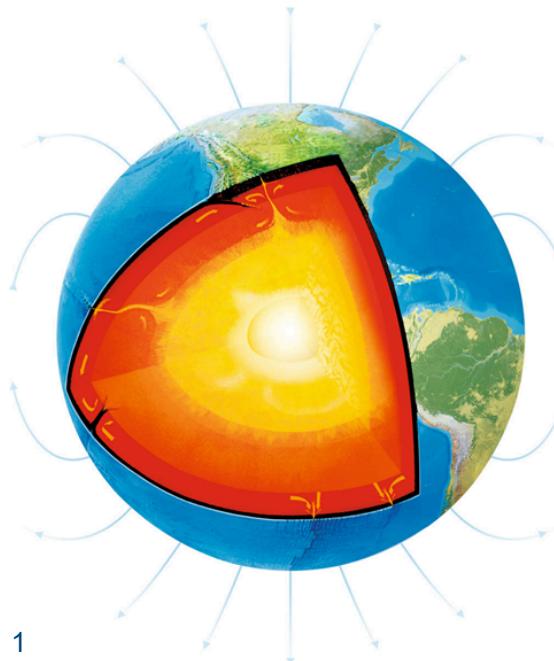


Einführung in die Geophysik

Teil 3: Gravimetrie+Geomagnetik

2. BSc Geophysik und Geoinformatik (BGIP)

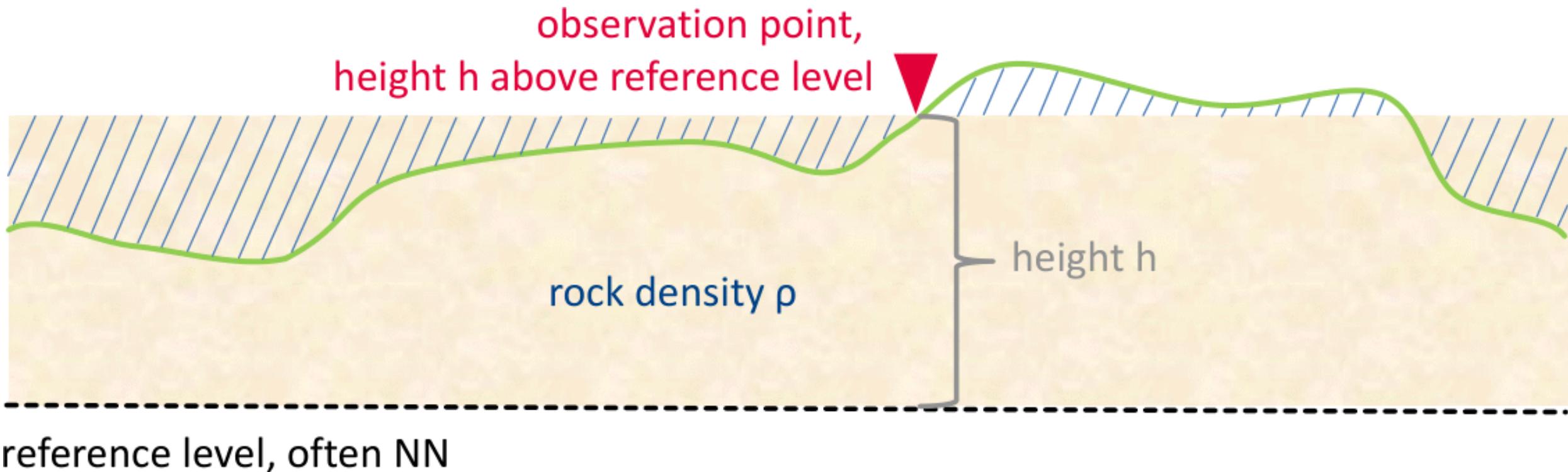


Thomas Günther
(thomas.guenther@geophysik.tu-freiberg.de)

Previously on AnGy

- Newtonsche Gesetze der Mechanik, Gravitationsbeschleunigung
- Potentialfeld (wegenabhängig)
- Kugel(schale) erzeugt Potential wie Punktmasse im Inneren
- Dichteverteilung & Beschleunigung im Erdinneren
- Residuen ($1\mu\text{Gal}-10\text{mGal}$) 1 Mio Mal schwächer als g
- Korrekturen: Normalschwere, Freiluft, Bouguer, Topographie

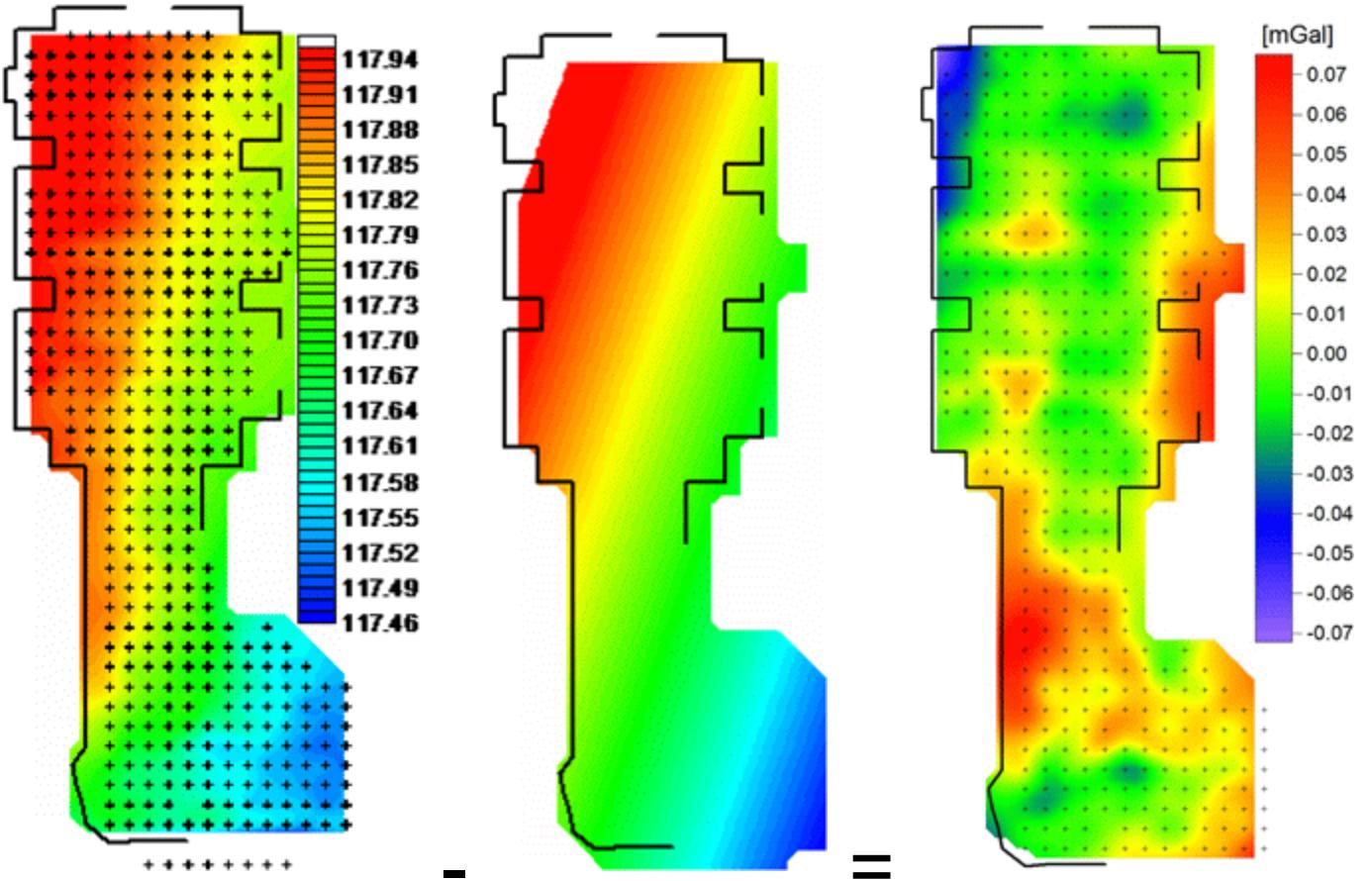
Bouguer-Anomalie



$$g'' = g_{obs} - [\gamma - 0.3086h - 2\pi G \varrho h - \delta g_{Topo}]$$

Normalschwere Referenzellipsoid: $\gamma = \gamma_e(1 + \beta \sin^2 \phi - \beta_1 \sin^2 2\phi)$

