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The Devonian Meggen SEDEX deposit, Germany: Vent-distal Fe-Zn-Pb sulfide and barite gel sedimentation in a black shale basin

Slide presentation and explanatory notes

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Meggen: Past production and grade

Ehrenberg et al. (1954), Thein (1985), Walther (1986), Gaul (1992)

Shale-free barite ore (1901-1977): 9.0 million tons

**Heavy-medium separated sulfide ore (-20% shale):
26.4 million metric tons for sulfuric acid (1853-1962)**

18.3 million tons for zinc and lead (1963-1992)

at 8.4% Zn, 1.1% Pb, 0.01% Cu, 4 g/t Ag,

0.1 g/t Au

Flotation plant 1963-92: grains < 50 μm ,

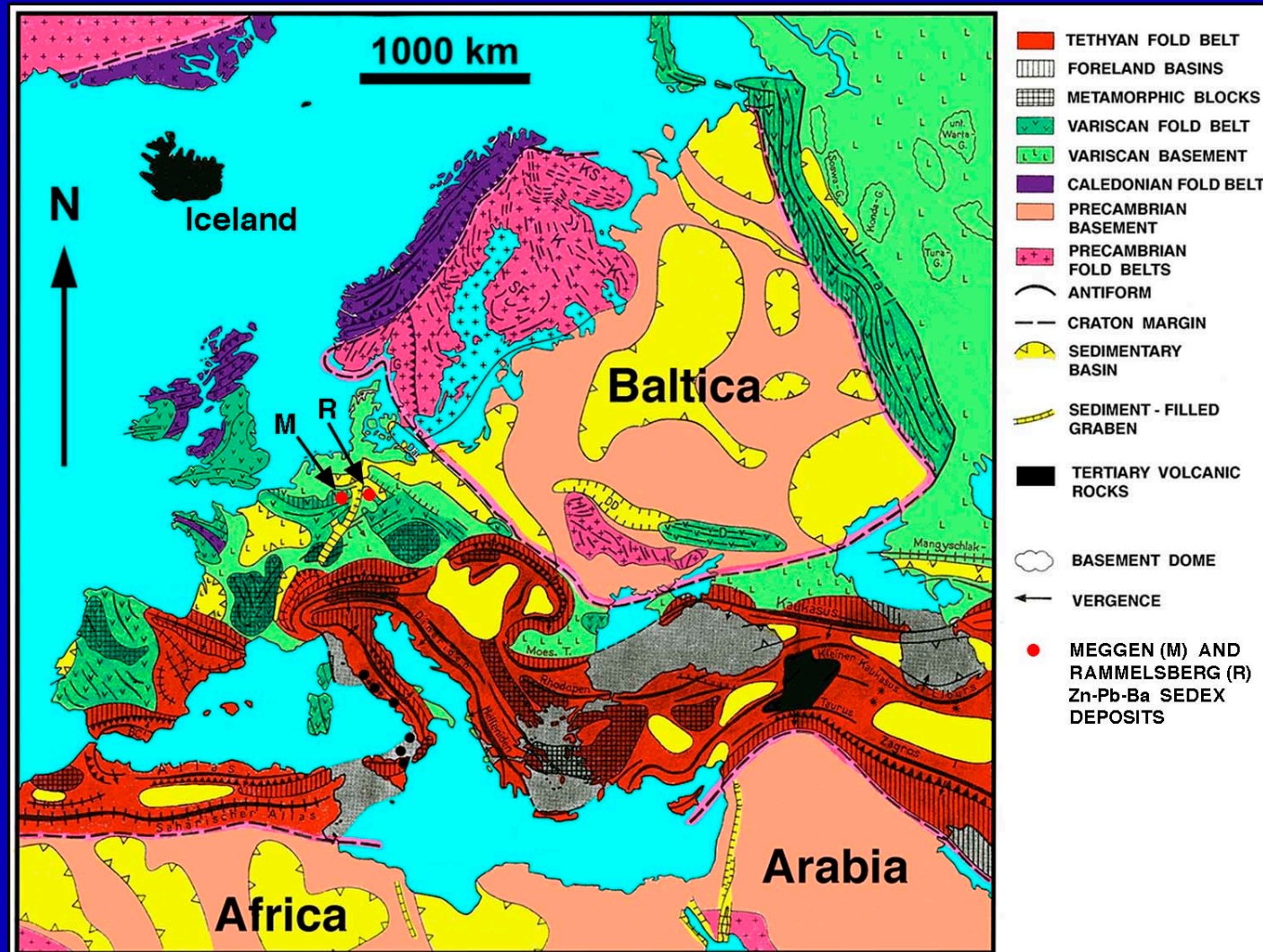
ZnS 92% and PbS 40% recovery

Reserves in 1992: 7.7 million tons at 5.2% Zn



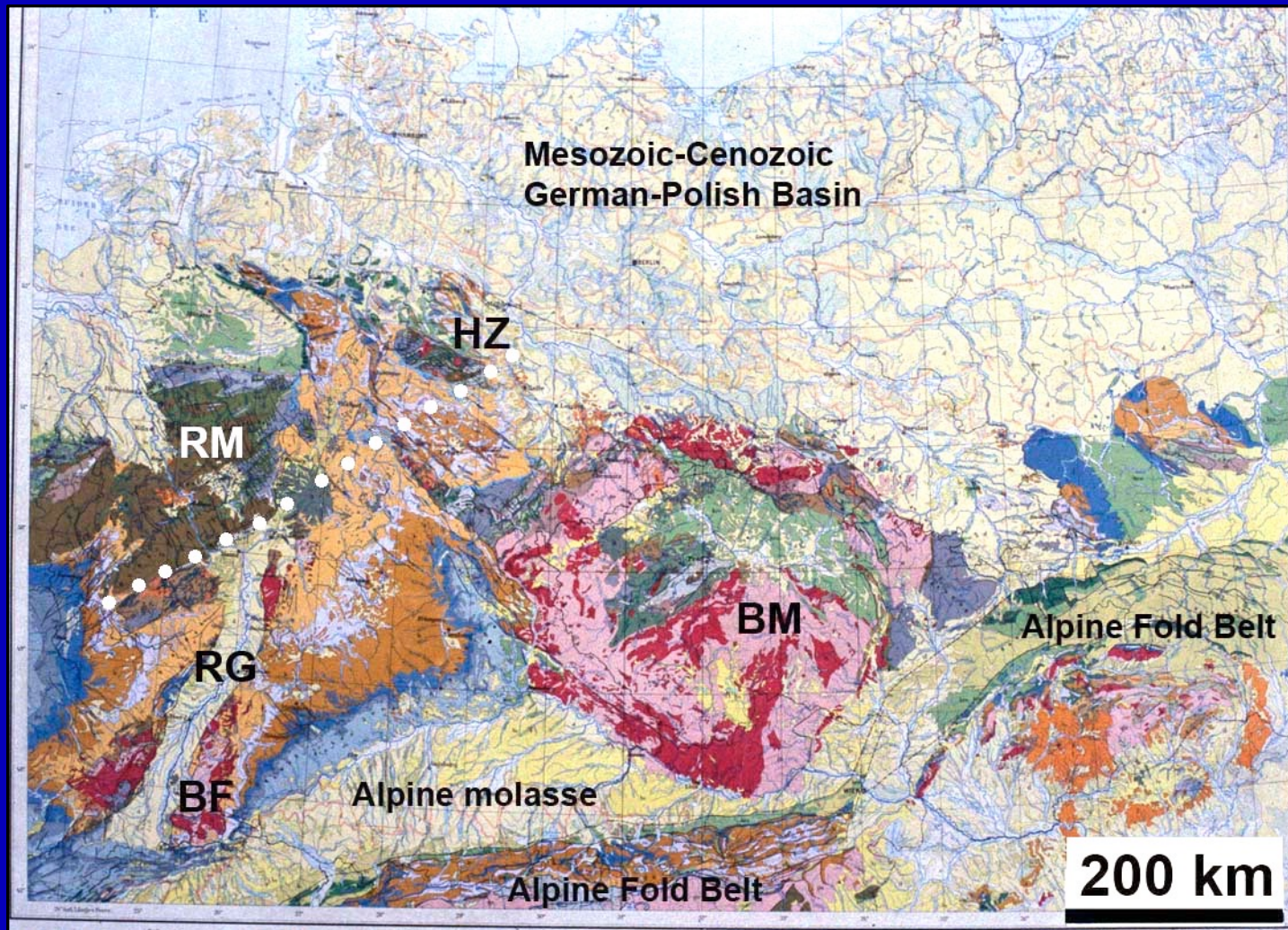
Europe: Cratons and orogenic belts

Modified from Meinhold (1971)



Geologic map of central Europe

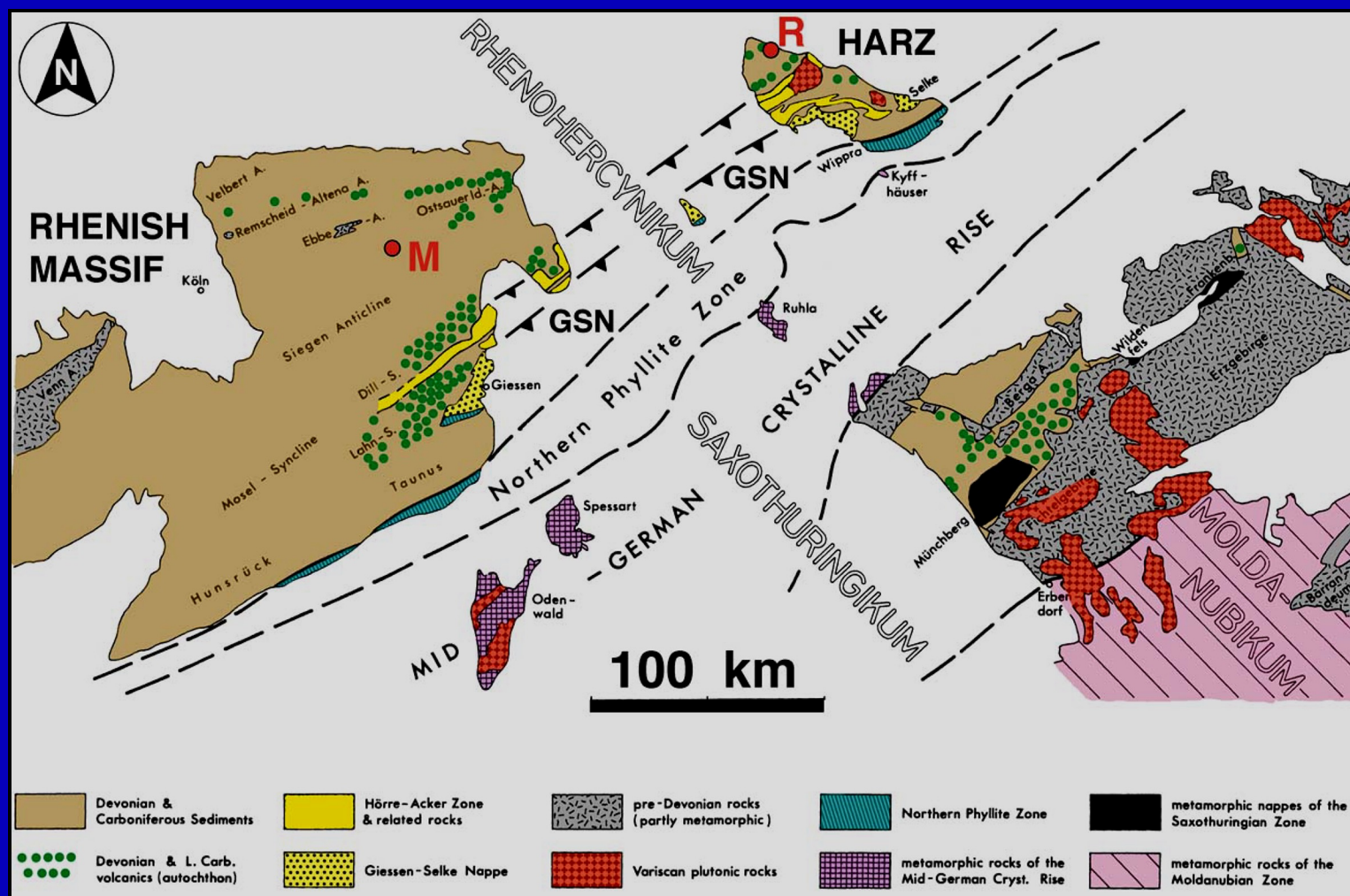
Modified from Schriel (1930)



