RECOMMENDED CITATION:

Mueller AG (2020) Structural setting and age of syn- and post-orogenic gold and Zn-Pb-Ag vein deposits, Variscan slate belt, Germany -- Slide presentation and explanatory notes. Society for Geology Applied to Mineral Deposits (SGA): www.e-sga.org/Publications/Mineral Deposit Archive

Structural setting and age of syn- and post-orogenic gold and Zn-Pb-Ag vein deposits, Variscan slate belt, Germany

Slide presentation and explanatory notes

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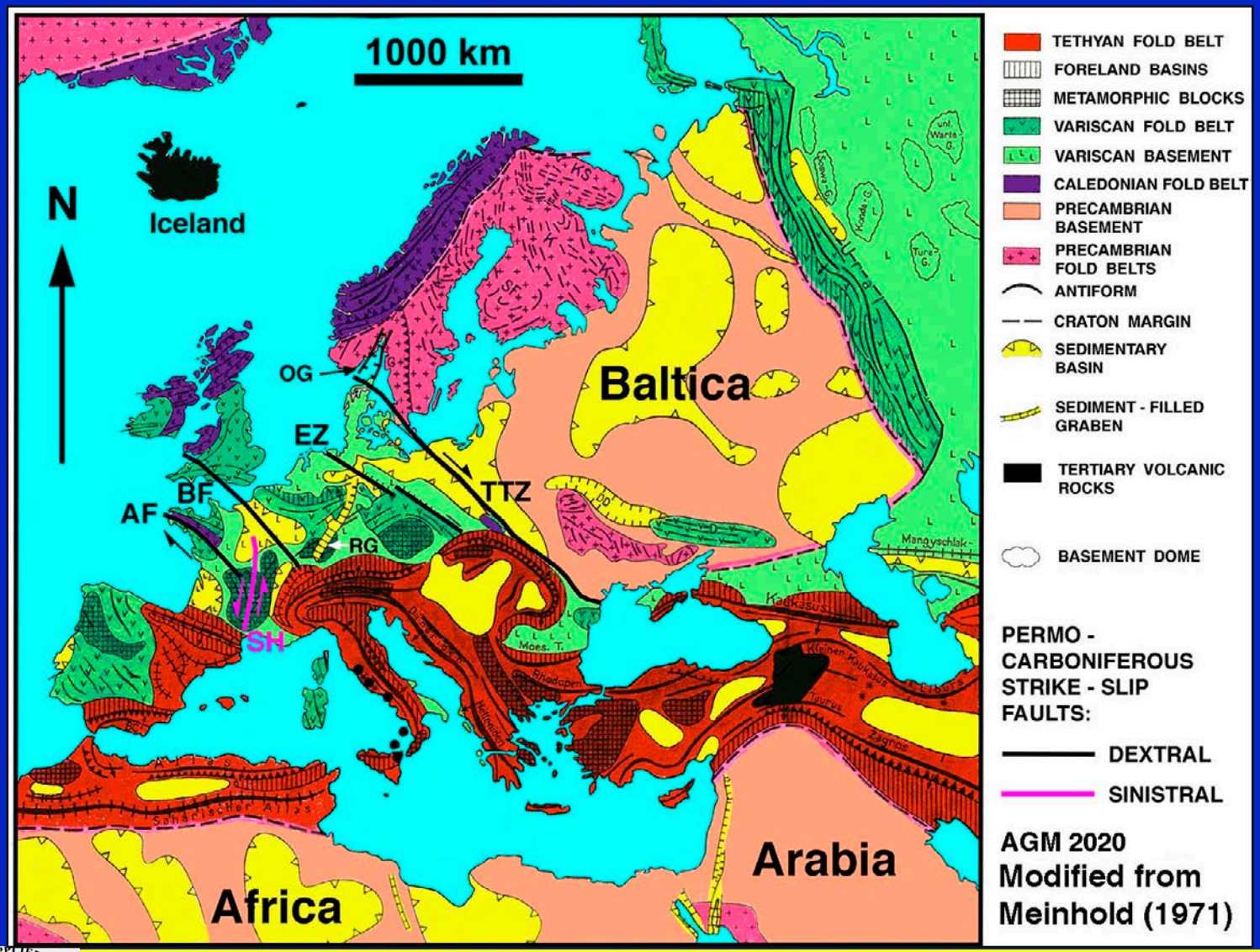
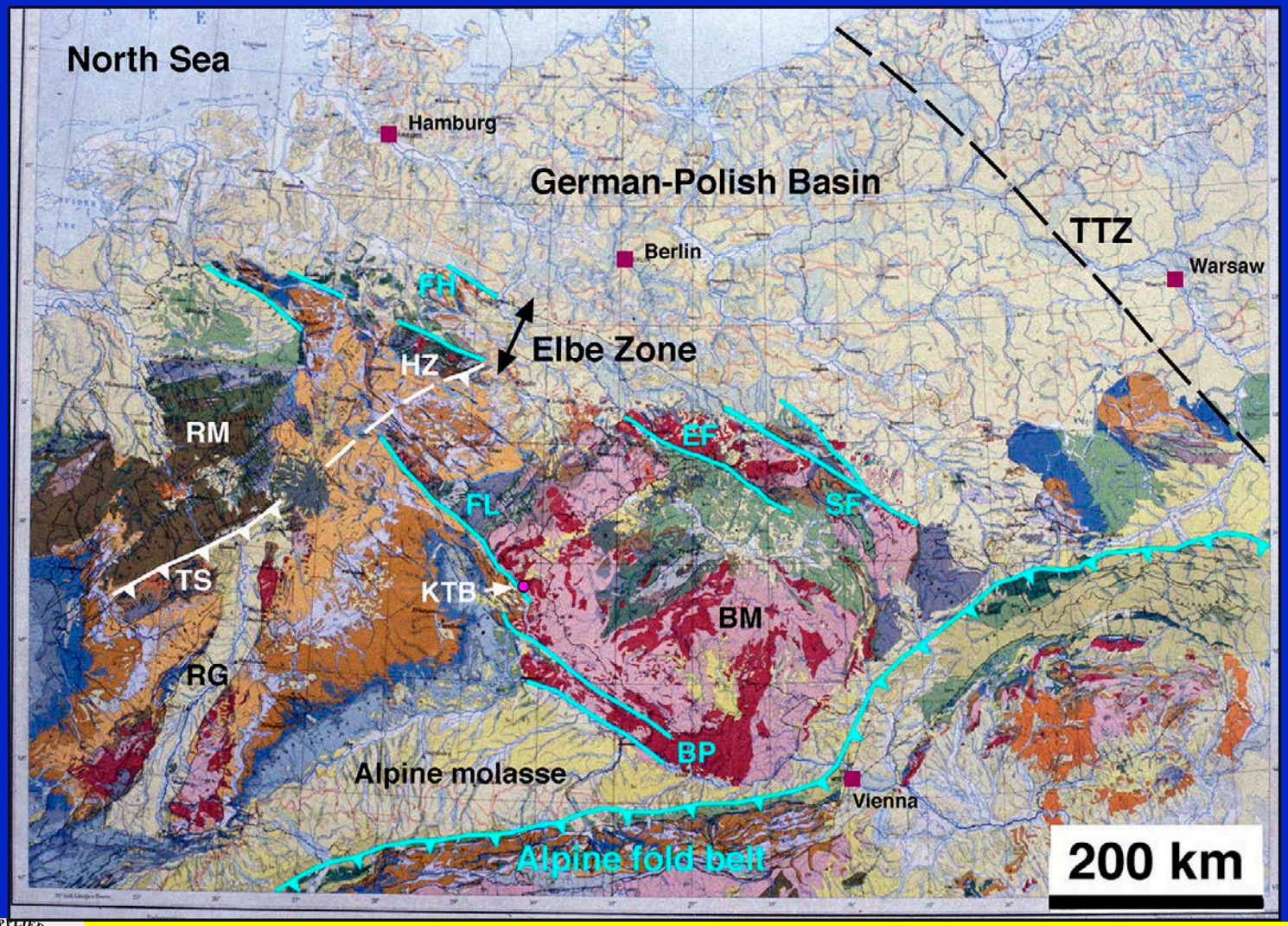
Version 1, November 2020

Europe: Cratons and orogenic belts



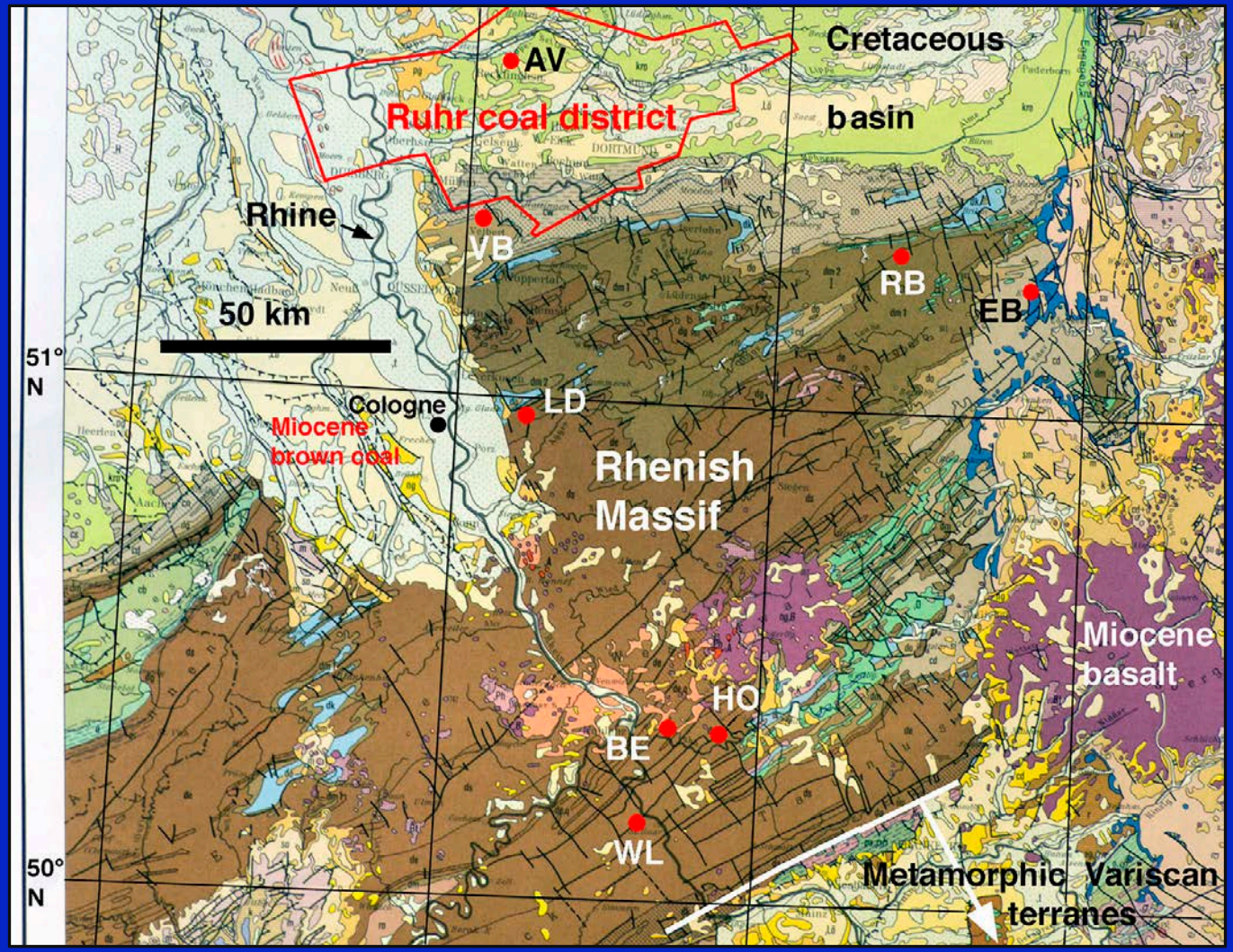
Orogenic belts in central Europe

Modified from Schriel 1930



Rhenish slate belt: Syn- and post-orogenic veins

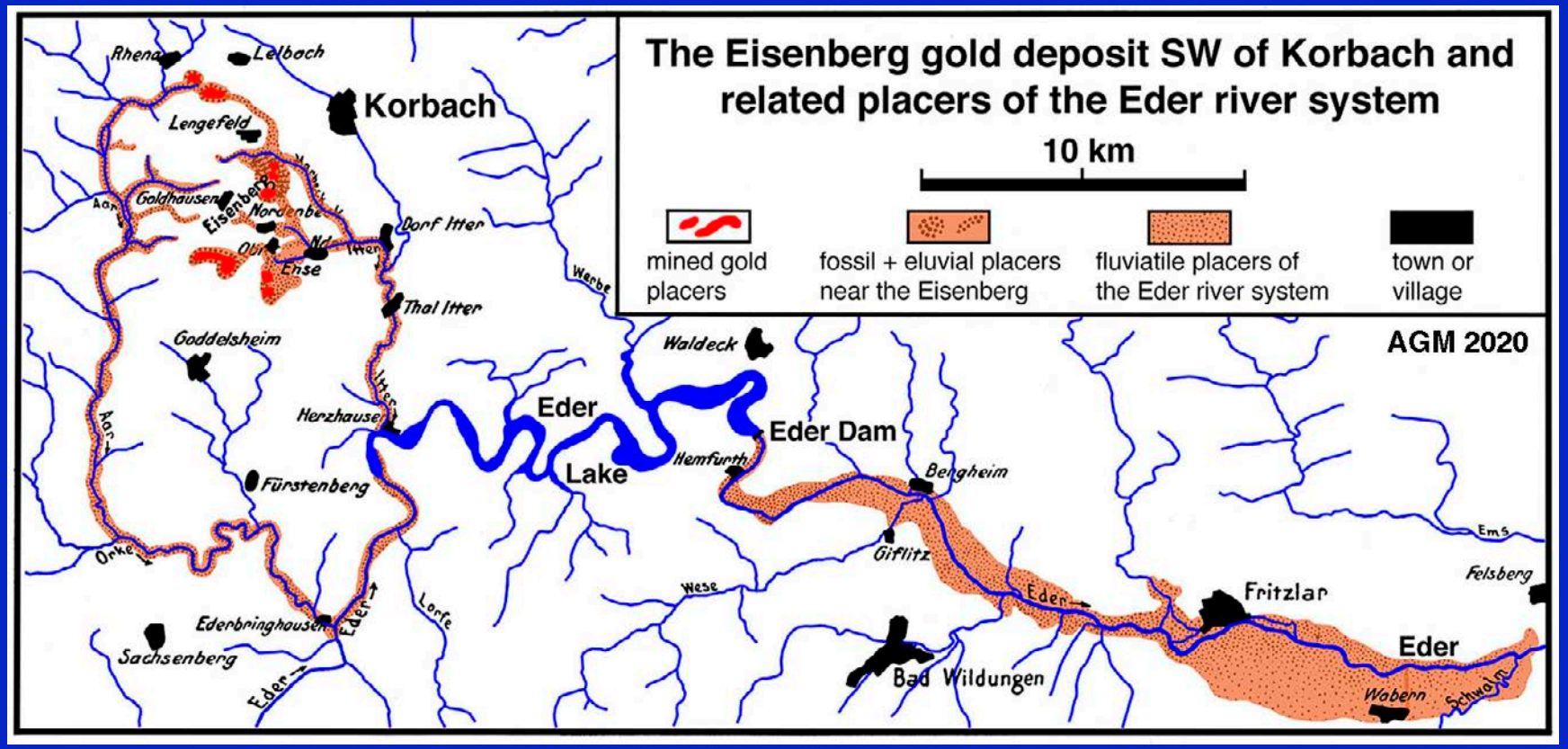
Modified from Walther and Zitzmann 1973; Drozdzewski 2011



Ruhr coal district: Production 9 billion metric tons. Open cut mining in the 14th century, underground mining since the 17th century AD, final closure in 2018.