Residuenbestimmung

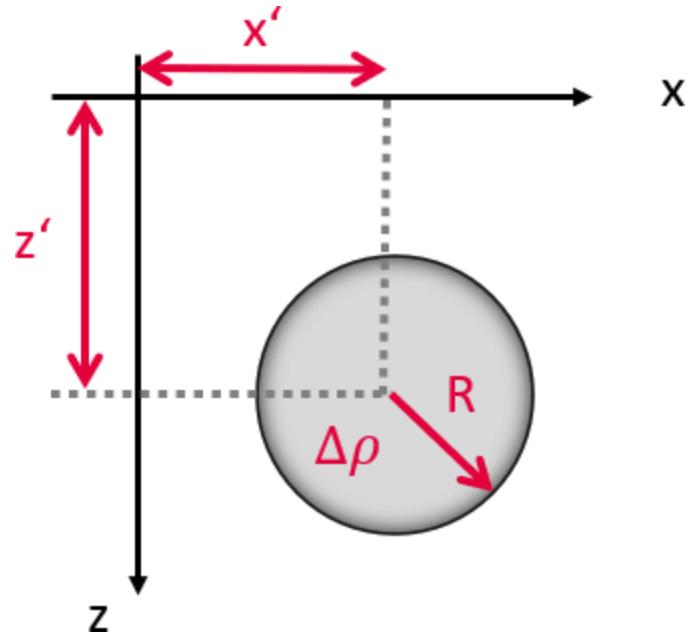


Abziehen des globalen
Anteils (Mittelwert und
Trend) ergibt Residuum

Anomalien erzeugt von
Dichteunterschieden

Störkörper-Formeln

$$\vec{g} = -G \int_{\text{body}} \frac{\varrho}{r^2} \frac{\vec{r}}{r} dV$$



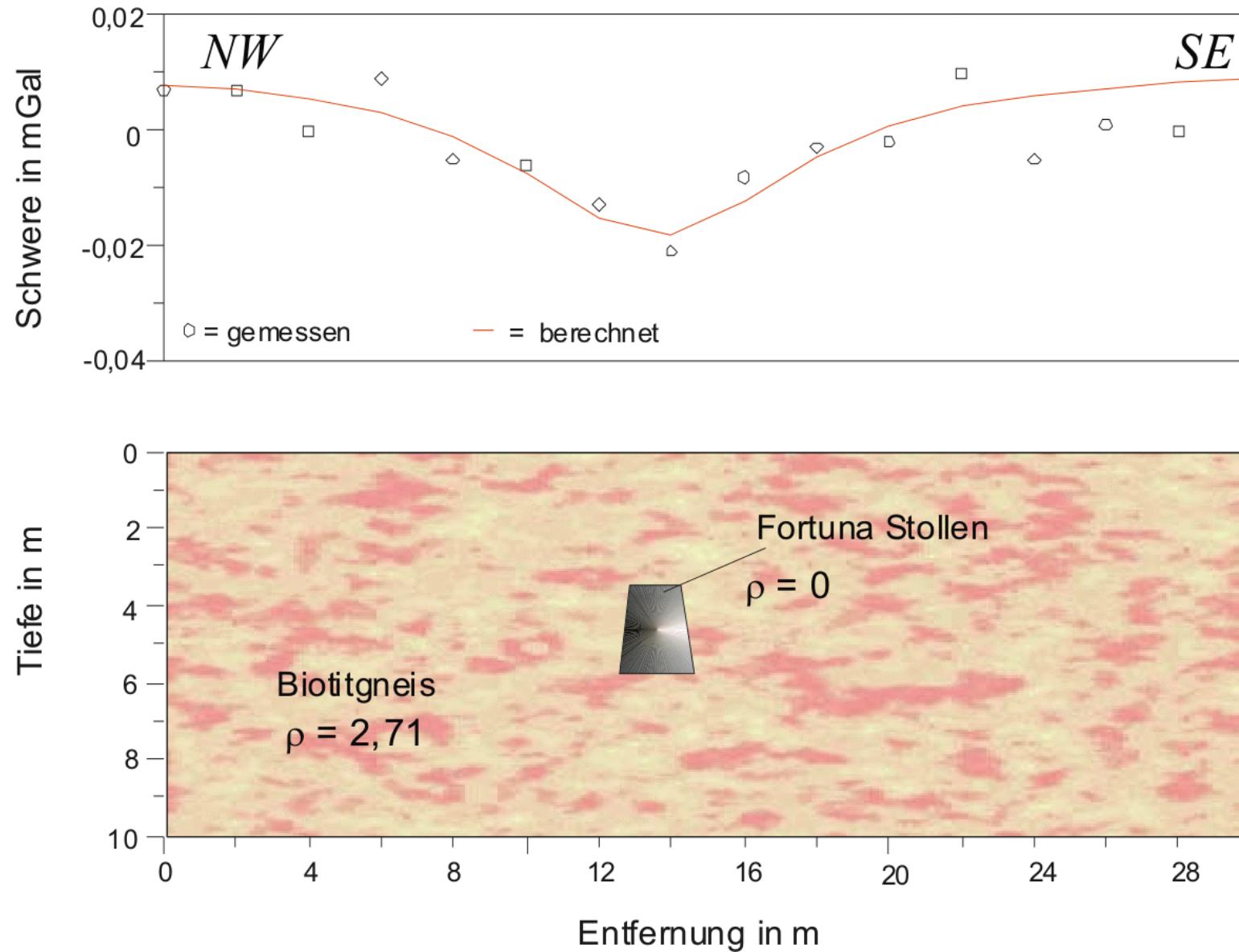
Kugel (=Punktmasse)

$$\vec{g} = Gm \frac{\vec{r}}{r^3} = \Delta\varrho G \frac{4}{3}\pi R^3 \frac{\vec{r}}{r^3}$$

Liegender Zylinder

$$\vec{g} = GA\Delta\varrho \frac{\vec{r}}{r^3} = \Delta\varrho G 2\pi R^2 \frac{d}{r^2}$$

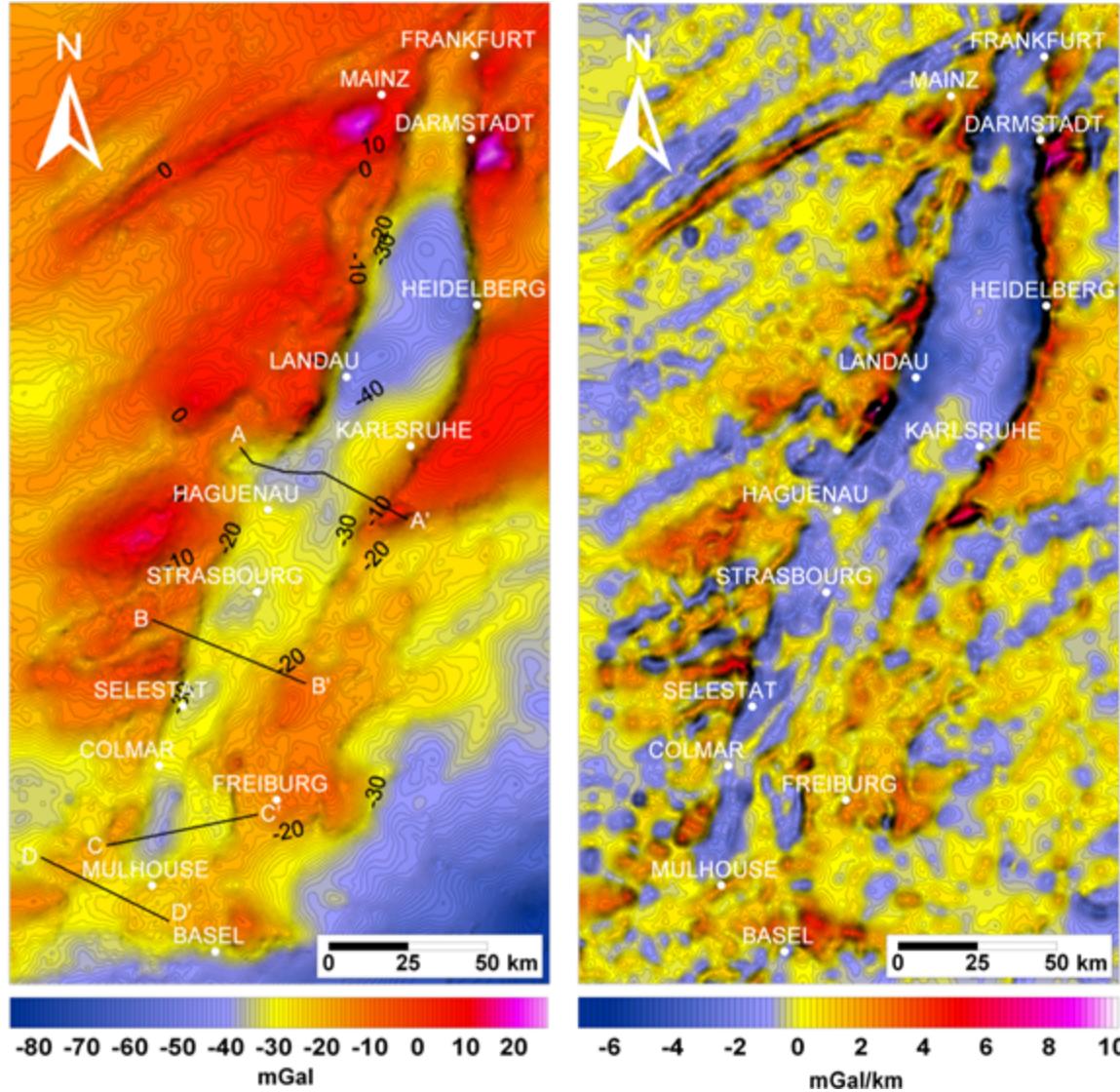
Hohlraumsuche Fortunastollen



Lindner & Casten
(Knoedel et al. 2005)