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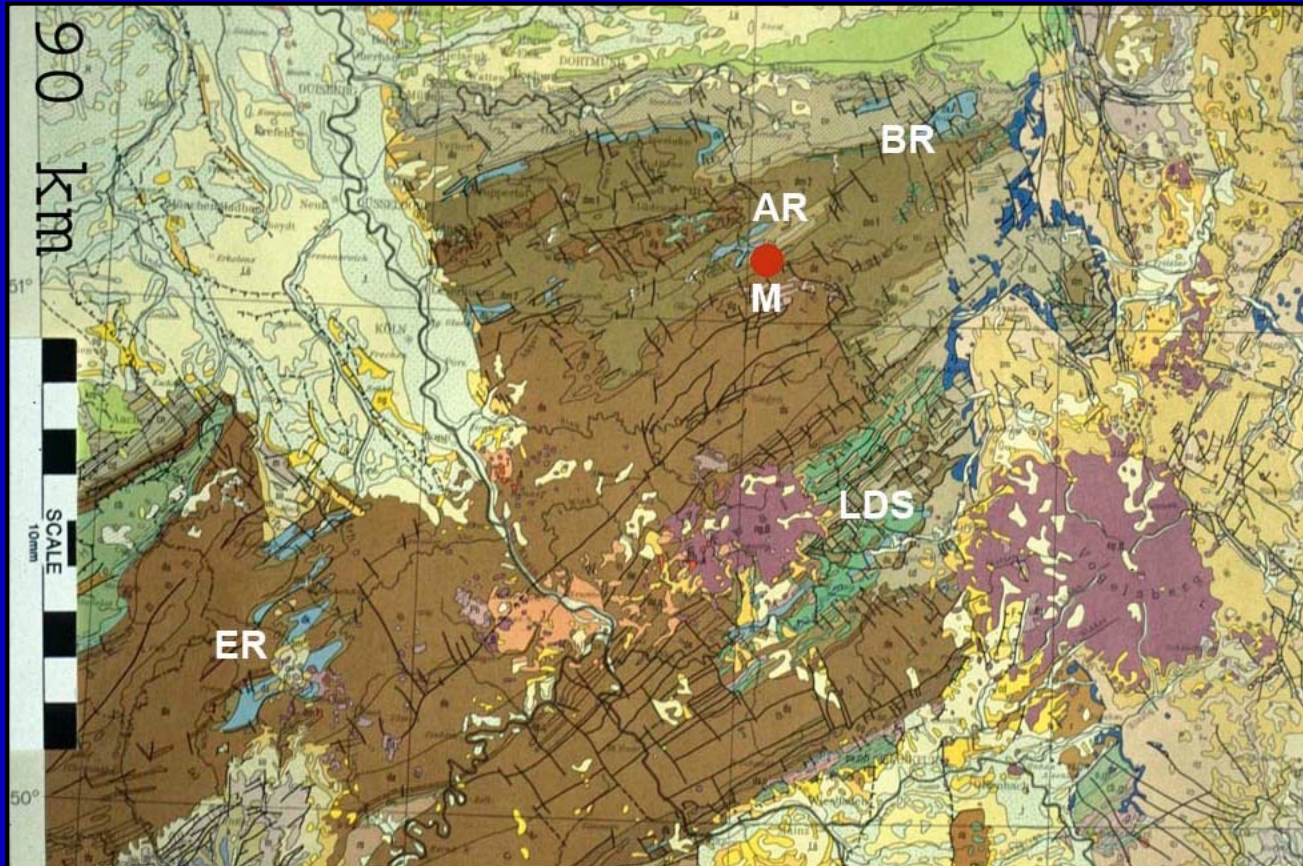
Variscan tectonic zones, Germany

Modified from Engel et al. (1983)



Rhenish Massif: Variscan slate belt

Modified from Walther and Zitzmann (1973)



Marine sandstone – shale succession



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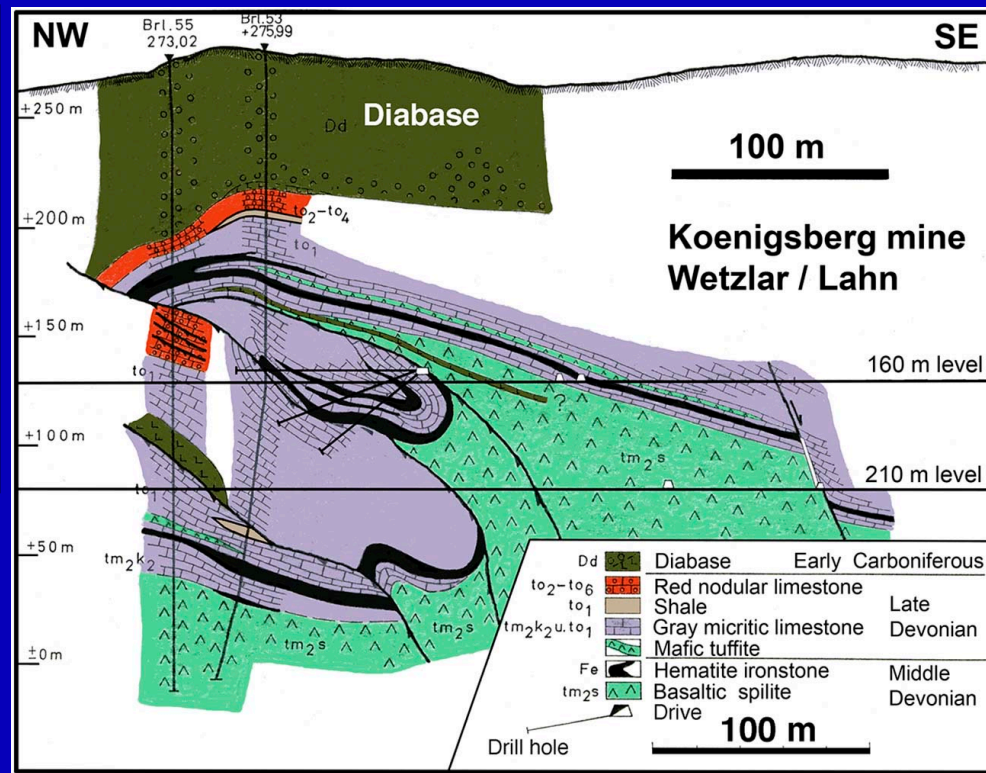
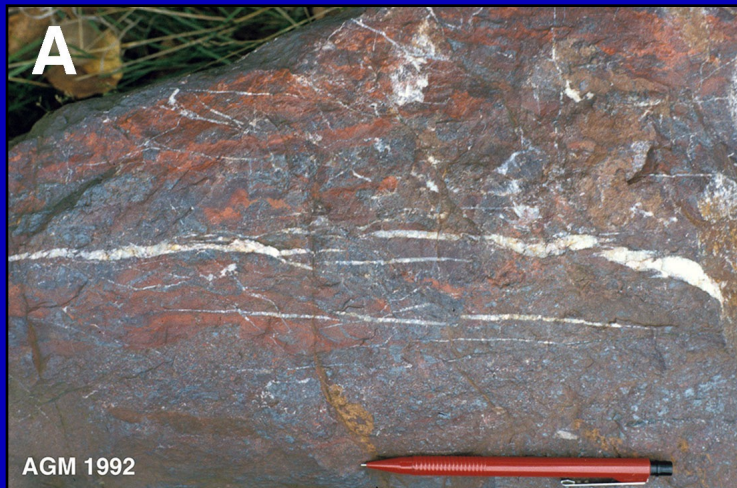
Middle Devonian Lahn-Dill Syncline



**Submarine bimodal
basalt – alkali rhyolite
suite:**

**Basaltic spilite (A + B)
Keratophyre (C)**

Middle Devonian Lahn-Dill iron ore

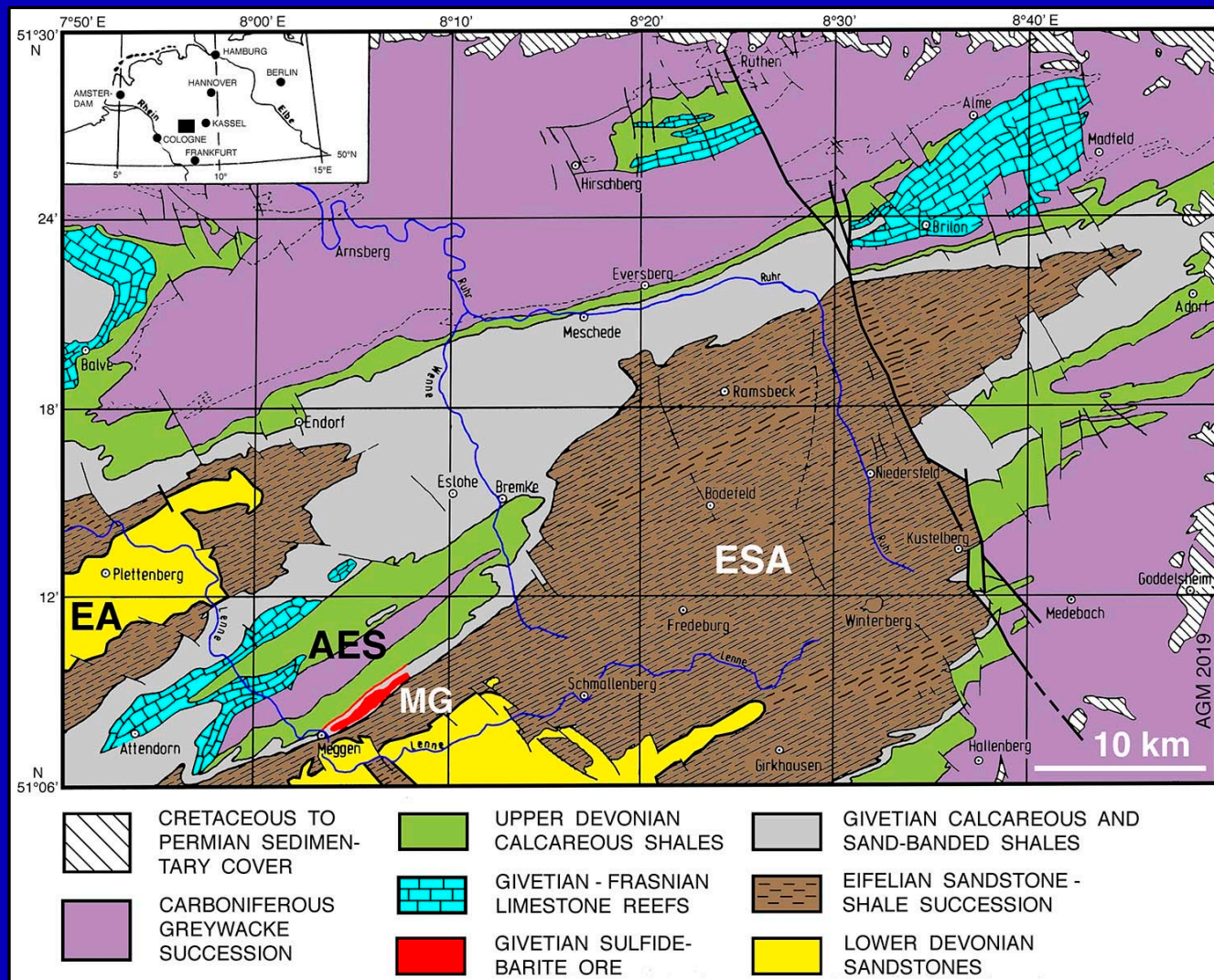


Section modified from Bottke (1965)
District production 1830 - 1983
97 million metric tons at
35 - 40 % iron