The Eisenberg vein & Eder placer gold deposits

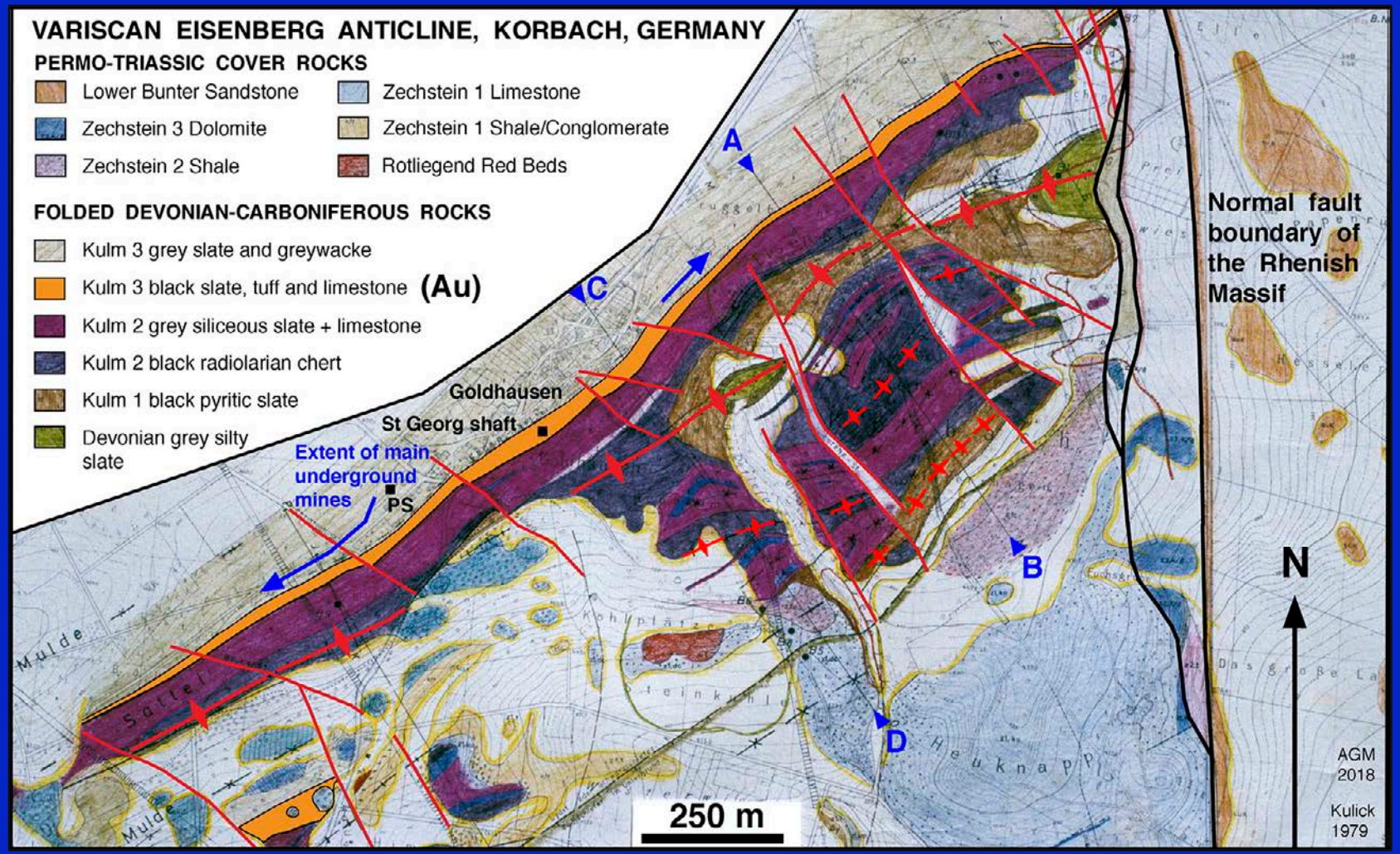
Modified from Beyschlag & Schriel 1923



1250 first written record in the Meissen chronicle
1480-1585 main period of underground mining, final closure in 1620 (30 year war). Production: UG 2.5 t Au, placers >1 t Au

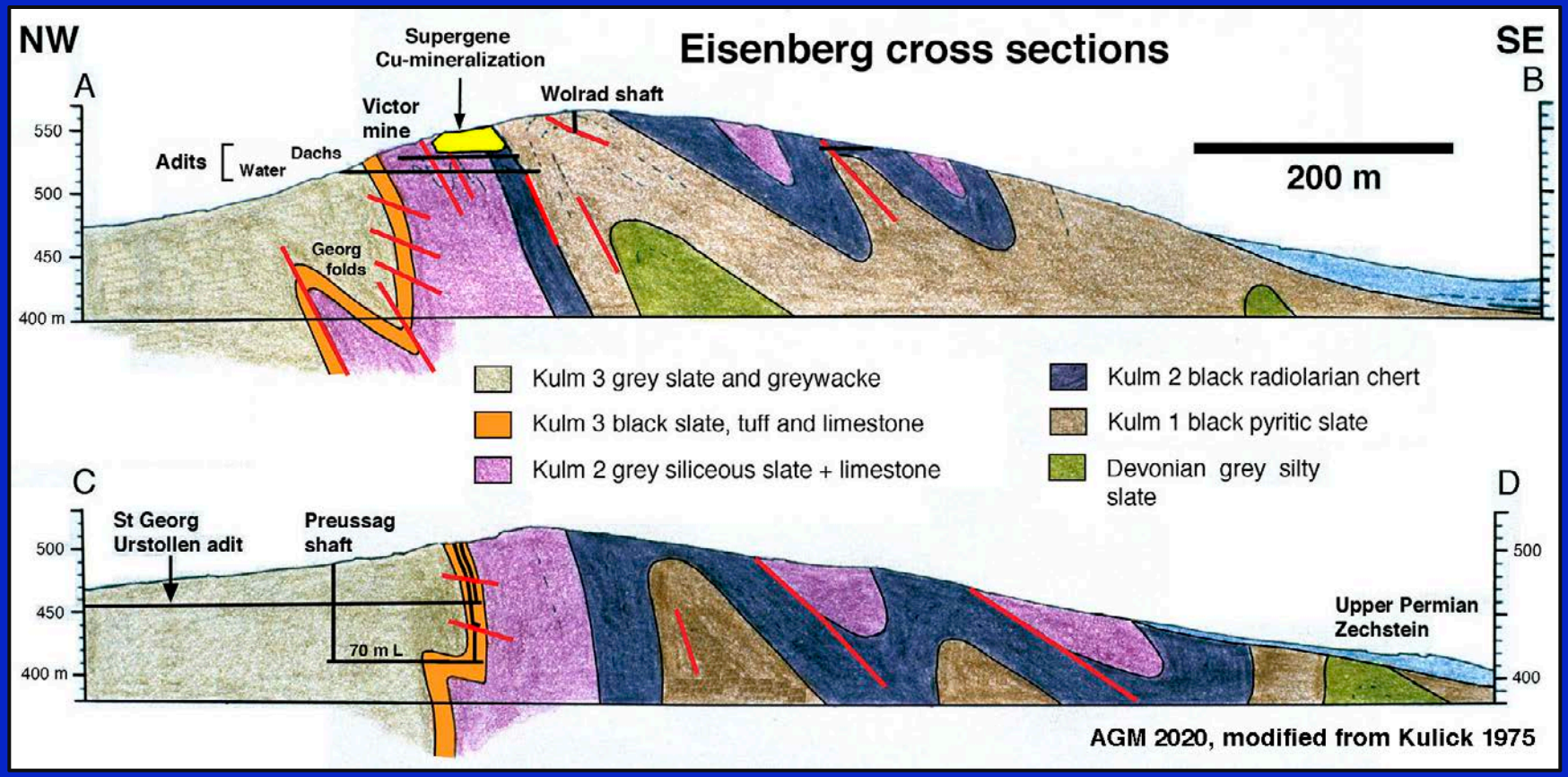
Stratabound gold veins in the Eisenberg anticline

Outcrop map modified from Kulick et al. 1997



Eisenberg anticline: Mine workings in cross section

Sections modified from Kulick and Theuerjahr 1983

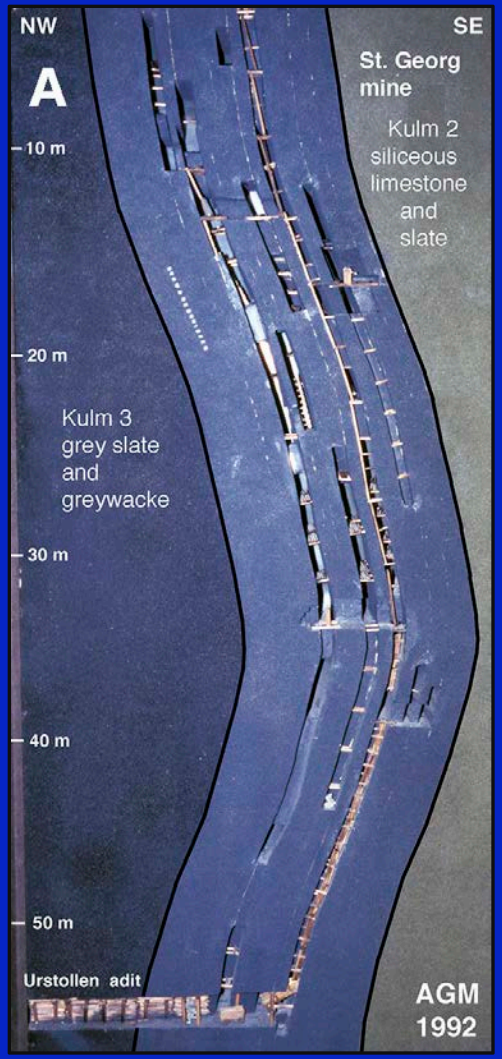


Section A-B: Gold in strike-parallel reverse faults

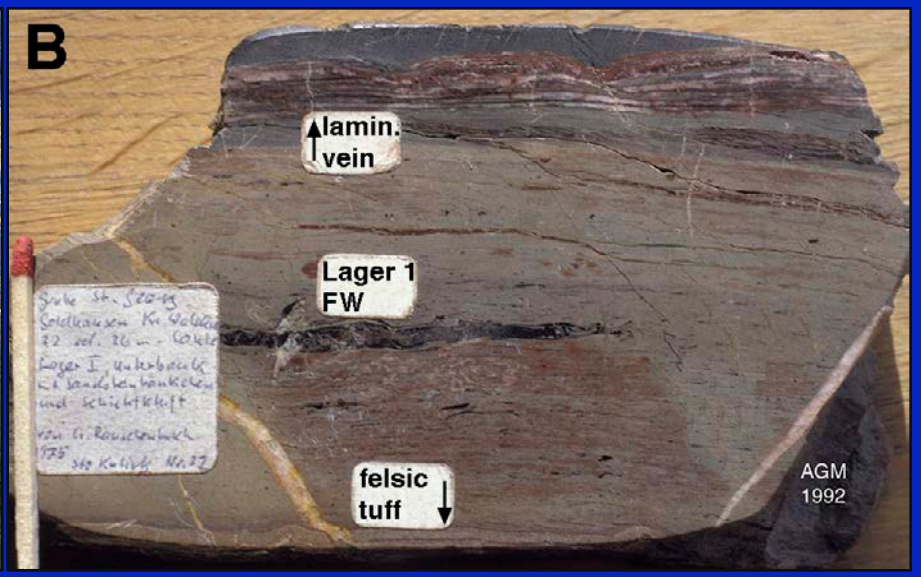
Section C-D: Gold in bedding-parallel veins

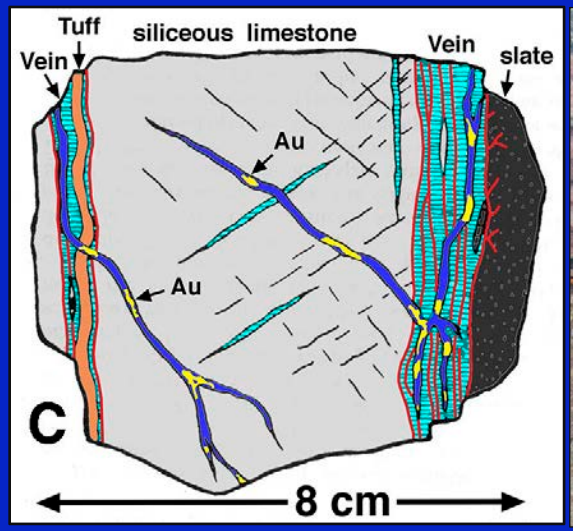
Eisenberg anticline: Bedding-parallel veins

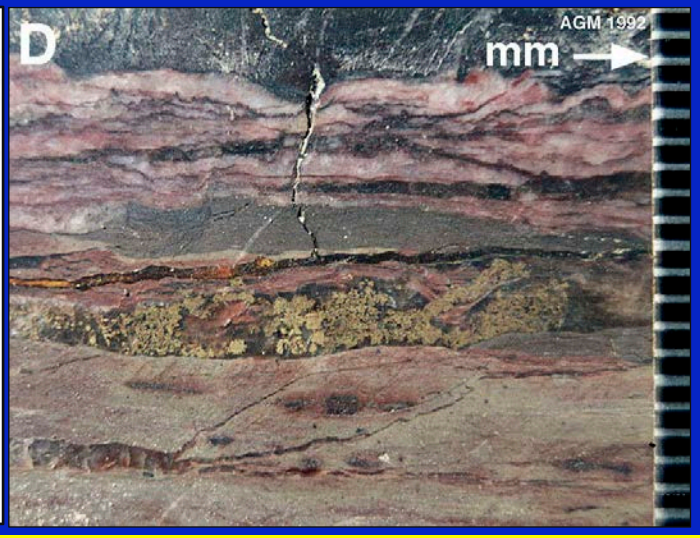
St Georg and St Sebastian mines

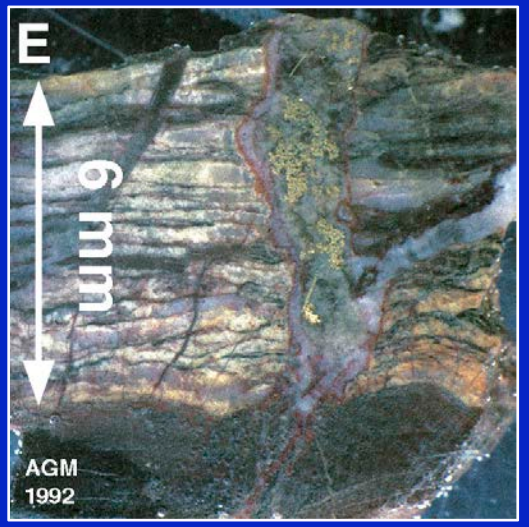


Eisenberg St Georg: Bedding-parallel veins



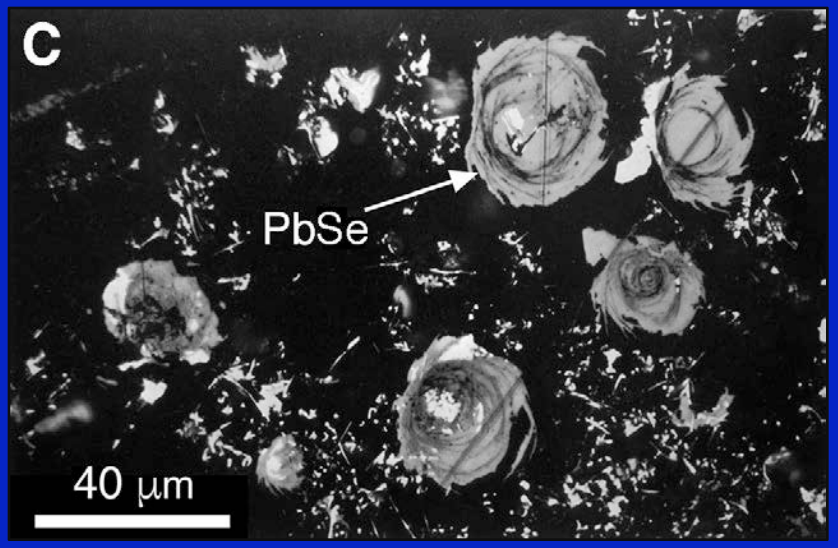






Eisenberg St Georg: Oxidized Au-Cu-Pb-Se ore

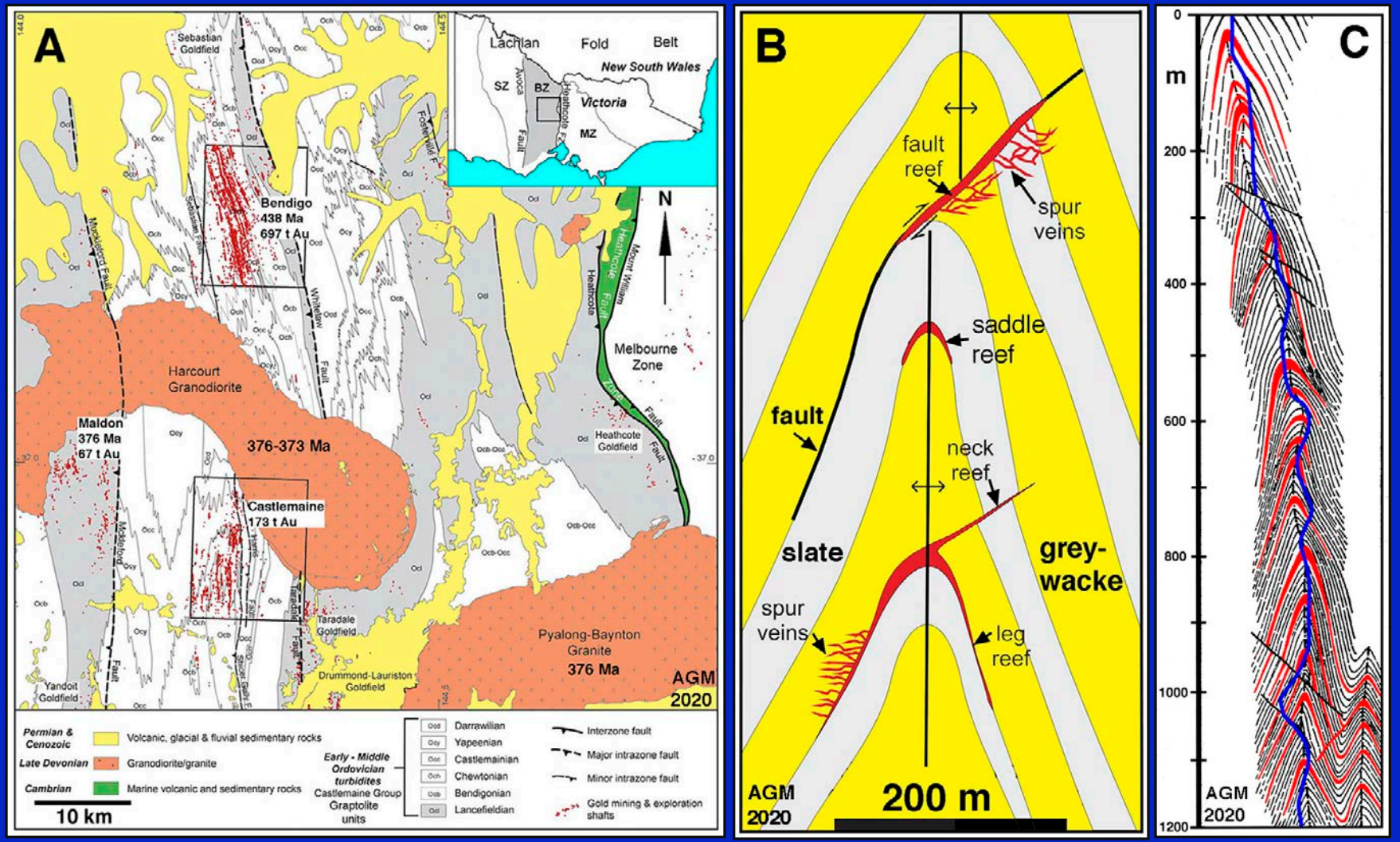
Ore mineralogy: Ramdohr 1932, Maucher and Rehwald 1961



