Heavy mineral analysis

What are heavy minerals?

→ minerals with a specific density ρ > 2.85 g/cm^3

→ accessory minerals in clastic sediments with a proportion of usually <1%

→ are smaller than the average grain size of the sediment

→ amphibole, pyroxene, zircon, tourmaline, rutile, apatite, ...

How to analyse them?

- fine to medium-grained sandstones, as fresh as possible (!)
- crushing and desaggregation (e.g., 10% acetic acid, ultrasonic, H_2O_2, etc.
- sieve fraction 63 – 125 µm (may be coarser, if necessary)
- separation of HM by specific density fluids such as Na-metatungstate
- counting of at least 200 grains under the microscope; embedded in special resins or waxes with well defined optical properties (e.g., Meltmount 1.66)
- for details see Mange & Maurer (1991, 1992)

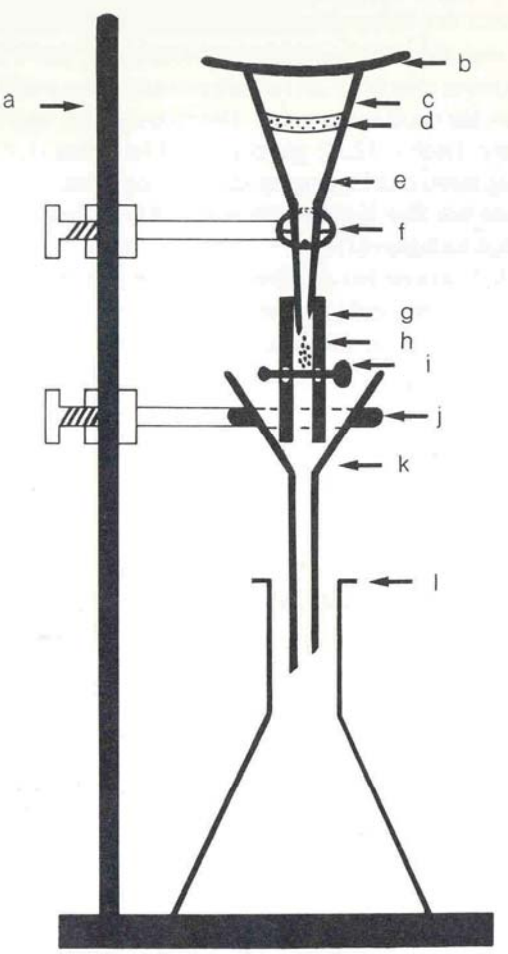
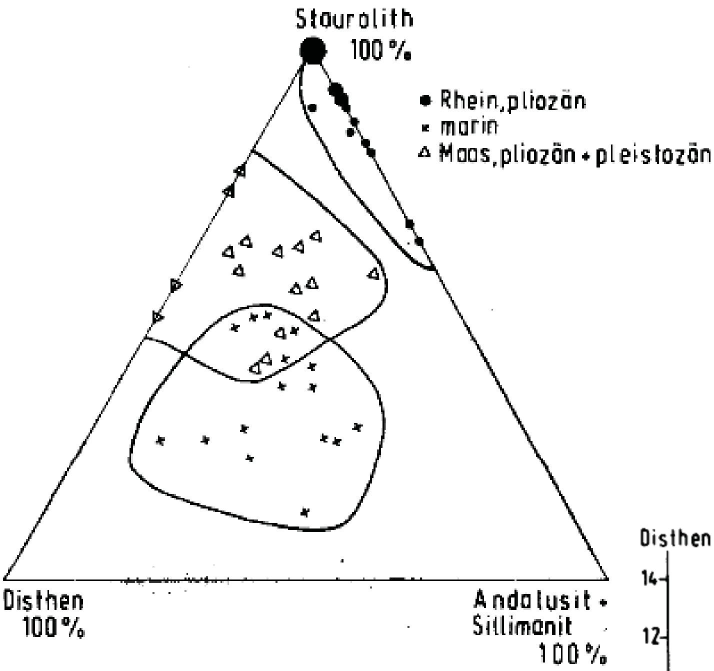
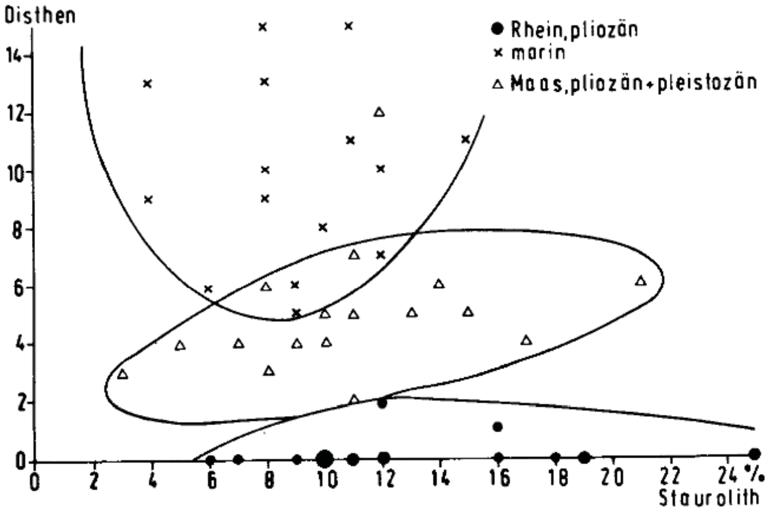


Abb. 1 Geräteaufbau zur gravitativen Trennung von Schwer- und Leichtmineralfraktion: (**a**) Stativ; (**b**) Uhrgläschen; (**c**) Scheidetrichter; (**d**) Lage der Leichtfraktion; (**e**) Schwereflüssigkeit; (**f**) Stativring; (**g**) Gummischlauch; (**h**) Lage des Schwererückstandes; (**i**) Schlauchklemme; (**j**) Stativring; (**k**) Trichter mit Filter; (**l**) Sammelflasche.

Tabelle 3 Gegenüberstellung von Schwerkrafttrennung und Zentrifugentrennung

	Schwerkrafttrennung	Zentrifugentrennung
Geräteaufwand	gering, Scheidetrichter	hoch, Zentrifuge, flüssige Luft
Kosten	mittel: etwas mehr Bromoform als beim Zentrifugieren	mittel: etwas weniger Bromoform, dafür aber Geräteeinsatz
Arbeitsgeschwindigkeit	50–100 Trennungen/Tag	50–100 Trennungen/Tag
Probenmenge	2–20 g/Analyse	1–3 g/Analyse
Qualität der Abtrennung		
bei 400–200 µm		
Menge	± 100%	90–100%
Reproduzierbarkeit	sehr gut	mäßig
bei 200–100 µm		
Menge	96–100%	98–100%
Reproduzierbarkeit	sehr gut	gut
bei 100–63 µm		
Menge	75–95%	± 100%
Reproduzierbarkeit	gut	sehr gut
bei < 63 µm		
Menge	60–80%	± 100%
Reproduzierbarkeit	mäßig	sehr gut