Meggen: District geologic map

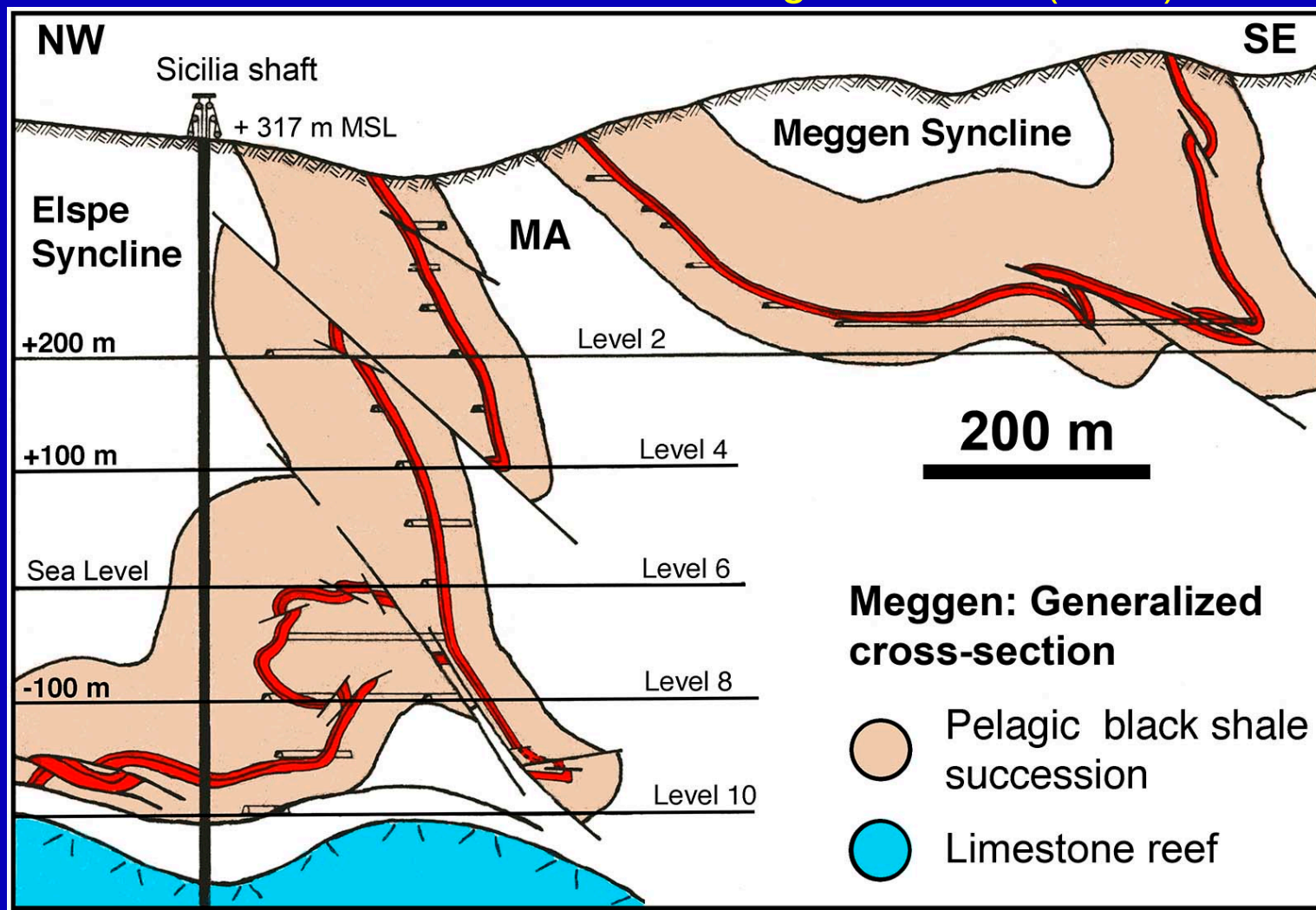
Modified from Behr (1977)



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Meggen: Composite cross section

Modified from Sachtleben Bergbau GmbH (1988)



Meggen: Limestone – shale succession



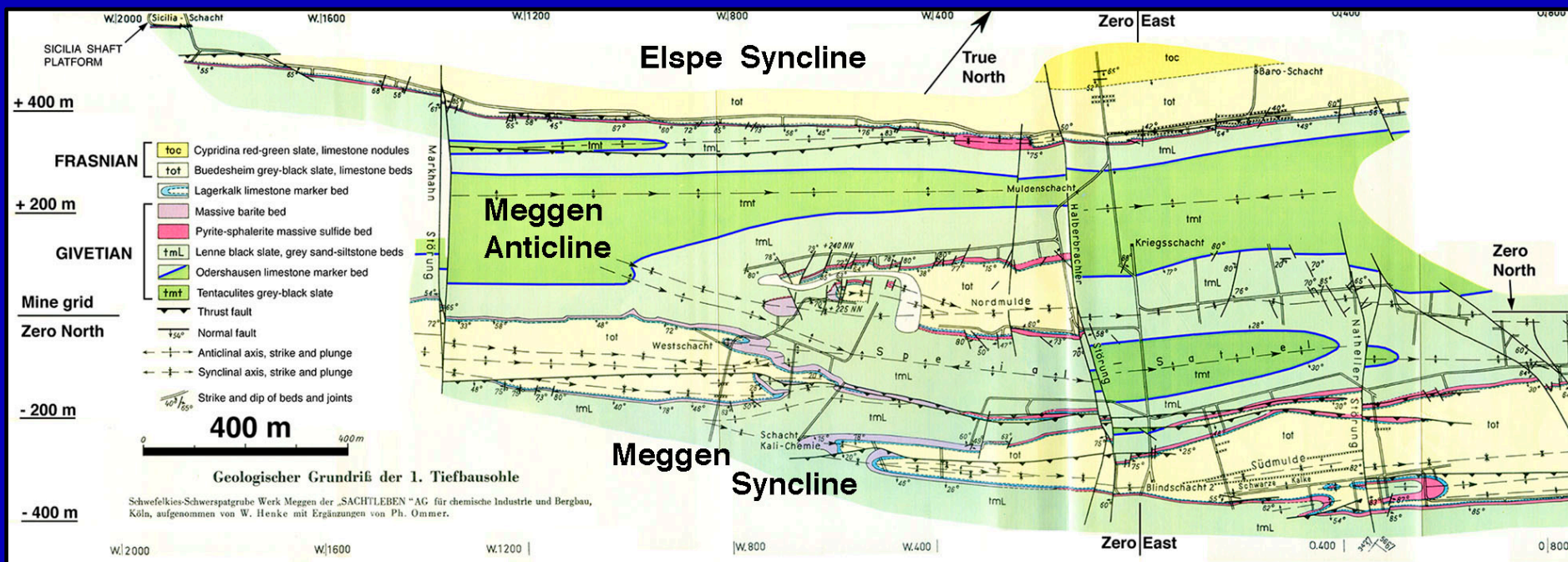
Middle to Upper Devonian

- A. Nodular limestone beds in shale, slaty cleavage
- B. Black pyritic Lenne shale
- C. Meggen Reef limestone



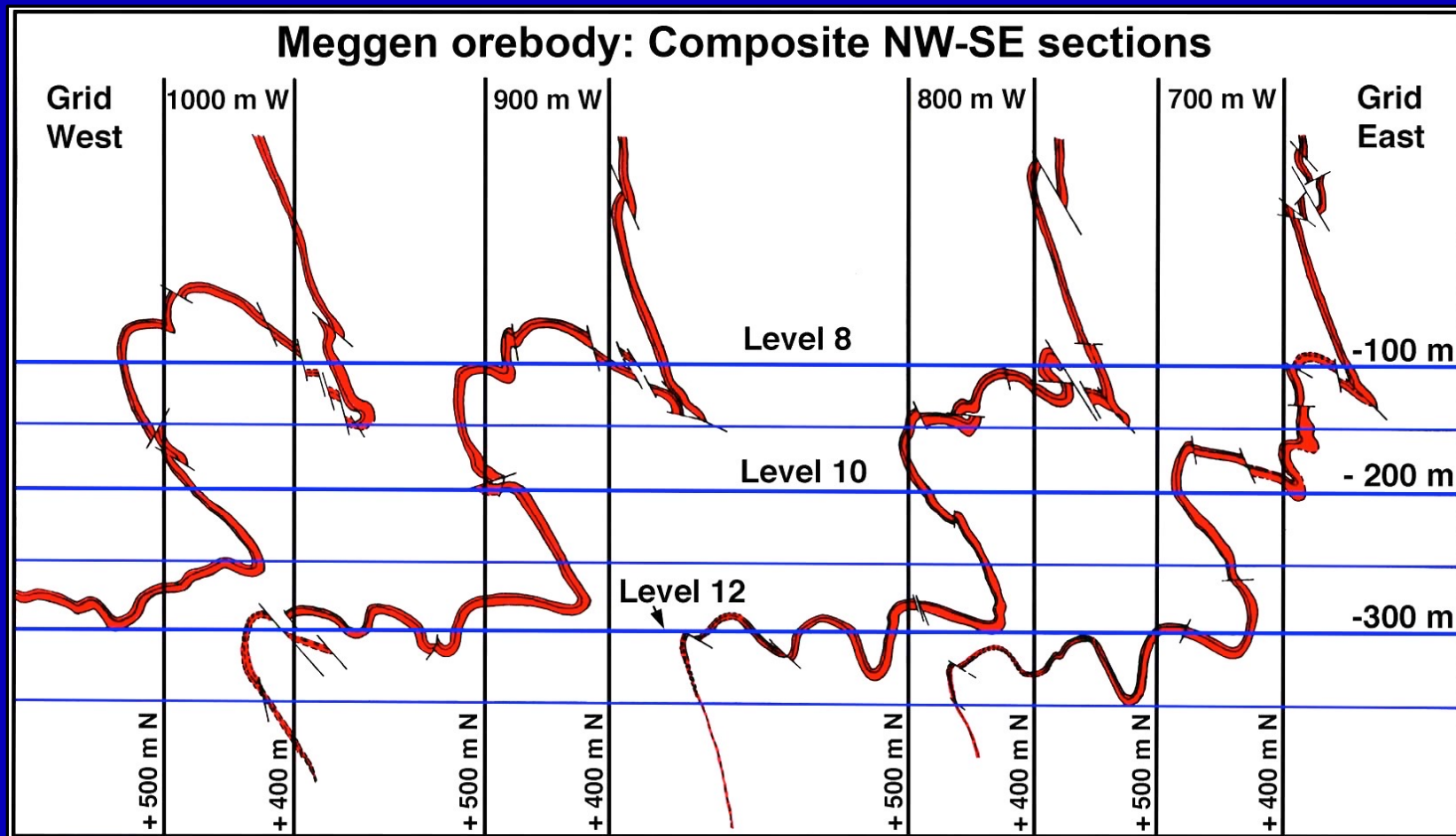
Meggen: Geology Sicilia shaft Level 1

Mapped by W. Henke and Ph. Ommer, modified from Ehrenberg et al. (1954)



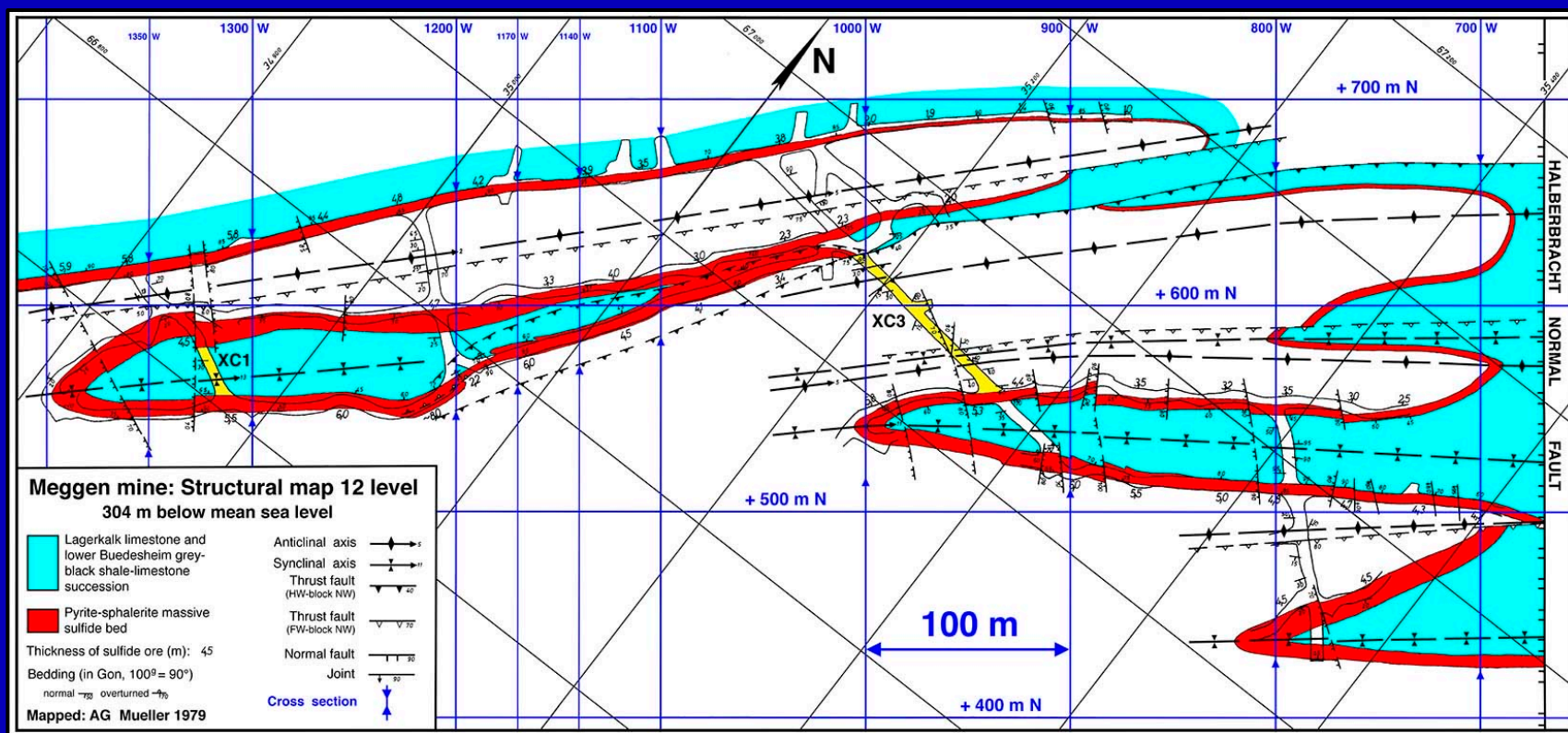
Meggen: Sulfide bed in the Elspe Syncline