1 Geophysiker, 1
Meßgehilfe (ich)

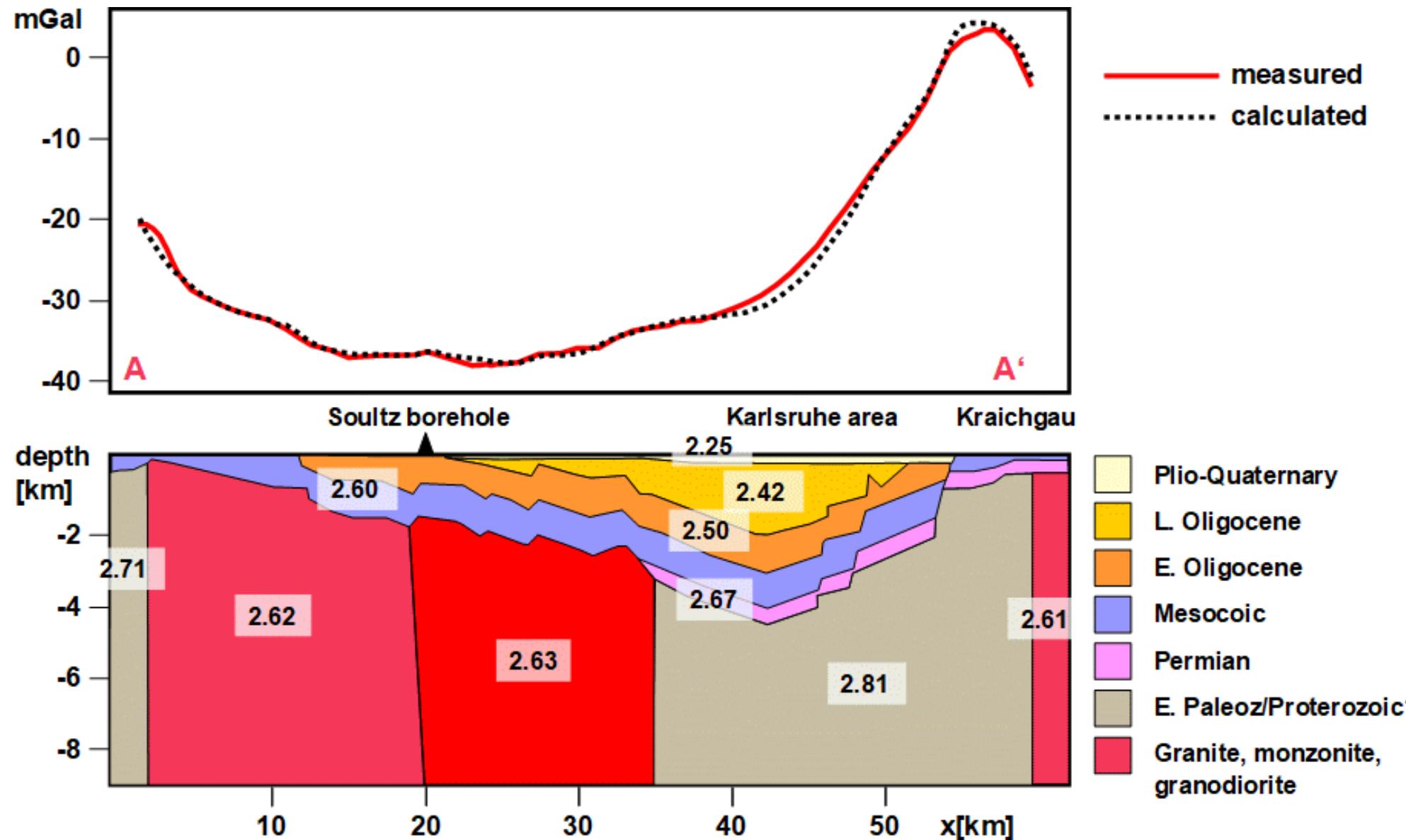
Anomalie Schwere und Schweregradient



Kartierung des Rheingrabens
(Rotstein et al., 2006,
Tectonophysics 425, 55-70)

Vertikal-Gradient g_{zz} hebt
(tektonische) Strukturen hervor

Modellierung



Wrap up gravimetry

1. Focus: geological exploration (large-scale), void search
2. anomalies 0.1-1-10-30 mGal ($1\text{e}-5 \text{ m/s}^2$) 1Mio times smaller than g!
3. variable (spatially & temporally) background field
4. very accurate instruments necessary ($\sim 10\mu\text{Gal}$ for near surface)
5. caused by density (kg/m^3) contrasts: air 0, water 1000, loose sediments 1500-2000, consolidated 2000-2500, hardrocks 2500-3500
6. equivalent models (ambiguity)
7. Solution by forward modelling (simple) structures \Rightarrow structural geological model (seismics helps a lot)
8. Further reading: Knoedel textbooks (DE or EN)

Magnetisierung und Erdmagnetfeld

- Einführung
- Das Erdmagnetfeld
- Messinstrumente
- Anomalien

Magnetfeld - historisches

Anziehung von Magnetit und Eisen früh erkannt
(Thales ca. 600 v.Ch.)

- Chinesischer nasser Navigations-Kompass 11.Jh
- Trockener Kompass durch Peregrinus 1269
- Erste wissenschaftliche Behandlung durch William Gilbert (1600), Erde als Ursache für die Ausrichtung der Kompassnadel erkannt
- Henry Gellibrand entdeckt 1635, dass sich Erdmagnetfeld ändert



Induzierte Magnetisierung

$$\text{Magnetisierung } \mathbf{M} = \kappa \mathbf{H}$$

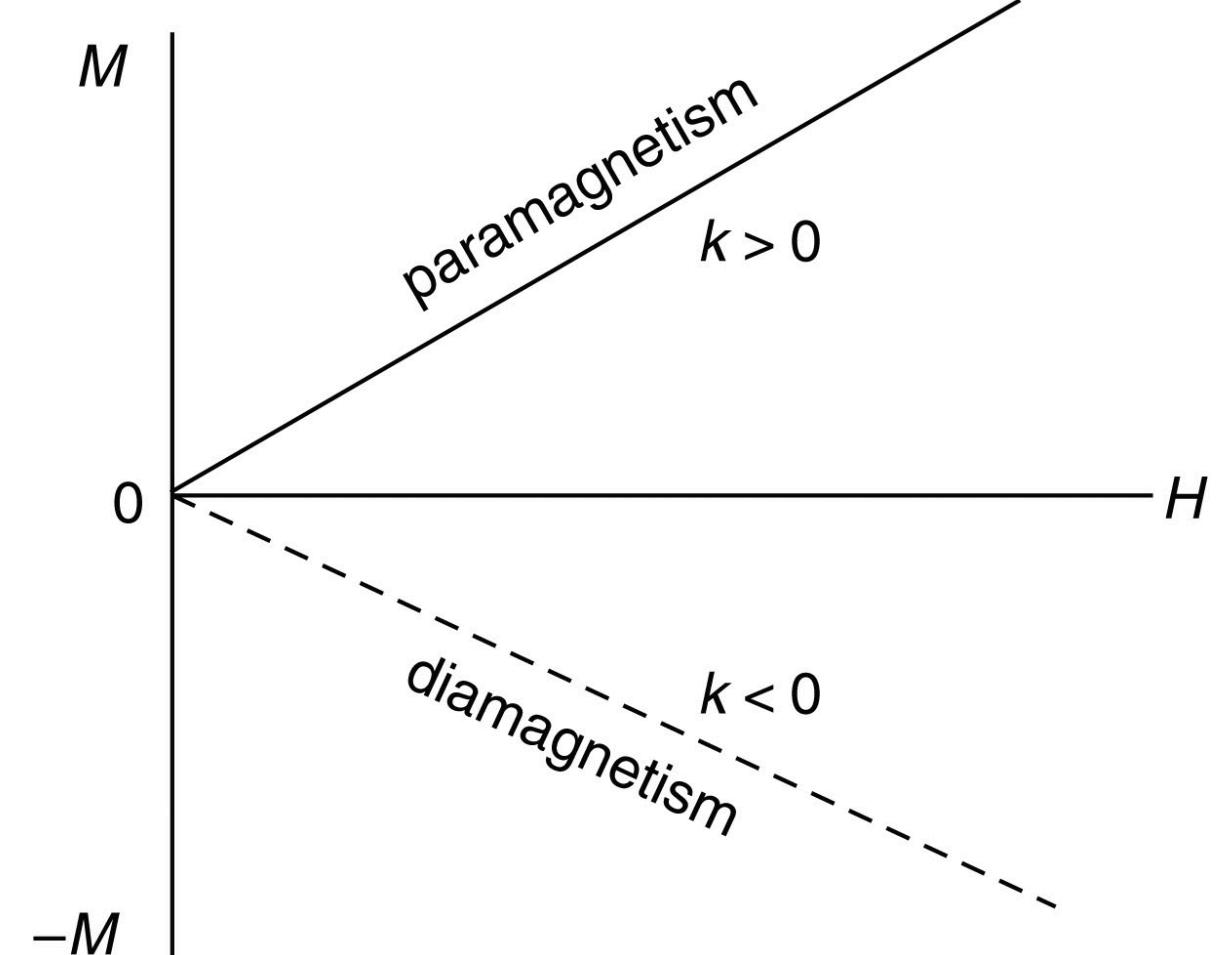
κ .. magnetische Suszeptibilität

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M}) = \mu_0\mathbf{H}(1 + \kappa)$$

$$\mathbf{B} = \mu_r \mu_0 \mathbf{H} \quad \mu_r = 1 + \kappa$$

dia: schwach (-1e-6) & reversibel

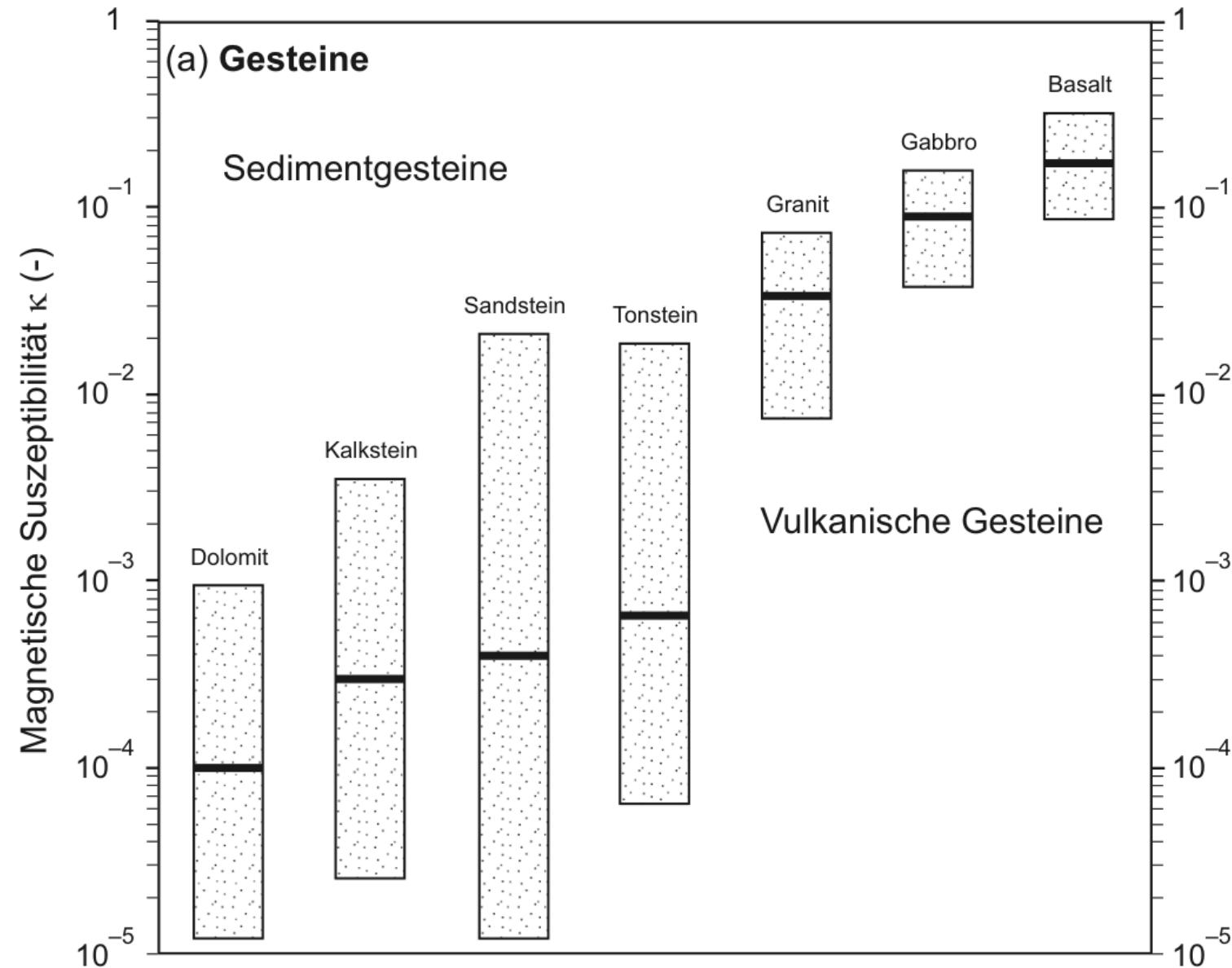
para: $\kappa k = C/T$ (1e-5..1e-4)