Boenigk 1983

Grain-size dependence of HM assemblages

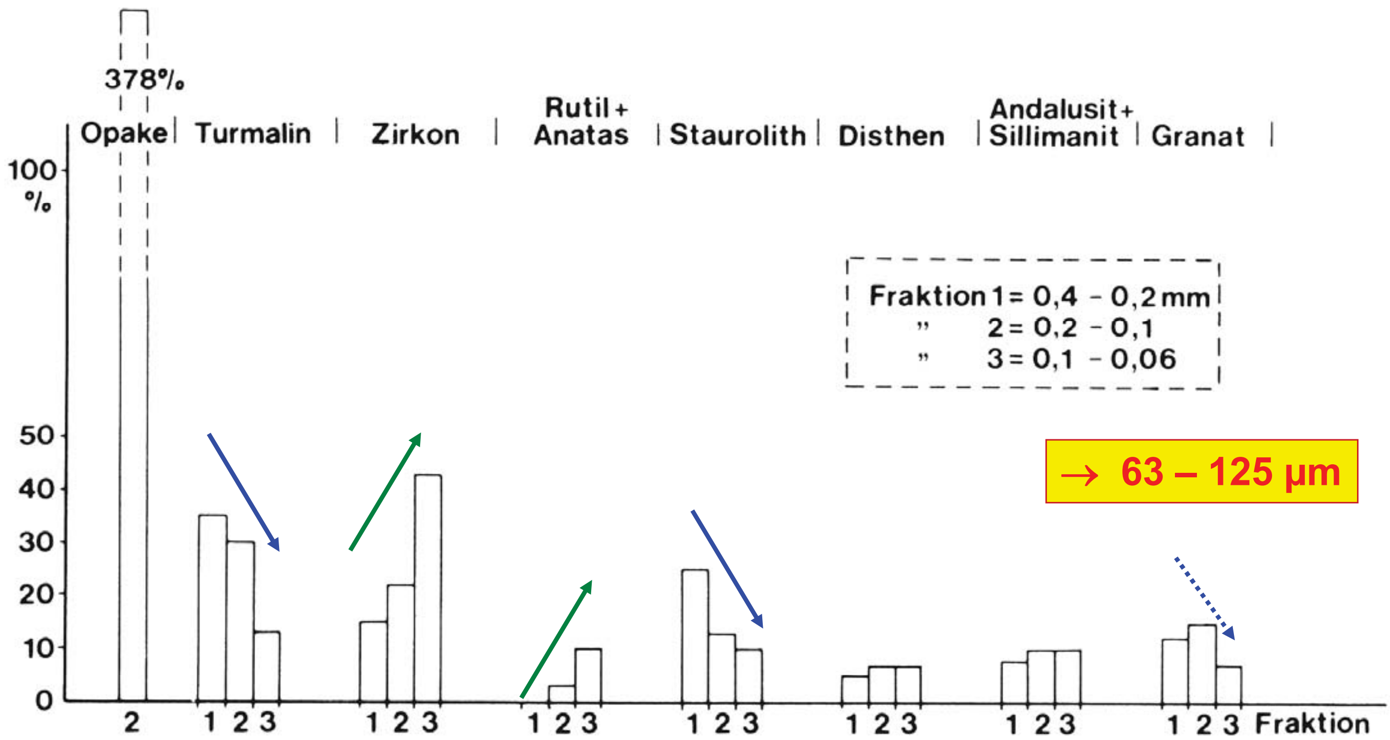
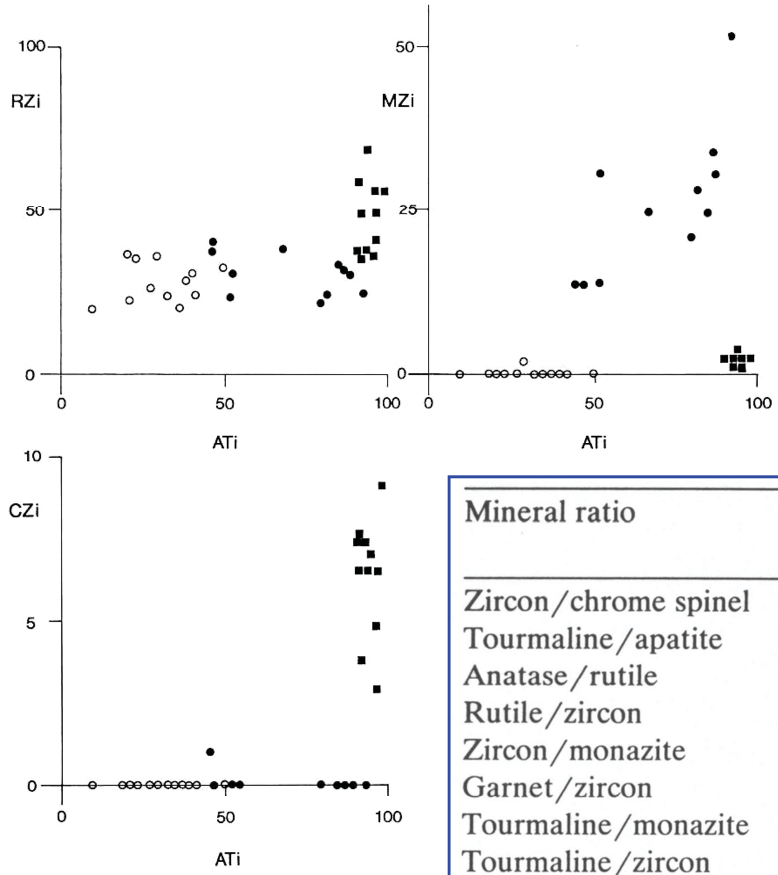


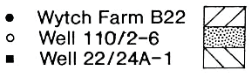
Abb. 17 Säulendiagramm einer fraktionierten Schwermineralanalyse

Boenigk 1983



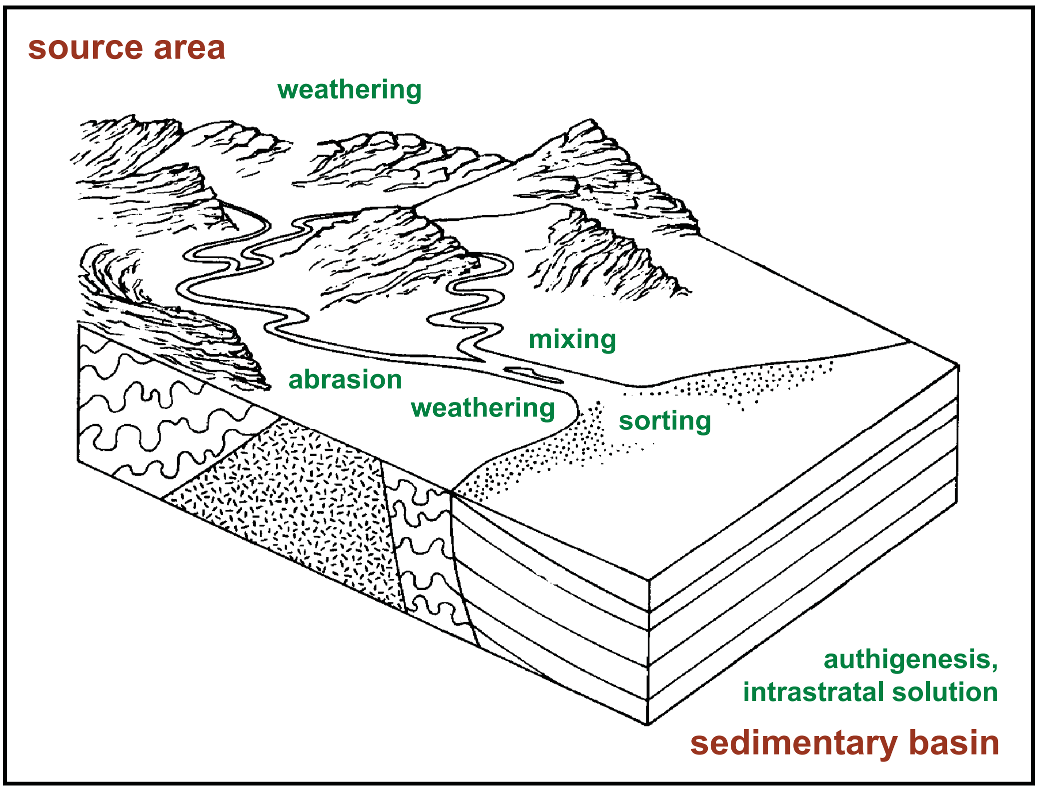
Hydraulic behavior

Mineral ratio	Density ratio	Density differential (%)
Zircon/chrome spinel	0.98	2
Tourmaline/apatite	0.97	3
Anatase/rutile	0.92	8
Rutile/zircon	0.91	9
Zircon/monazite	0.90	10
Garnet/zircon	0.88	12
Tourmaline/monazite	0.61	39
Tourmaline/zircon	0.67	33



Morton & Hallsworth 1994

Modification of HM assemblages



Morton & Hallsworth 1994

sehr instabil
- Olivin

instabil
- Hornblende
- Aktinolith
- Augit
- Diopsid
- Hypersthen
- Andalusit

mäßig stabil
- Epidot
- Disthen
- Granat (Fe-reich)
- Sillimanit
- Titanit
- Zoisit

stabil
- Apatit
- Granat (Fe-arm)
- Staurolith
- Monazit

extrem stabil
- Rutil
- Zirkon
- Turmalin
- Anatas

Mange & Maurer 1991

Occurrence and stability of HM (weathering profiles)