Mapped by W. Fuchs, modified from Sachtleben Bergbau GmbH (1988)



Meggen: Structural map Level 12

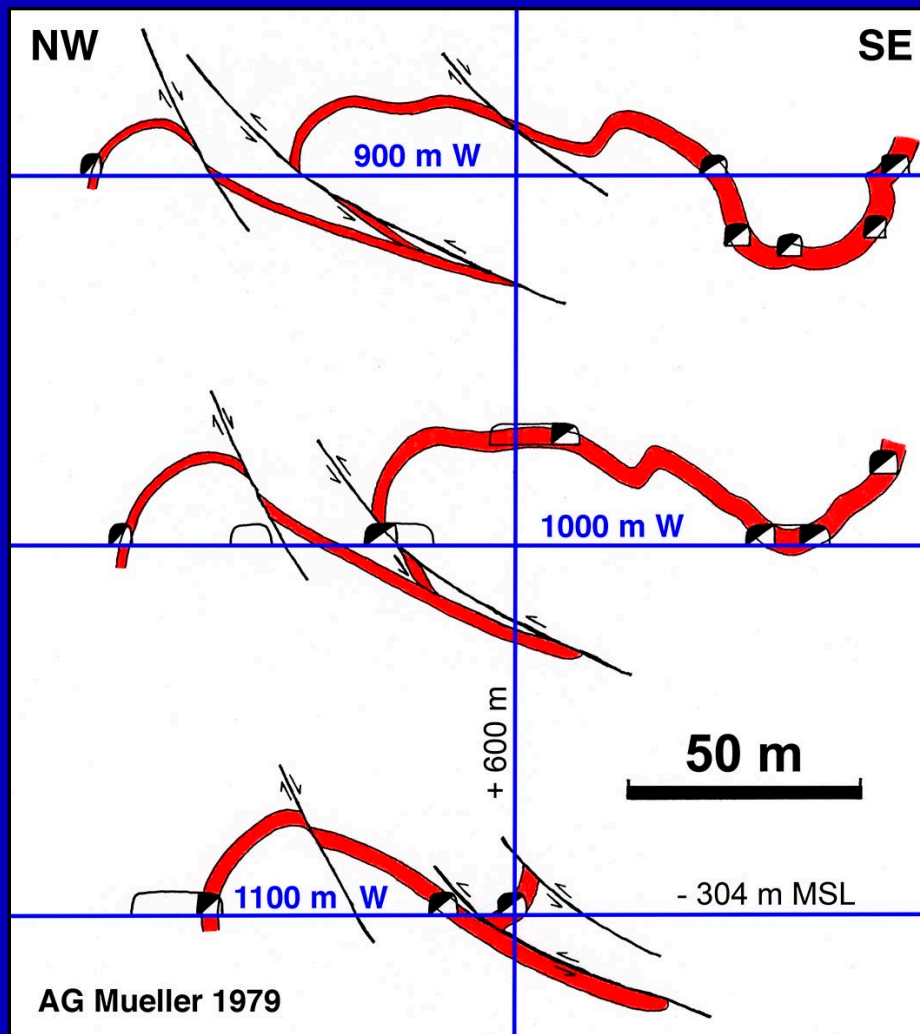
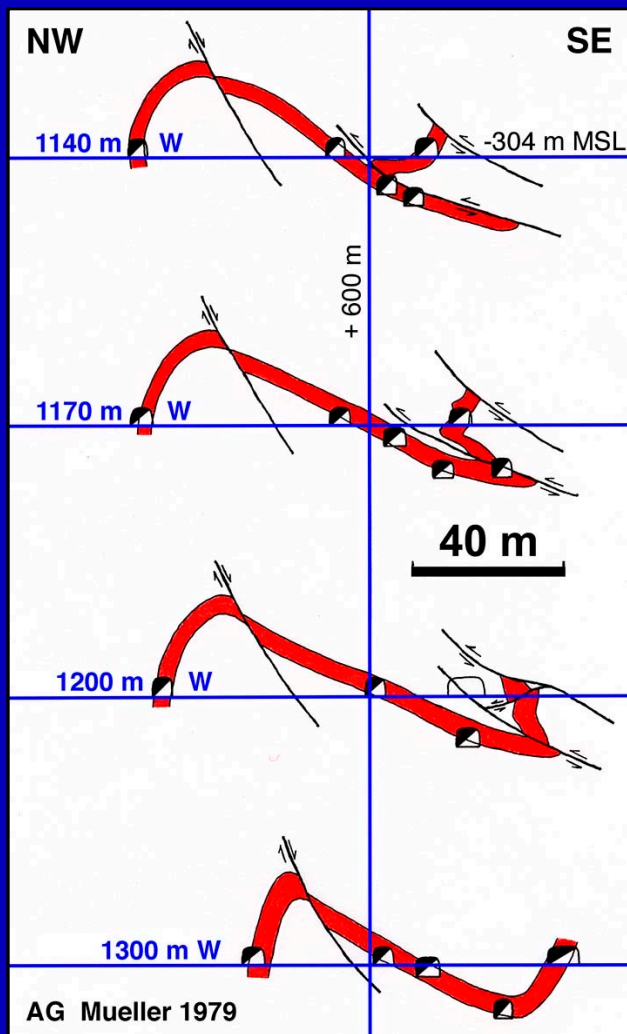
304 m below sea level, mapped by AG Mueller (1979)



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Meggen mine: Cross sections Level 12

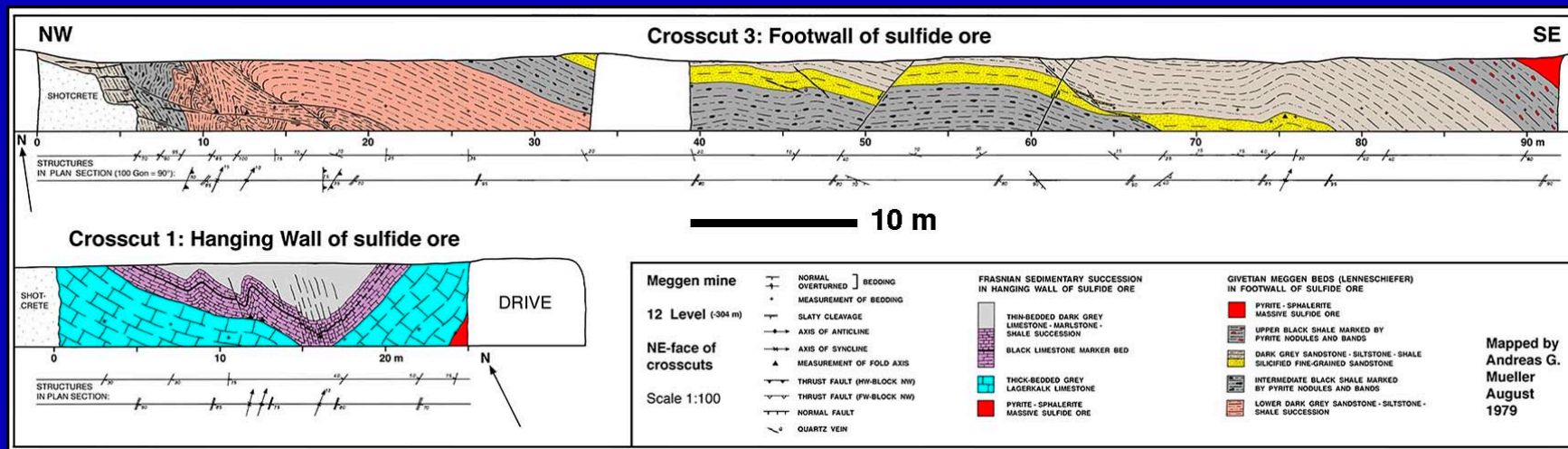
Structural sections of sulfide ore, constructed by AG Mueller (1979)



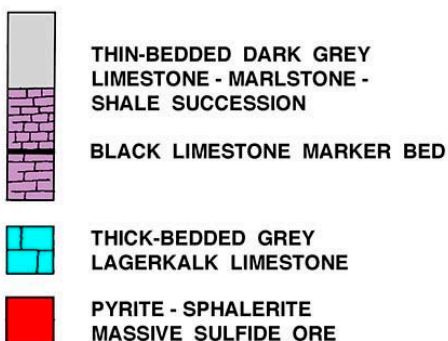
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Meggen: Stratigraphy of the ore horizon

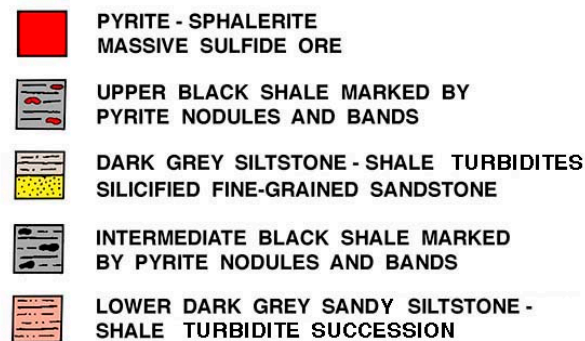
Exposures in crosscuts on Level 12, AG Mueller (1979)



