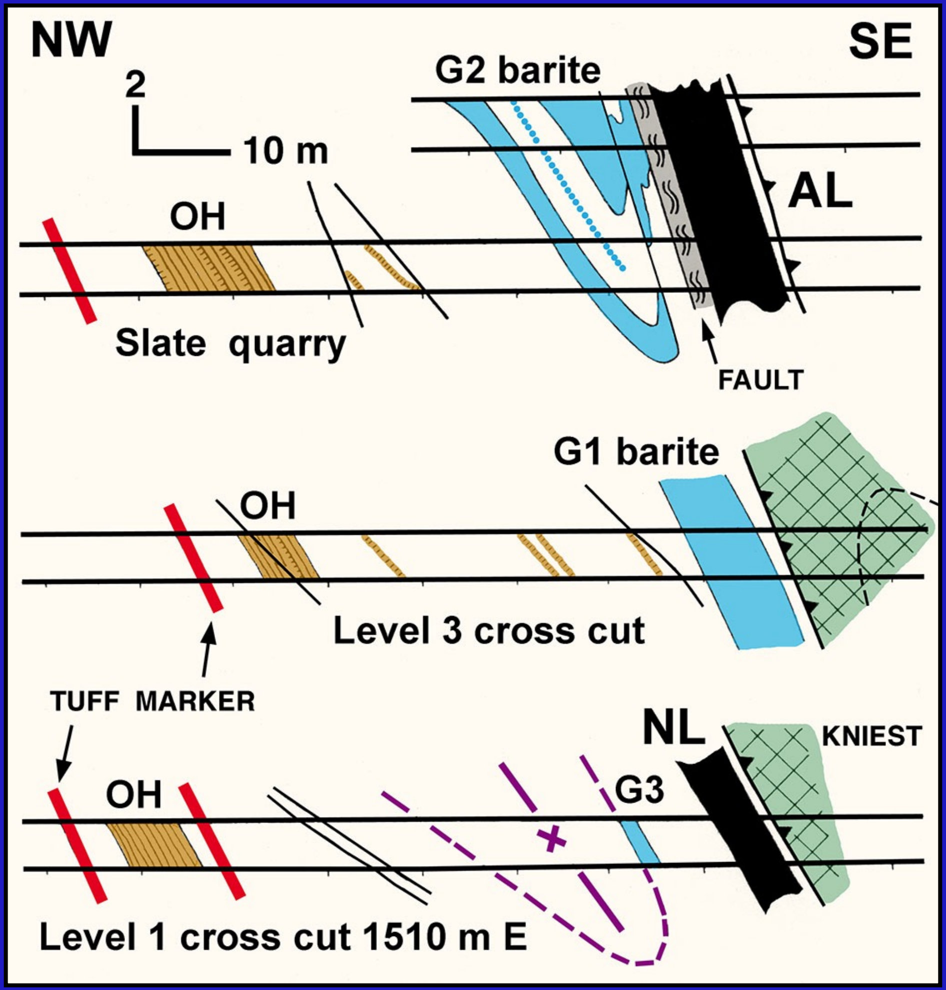
19 million metric tons

A. Pb-Zn-barite ore (black in the projection above)

B. Complex Cu-Zn-Pb ore (grey), 3 g/t Au, 230 g/t Ag

Ore marker horizon, tuffs and barite beds

Sections modified from Gunzert (1979)