Gneiss, Dolerite, Amphibolite	Crystalline schist	Granite	Tertiary kaolinitic sand	Bavarian molasse	Calcareous sandstones	Aeolian coversands
Northern USA Goldich (1938)	Northern USA Dryden and Dryden (1946)	Germany Piller (1951)	Germany Weyl and Werner (1951)	Germany Grimm (1973)	Germany Lemcke et al. (1953)	England Bateman and Catt (1985)
	Zircon	Zircon		Zircon, Rutile	Zircon, Rutile, Tourmaline, Staurolite	Zircon, Rutile, Tourmaline, Andalusite, Kyanite, Staurolite, Titanite
		Tourmaline		Tourmaline, Andalusite, Kyanite		
	Sillimanite					
	Monazite					
	Kyanite		Kyanite		Kyanite, Epidote	
	Calcic amphibole				Calcic amphibole	
	Staurolite		Staurolite	Staurolite		
			Epidote	Epidote		
					Apatite	
Garnet	Garnet	Garnet	Garnet	Garnet, Apatite	Garnet	Garnet
Calcic amphibole			Calcic amphibole	Calcic amphibole		
						Epidote
Clinopyroxene	Orthopyroxene			Clinopyroxene, Olivine		Clinopyroxene, Orthopyroxene, Calcic amphibole
		Apatite				Apatite
Olivine						

- decreasing stability -

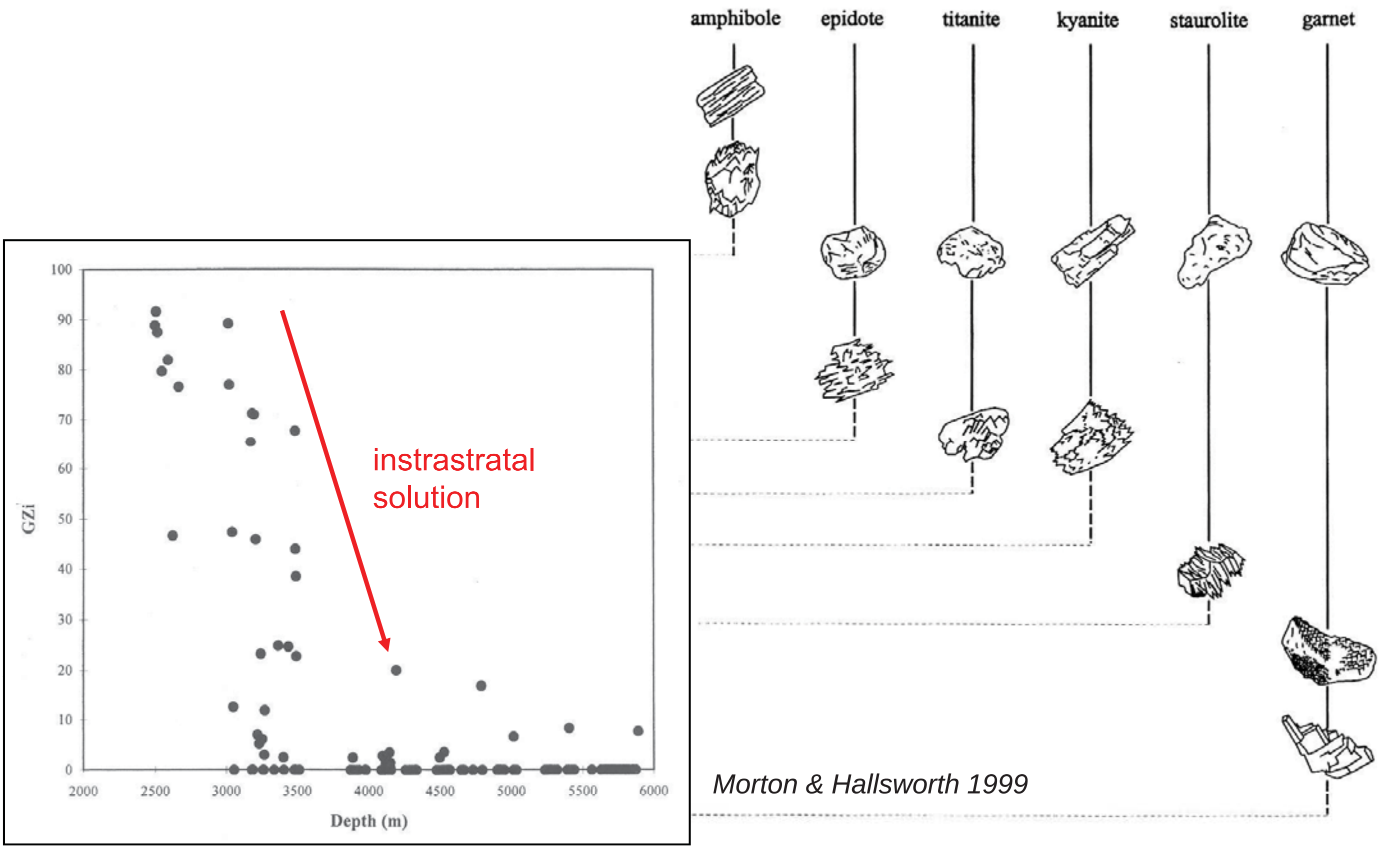
Morton & Hallsworth 1999

Tabelle 1 Beständigkeitsreihe und verallgemeinerte Stabilitätsreihe der häufigsten Schwerminerale. Die Minerale sind mit zunehmender Stabilität von oben nach unten aufgelistet.