FRASNIAN SEDIMENTARY SUCCESSION IN HANGING WALL OF SULFIDE ORE

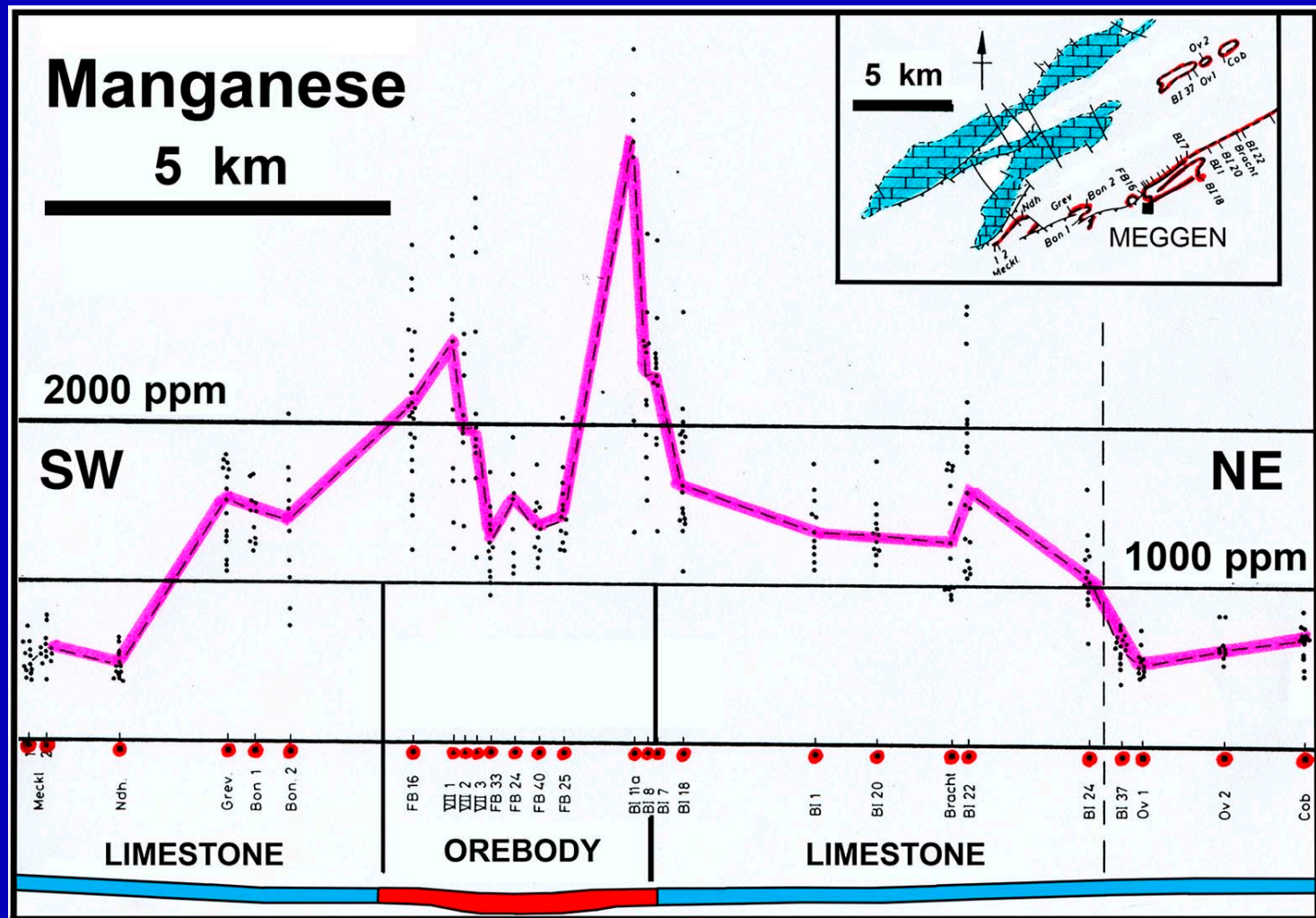


GIVETIAN MEGGEN BEDS (LENNESCHIEFER) IN FOOTWALL OF SULFIDE ORE



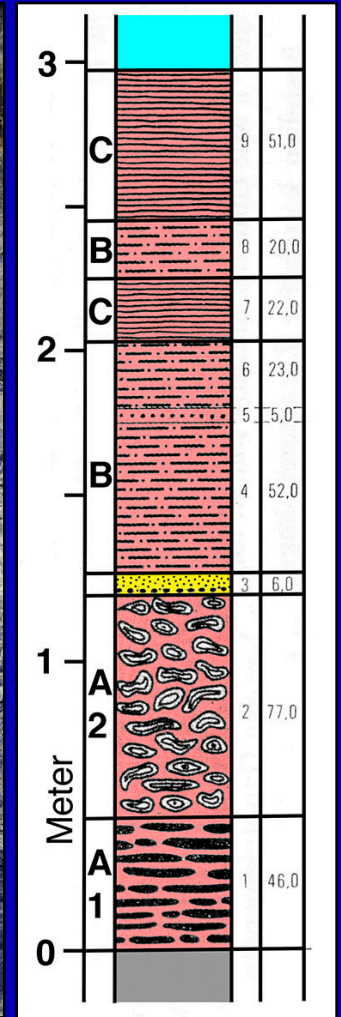
Meggen: Manganese in Lagerkalk limestone

Modified from Gwosdz and Krebs (1977)



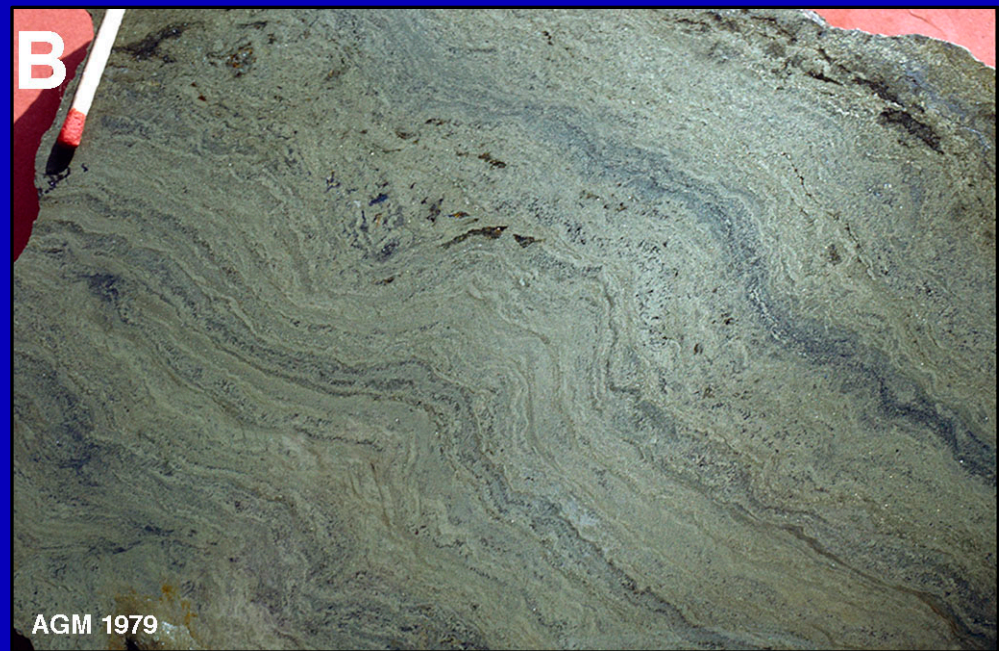
Meggen Level 8: Sulfide ore

Standard sulfide ore section on right modified from Gasser (1974)



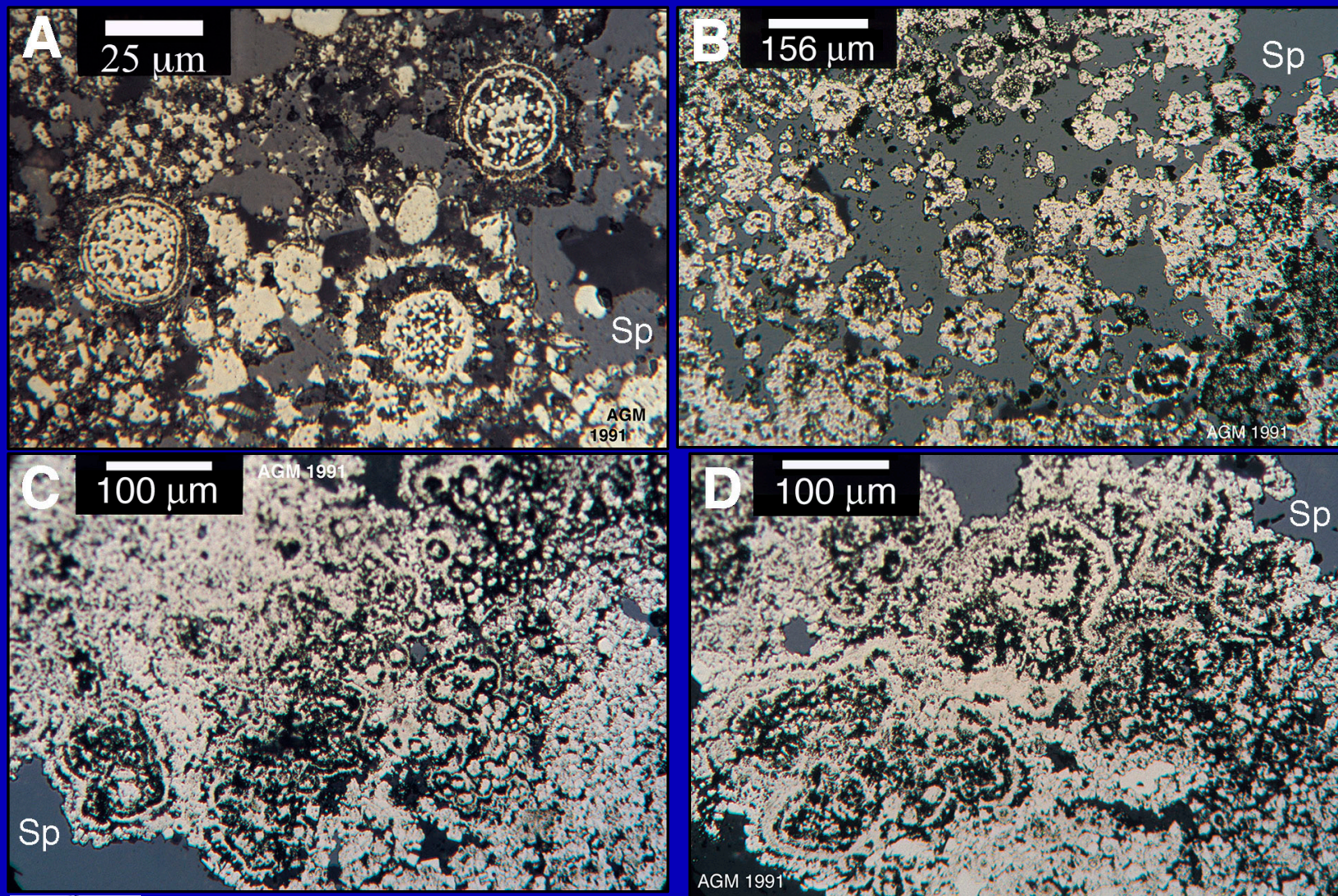
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Meggen: Bedding in sulfide ore