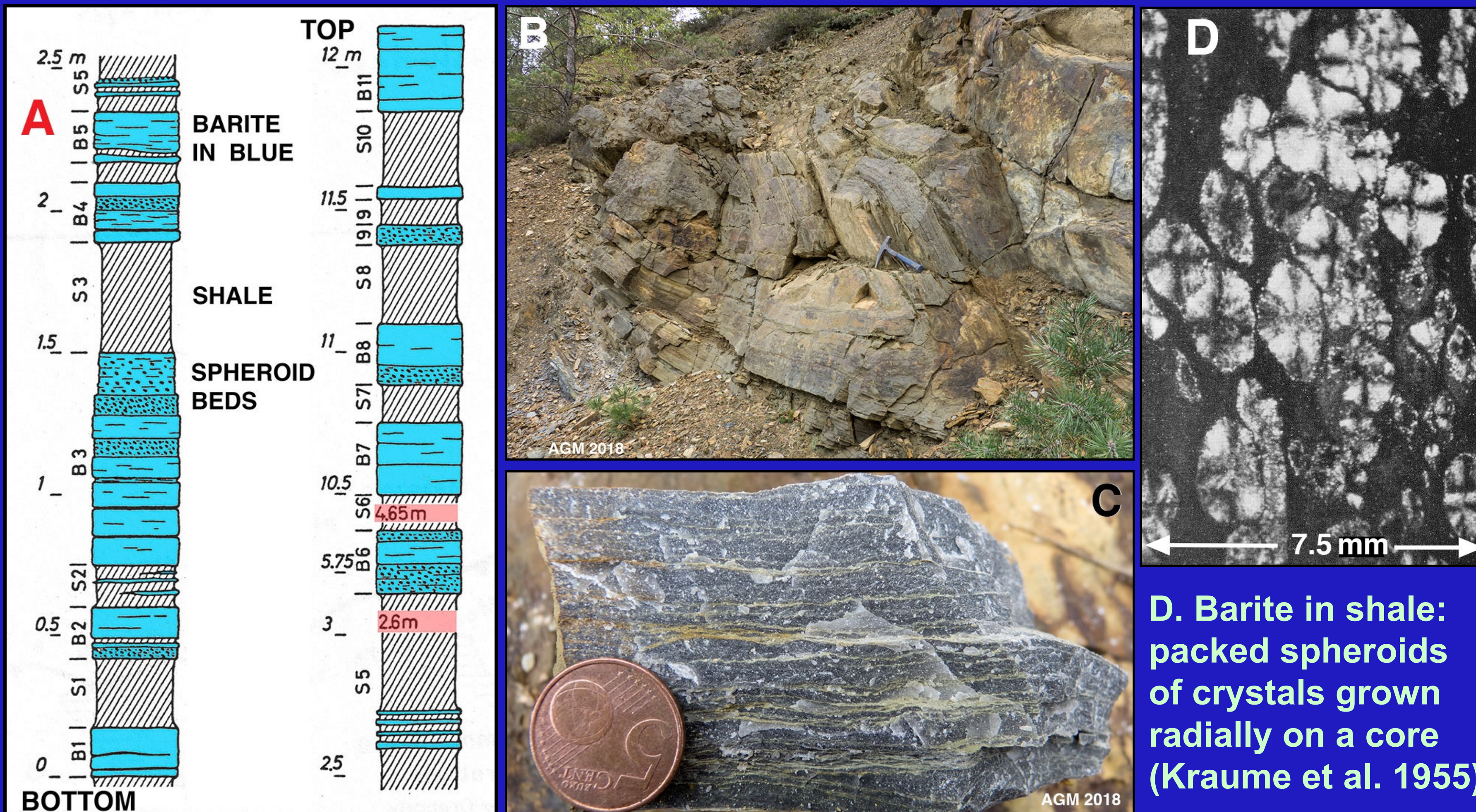


G1 barite ore: 0.2 Mt, 80% Ba, 3.8% Zn, 2.8% Pb, 140 g/t Ag

Ore horizon (OH): Fe-chlorite, Fe-dolomite, pyrite

Felsic tuffs: qtz-illite schist, igneous qtz, biotite, zircon

G2 barite syncline in Schiefermuehle quarry



D. Barite in shale: packed spheroids of crystals grown radially on a core (Kraume et al. 1955)

A. Stratigraphic section (Hannak 1981), breaks are in red B. Syncline in barite beds
C. Finely crystalline barite with shale partings