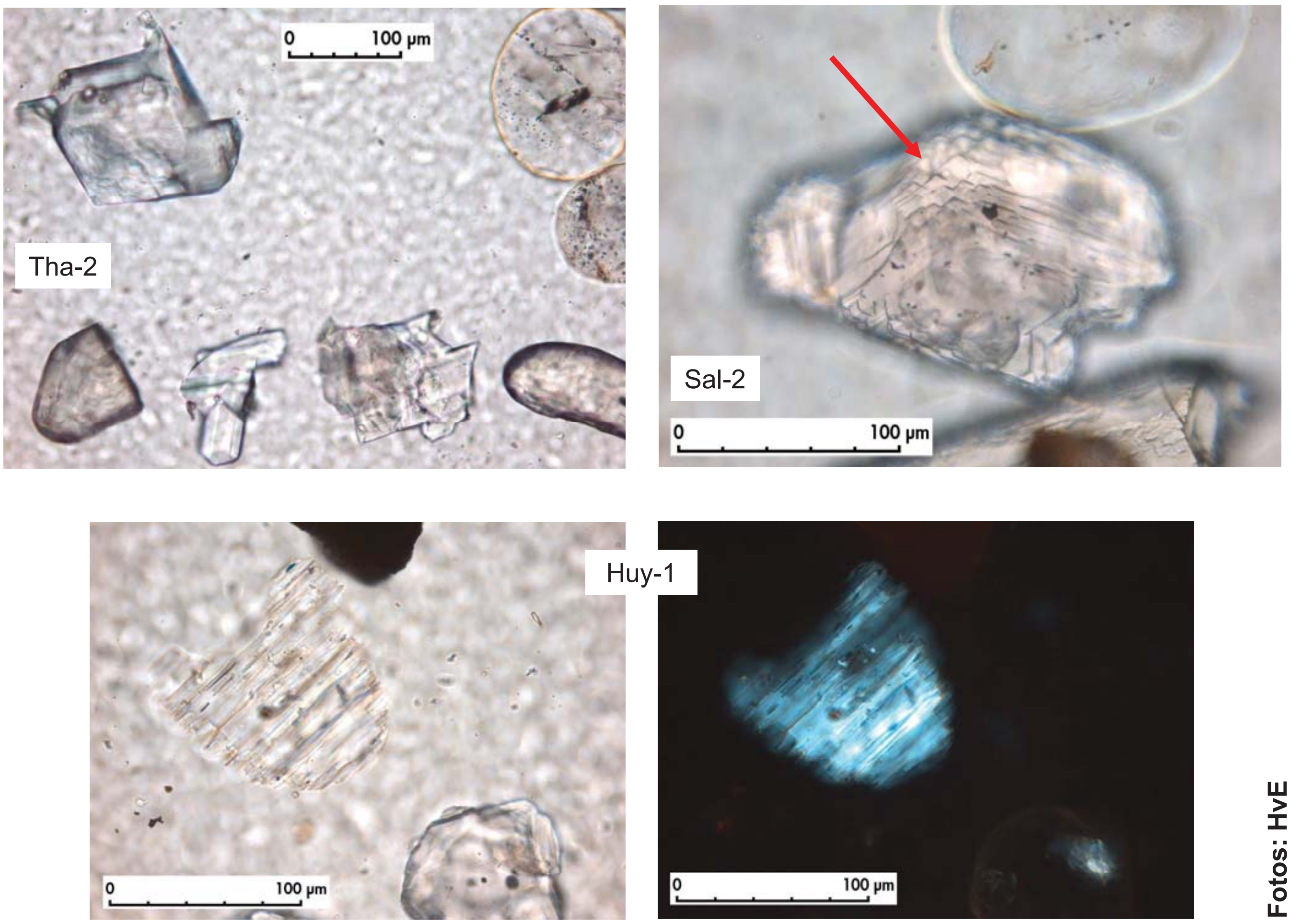
Beständigkeitsreihe	Verallgemeinerte Stabilitätsreihe		
modifiziert nach PETTIJOHN (1941)	nach PETTIJOHN et al. (1973) (Glimmer und opake Minerale ausgenommen)	Stabilität gegenüber saurer Auslaugung (nach MORTON 1985a)	Stabilität gegenüber tiefer Versenkung, salziger oder alkalischer Porenflüssigkeit (nach MORTON 1985a)
Olivin Sillimanit Pyroxene Titanit Andalusit Ca-Amphibole Glaukophan-Riebeckit-Reihe Epidot Disthen Staurolith Monazit Xenotim Apatit Granat Zirkon Turmalin Rutil	*sehr instabil* Olivin *instabil* Hornblende Aktinolith Augit Diopsid Hypersthen Andalusit *mäßig stabil* Epidot Disthen Granat (Fe-reich) Sillimanit Titanit Zoisit *stabil* Apatit Granat (Fe-arm) Staurolith Monazit *extrem stabil* Rutil Zirkon Turmalin Anatas	Olivin, Pyroxene Amphibole Titanit Apatit Epidot, Granat Chloritoid, Spinell Staurolith Disthen Andalusit, Sillimanit, Turmalin, Rutil, Zirkon	Olivin, Pyroxene Andalusit, Sillimanit Amphibole Epidot Titanit Disthen Staurolith Granat* Apatit*, Chloritoid, Titanit, Rutil, Turmalin, Zirkon * nach neueren Beobachtungen von M. MANGE scheint Granat und Apatit stabiler als Chloritoid zu sein. Die Reihe zunehmender Stabilität ab Staurolith lautet daher: Staurolith Chloritoid Granat Spinell Apatit Rutil, Turmalin, Zirkon

Mange & Maurer 1991

Modification of HM assemblages



Morton & Hallsworth 1999



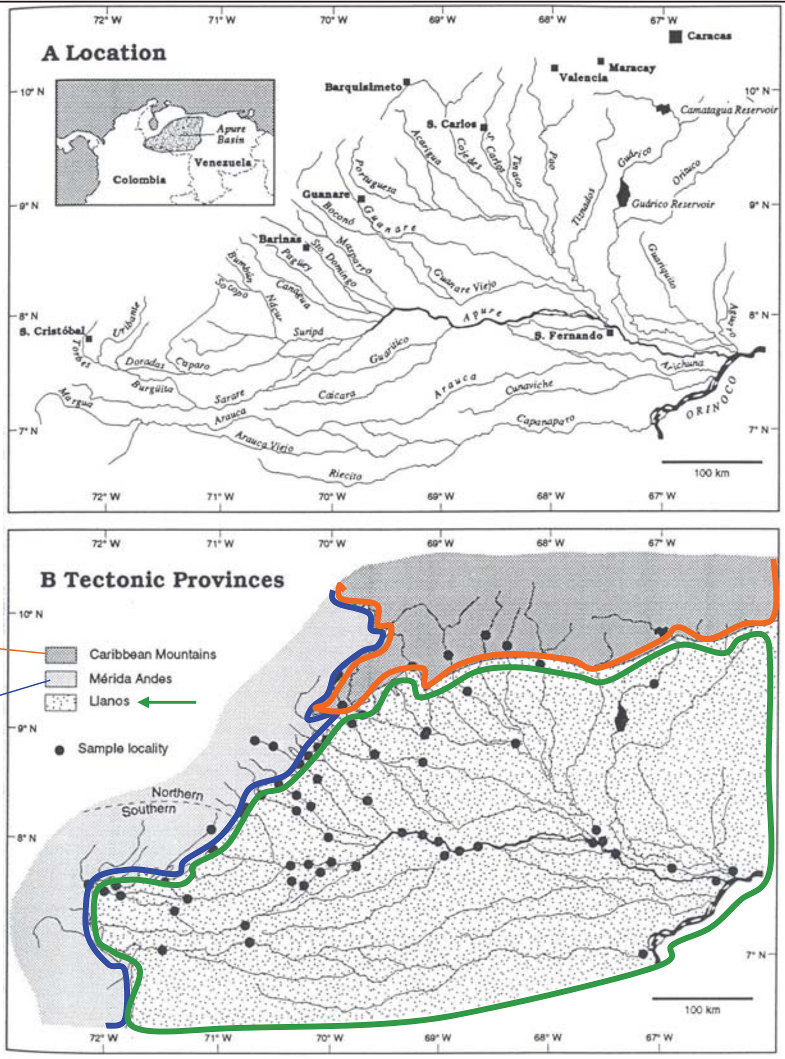
Fotos: HvE

Weathering on transit (alluvial storage)