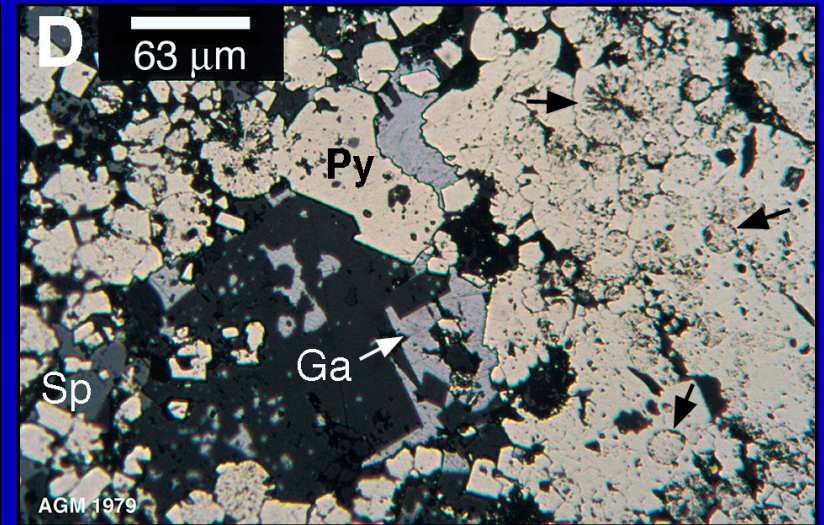
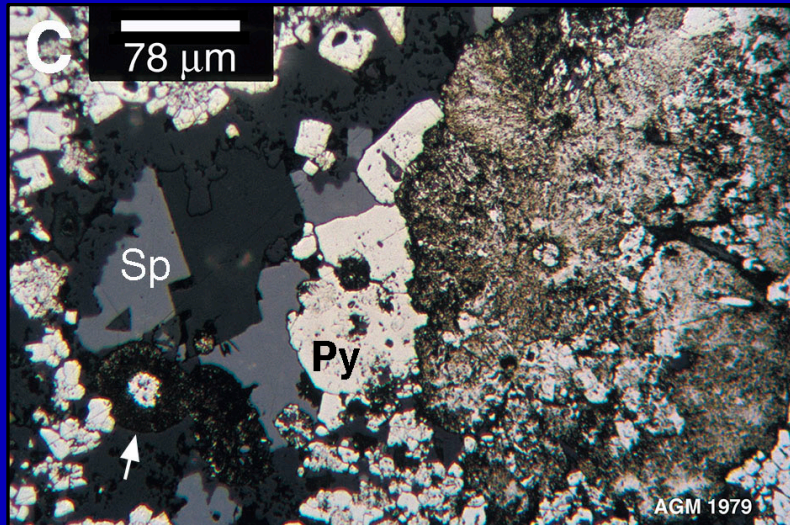
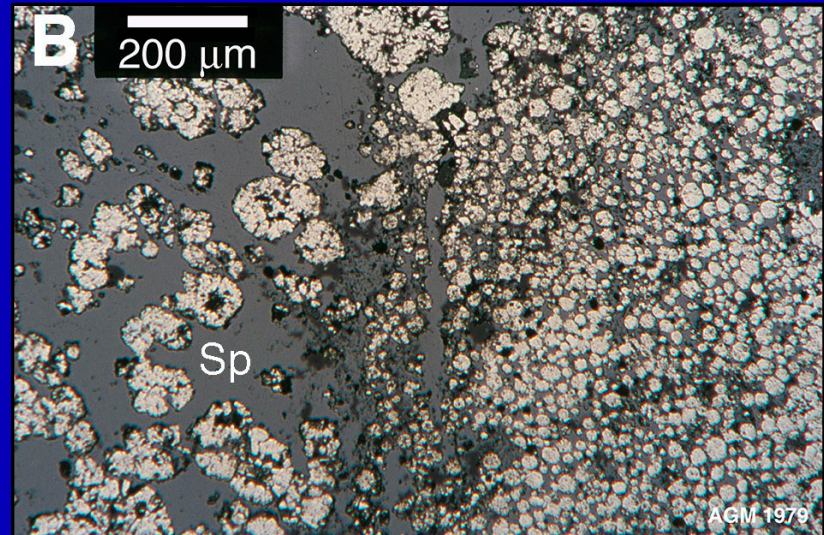
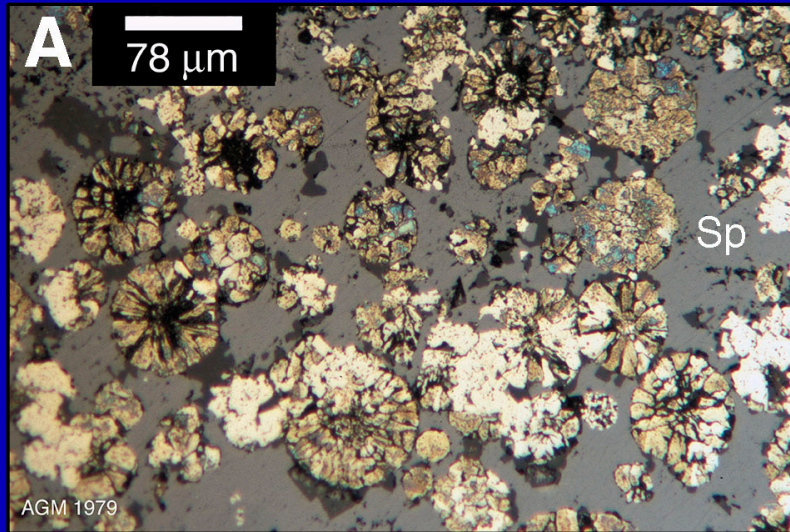


- A. Lower sulfide ore type A2, conorted beds, massive, nodular, sphalerite $\pm$ galena interstitial**
- B. Upper sulfide ore type C, pyrite + sphalerite bedded on a mm-scale**

Meggen: Gel textures in lower sulfide ore



Meggen: Spheroids in upper sulfide ore



Meggen ore: Mineralogy and isotopes

Ehrenberg et al. (1954), Buschendorf et al. (1963), Gasser & Thein (1977), Nielsen (1985)

Sulfide ore (volume %)

Sulfur isotopes
(per mil)

Pyrite (60 %): Mn, Ni, Co, As

$\delta^{34}\text{S}$ +19.8

Melnicovite pyrite (5 %): As, Tl

Marcasite (1 %): Ni, Co

Sphalerite (13 %): 1.1% Fe, Cd

$\delta^{34}\text{S}$ +16.4

Galena (0.5 %): Ag, Sb

$\delta^{34}\text{S}$ +18.0

Barite (0.3-0.4 %): Sr

Gangue (20 %): Illite + quartz $\pm$ carbonate

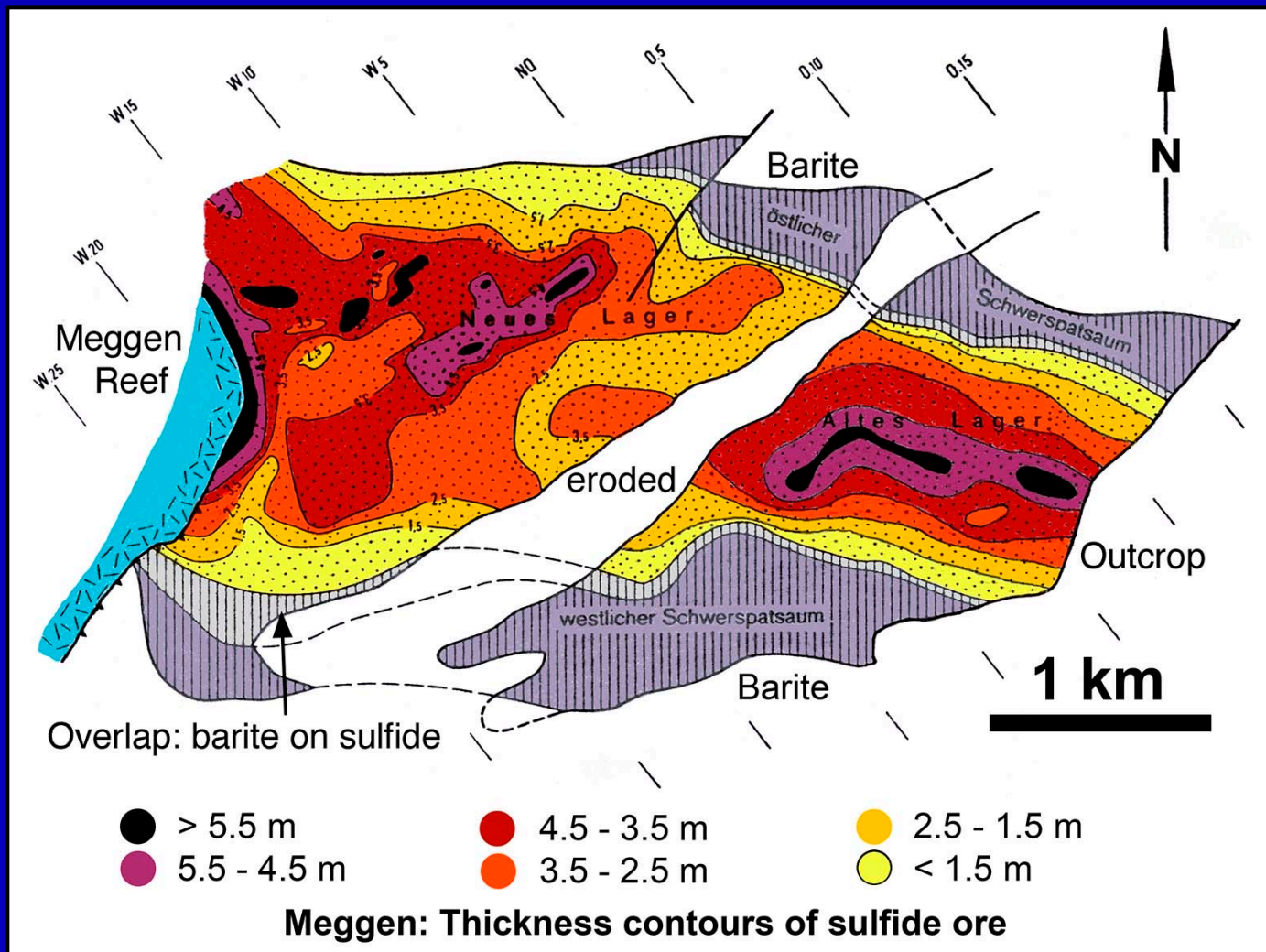
Peripheral barite (95 % pure)

$\delta^{34}\text{S}$ +22.8



Meggen deposit: Unfolded ore body

Compiled from Ehrenberg et al. (1954) and W. Fuchs in Clausen (1978)



Meggen sulfide ore body: Metal zoning

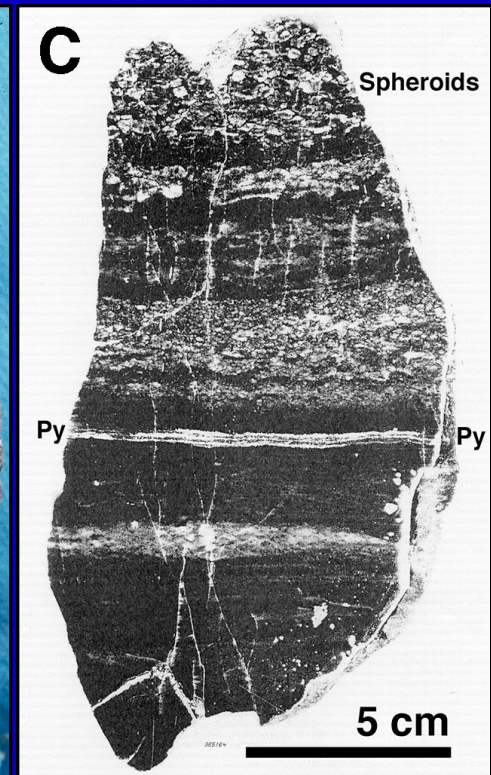
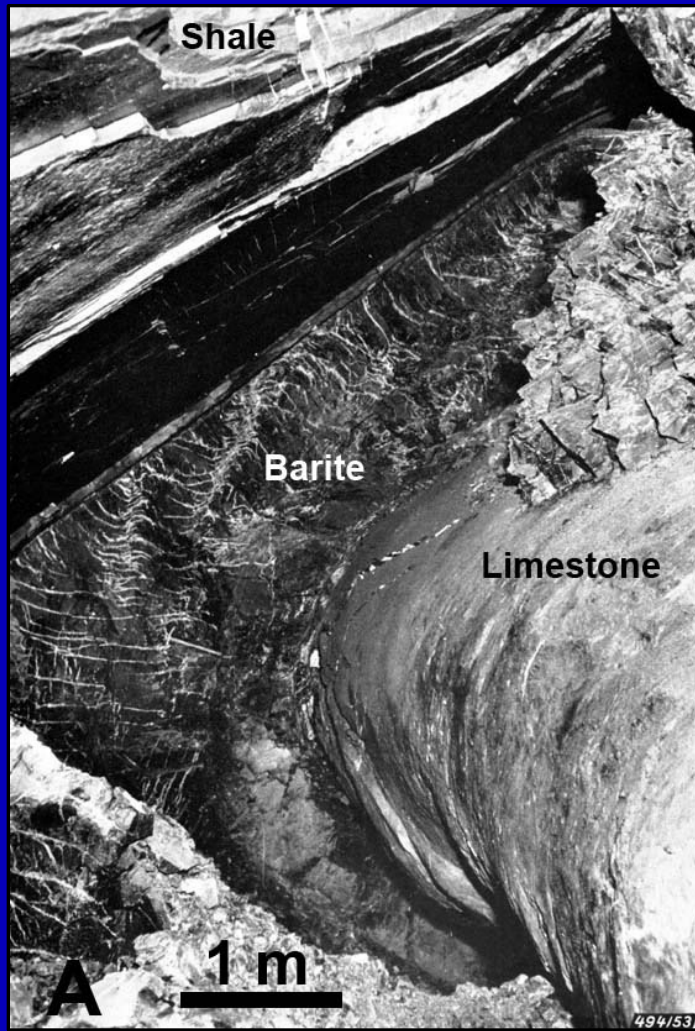
Gasser and Thein (1977), Thein (1985), Werner (1988)

	Central	Marginal	FW Shale
Sulfur	41.8 %	40.4 %	1.03 %
Zn	7.92 %	4.81 %	195 ppm
Pb	1.05 %	0.56 %	52 ppm
As	644 ppm	270 ppm	19 ppm
Ni	209 ppm	130 ppm	502 ppm
Tl	200 ppm	300 ppm	193 ppm
Ba	169 ppm	874 ppm	0.23 %
Clay/Silt	15.7 %	20.7 %	93 %



Meggen: Peripheral barite ore

Ehrenberg et al. (1954), Buschendorf and Puchelt (1965)