Rammelsberg: Sulfur isotopes

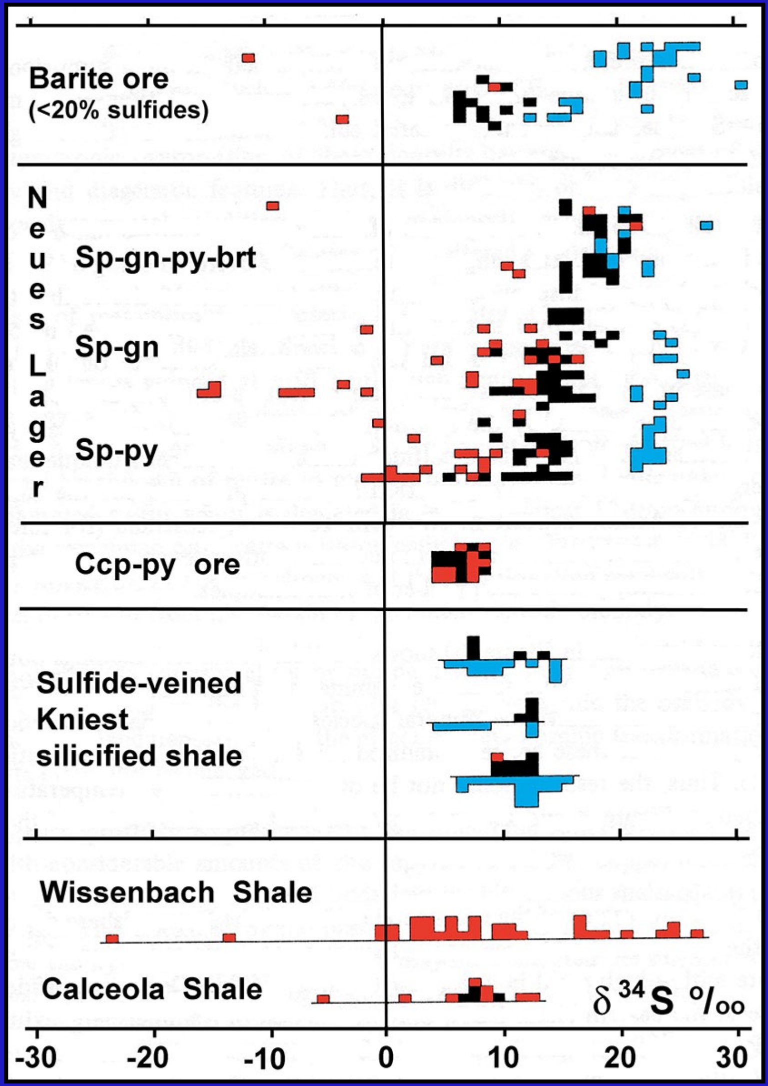


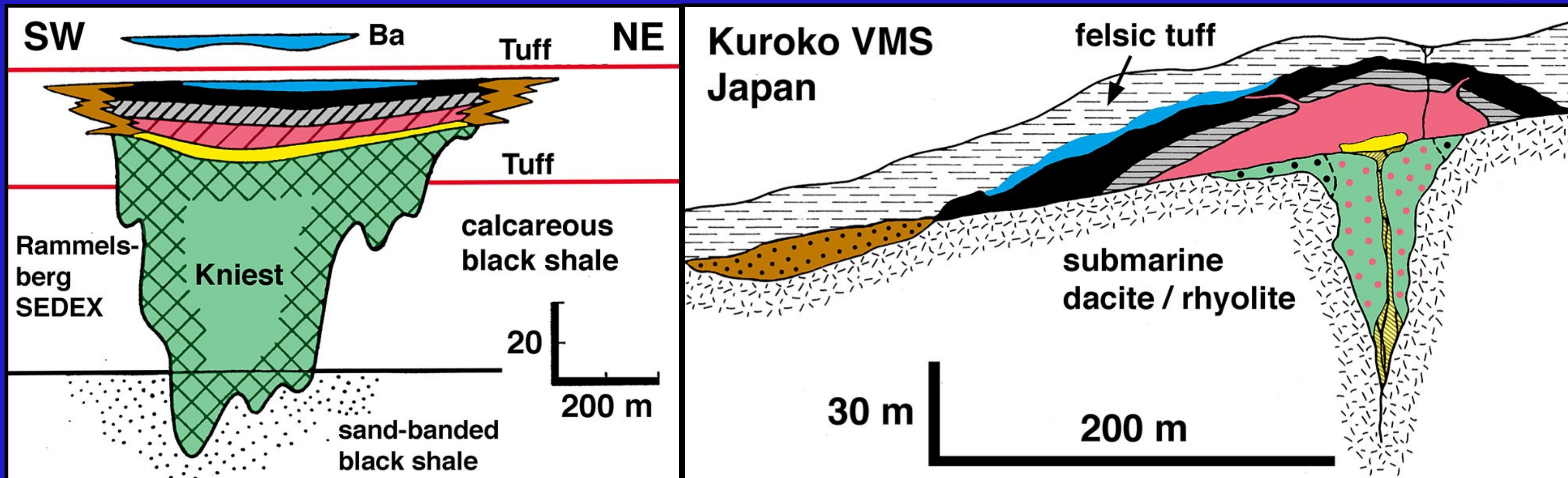
Diagram modified from Nielsen (1985)

For sulfides, H2S in fluid derived from marine sulfate in the sediments below by inorganic reduction. Seawater sulfate for barite. Isotope fractionation at 300±150 ° C. Diagenetic pyrite by bacterial sulfate reduction.