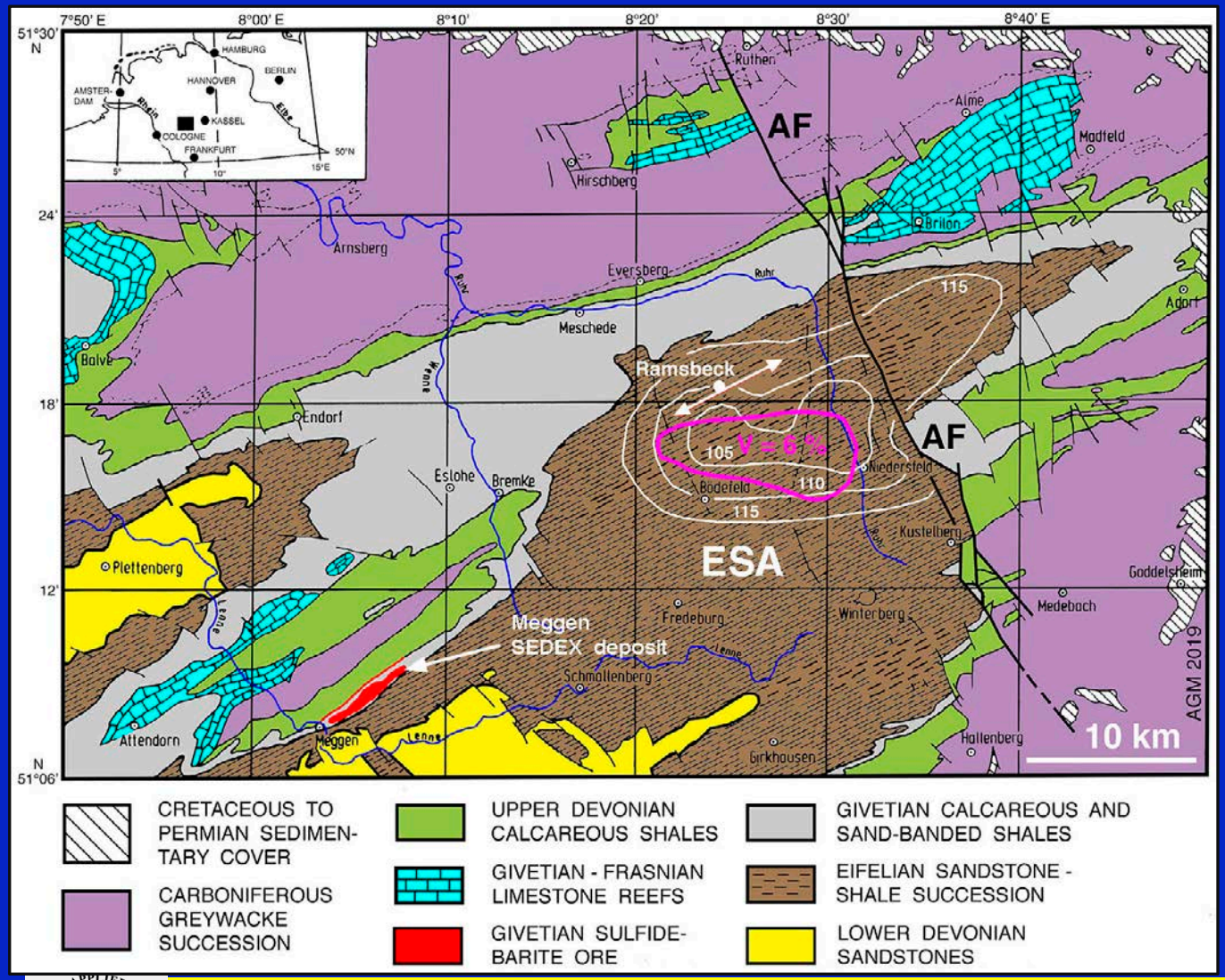
Native gold, clausthalite (PbSe), chalcopyrite, bornite, digenite, pyrite, sphalerite. Goethite, hematite, magnetite.

Saddle Reefs in folds: Type locality Bendigo

Modified from Baragwanath 1930; Willman 2007; Leader et al. 2013



Ramsbeck Zn-Pb-Ag veins: Setting in a regional anticline

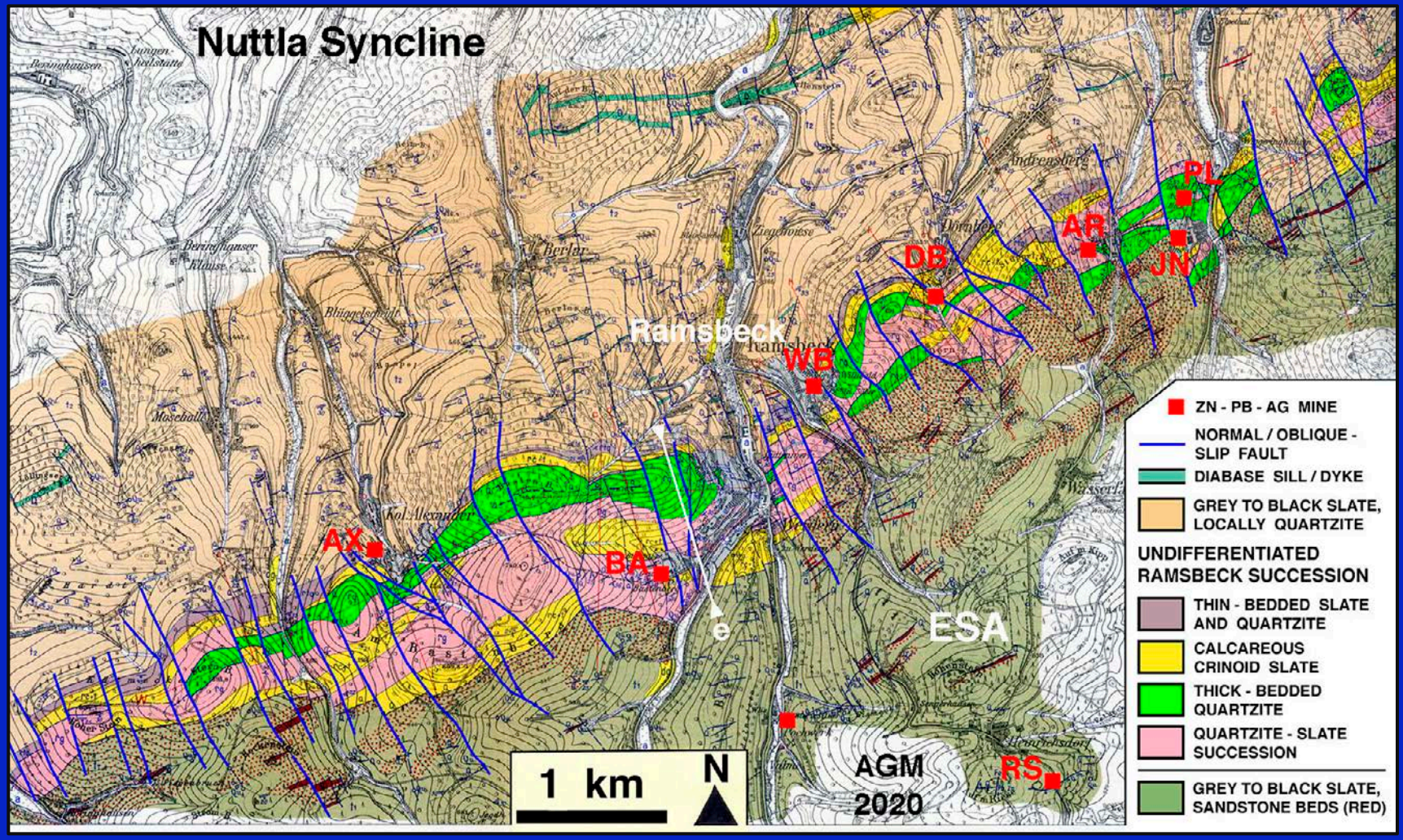


Map modified from: Weber 1977; Werner 1988

Production 1840-1974: 16.7 Mt at 4.4 % Zn + 2.1 % Pb (= 0.752 Mt base metals) Galena concentrate 900 g/t Ag (Bauer et al. 1979)

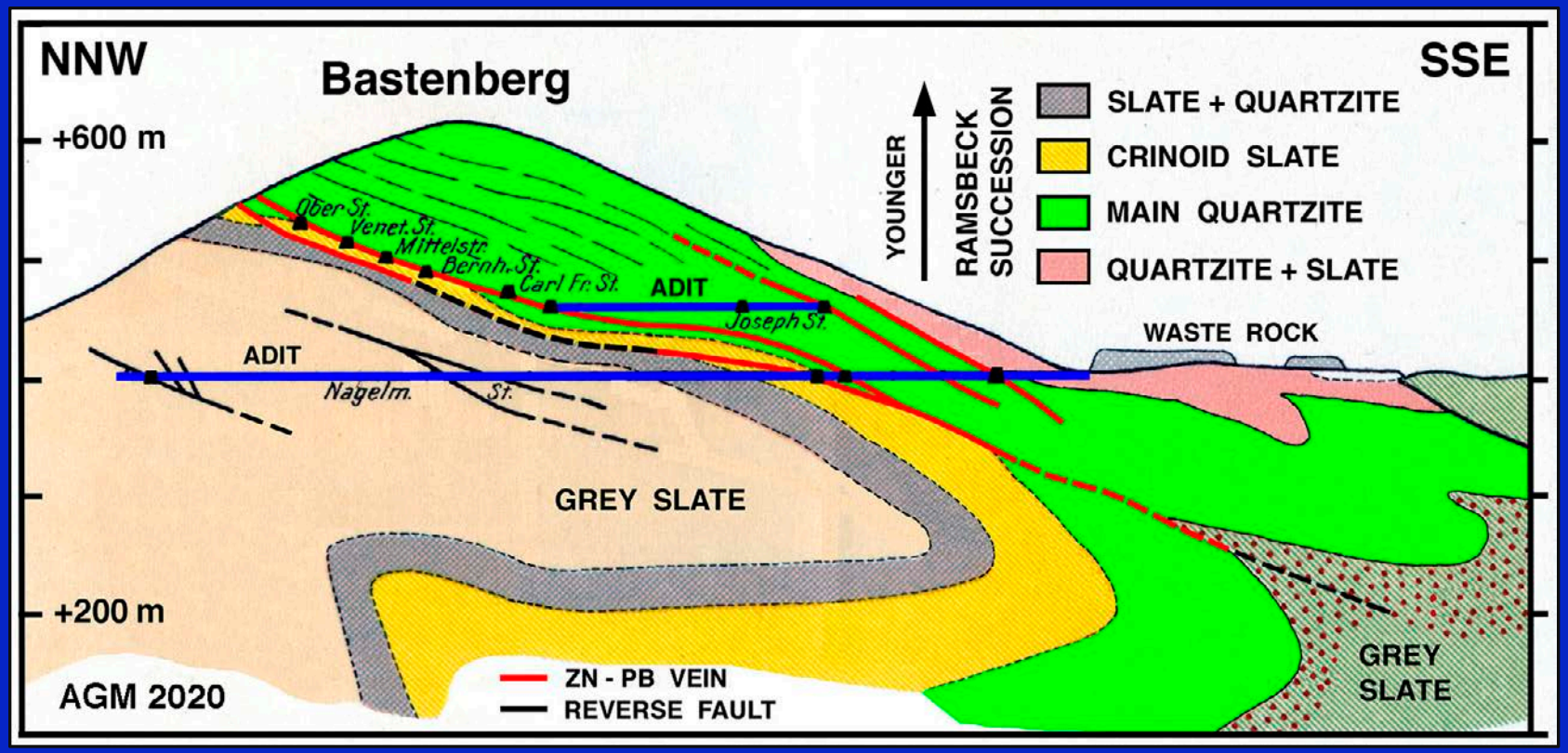
Ramsbeck Zn-Pb-Ag veins in foliated quartzite + slate

Surface map modified from Behrend & Paeckelmann 1937



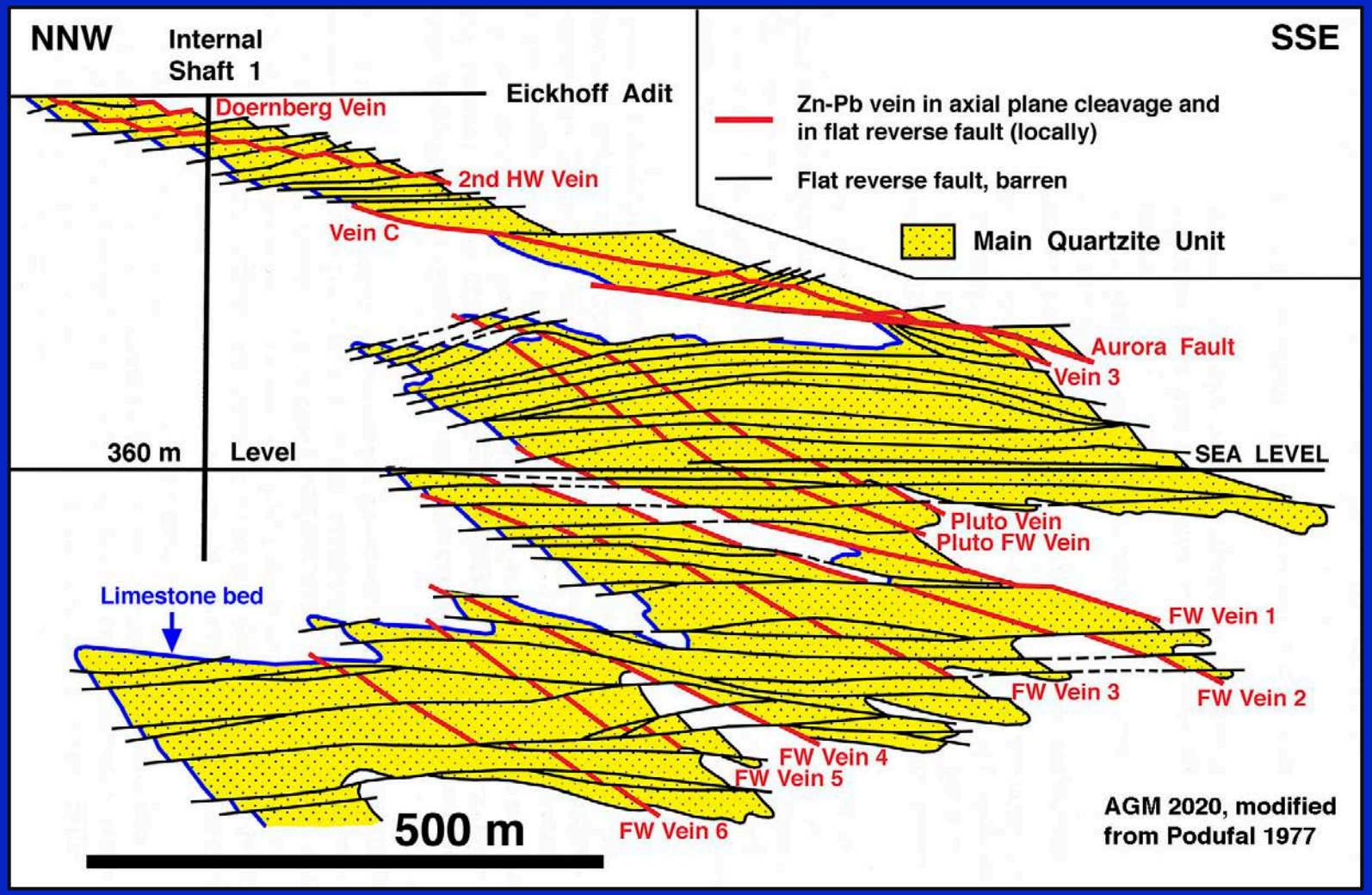
Ramsbeck Zn-Pb-Ag veins in slaty cleavage and faults

Modified from Behrend and Paeckelmann 1937



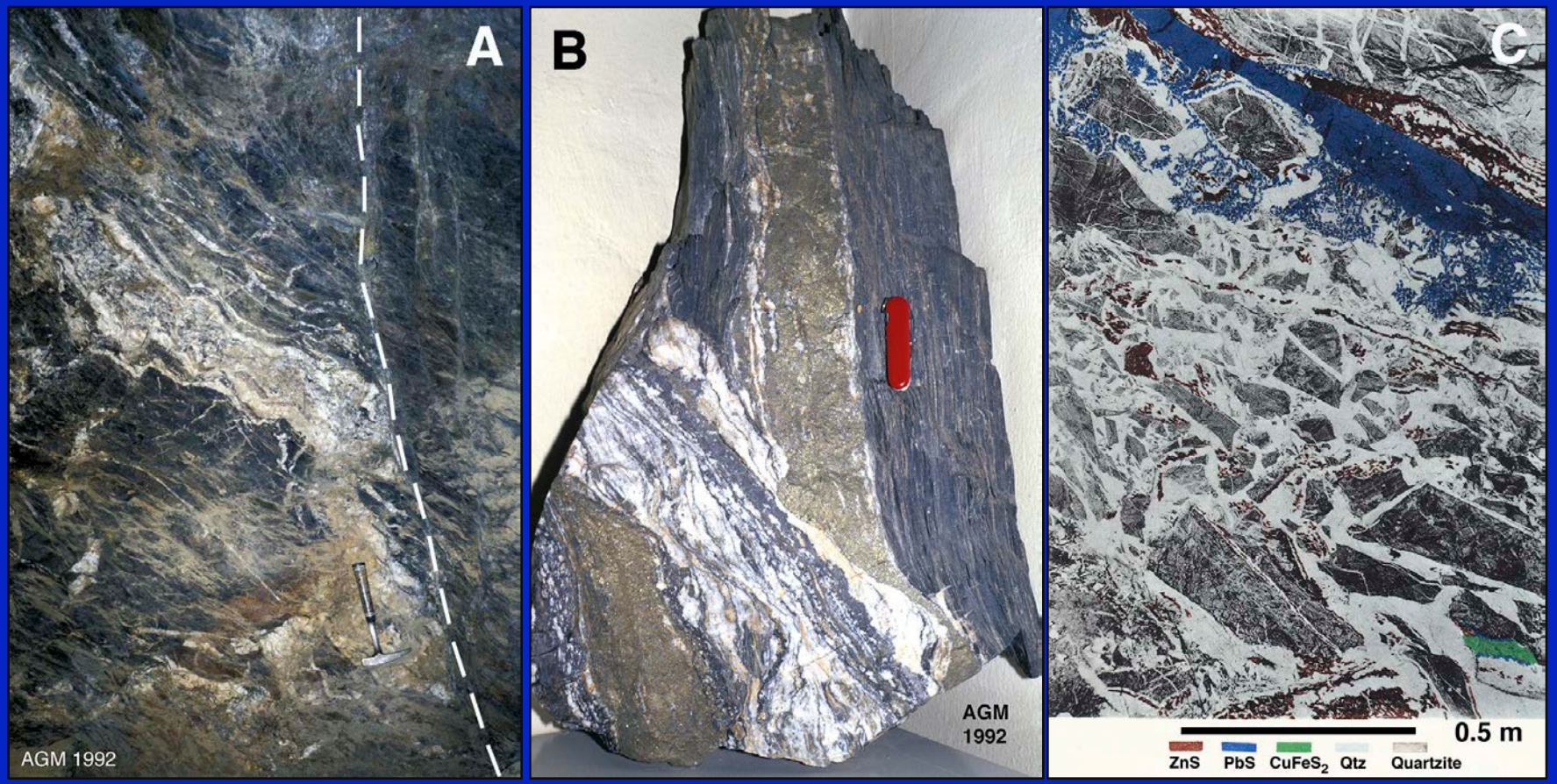
Venitian adit: Bronze Age ca. 1800 B.C., mining for silver?
1518: first written record, mining for silver + lead ± copper
1850: first zinc production, 1927: sulfide flotation plant