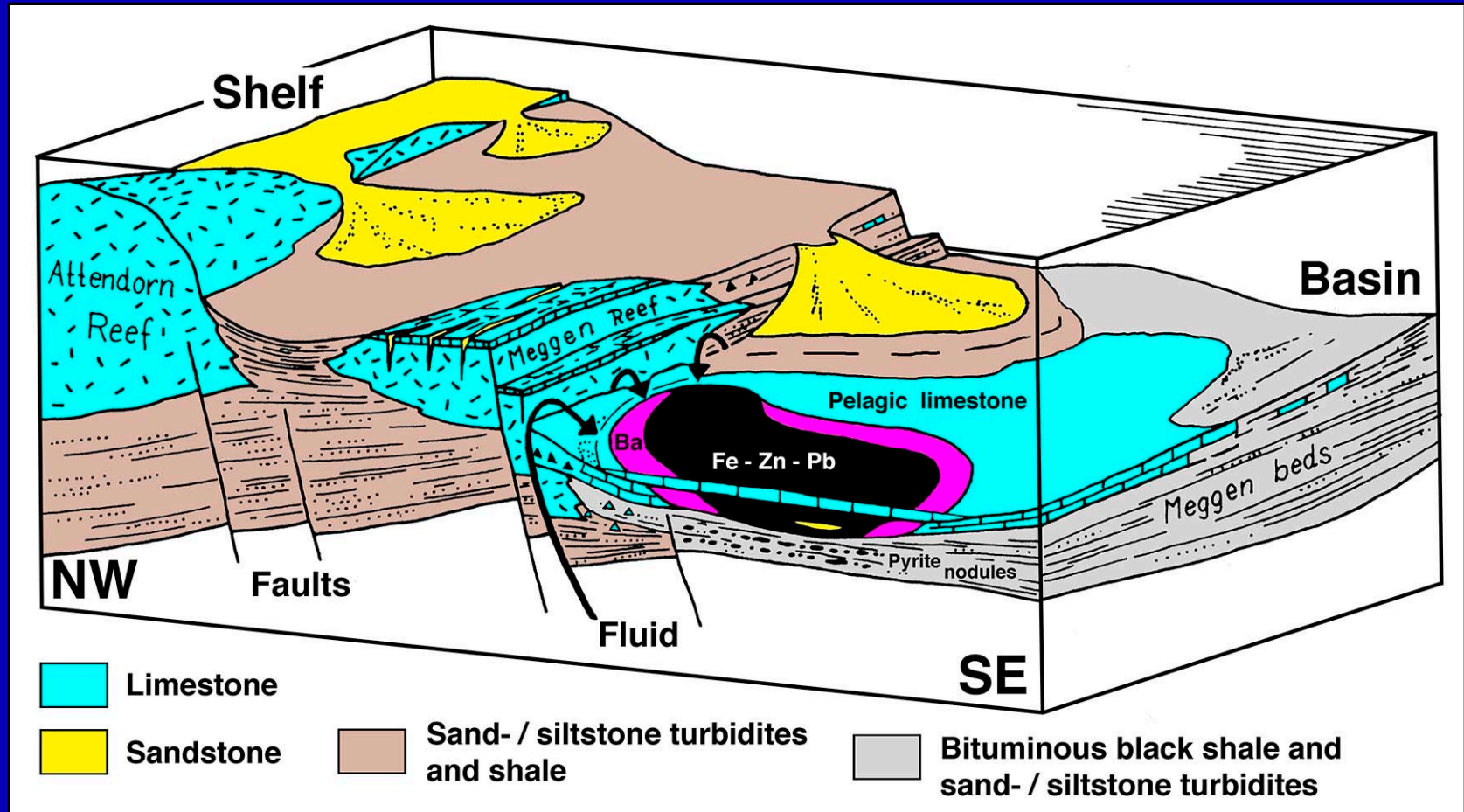
**Barite ore: 95 wt.% barite,
0.3-0.8 % Sr, 0.3 % pyrite.**



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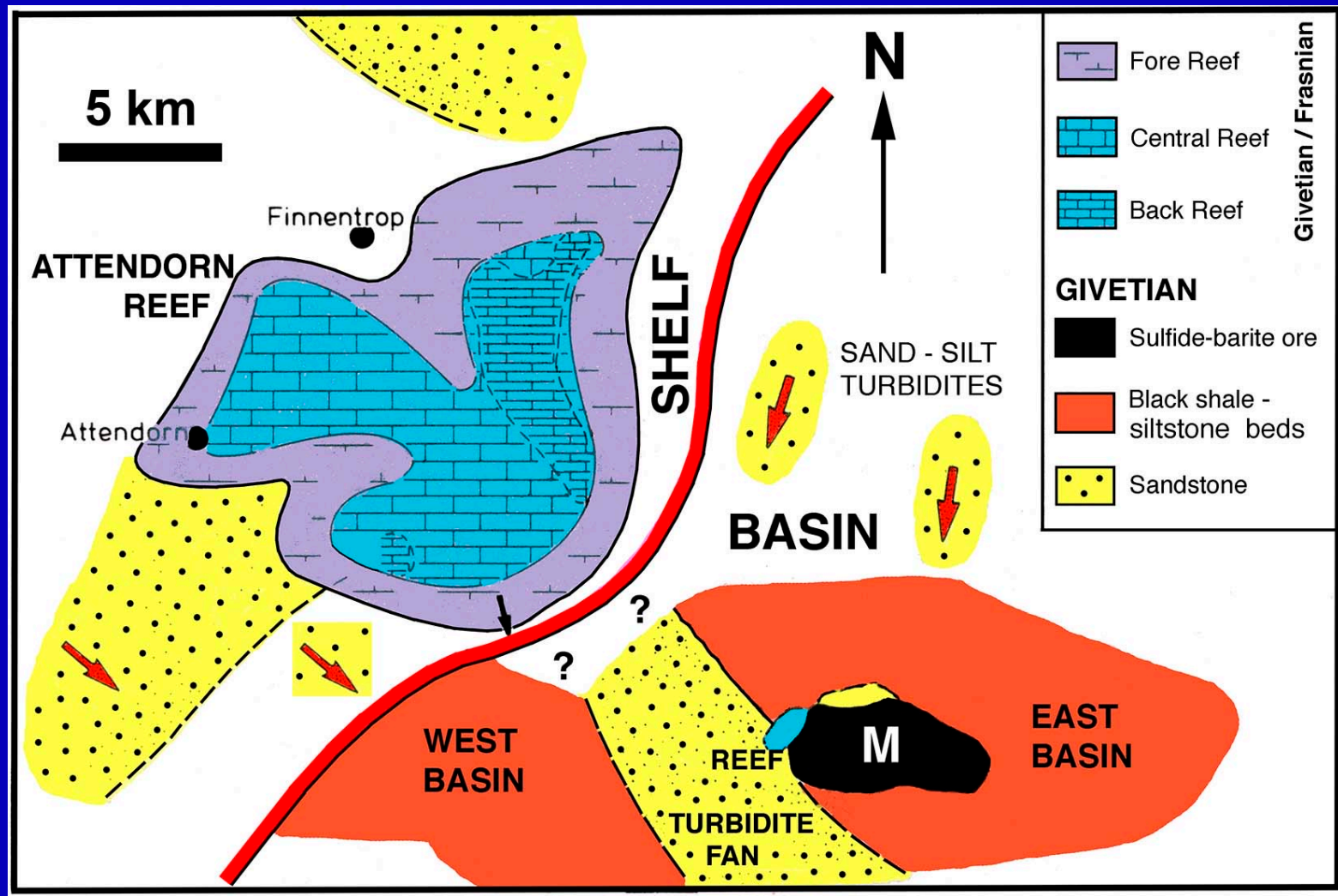
Meggen: Gel deposition in an euxinic basin

Modified from Thein (1985)



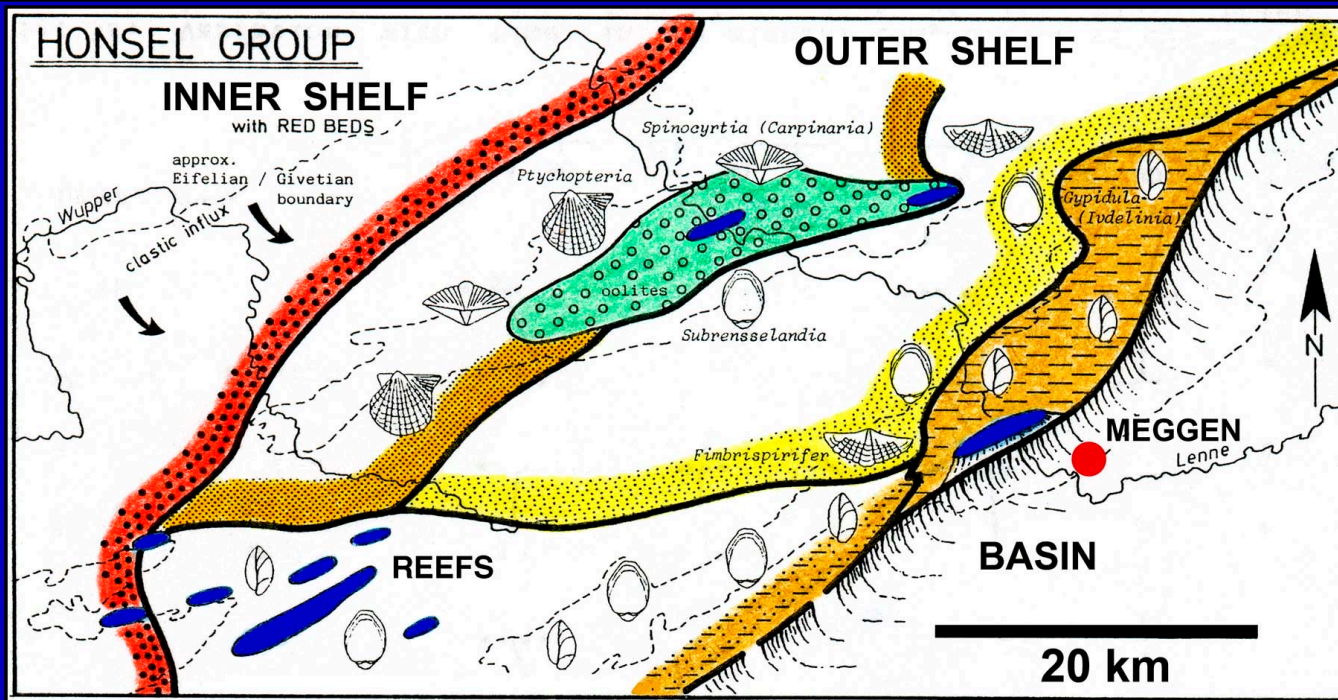
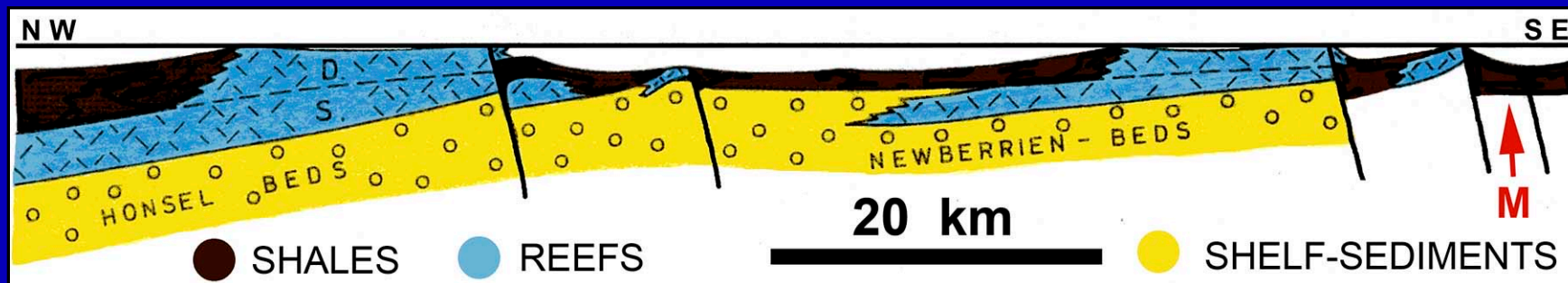
Meggen district: Shelf-margin paleogeography

Modified from Werner (1988)