Metamorphism: Barite in Kniest veins formed by oxidation and dissolution of Lager sulfide. Magnetite + calcite in massive sulfide by oxidation of ankerite?

Sedex brine pool versus Kuroko mound

Modified from Gunzert (1969) and Eldridge et al. (1983)

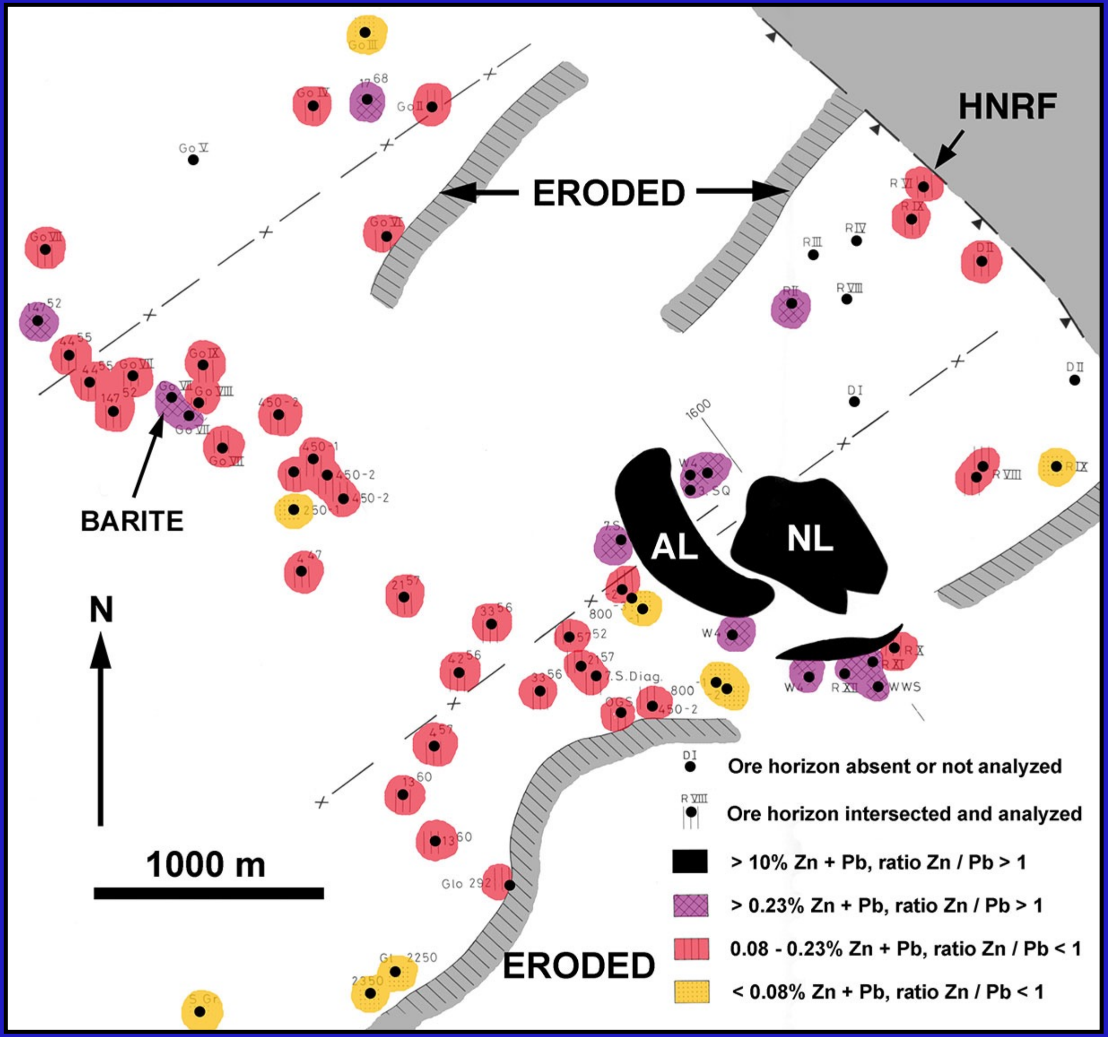


Rammelsberg: sulfide mud in brine pool, interbedded with black shale at margin. Discharge fluid: 300° C ? Seawater deeply circulated in faults ± magmatic fluid, primary fluid not trapped .