Ramsbeck Zn-Pb-Ag veins: Dörnberg section



Veins controlled by axial plane cleavage and flat reverse faults

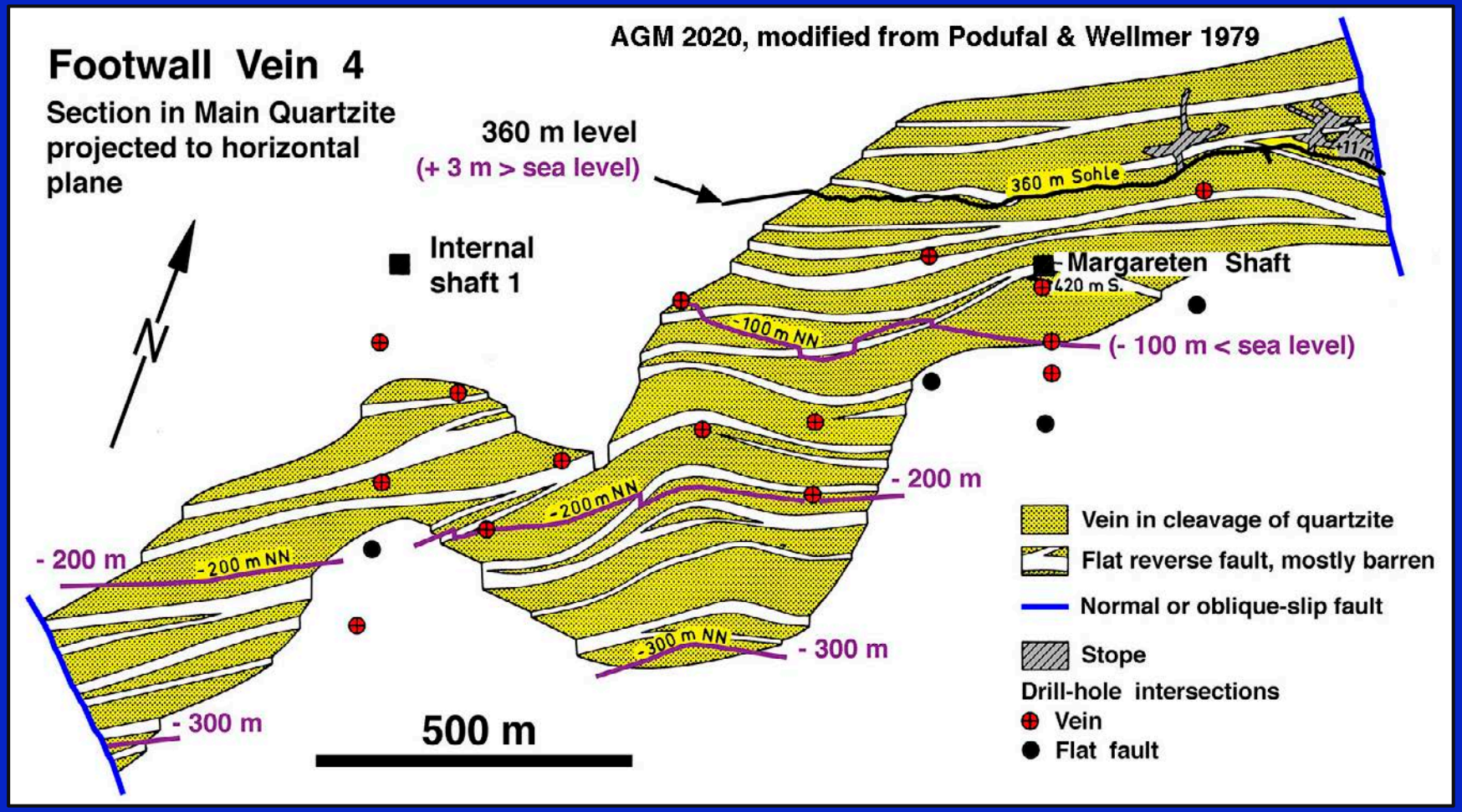
Ramsbeck: Veins in the axial plane cleavage and in flat reverse faults



Doernberg mine: (A) Doernberg Vein, (B) Footwall Vein 1, (C) Aurora Vein

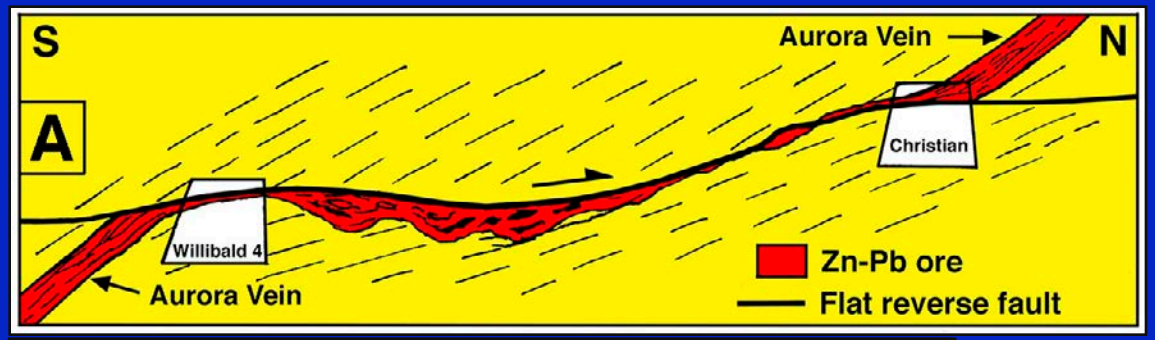
Ramsbeck: Vein-fault system in plan section

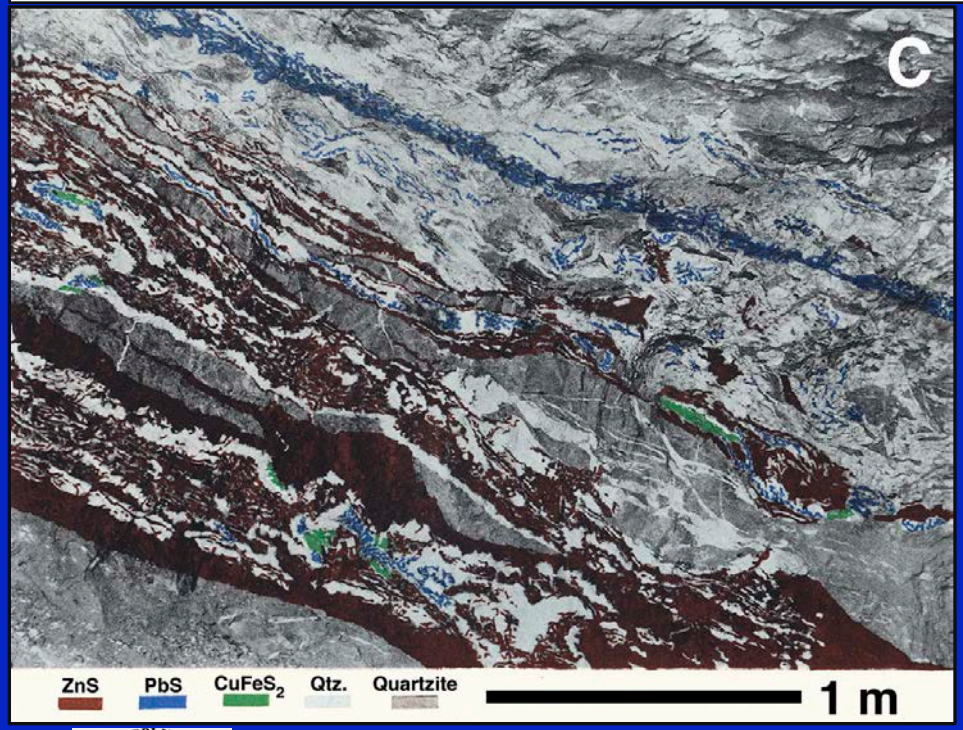
Modified from Podufal and Wellmer 1979



Ramsbeck: Vein-fault system in cross section

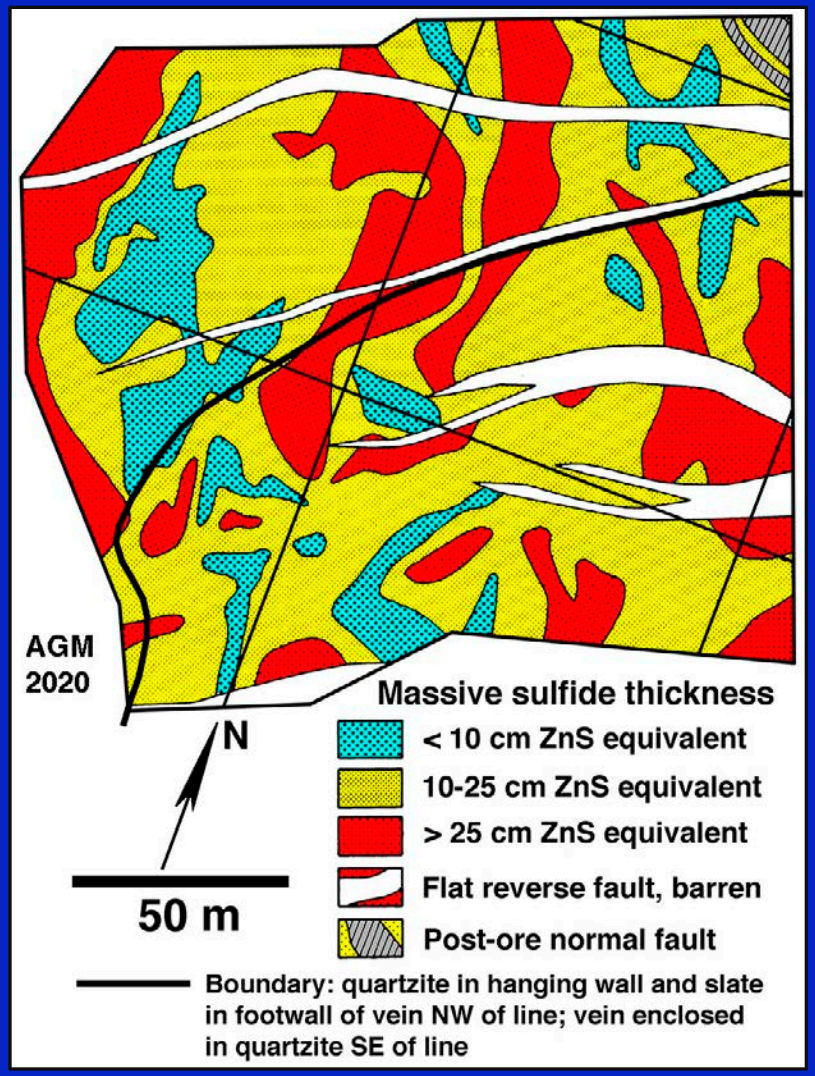
Modified from Bornhardt 1912; Behrend & Paeckelmann 1937

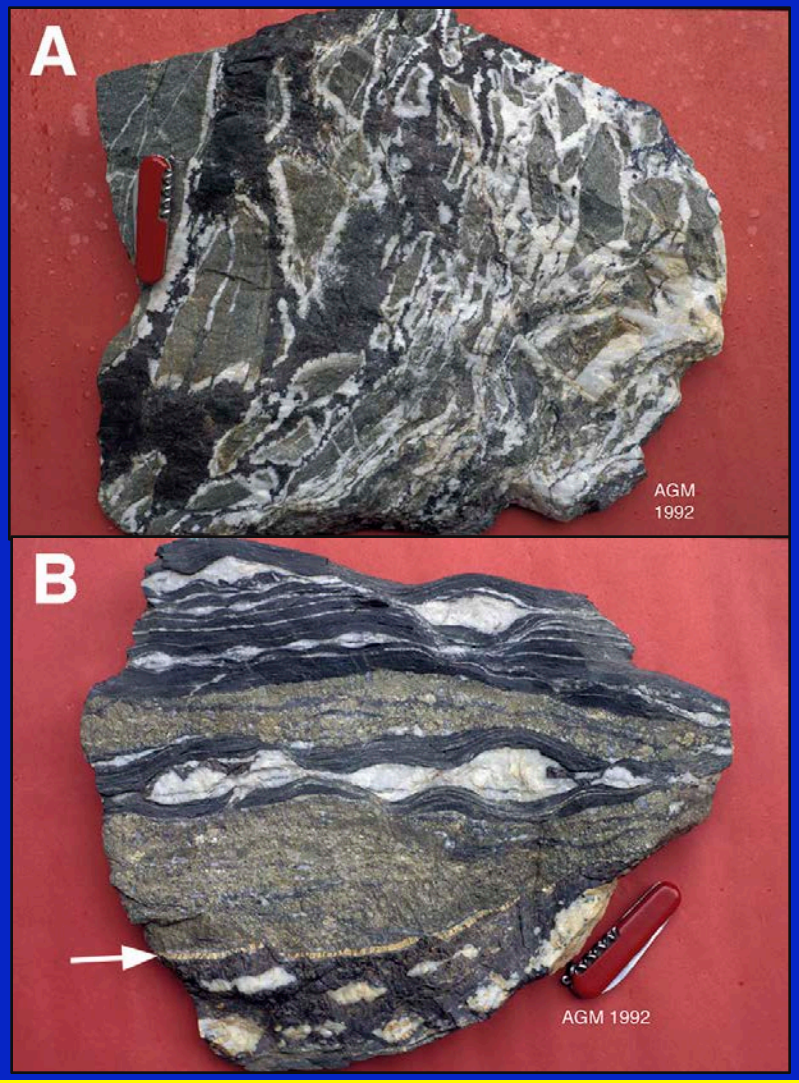




Ramsbeck: Zn-Pb grade, vein textures, alteration

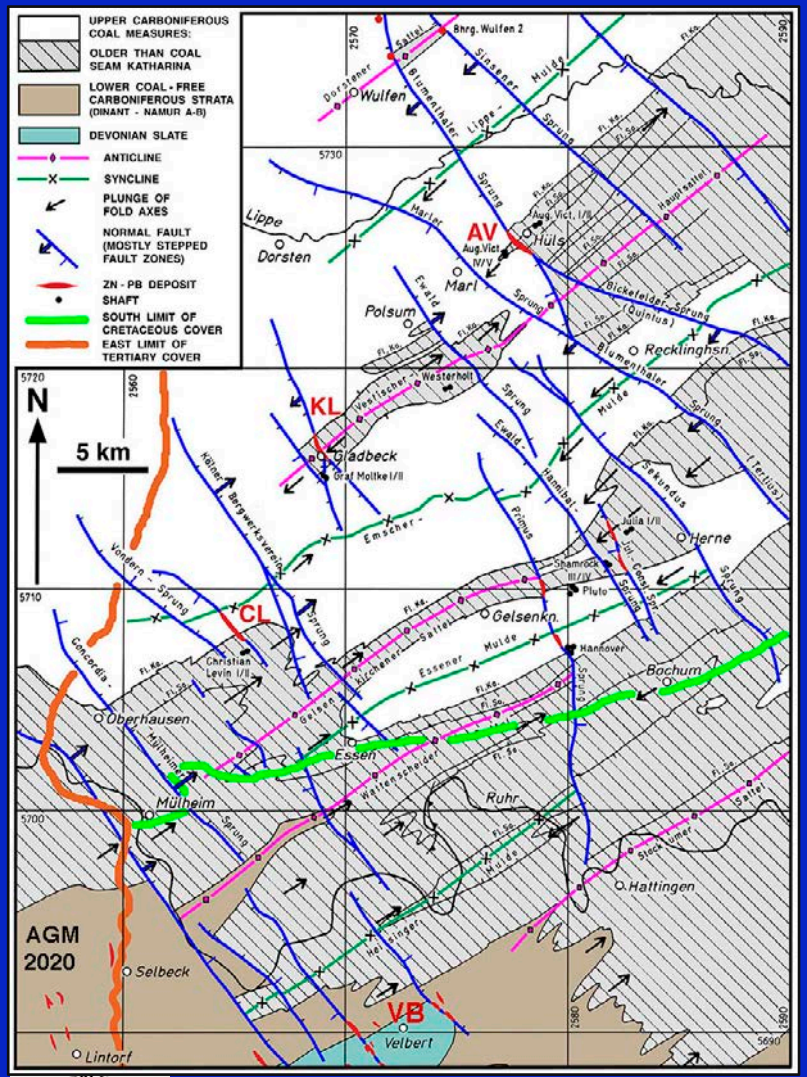
Map modified from Podufal and Wellmer 1979