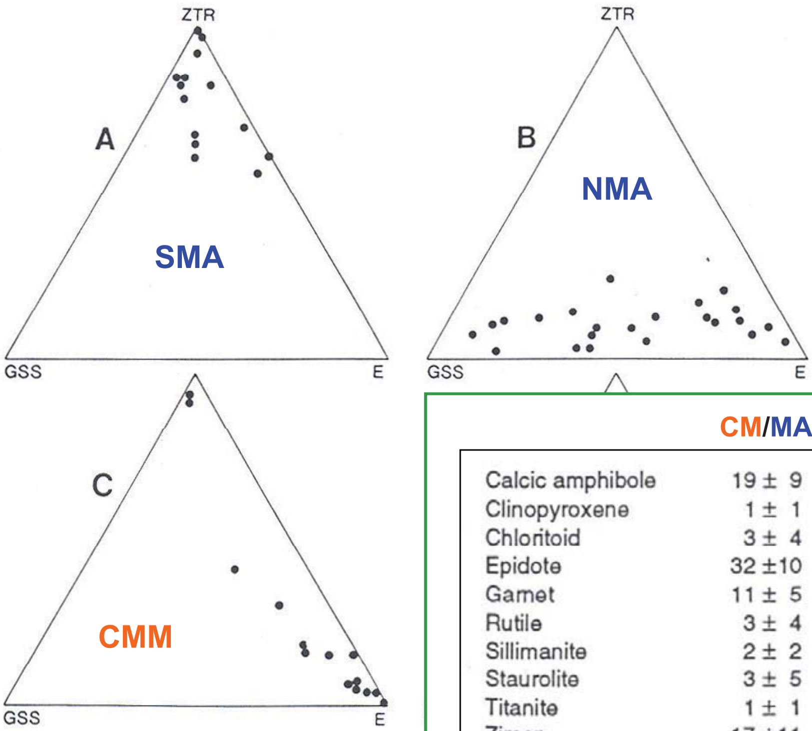
example by Morton & Johnsson 1993

CMM

SMA / NMA



Weathering on transit

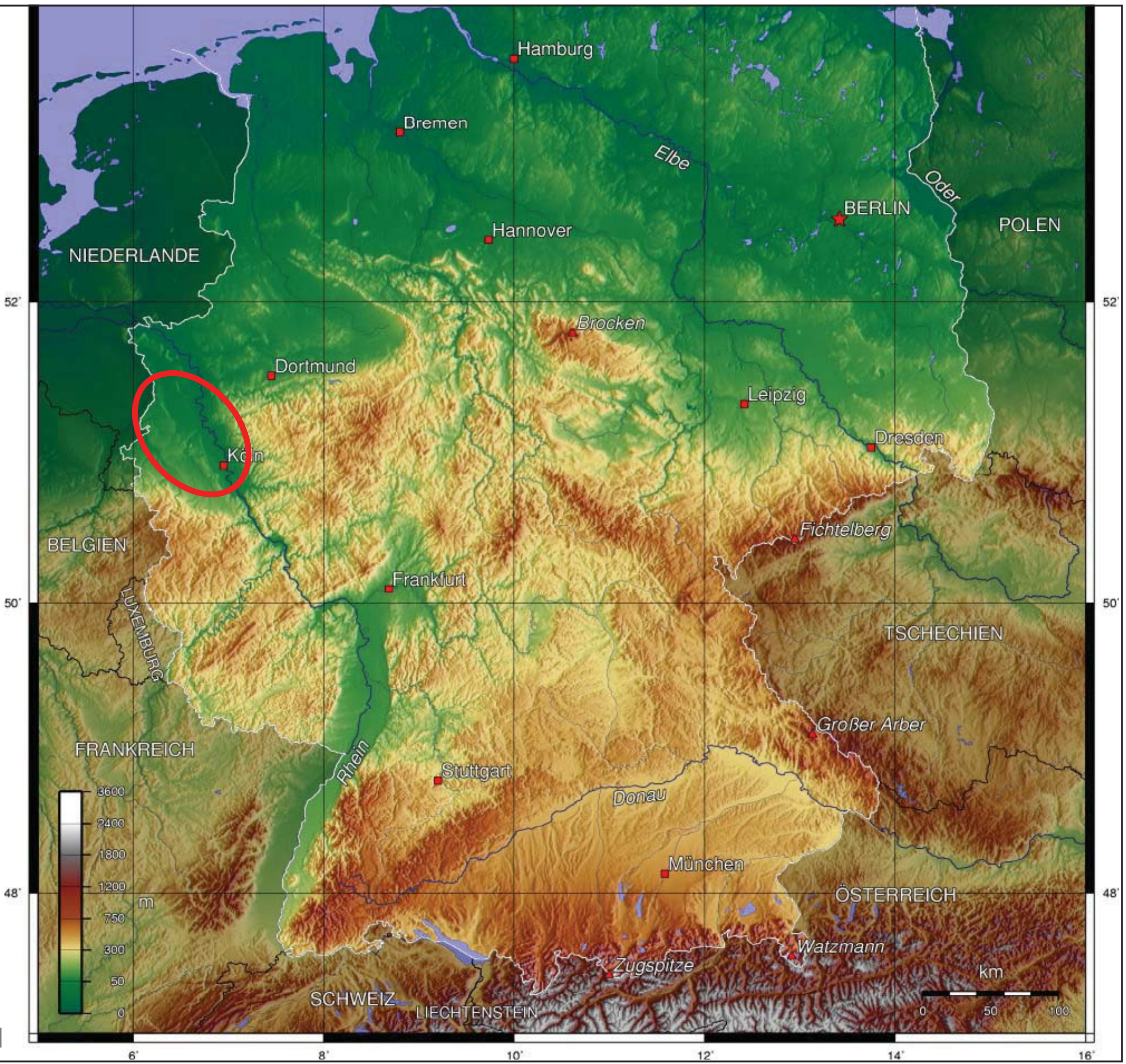


Morton & Johnsson 1993

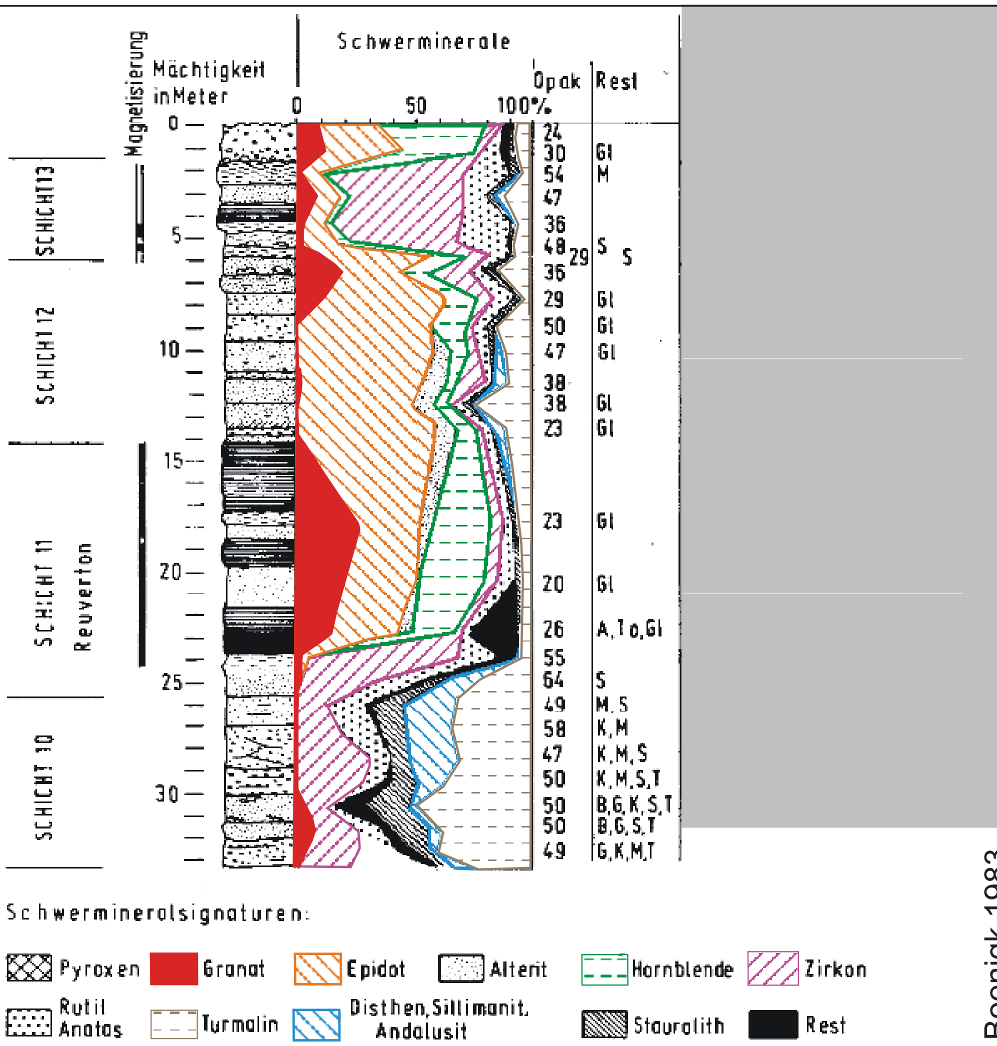
	CM/MA	prox.	mid.	dist.
		Llanos		
Calcic amphibole	19 ± 9	25 ± 7	23 ± 6	19 ± 8
Clinopyroxene	1 ± 1	5 ± 3	1 ± 1	0.1 ± 0.3
Chloritoid	3 ± 4	4 ± 5	1 ± 2	1 ± 2
Epidote	32 ± 10	28 ± 8	32 ± 6	30 ± 22
Garnet	11 ± 5	7 ± 3	7 ± 3	6 ± 4
Rutile	3 ± 4	5 ± 3	3 ± 1	4 ± 4
Sillimanite	2 ± 2	4 ± 2	4 ± 1	3 ± 1
Staurolite	3 ± 5	2 ± 2	1 ± 1	2 ± 1
Titanite	1 ± 1	2 ± 1	2 ± 1	3 ± 3
Zircon	17 ± 11	20 ± 10	17 ± 9	28 ± 29
Number of samples	25	25	10	5
ZTR Index†	26 ± 14	24 ± 12	23 ± 11	35 ± 32
Apatite-tourmaline index (ATi)	57 ± 13	51 ± 11	43 ± 17	20 ± 17

Example:

Lower Rhine Bay, Cologne

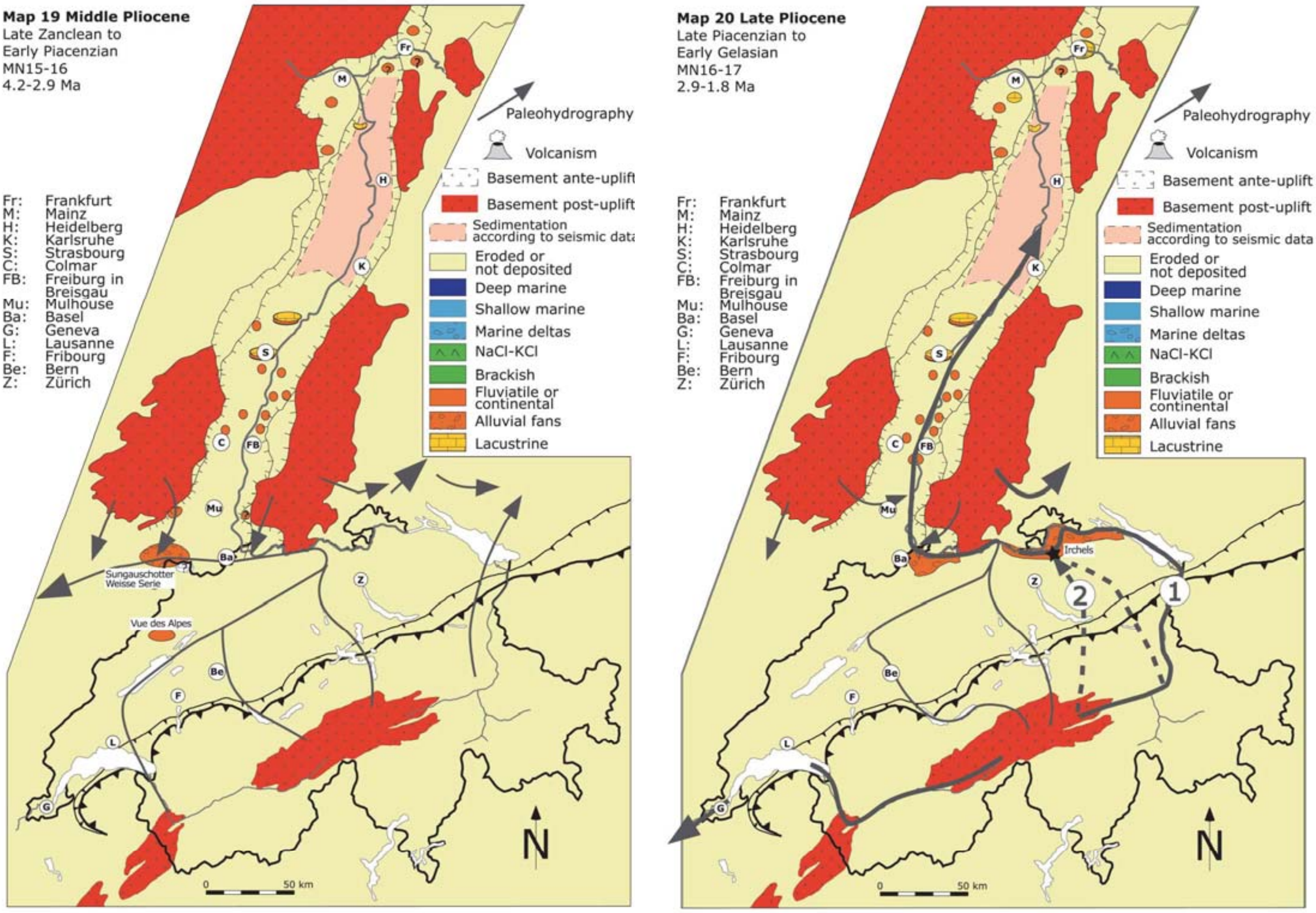


HvE - Sedimentpetrol



Boenigk 1983

HvE - Sedimentpetrologie



Berger et al. 2005

Schwerminerale

→ Minerale mit spezifischer Dichte ρ > 2.89 (2,86) g/cm^3
(engl.: *heavy minerals* oder *dense minerals*)

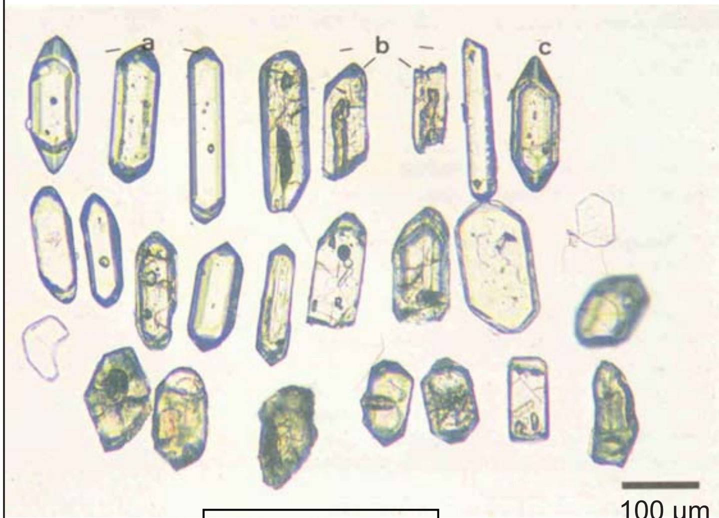
→ <u>Charakteristische Merkmale:</u>

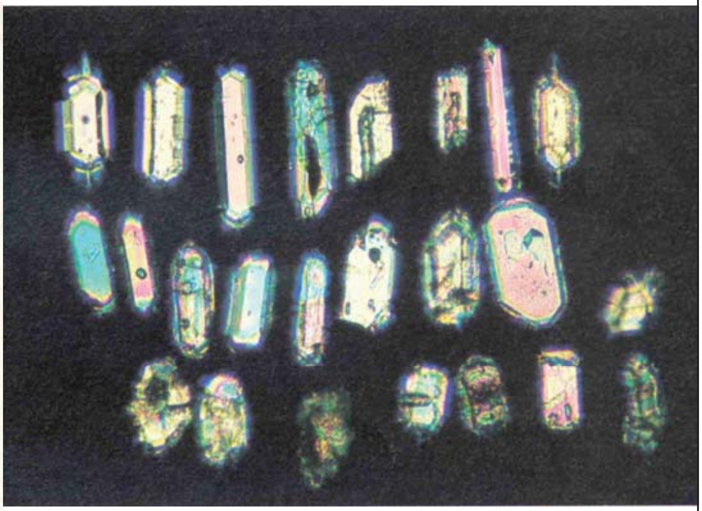
- Habitus (Form, Spaltbarkeit, Oberflächenstruktur, ...)
- Farbe (Pleochroismus!)
- Lichtbrechung (unterschiedl. Einbettungsmittel!)
- Doppelbrechung (Mineraldicke und -orientierung beachten!)
- Auslöschung, opt. Charakter/Interferenzbild, Einschlüsse, ...

→ für die spezifische Merkmale der einzelnen Minerale siehe v.a. **Mange & Maurer 1991;** im Skript sind nur einige Folien enthalten mit Bezug zur Schwermineralchemie