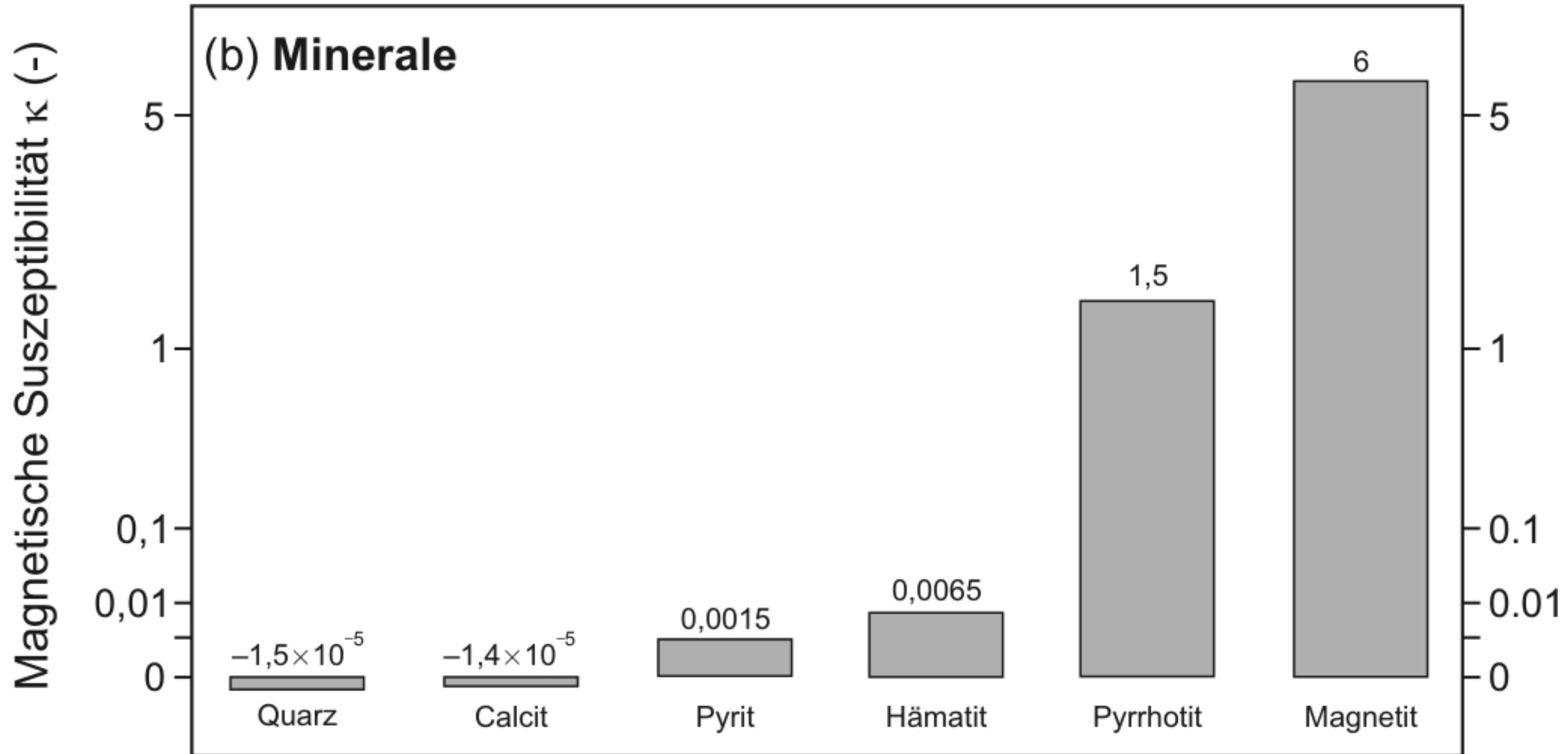
Gesteinsmagnetisierung

	Ferromagnet	Antiferromagnet	Ferrimagnet	Antiferrimagnet (abgeschrägt)
	Fe, Co, Ni	NiO, MnO	Magnetit (Fe_3O_4)	Hematit (Fe_2O_3)
Atomare magnetische Momente				
spontane Netto- Magnetisierung		Null		