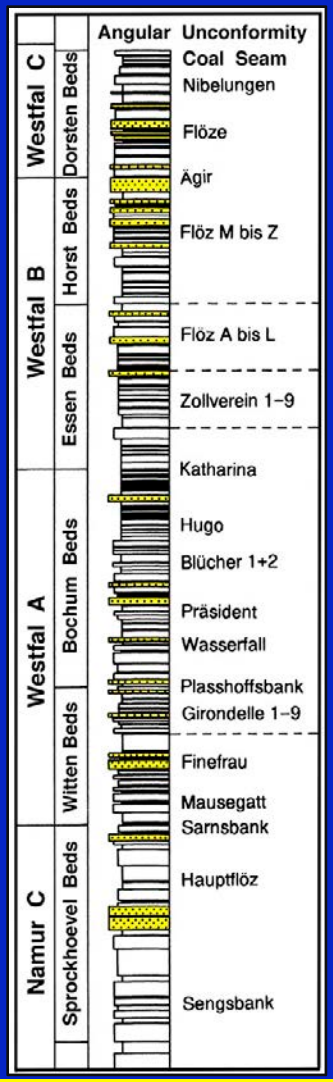




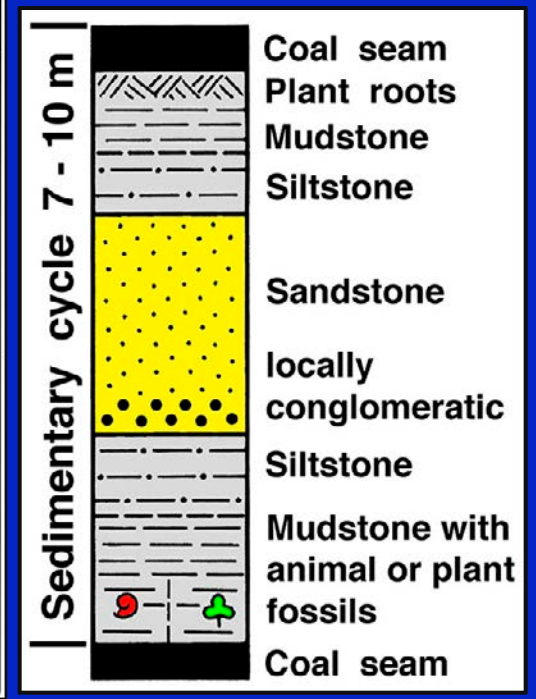
Ruhr coal district: Zn-Pb-Ag ore in normal faults

Modified from Pilger et al. 1961; Henningsen & Katzung 2002; Drozdzewski 2011



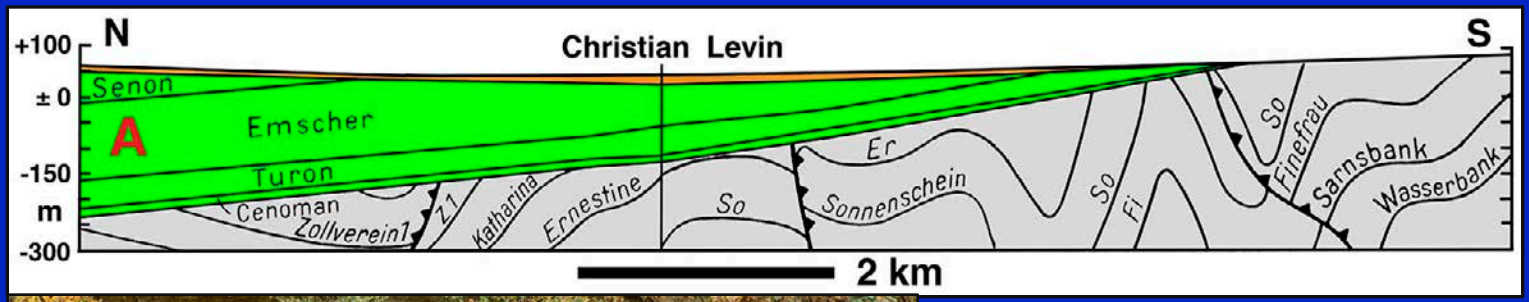


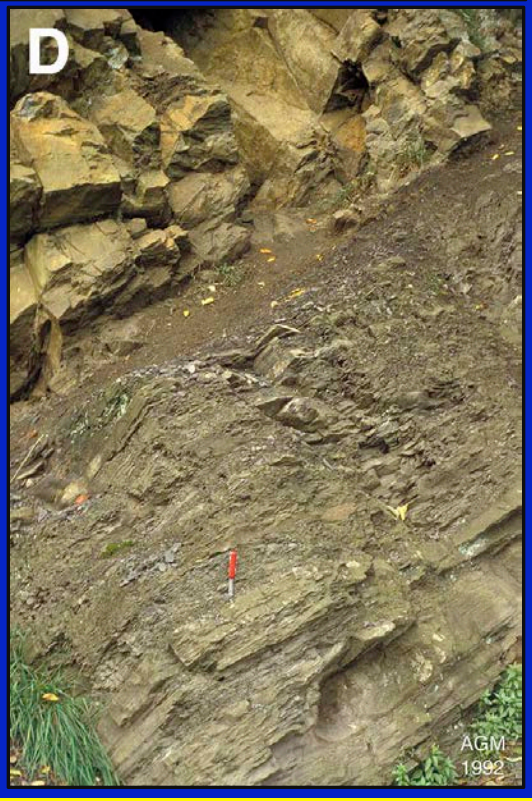
Auguste Victoria 1938-1962: 5.2 million tons at 7% Zn + 4% Pb + 65 g/t Ag. Reserves 1962: 3.5 Mt at 8% Zn, 2% Pb (Krassmann 2019)



Ruhr district: Folded coal measures

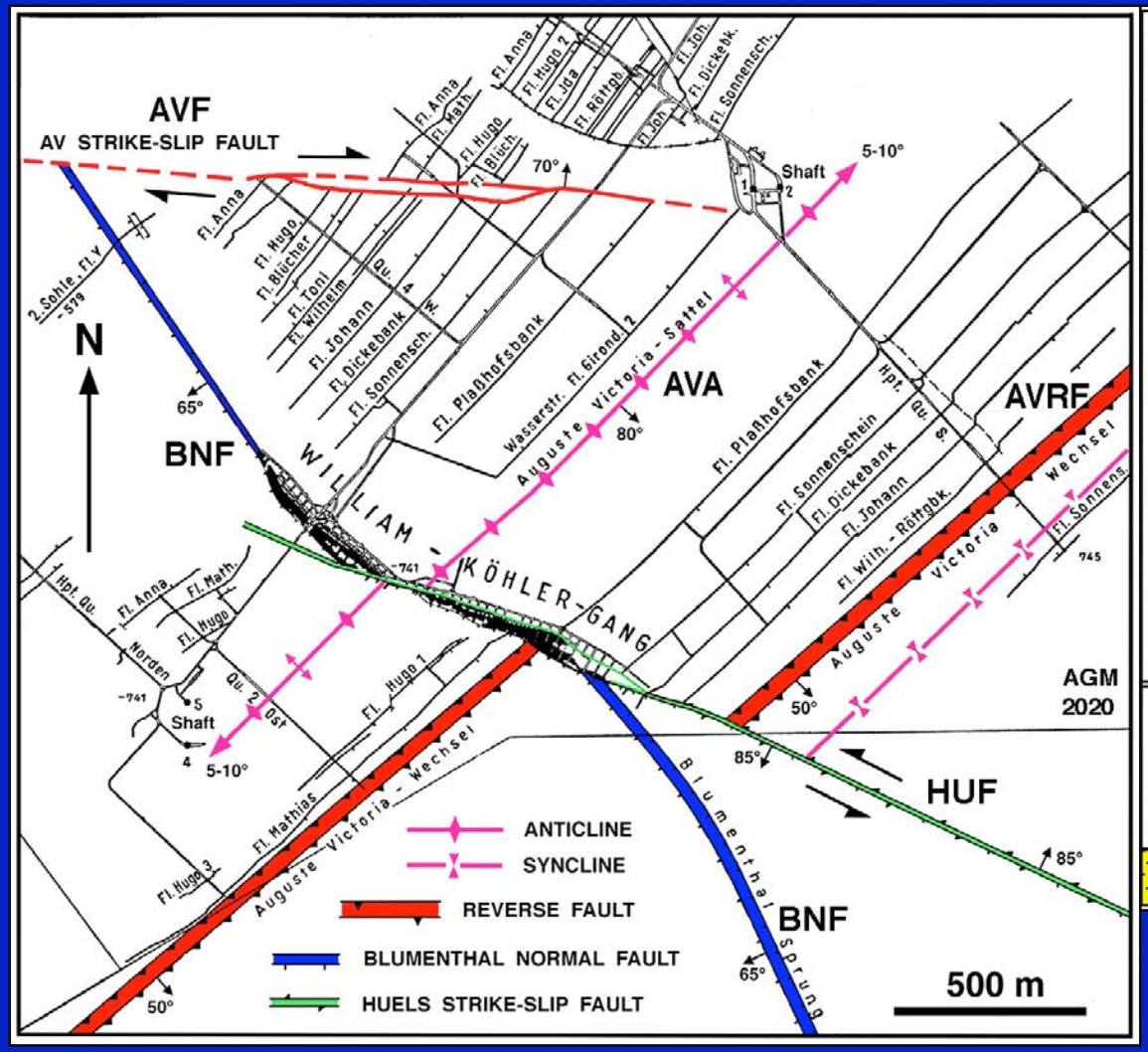
Section modified from Buschendorf et al. 1957

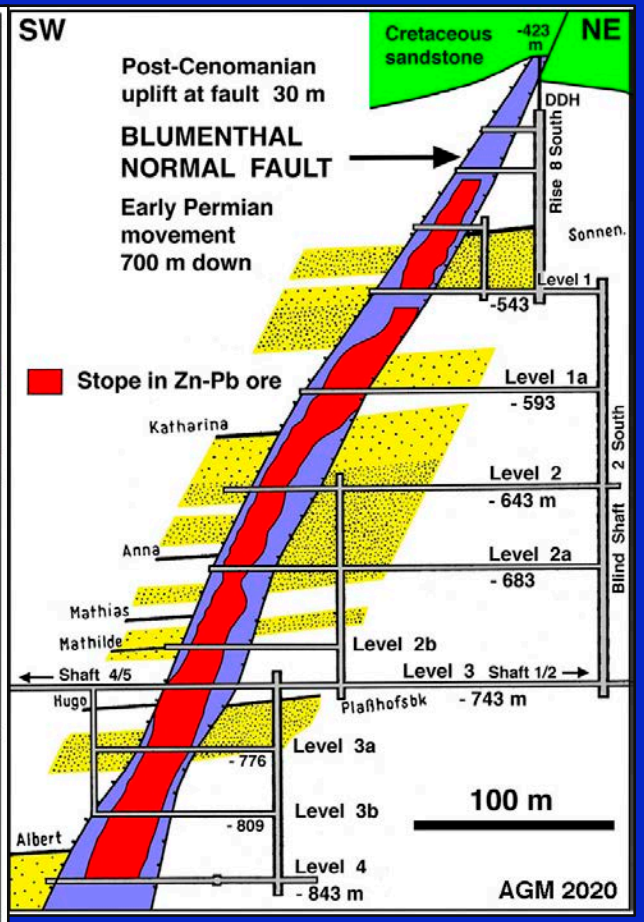




Auguste Victoria: Faults in plan and section

Modified from Hesemann & Pilger 1951

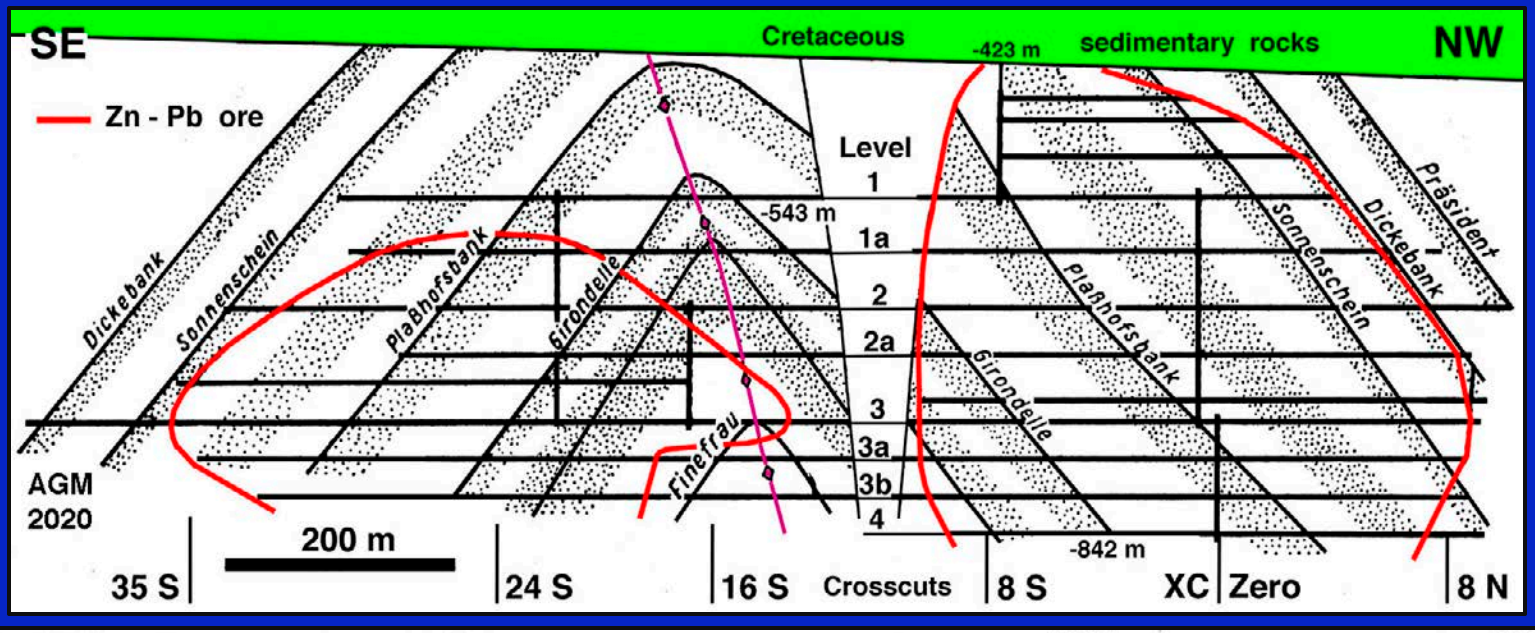


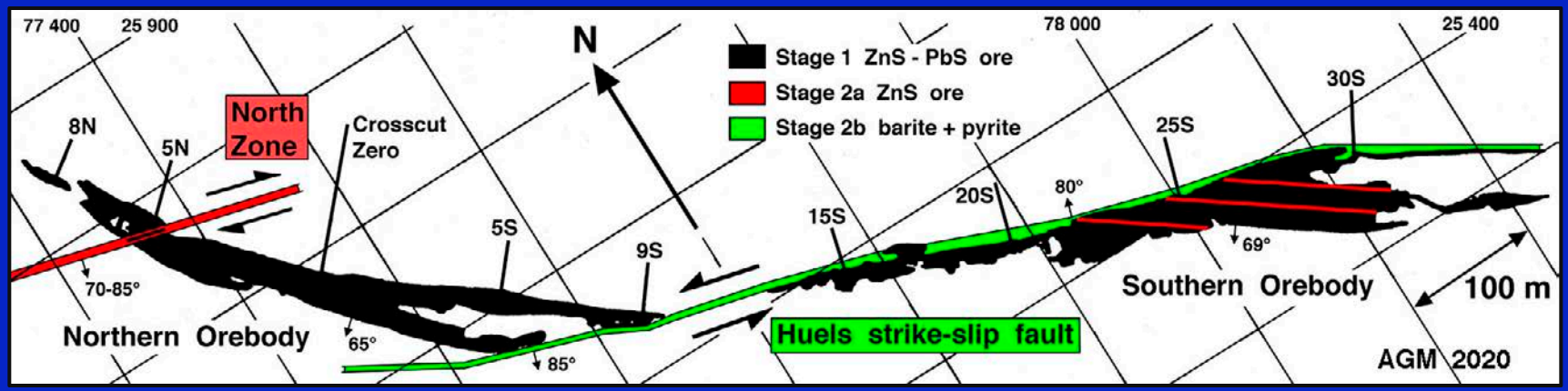


Syn-tectonic breccia ore in the Blumenthal Fault

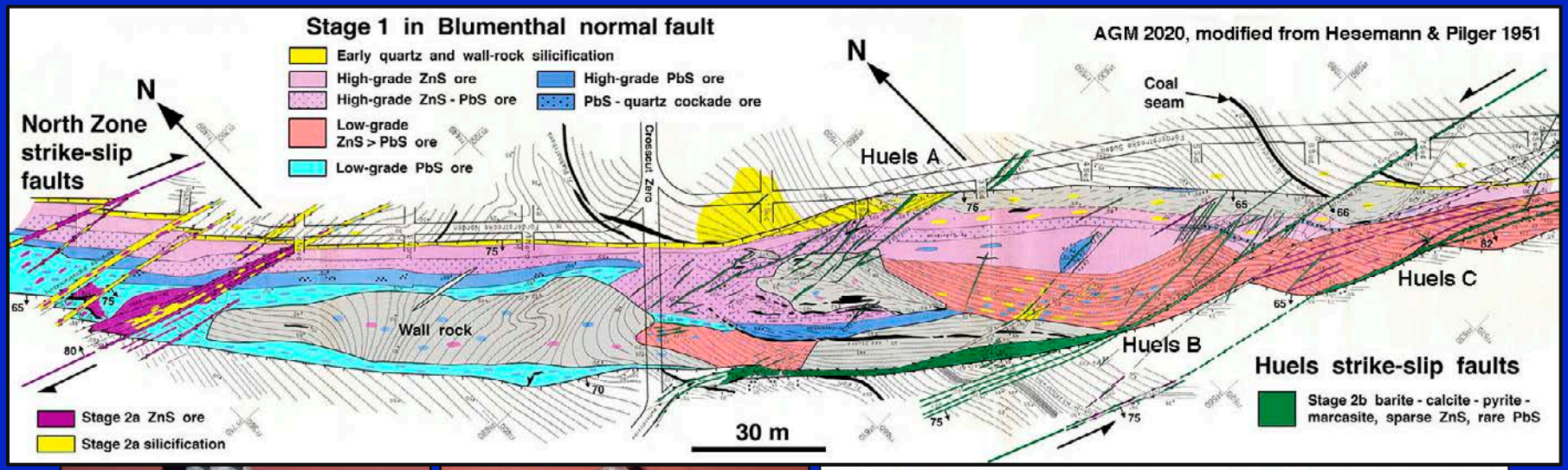
Auguste Victoria Zn-Pb ore: Structural controls