zircon

a: Eocene tuff horizon
b: Carboniferous sediments





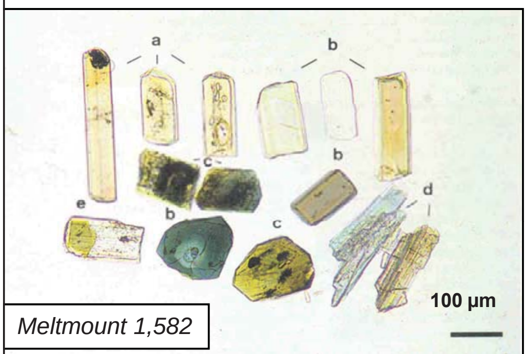
Meltmount 1,662

tetragonal,
ρ = 4.60 – 4.79
n = 1.92 – 2.02
Δ = 0.042 – 0.065

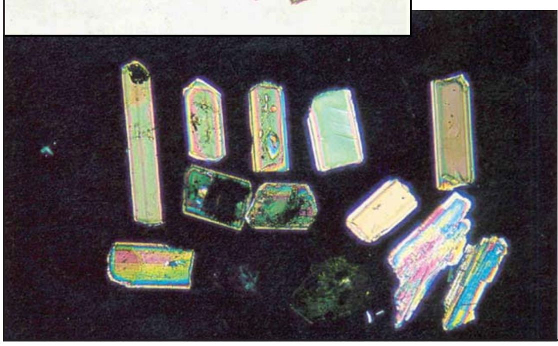
Mange & Maurer 1991

tourmaline

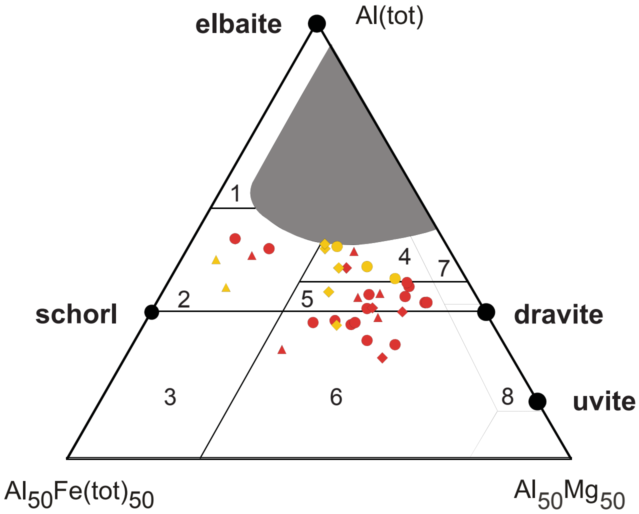
trigonal, **1- ,** ρ = 3.00 – 3.25, n = 1.61 – 1.66, Δ = 0.017 – 0.036



Meltmount 1,582



Mange & Maurer 1991



1,2: granitoid host (source) rocks
4,5,6: metasedimentary host (source) rocks

detrital tourmaline grains: EY 6-1 (LOS), H 1021-5 (BRA), EY 9-34 (BRA)
tourmaline from metasandstone clasts: EY 6-3/b (LOS), EY 6-3/c (LOS), EY 6-3/d (LOS)

Henry & Guidotti 1985,
von Eynatten & Gaupp 1999

rutile – properties and occurrence


Mange & Maurer 1991

- beside sphene and ilmenite the most important Ti - mineral in the earth's crust
- chemistry:

  TiO_2 (>99 wt.-%)

  but ... →

Nb	→	**28000 ppm**
Cr	→	**4400 ppm**
Fe	→	**>30000 ppm**
Zr	→	**8400 ppm**
V	→	**7600 ppm**
W	→	**8100 ppm**
U	→	**84 ppm**

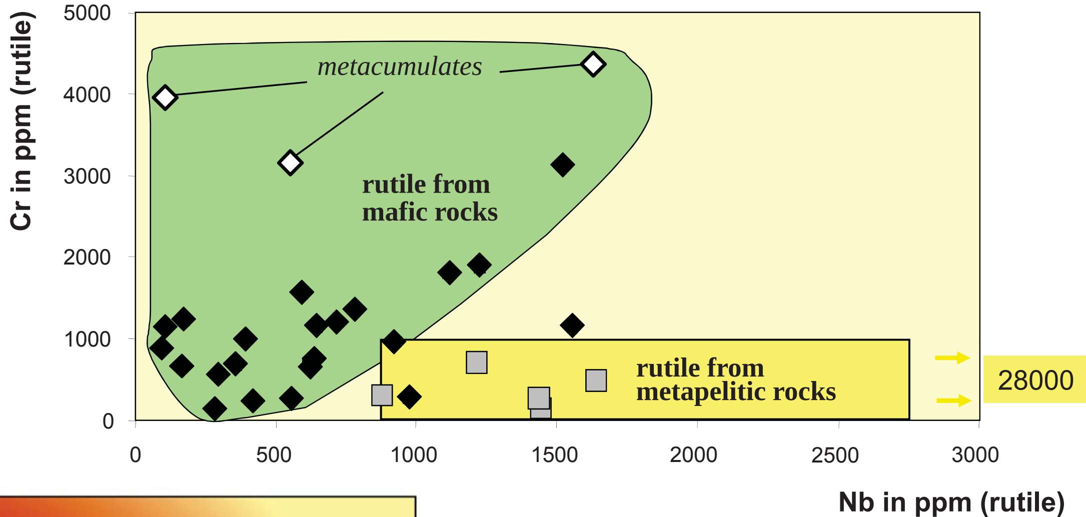
tetragonal, **1 +**
n = 2.61 – 2.90
Δ = 0.286 – 0.296

- main primary occurrence in medium to high-grade metamorphic rocks
- stable in sedimentary environments

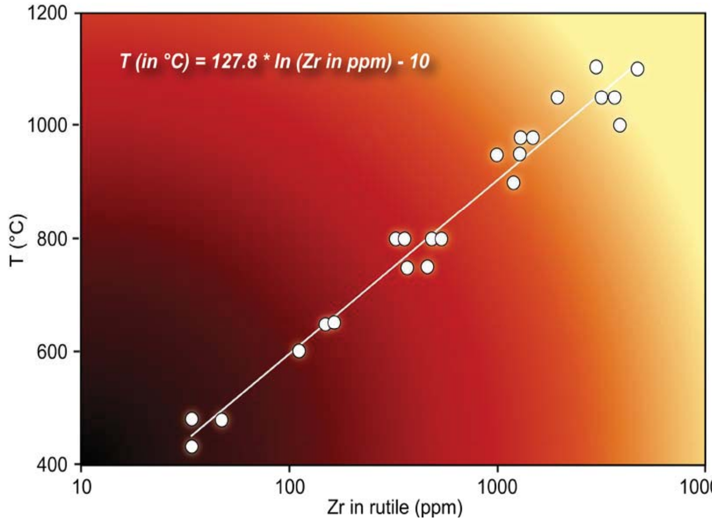
→ **frequent occurrence as heavy mineral in (mature) clastic sediments**

→ **used for maturity (ZTR) and other indices reflecting source materials (RZi)**