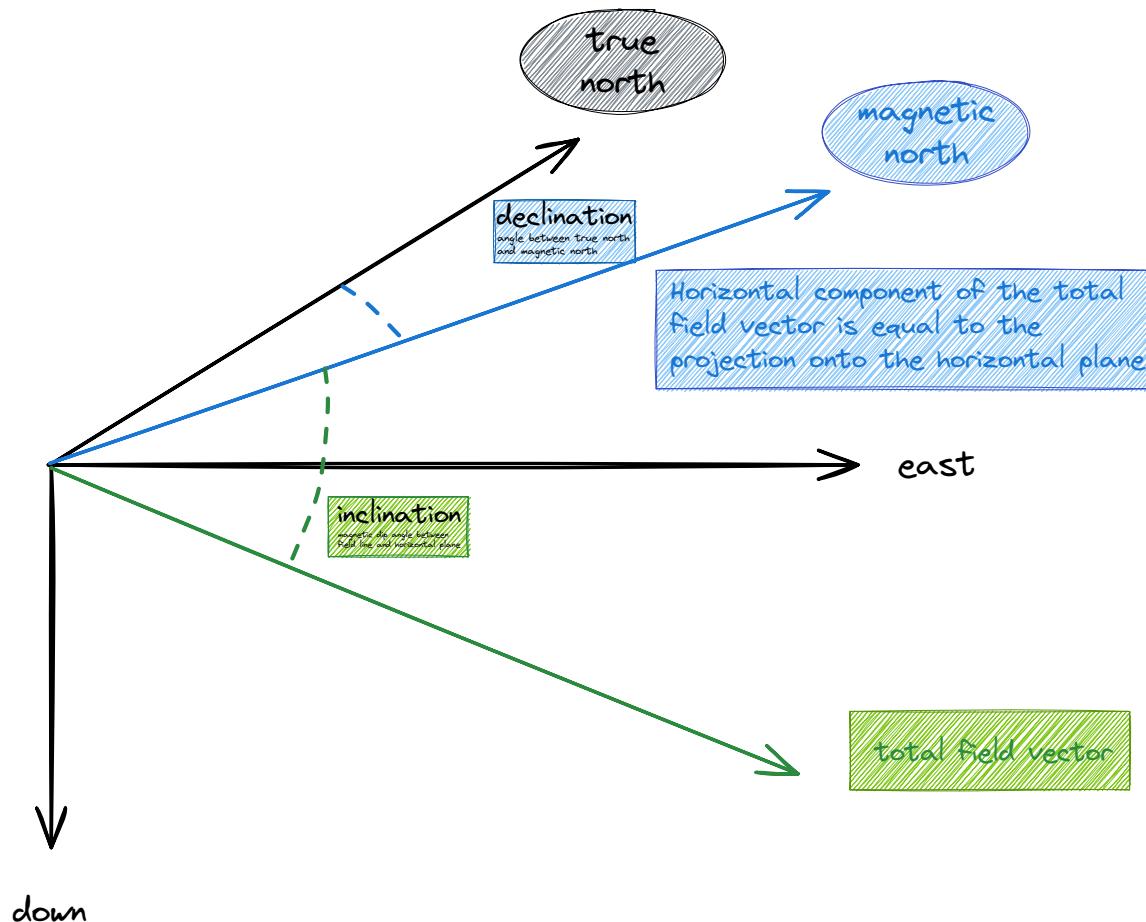
Suszeptibilitäten



Suszeptibilitäten



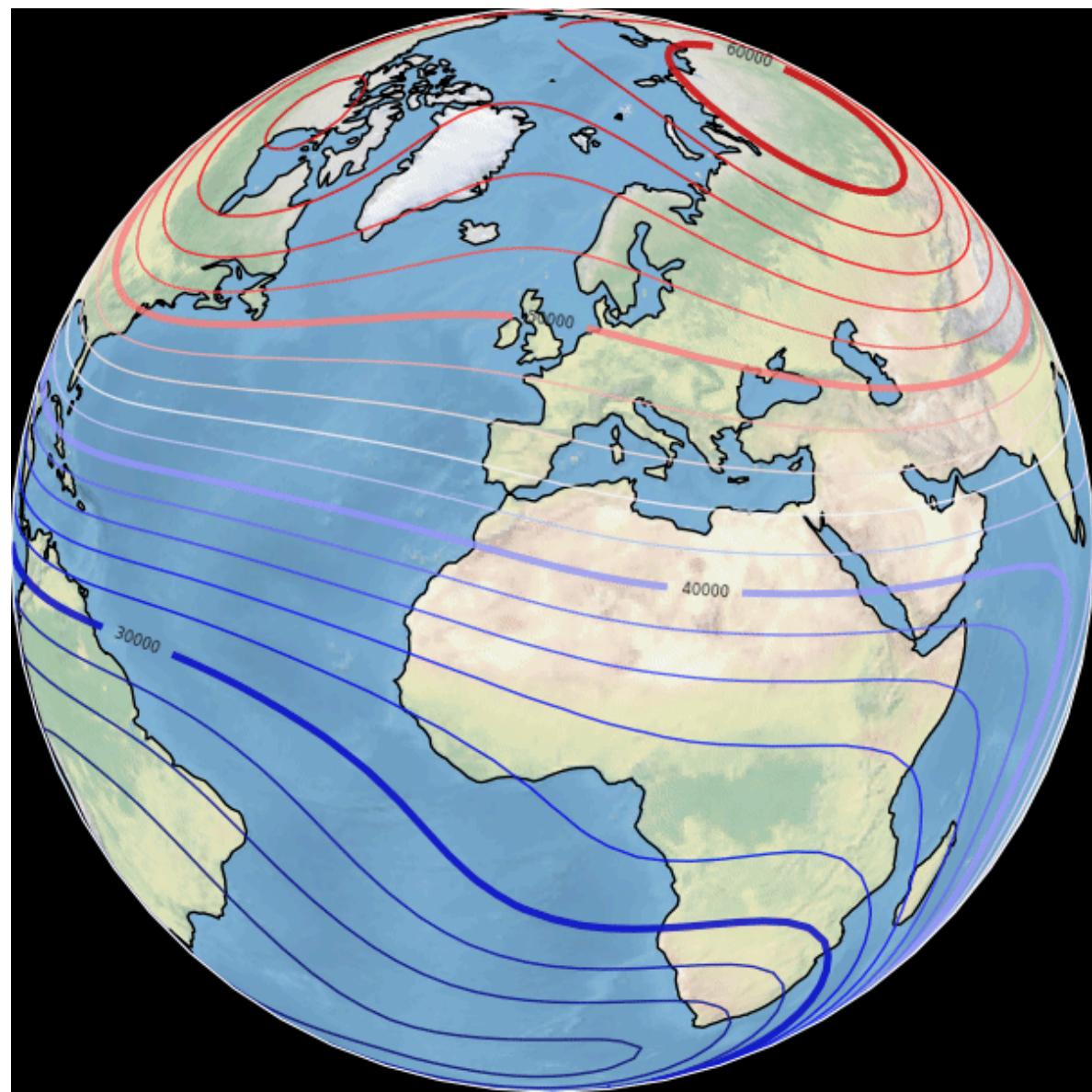
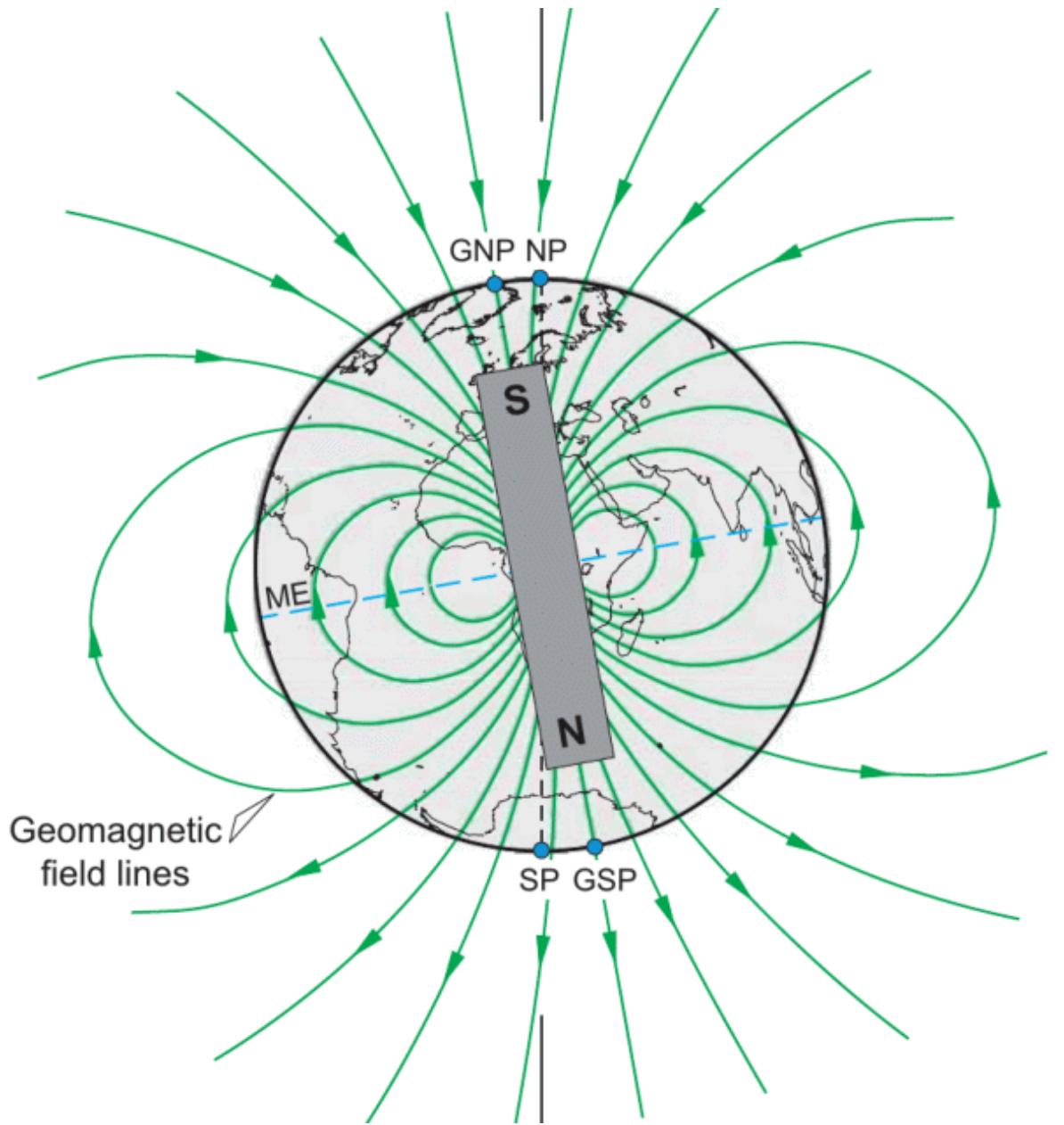
Magnetfeld-Messungen



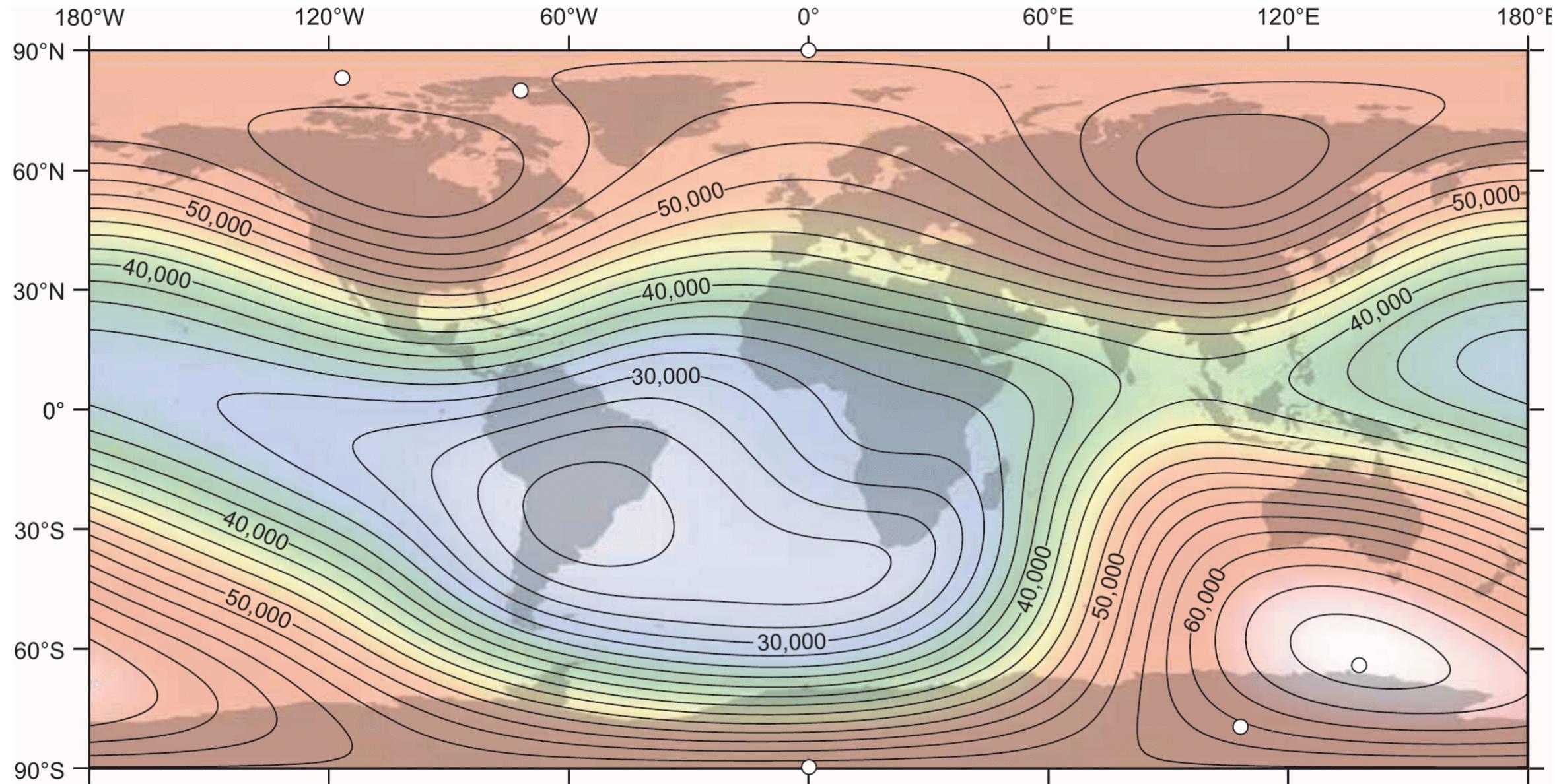
Beschrieben durch 7 Größen

- Totalfeld T
- Horizontalfeld H
- Horizontalkomponenten X & Y
- Deklination (Missweisung) D
- Vertikalfeld Z
- Inklinations I