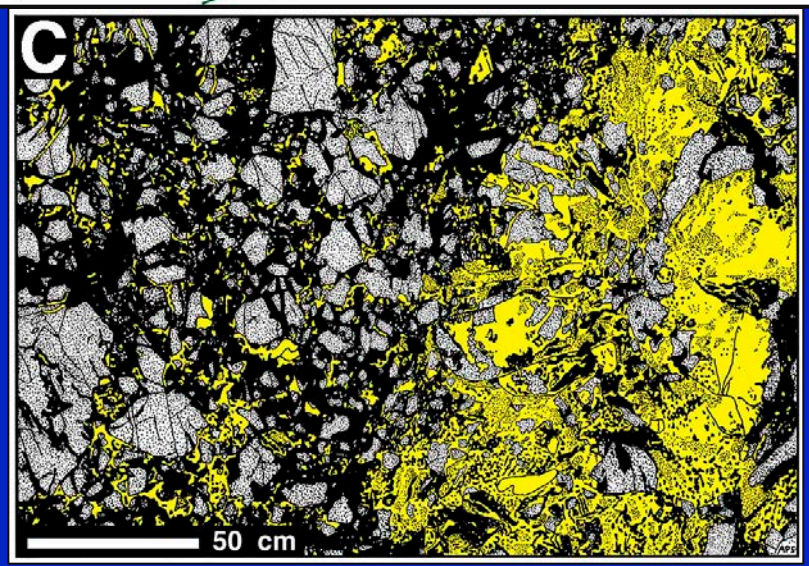
Modified from Hesemann & Pilger 1951; Pilger et al. 1961





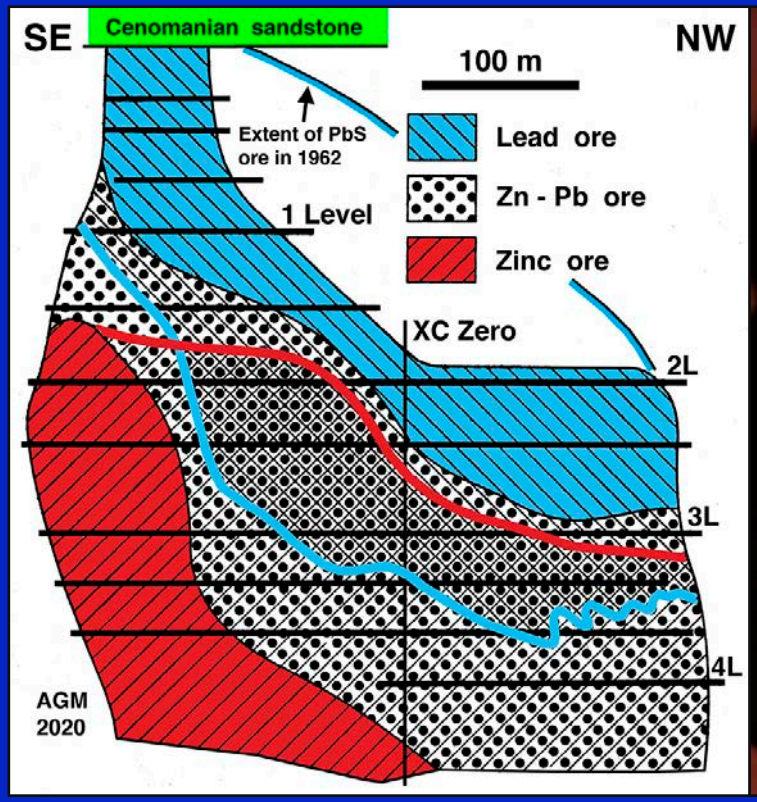
Auguste Victoria: Ore formation during faulting

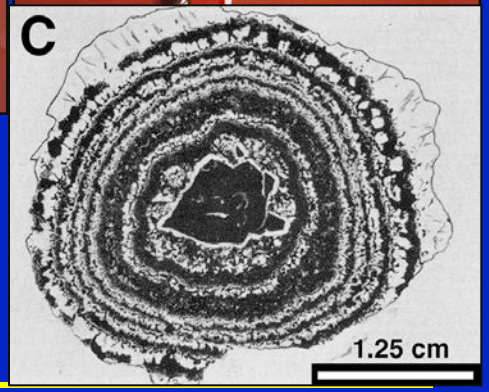




Auguste Victoria: Stage 1 ore in normal fault

Section modified from Hesemann and Pilger 1951

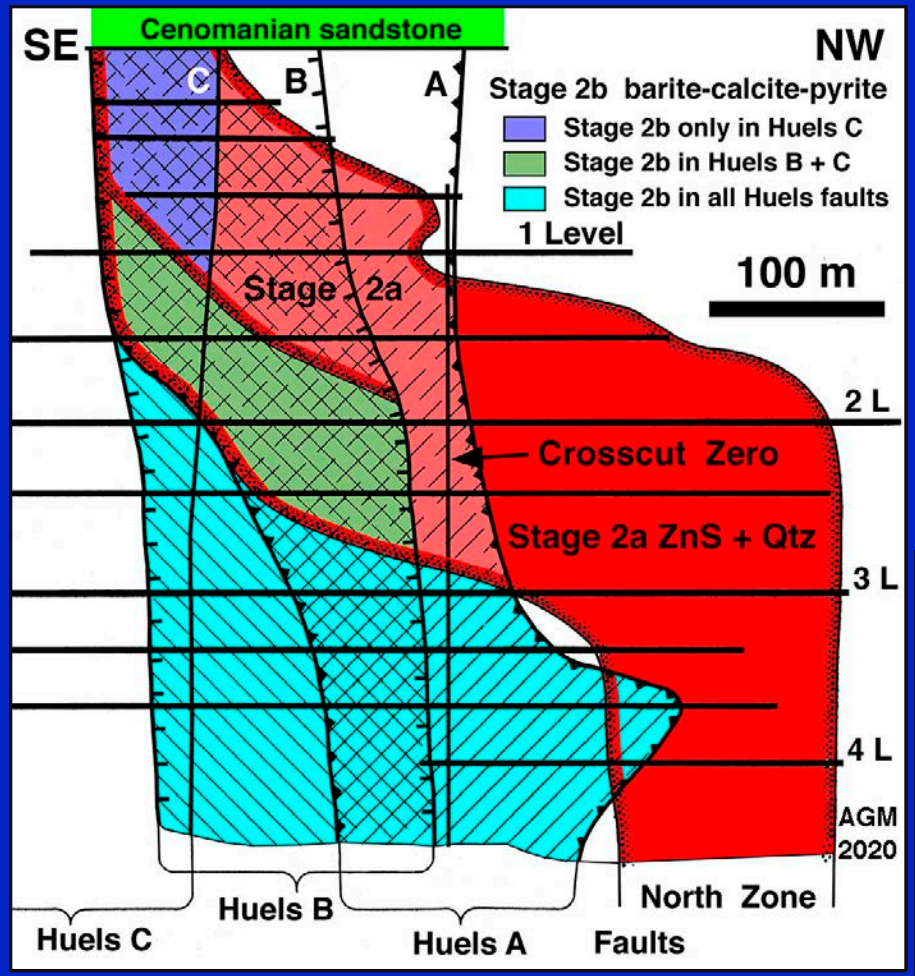




ZnS concentrate: 57-60% Zn, 0.15% Sb, 95-135 g/t Ag PbS concentrate: 73-78% Pb, 0.25% Sb, 1000-1200 g/t Ag. Gel structures in Stage 1b cockade ore.

Auguste Victoria: Stage 2 ore in strike-slip faults

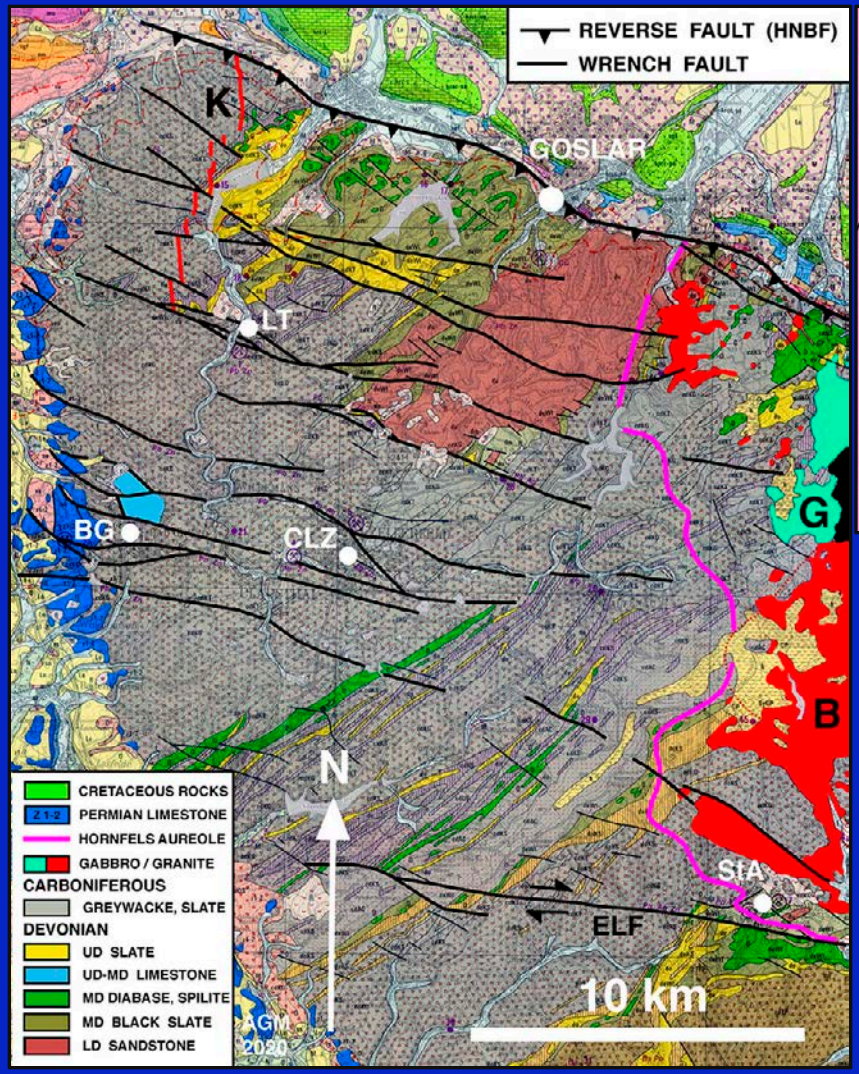
Section modified from Hesemann and Pilger 1951

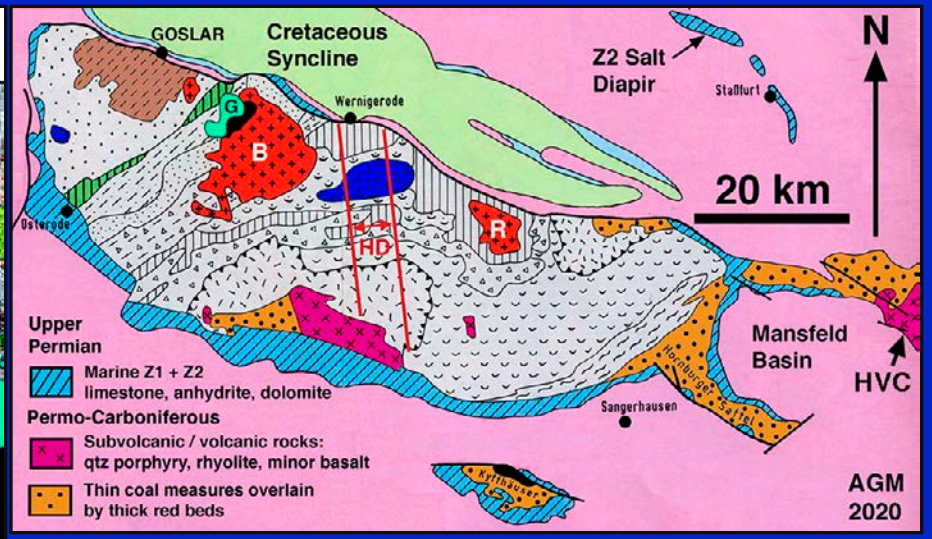


Age: North Zone > Huels A > B > C

Harz Block: Zn-Pb-Ag ore in wrench faults

Maps modified from Hinze et al. 1998

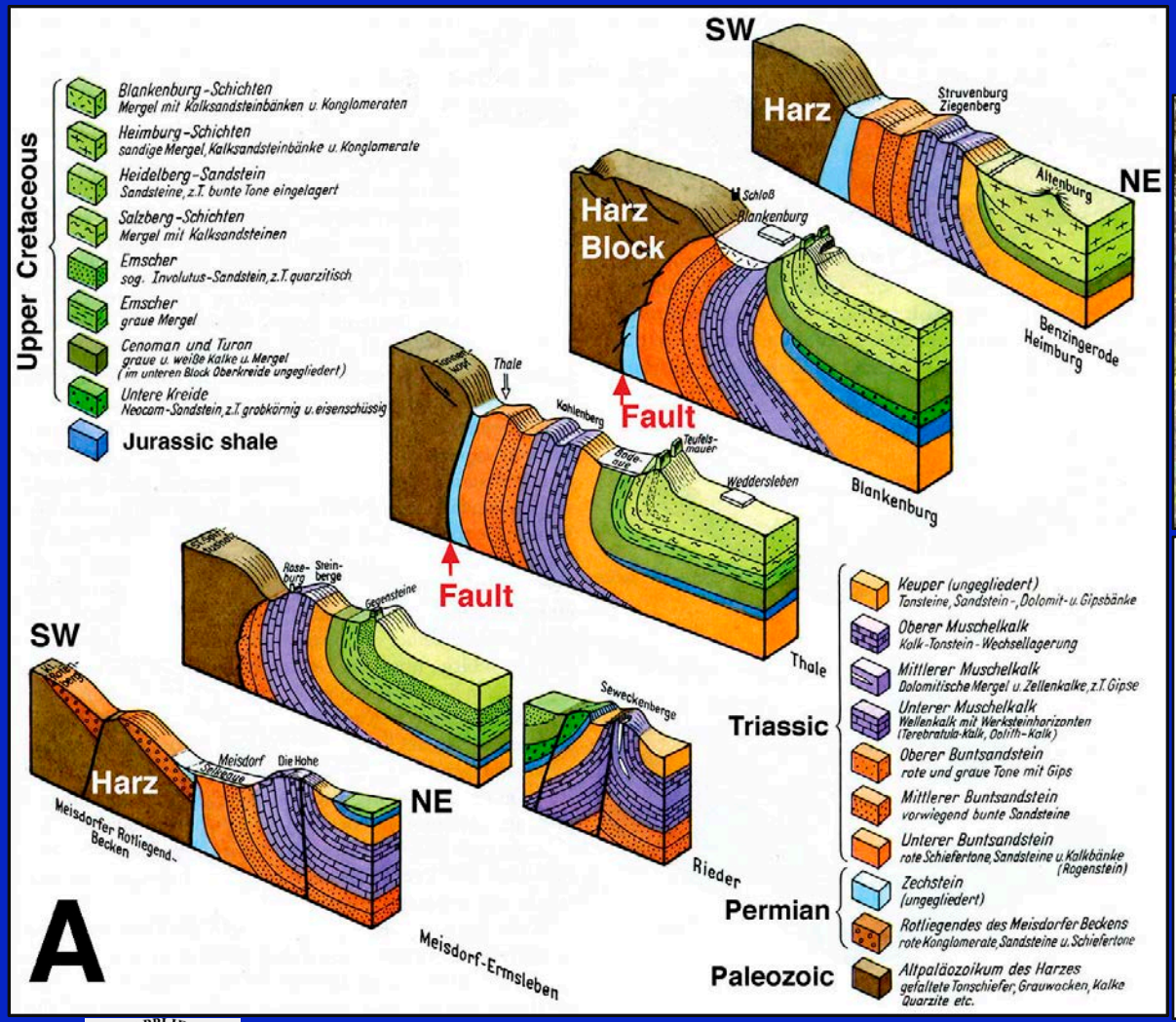




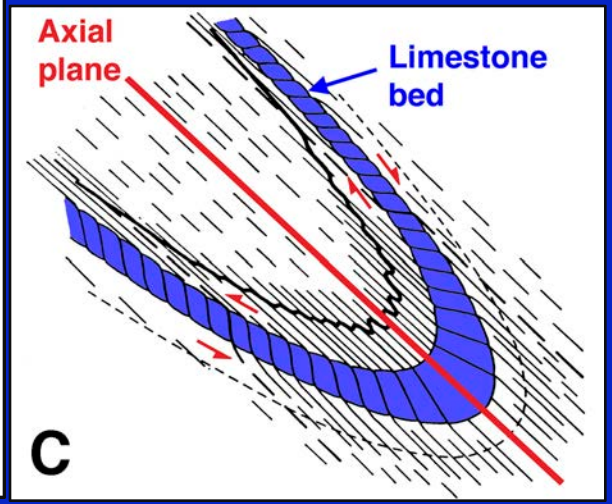
Upper Harz district:
Ore production 1524-1992
37.8 million metric tons
at 5.1% Pb + 3.9% Zn +
135 g/t Ag (Stedingk 2012)