Kuroko: massive sulfide mound on volcanic surface, partly transported. Exchanged sea ± magmatic hydro-thermal water (3.5-7 wt. % NaCleq) Black Zn-Pb ore: 200-300° C Yellow Cu ore: 300-350° C

Total Zn-Pb content of the ore horizon

Modified from Sperling and Walcher (1990)



Ore deposit prior to erosion: 35-40 Mt at 25% Zn + Pb = 9-10 Mt base metal

Ore horizon (20 m thick) at 0.5-3km distance from deposit grades 620 ppm Pb + 300 ppm Zn

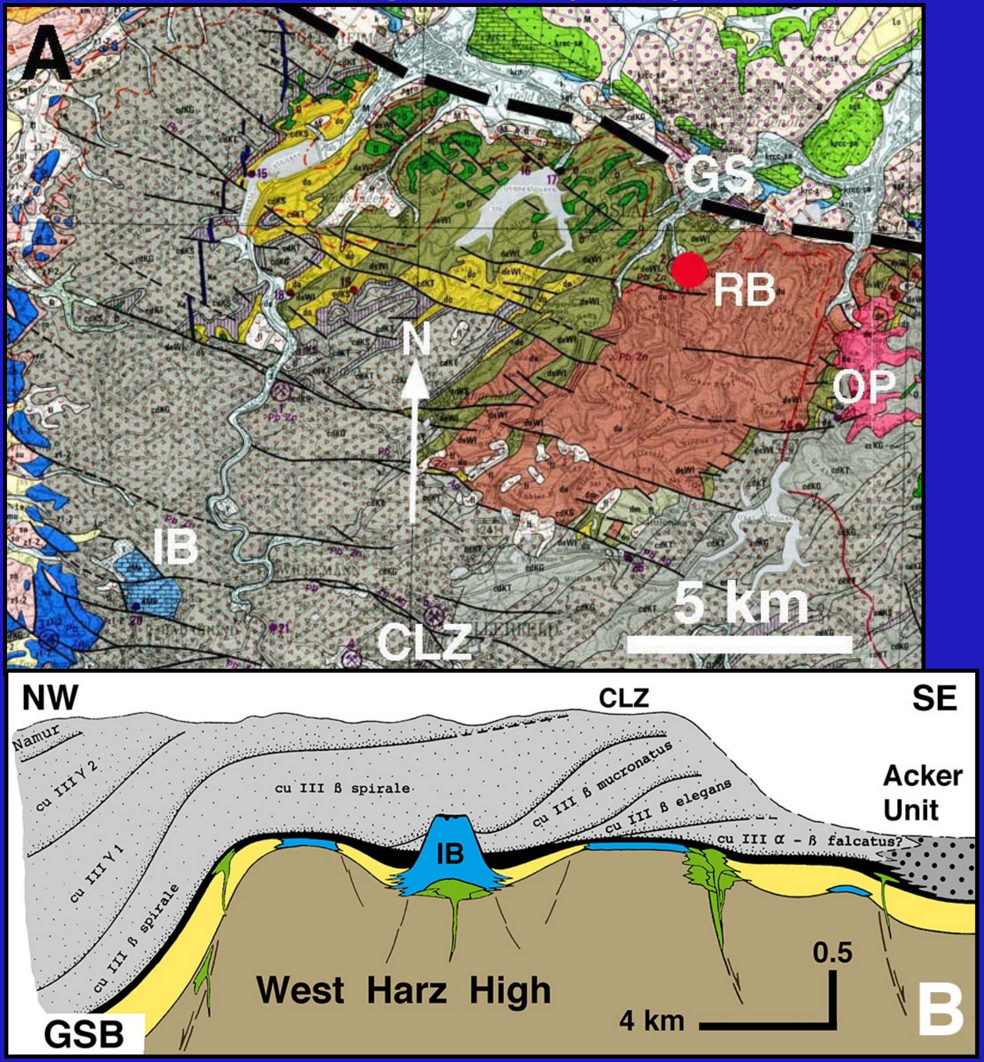
Local shale: 48 ppm Pb + 105 ppm Zn

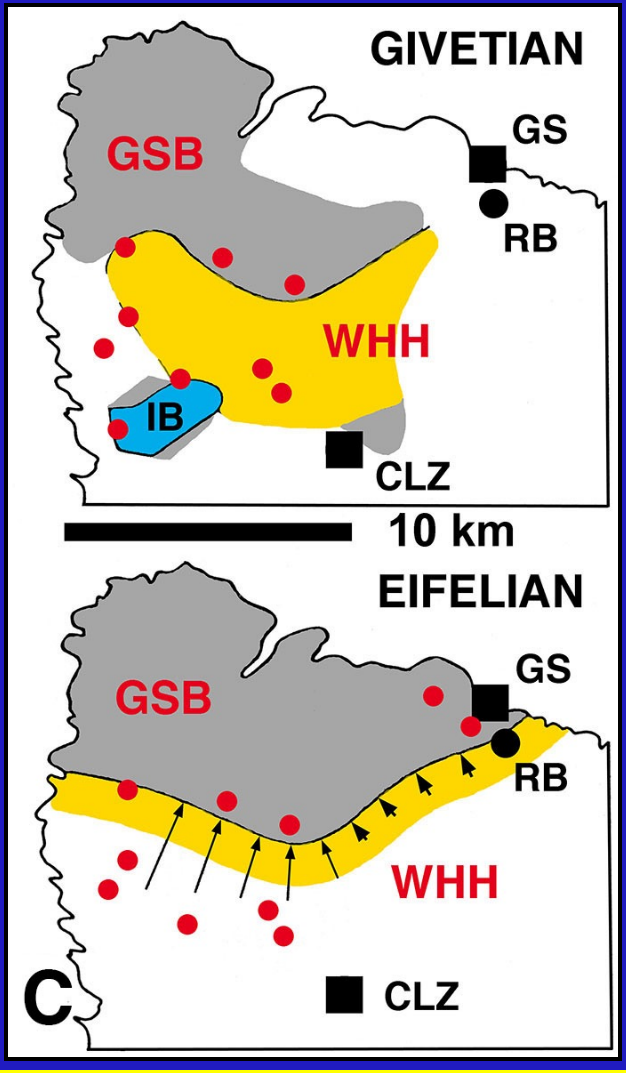
Ore horizon in 3 km radius: 13 Mt metal

Total system: > 22 Mt Zn + Pb

Harz: Middle Devonian Goslar basin

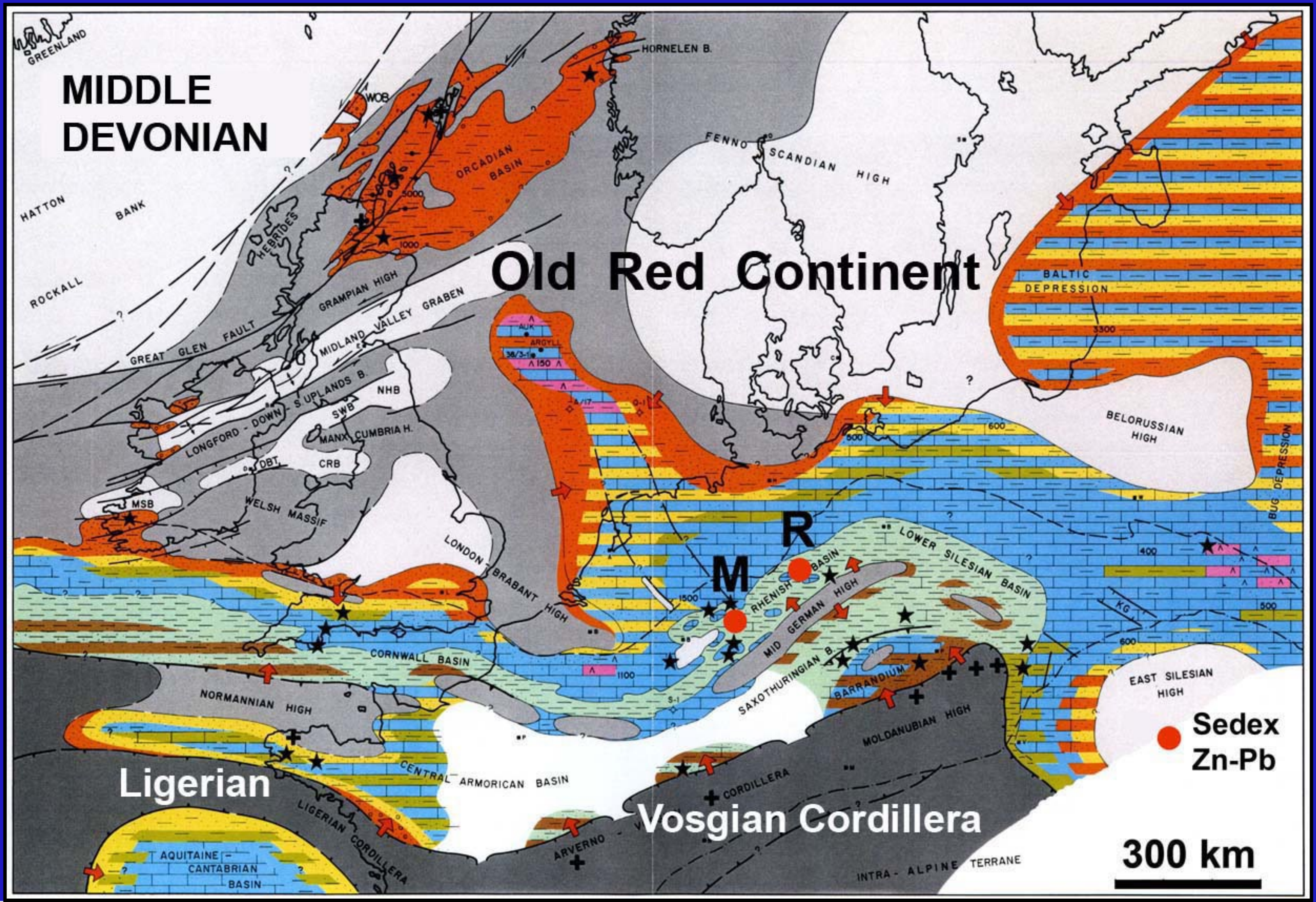
Modified from Engel et al. (1983), Brinckmann et al. (1986), Hinze et al. (1998)