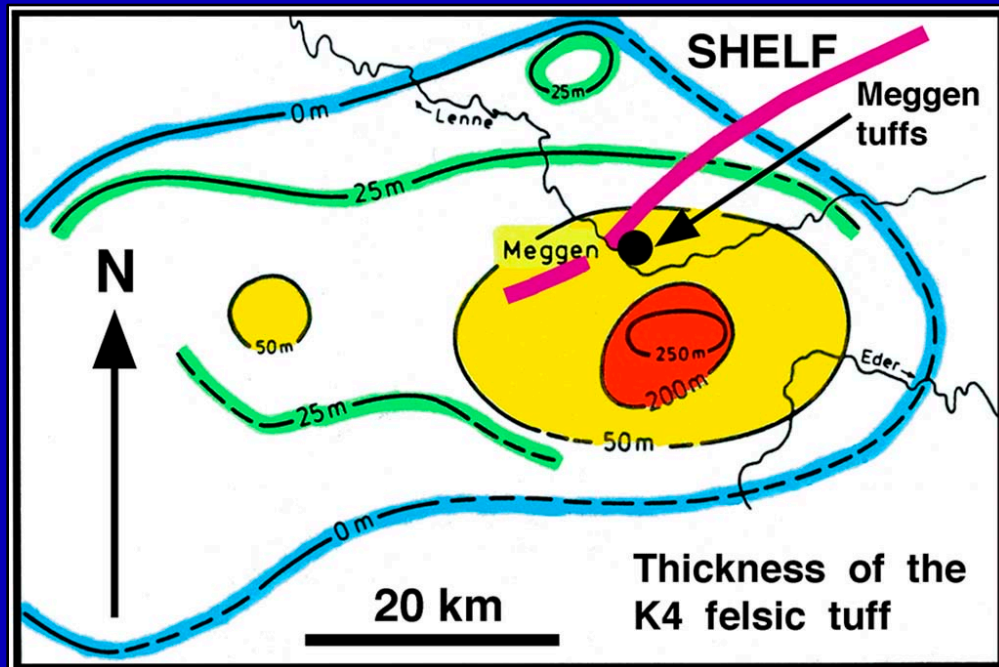
Meggen: Regional paleogeography

Modified from Krebs (1981) and Langenstrassen (1983)



Meggen basin: Devonian volcanism

Modified from Rippel (1954) and Krebs (1981)



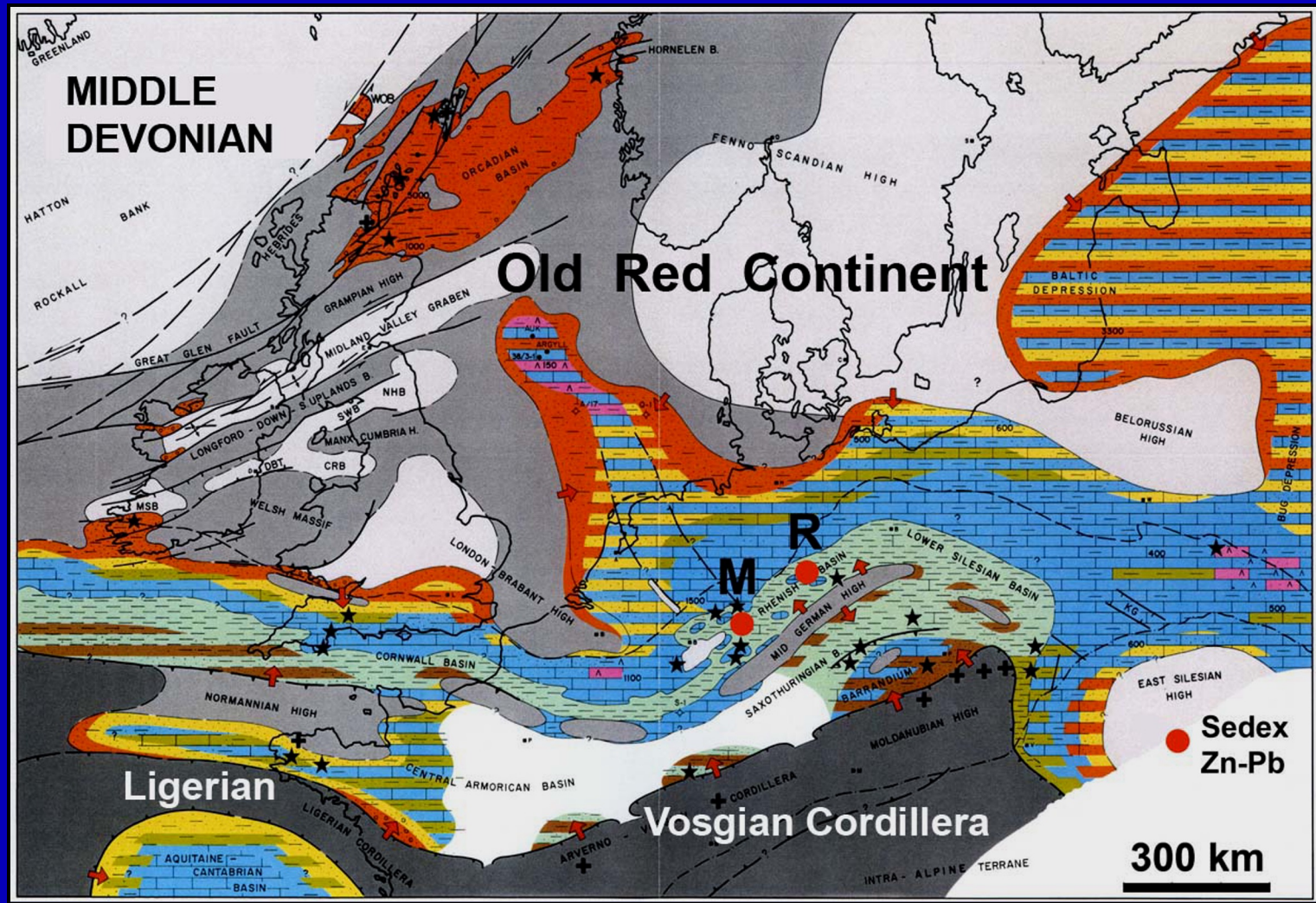
SEDEX mineralization and associated submarine felsic volcanism

Stage	Ma	Felsic volcanism	Mineralization
Famennian	372		2nd pyrite band
Frasnian	383	Meggen tuffs	1st pyrite band
		MT4	
		MT3	
		MT2	Meggen ore
Givetian	388	MT1	
			Pyrite bands
Eifelian	393		Pyrite bands
		Keratophyre horizons	Siderite nodules
Emsian	408	K7	Pyrite
		K6	
		K5	
		K4	Siderite nodules
Pragian		K3	



Back-arc basin in the Old Red Continent

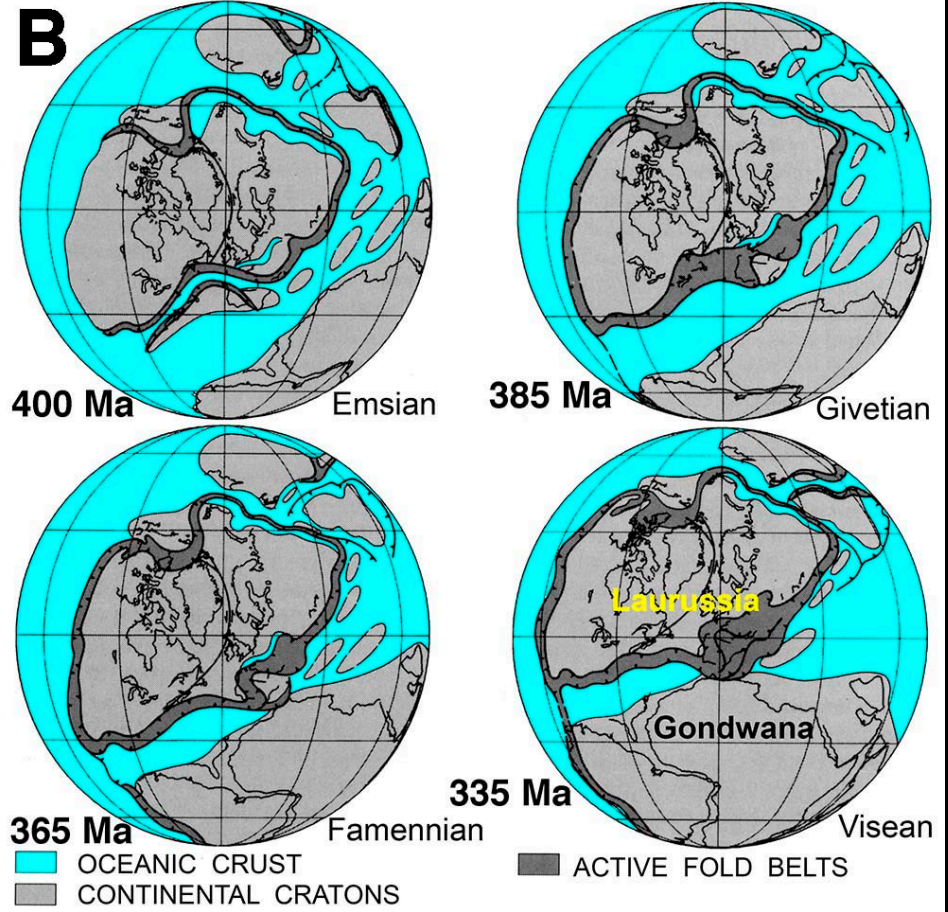
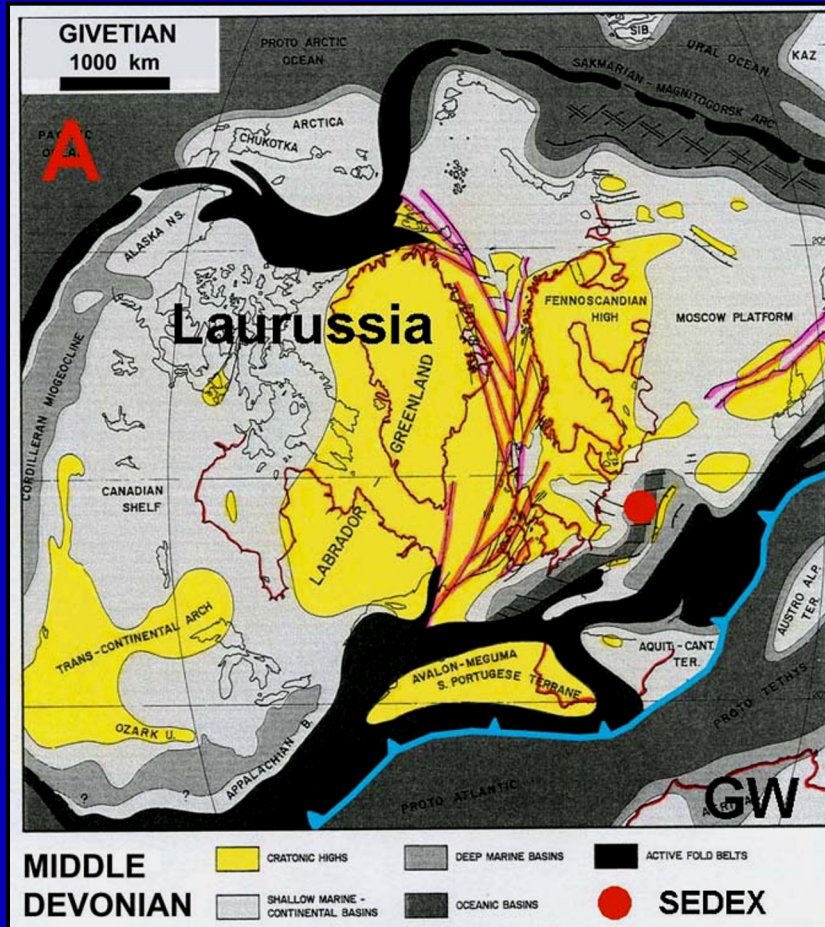
Modified from Ziegler (1990)



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Devonian plate-tectonic setting

Modified from Ziegler (1990)



Meggen: Key genetic features

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

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

Submarine ore deposits: Hematite ironstone on volcanic ridges composed of basaltic spilites, distal SEDEX sulfide-barite ore in black shale basins containing interbedded felsic tuffs

Meggen deposit: Formed in a pelagic euxinic basin at the faulted margin of the continental shelf, shielded from turbidite input by the Attendorn and Meggen reefs

Fe-Zn-Pb sulfides: Vent-distal sedimentation as sulfide gels in a brine pool at 150-200° C, peripheral barite by mixing with seawater