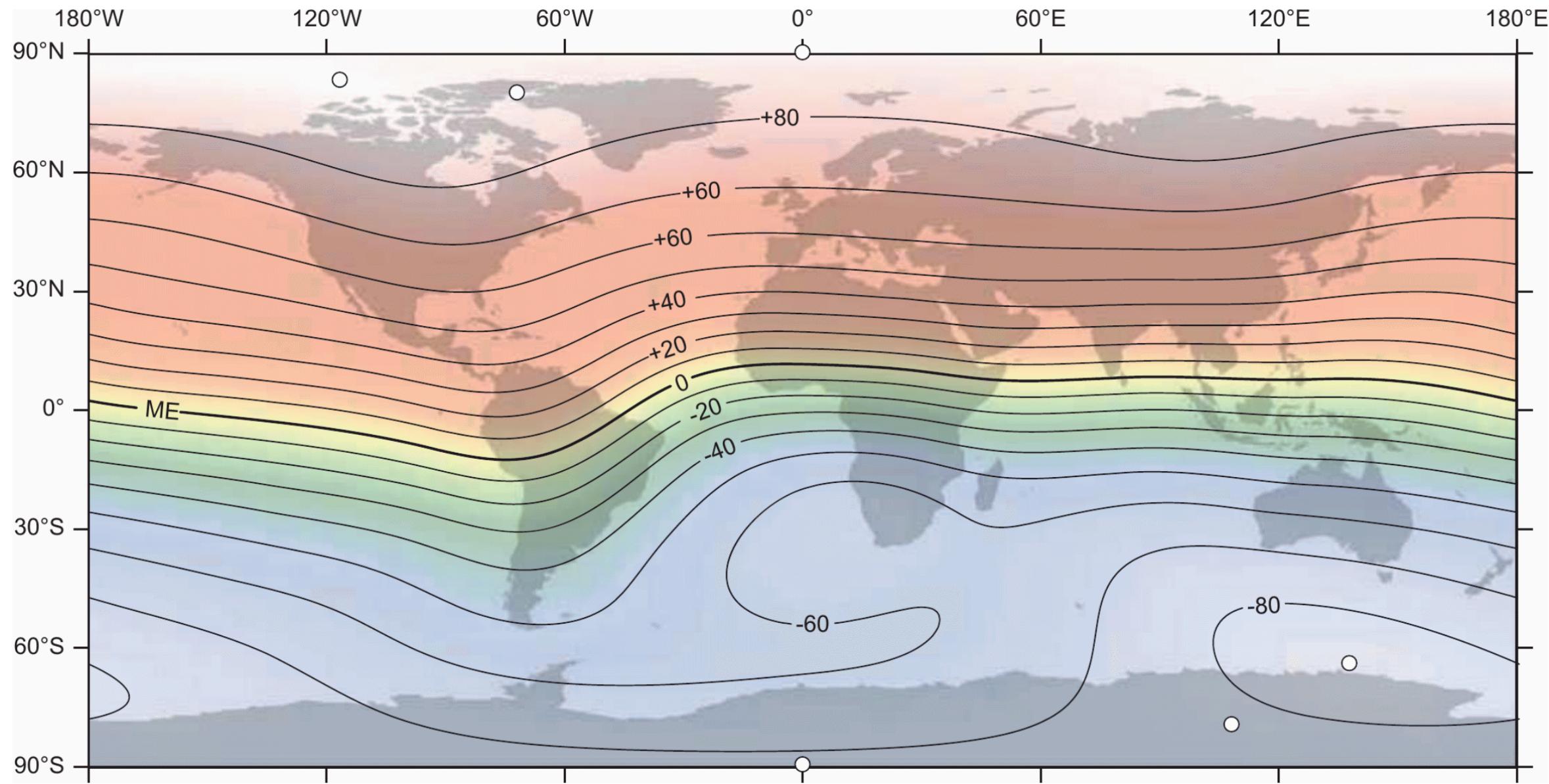
Das globale Erdfeld (beschrieben durch IGRF)



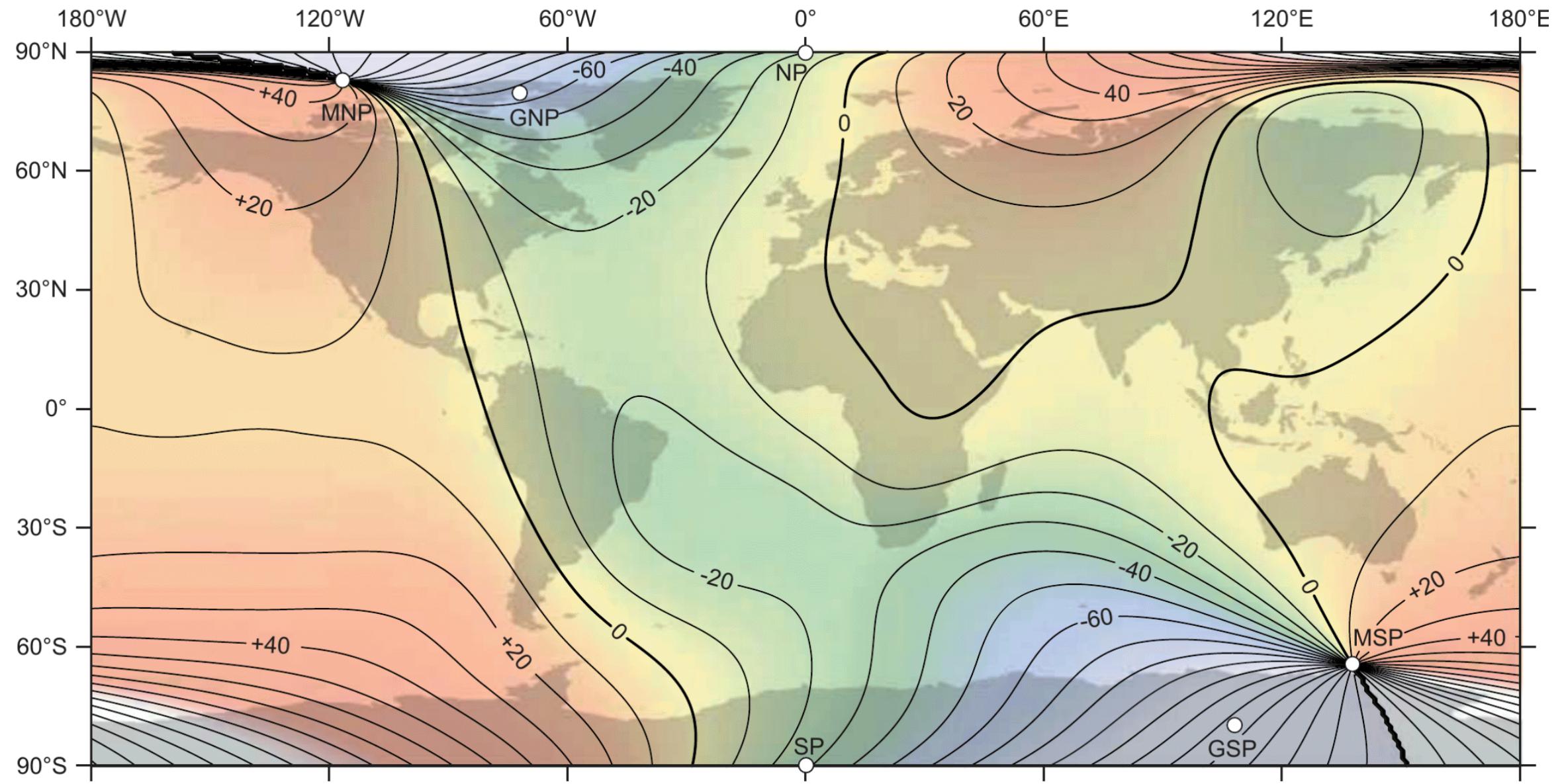
Magnetfeld in nT (Dentith & Mudge, 2014)



Inklination in ° (Dentith & Mudge, 2014)



Deklination in ° (Dentith & Mudge, 2014)