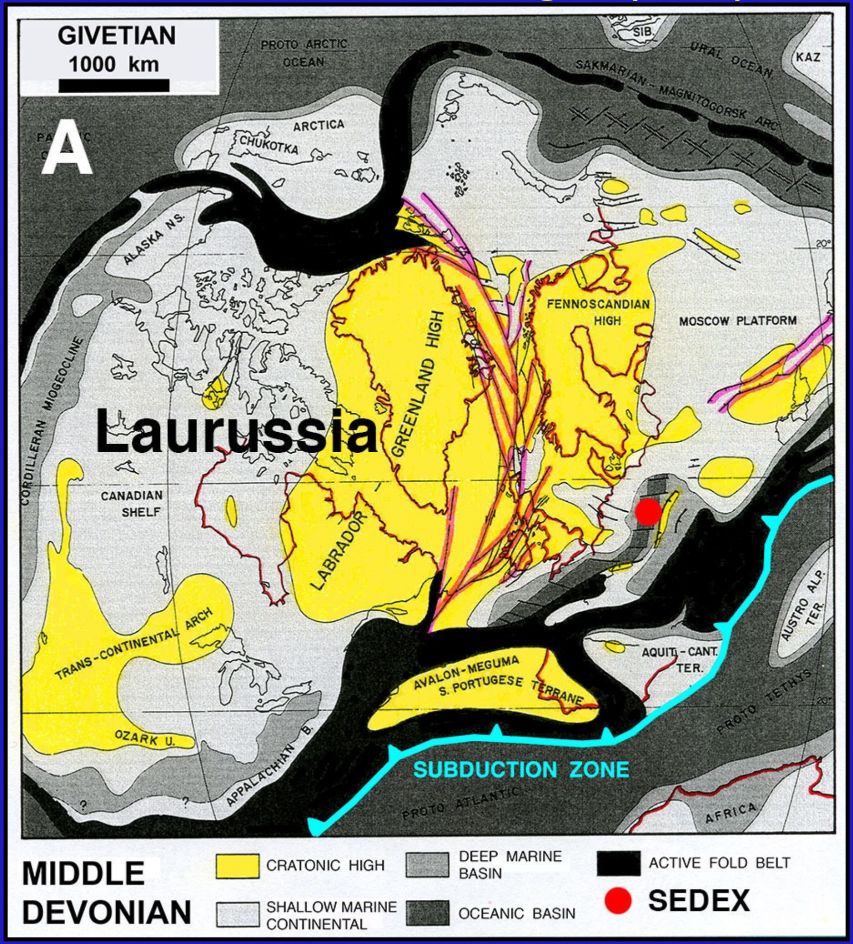
Europe: Devonian back-arc rift basin

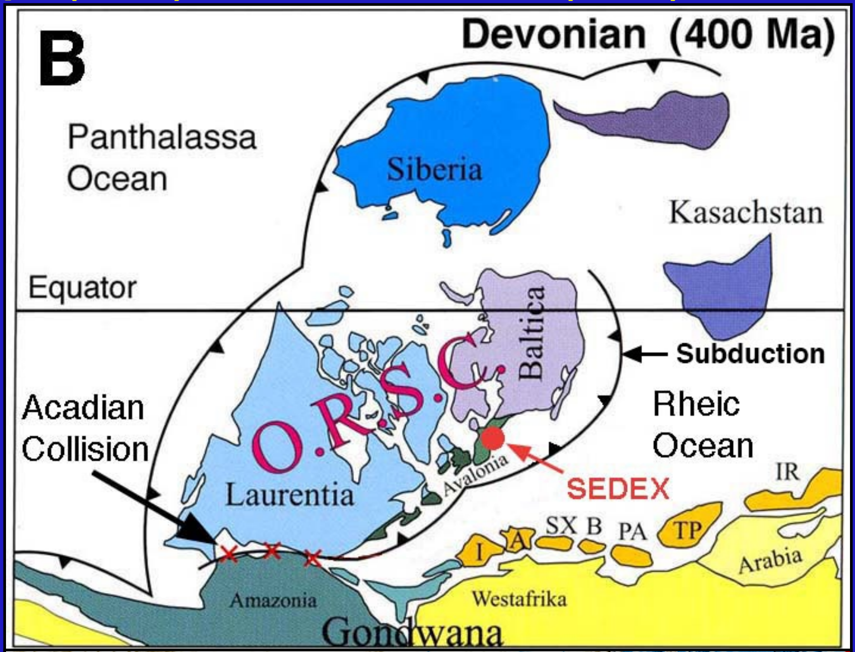
Modified from Ziegler (1990)

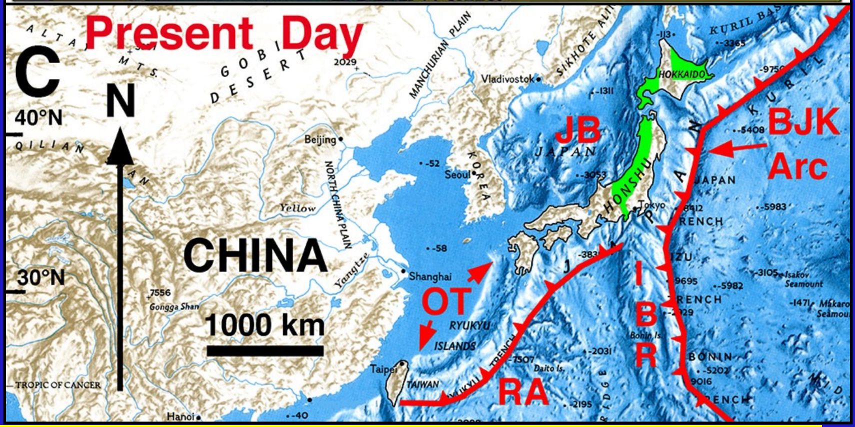


Devonian plate-tectonic setting

Modified from Ziegler (1990), Shupe (1992), Linnemann et al. (2003)







Rammelsberg: Key genetic features

Plate-tectonic setting: Continental-margin, sediment-filled, rifted back-arc basin

Submarine bimodal volcanism: Rift-related basalt and trachyte / alkali rhyolite lavas and tuffs, district-scale spilitization

Submarine ore deposits: Proximal hematite beds with basalt, pyrite mineralization with trachyte / rhyolite on volcanic ridges. Distal SEDEX sulfide-barite ore in black shale basins.

Rammelsberg deposit: Located at the margin of a deep-water black shale basin structured by rift faults. Feeder Fault marked by reduced quartz-chlorite-ankerite replacement

Cu-Zn-Pb sulfides: Vent-proximal deposition of sulfides as mud at 250-350° C in a brine pool, barite by mixing with seawater