rutile



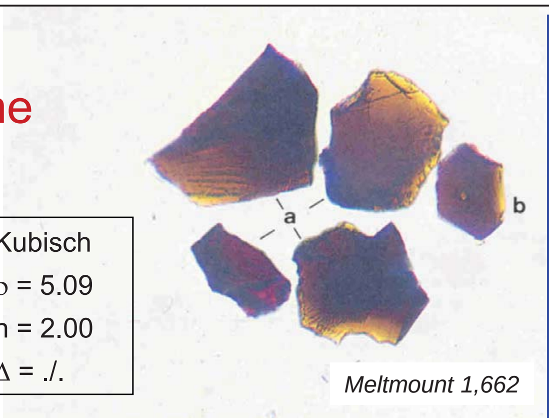
Zack et al. 2002, Chem Geol 184

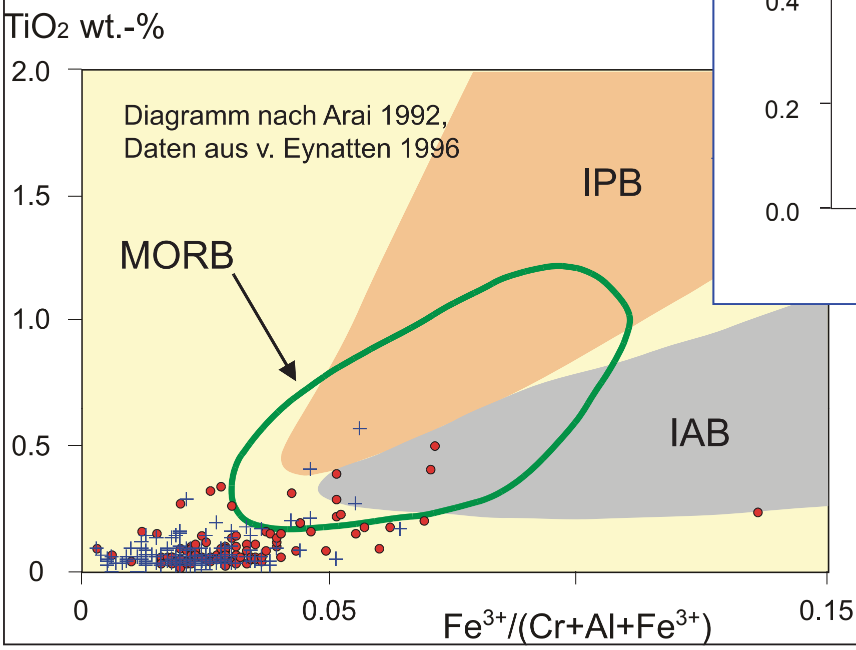


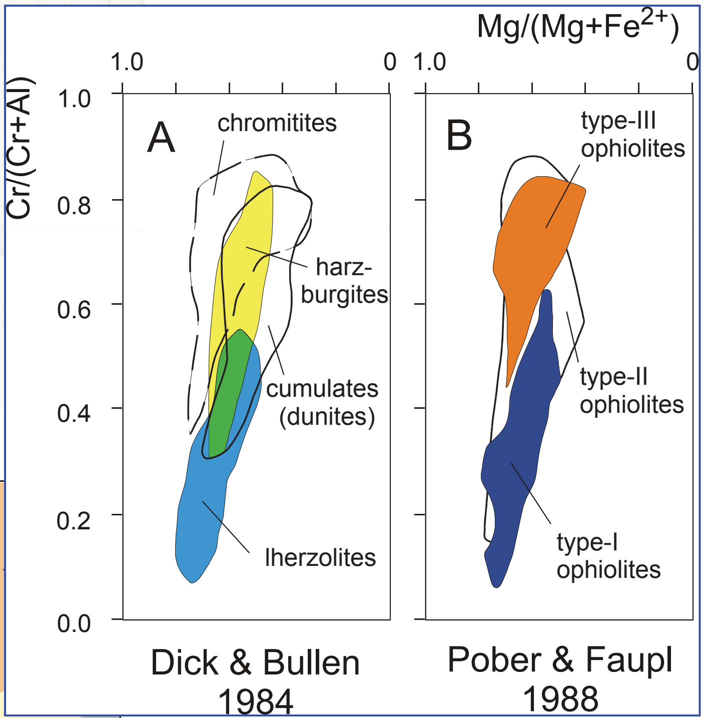
Zack et al. 2004, CMP 184

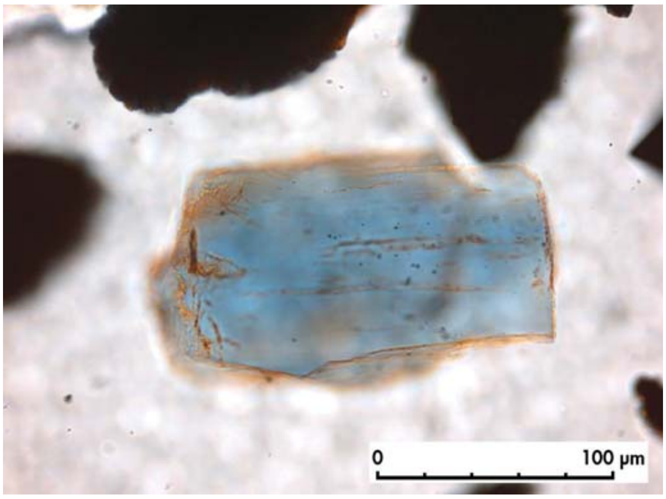
chrome spinel

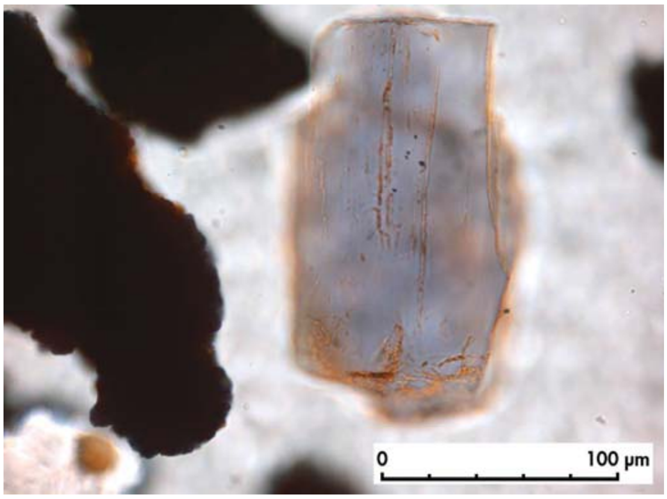
Kubisch
ρ = 5.09
n = 2.00
Δ = ./.



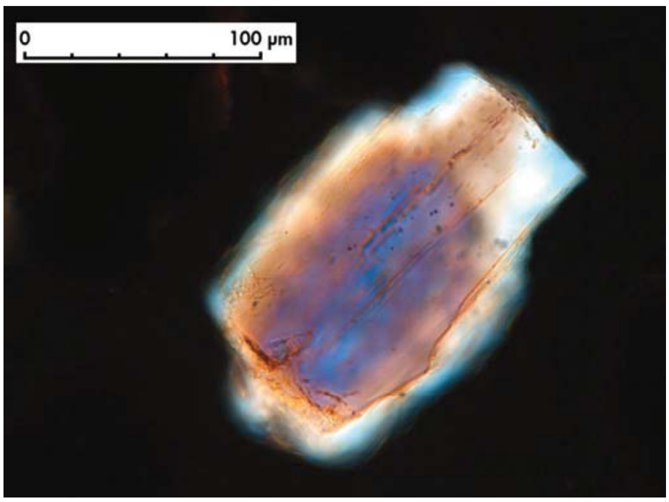




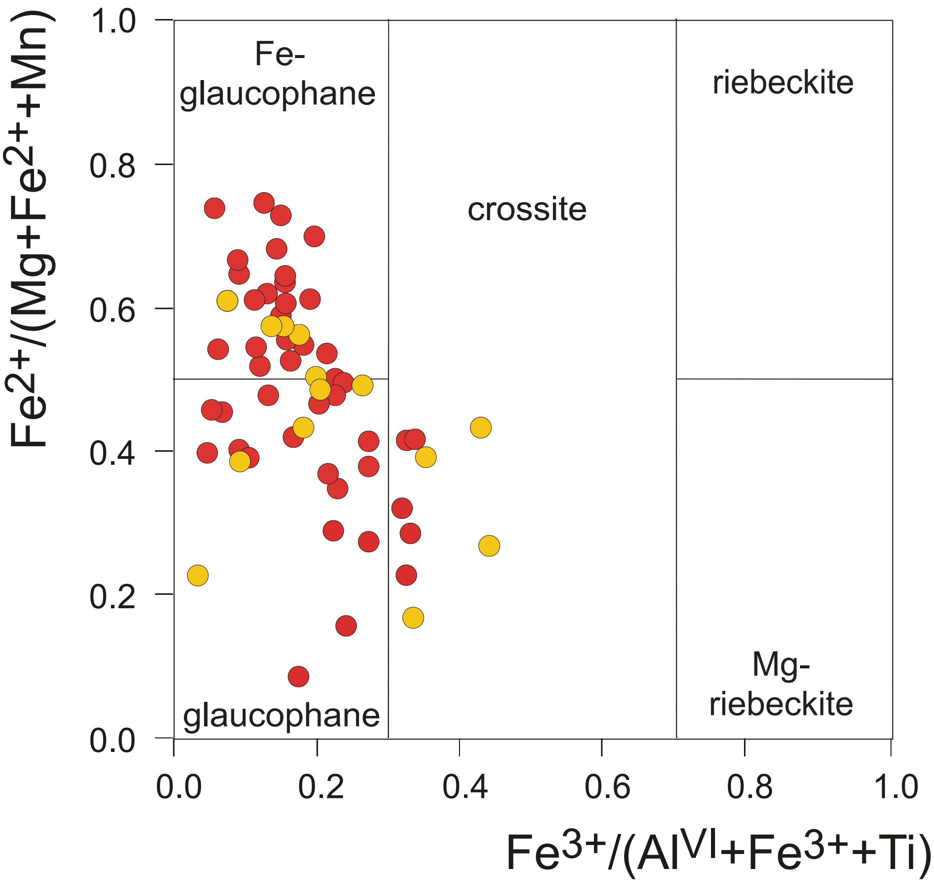




amphibole - ?



blue sodic amphiboles



von Eynatten et al. 1999, Sed. Geol.

(G) Case Studies

1. Oligo-/Miozänes Vorland der Betischen Kordillere

2. Schweizer Molassebecken (Zentralalpen-Vorland)

3. Subherzynes Kreidebecken (Harz-Vorland)

4. ... ...