Elbe Zone: Harz North Boundary Fault

Modified from Wagenbreth & Steiner 1990

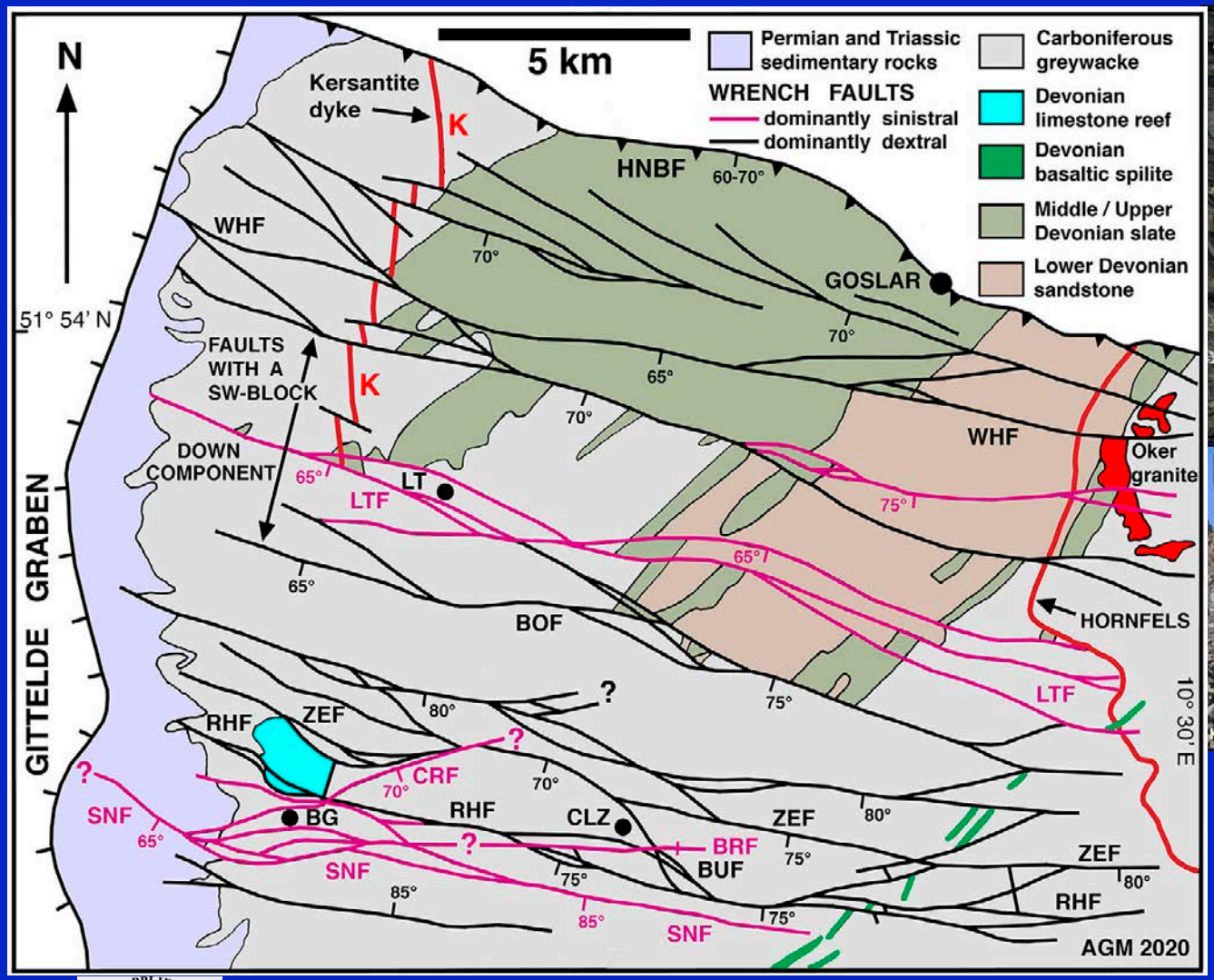


Harz Slate Belt



Harz Block: Post-orogenic wrench faults

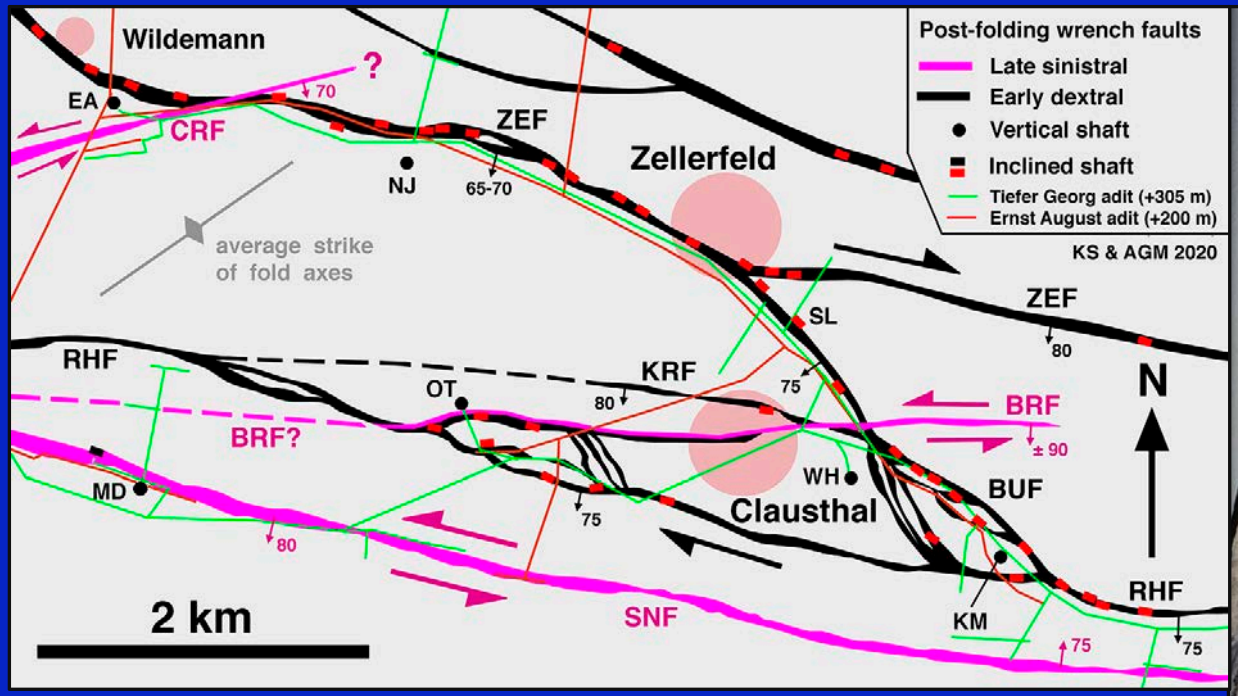
Modified from Jacobsen and Schneider 1950; Sperling and Stoppel 1981



500 - 800 m fault slip at 300-280 Ma

Clausthal-Zellerfeld: Zn-Pb veins in dextral faults

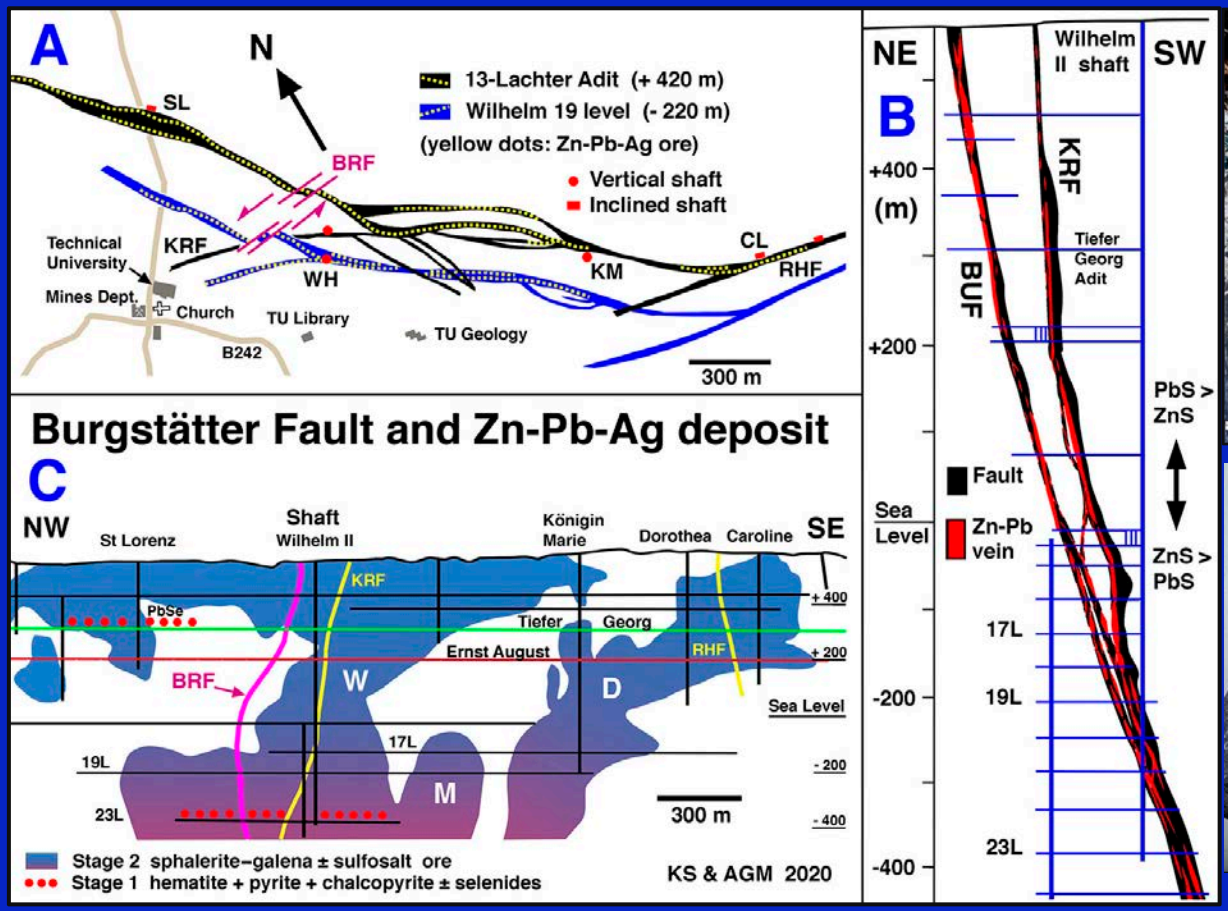
Data from Sperling & Stoppel 1981; map modified from Stedingk 2012



Total 1524-1930: 10.8 million metric tons
Estimated > 1200 t Ag. Recovered grades:
Zellerfeld Fault (ZEF): 1.3 Mt at 8.9% Pb
Rosenhof Fault (RHF): 2.1 Mt at 4.3% Zn, 5.3% Pb
Burgstaetter Fault (BUF): 7.5 Mt at 4.4% Zn, 3.6% Pb

Clausthal-Zellerfeld: Burgstaetter dextral fault

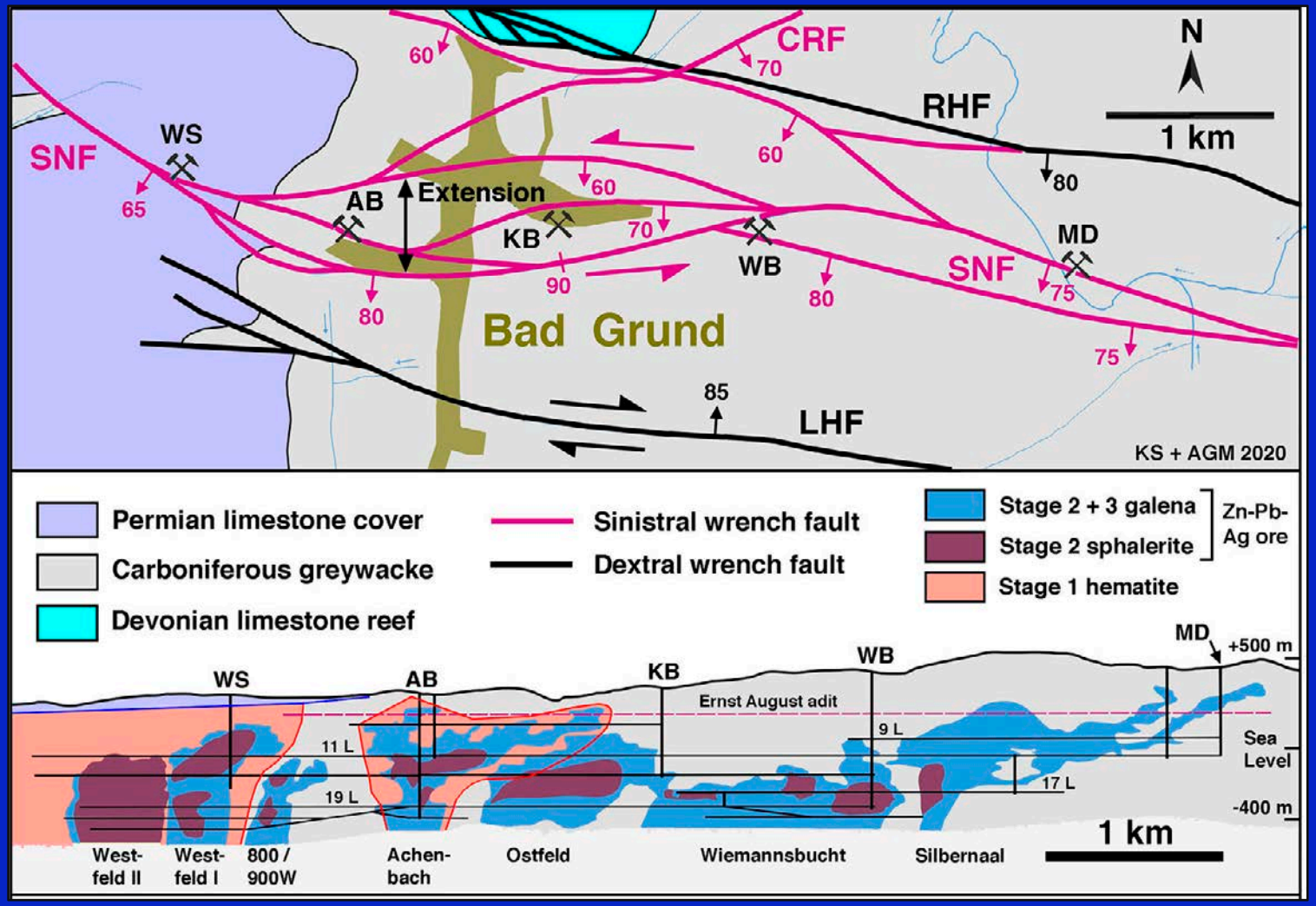
Sections modified from Stedingk 2012



Stage 1: hematite + pyrite + chalcopyrite ± selenides
Stage 2: sphalerite + galena ± chalcopyrite ± Sb-Ag sulfosalts

Bad Grund: Zn-Pb veins in a sinistral extensional duplex

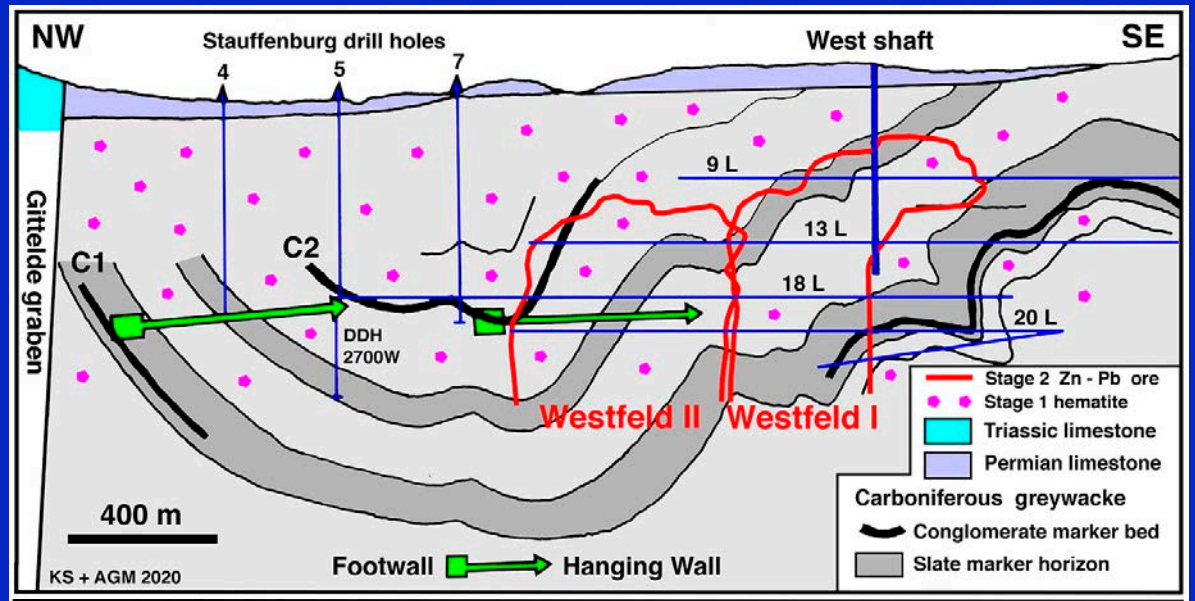
Modified from Sperling 1973, Sperling and Stoppel 1979, and Stedingk 2012