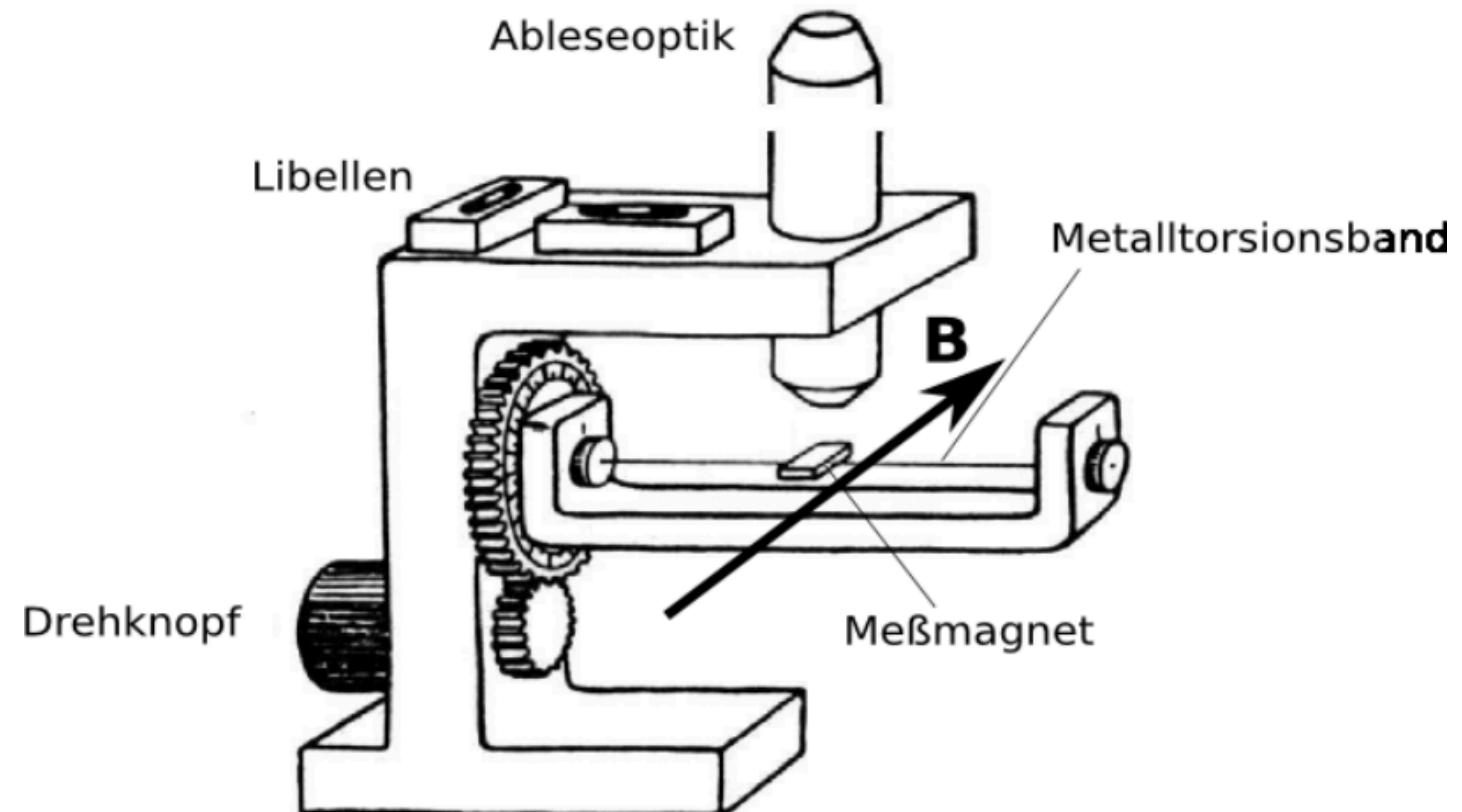
Magnetfeld-Sensoren

- Torsionsmagnetometer/Feldwaage
- Kernsättigungs-/Fluxgate-Magnetometer
- Protonen/Kernpräzessions-Magnetometer
- Optisch gepumptes Magnetometer
- SQUID-Magnetometer
- Induktions-Spule (Wechselfeld)

Torsionsmagnetometer

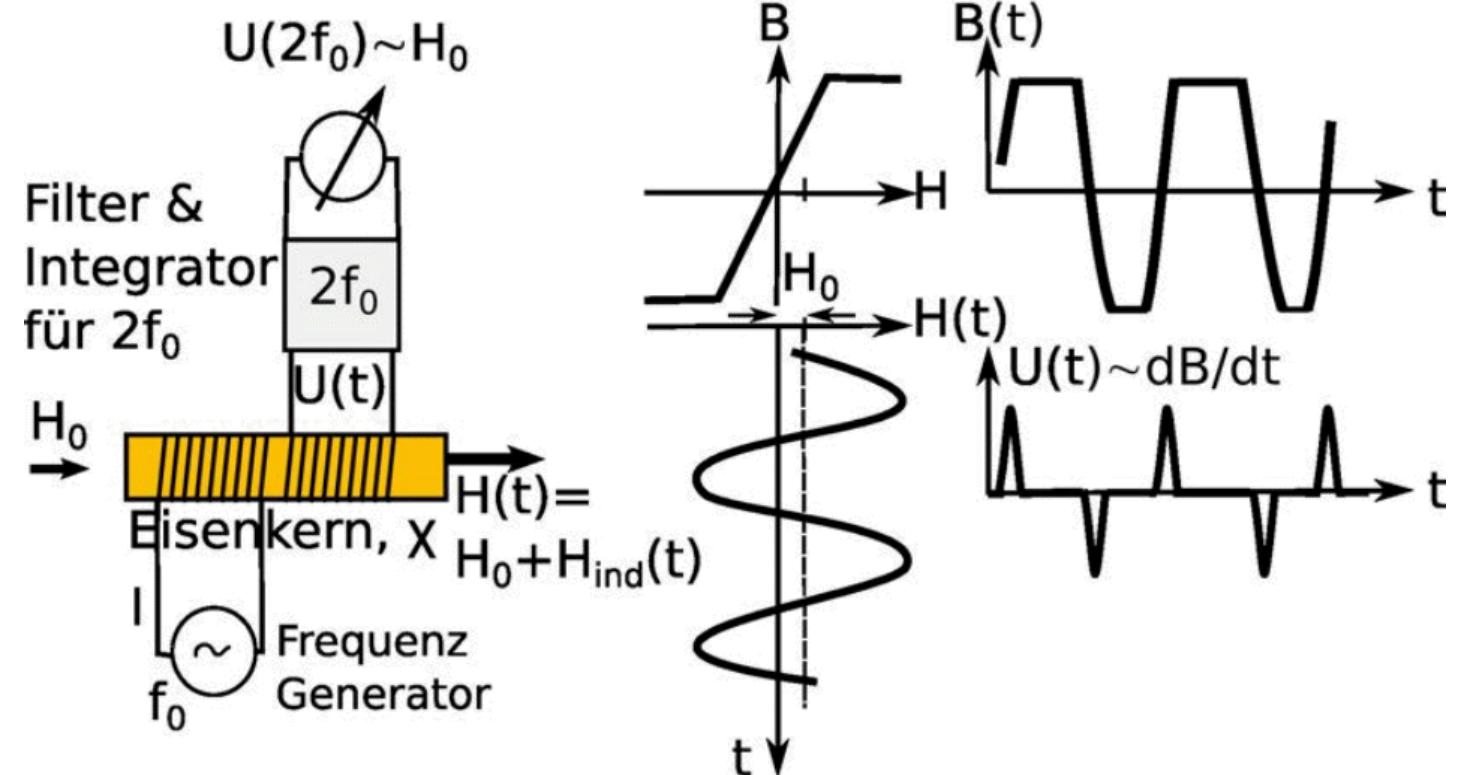
("Feldwaage")

- historisch
- 2 Metallbändchen mit Stabmagnet
- Drehwinkel $\propto B_z$



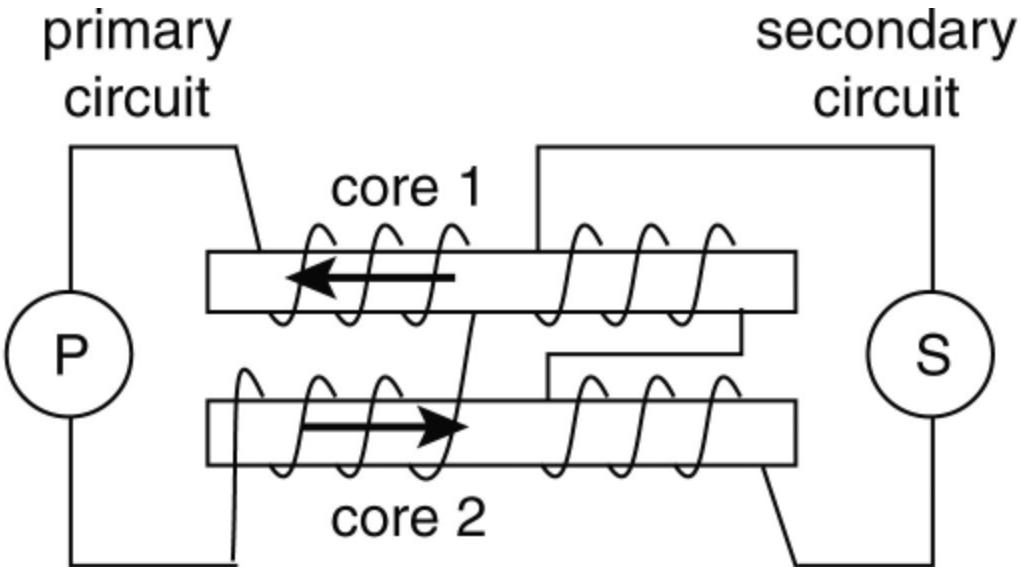
Kernsättigungsmagnetometer

- fluxgate, “Fürster-Sonde”
- Eisenkern durch Wechselfeld gesättigt
- Erdfeld verschiebt Symmetrie der Magnetisierung
- sehr preisgünstig
- 3 Spulen: vektorielle Messung