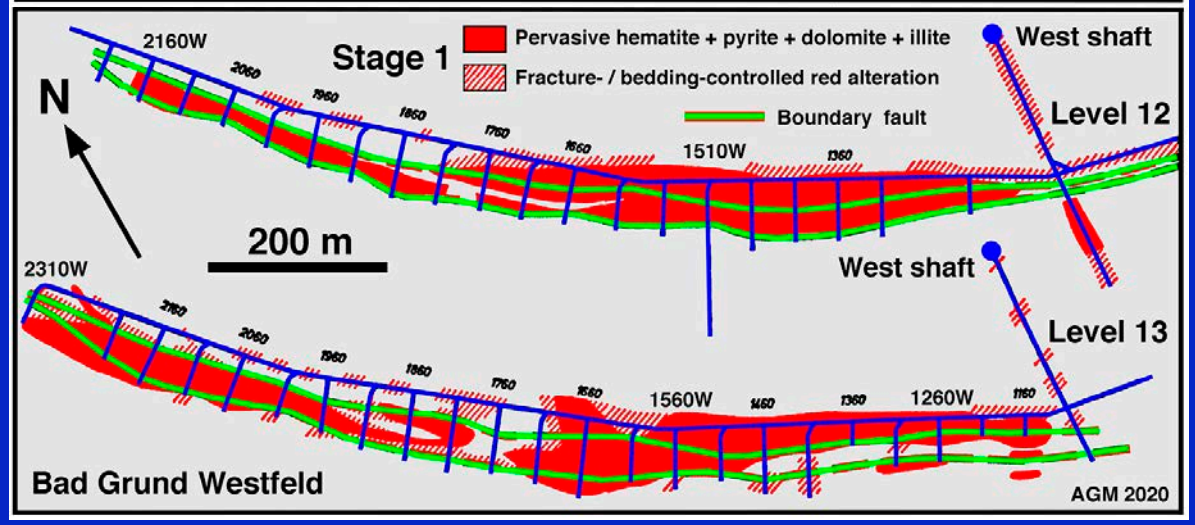


Production 1831-1992 19.1 million tons at 5.8% Pb + 3.9% Zn + 117 g/t Ag. (2240 t Ag)

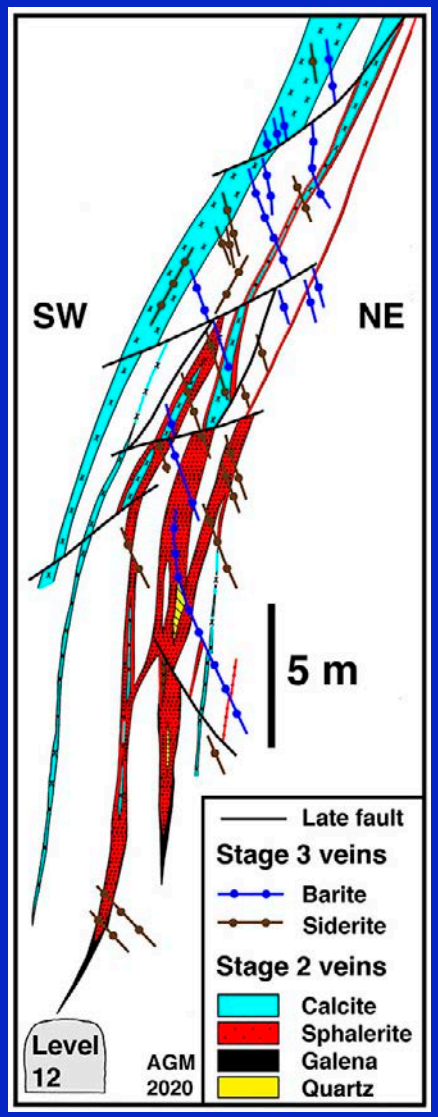
Galena concentrate 1000 – 2000 g/t Ag

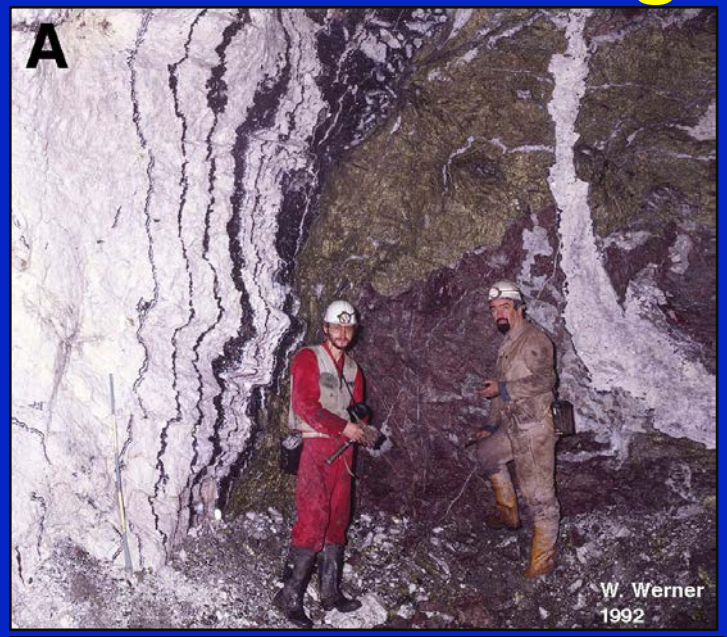
Bad Grund Westfeld: Stage 1 hematite + pyrite

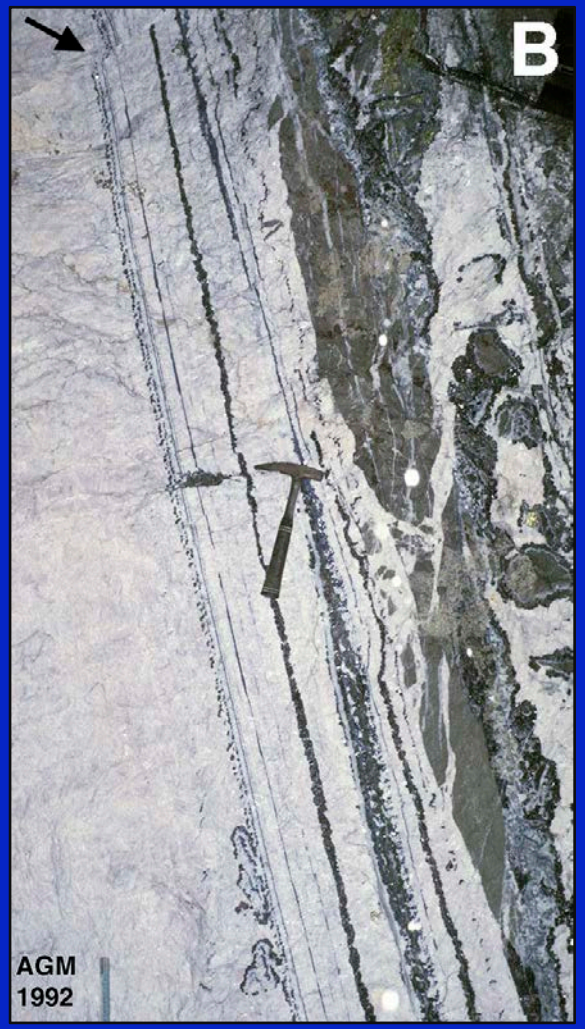




Bad Grund Westfeld: Stage 2 Zn-Pb ore

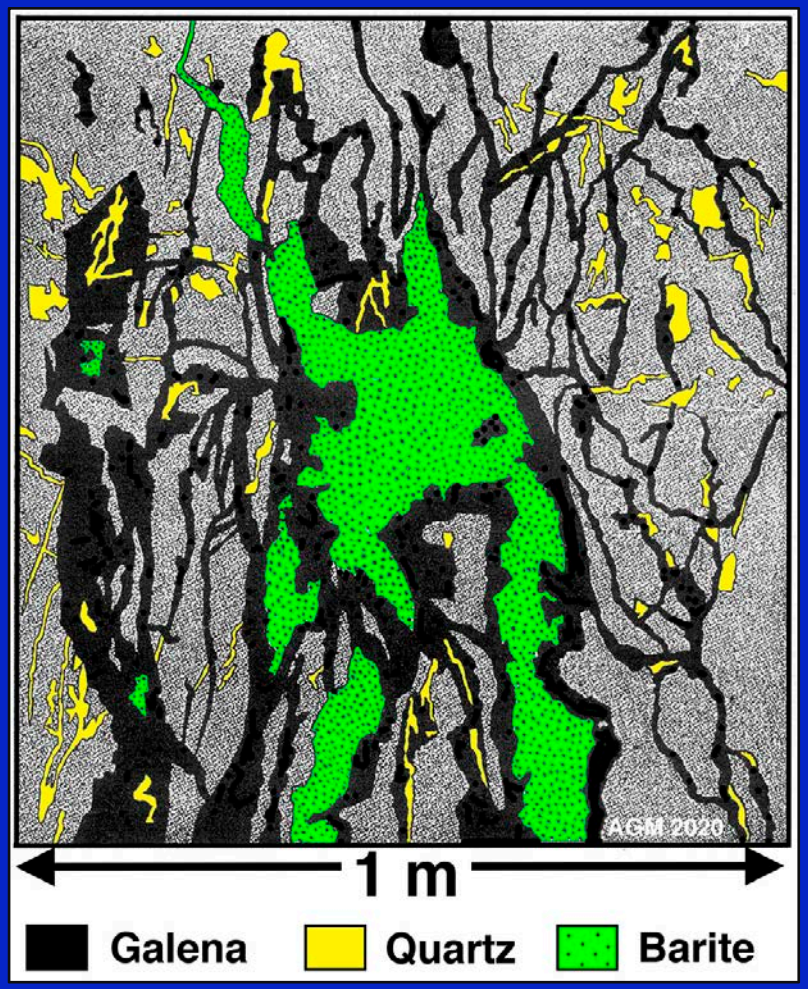


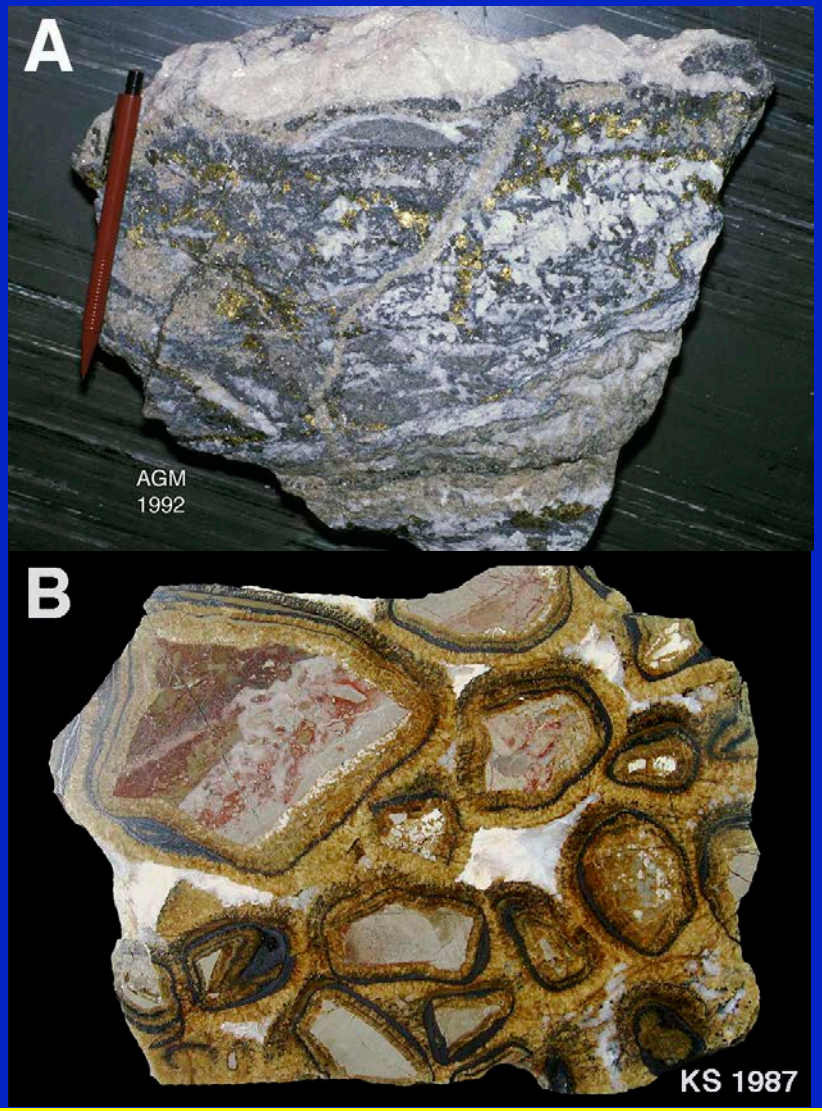




ZnS > PbS > $CuFeS_2$

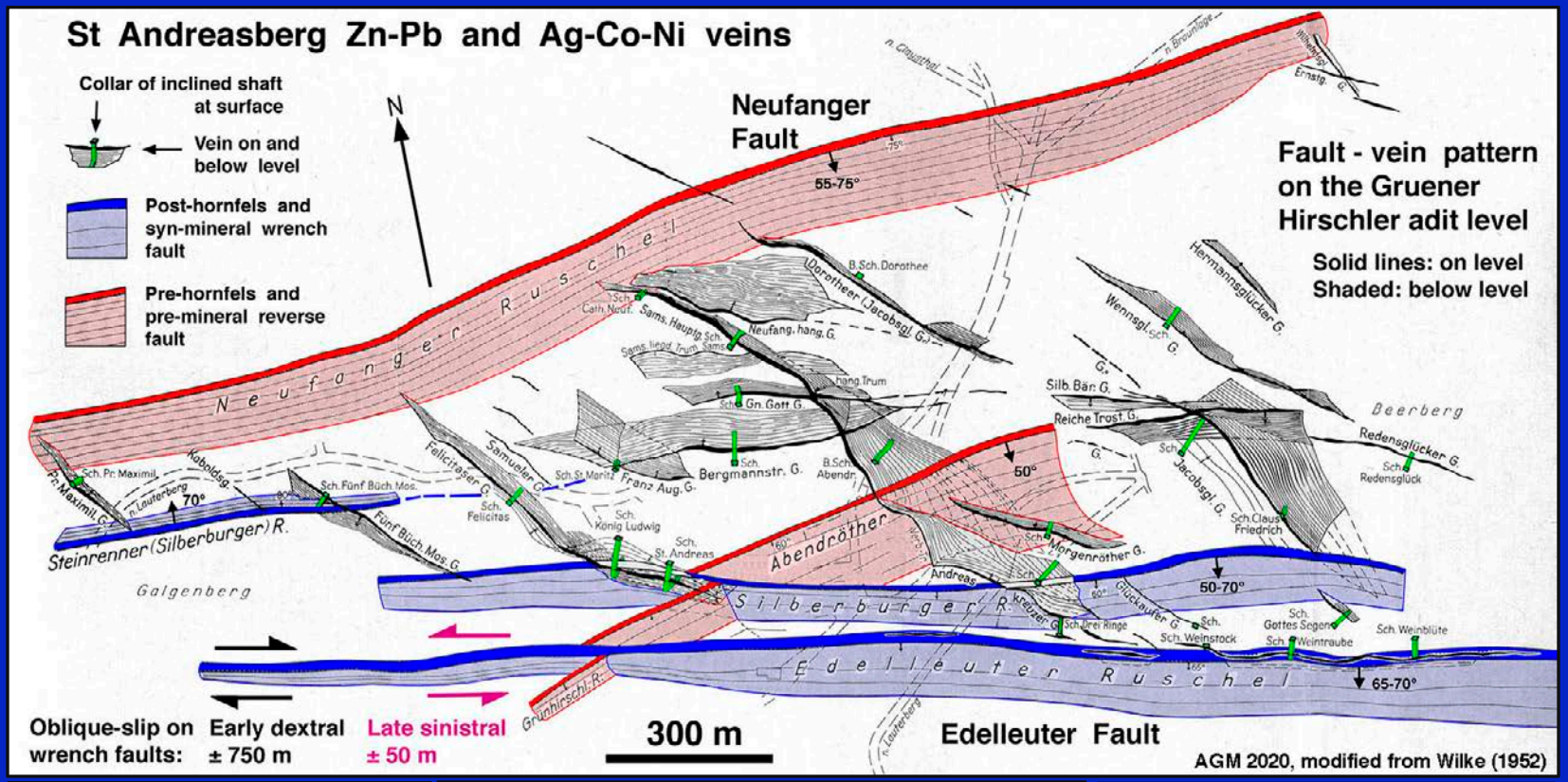
Bad Grund East: Stage 3 Pb-Ag ore

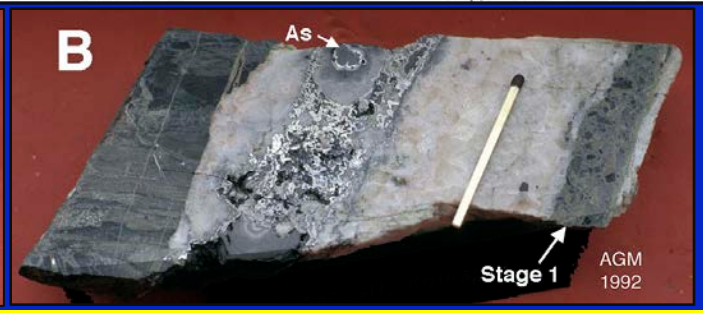




Silbernaal ore body: 1831-1899
1.6 Mt at 9% Pb + 230 g/t Ag

St Andreasberg veins: Wrench fault reversal





Variscan veins: Key features

Structural setting: Syn-orogenic in bedding-parallel "saddle reefs" and in the axial plane cleavage of anticlines. Post-orogenic in normal and wrench faults crosscutting folds in the Variscan slate belt.

Absolute age: During main-stage folding and granite emplacement at ca. 305 Ma (Eisenberg, Ramsbeck). Post-folding in regional faults at or prior to 260-240 Ma (Auguste Victoria, Upper Harz).

Ore deposits: Gold-hematite-chalcopyrite-PbSe in carbonate veins. Sphalerite-galena ± chalcopyrite in quartz-carbonate ± barite veins enriched in silver (900-2000 g/t Ag in PbS concentrates).

Ore formation: Eisenberg, gold + Cu-Pb sulfide-selenide + hematite at >200°C in black slate. Zn-Pb-Ag: Ramsbeck at >300°C, Auguste-Victoria at 260°C, Upper Harz at 360-220°C including a pre-ore, oxidized Stage 1 with local Cu-Pb sulfide-selenide.