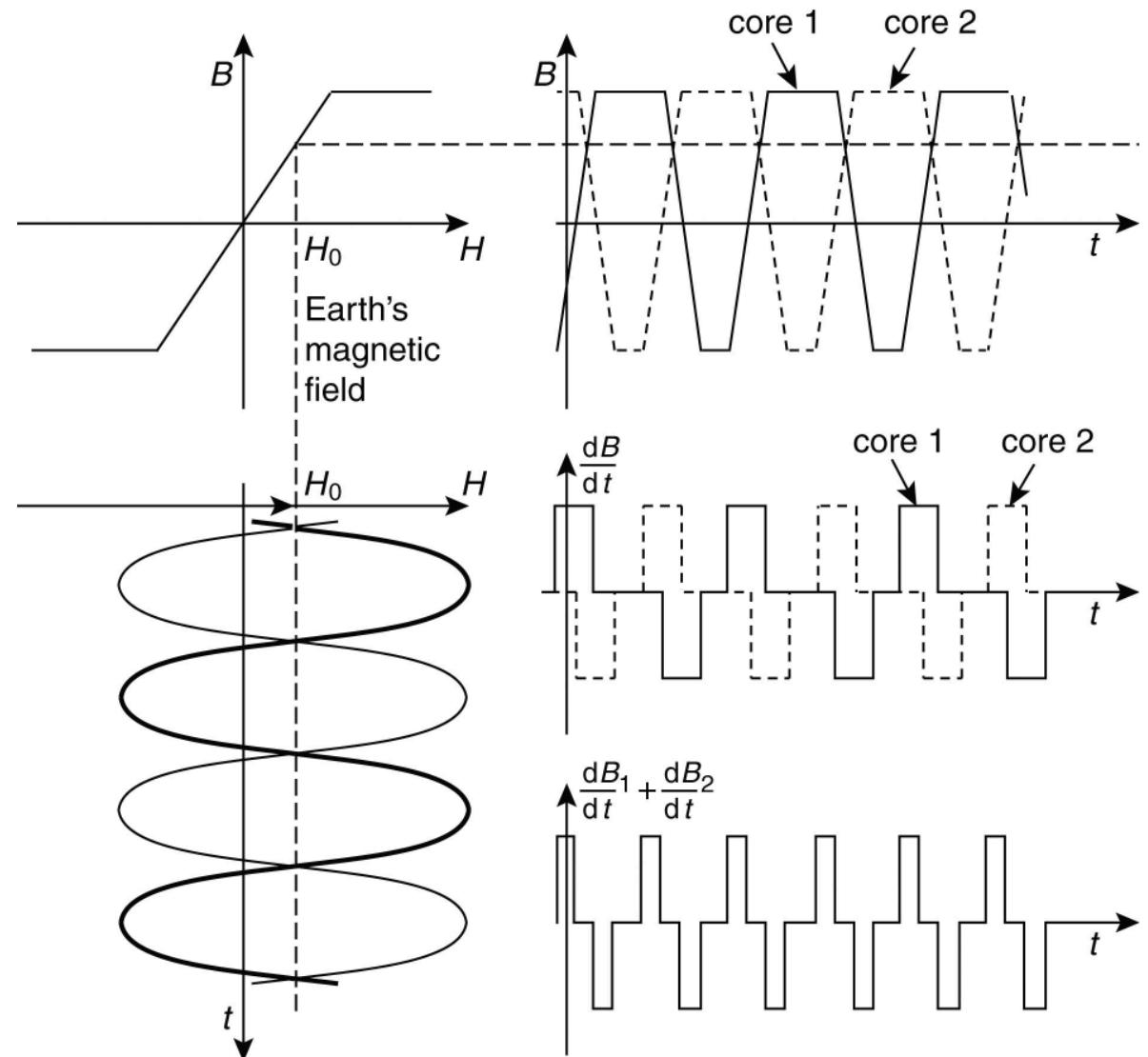


Fluxgate-Sensor

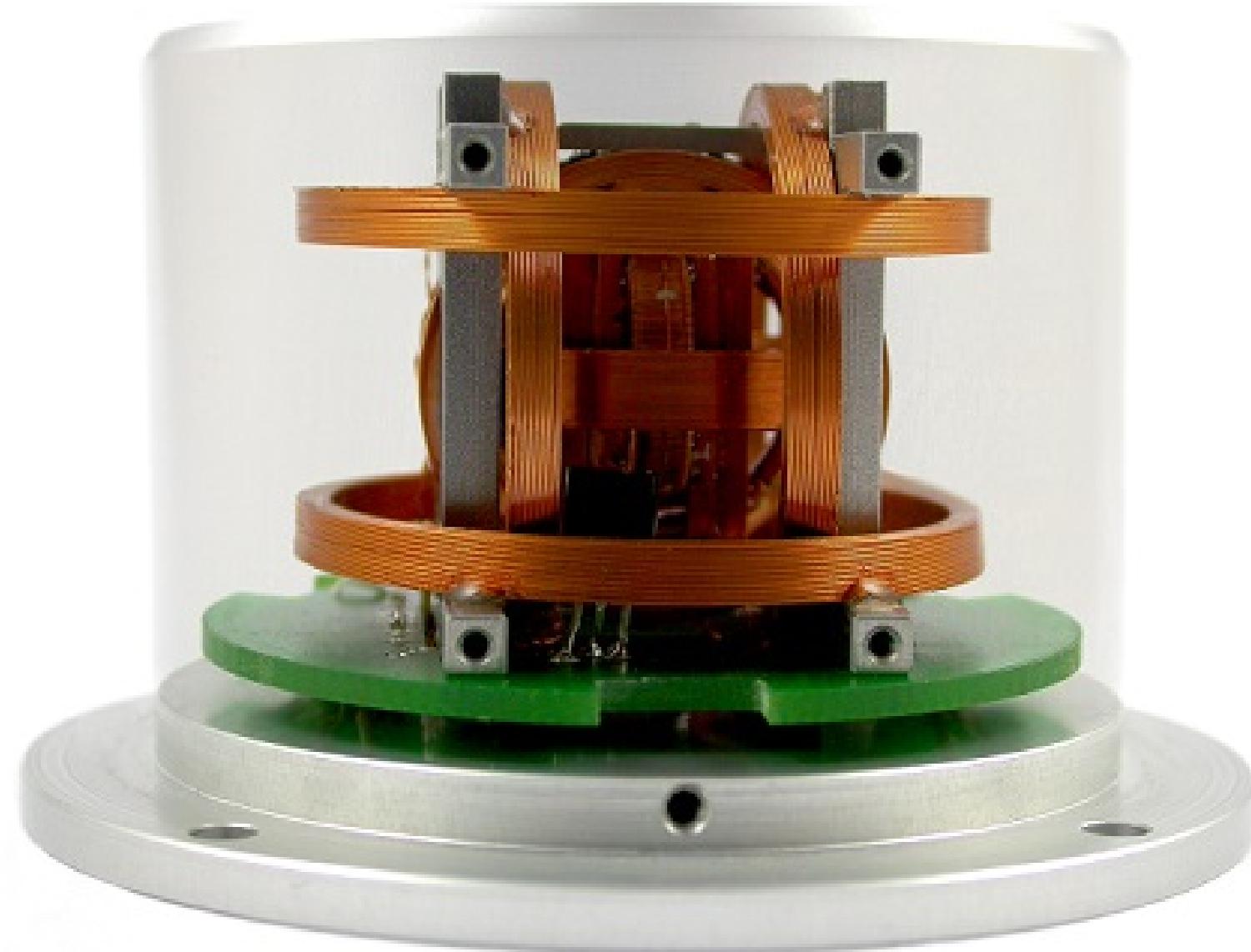
- Doppelkern mit hoher Suszeptibilität: Permalloy (Ni+Fe)



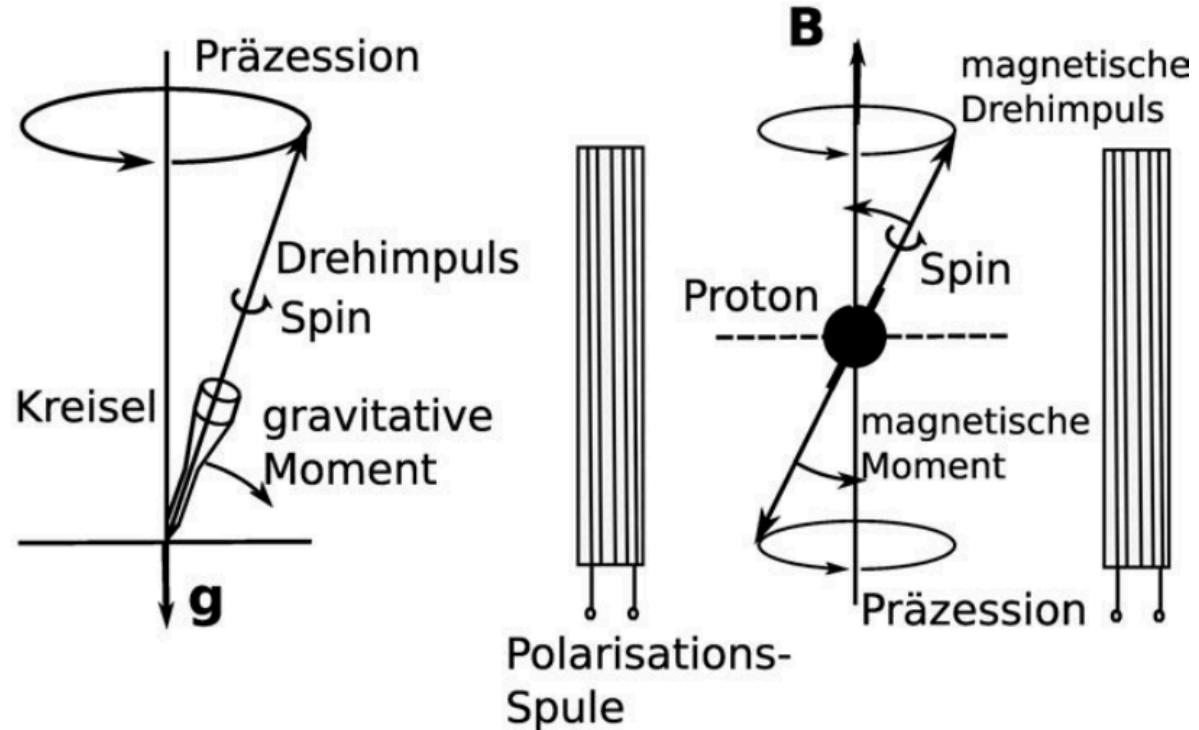
- $\delta B = 1 \text{nT}$
- Kalibrierung nötig



3-Achsen-Fluxgate von Magson



Protonenmagnetometer von Langeo



Präzession bei Kreisel und Proton

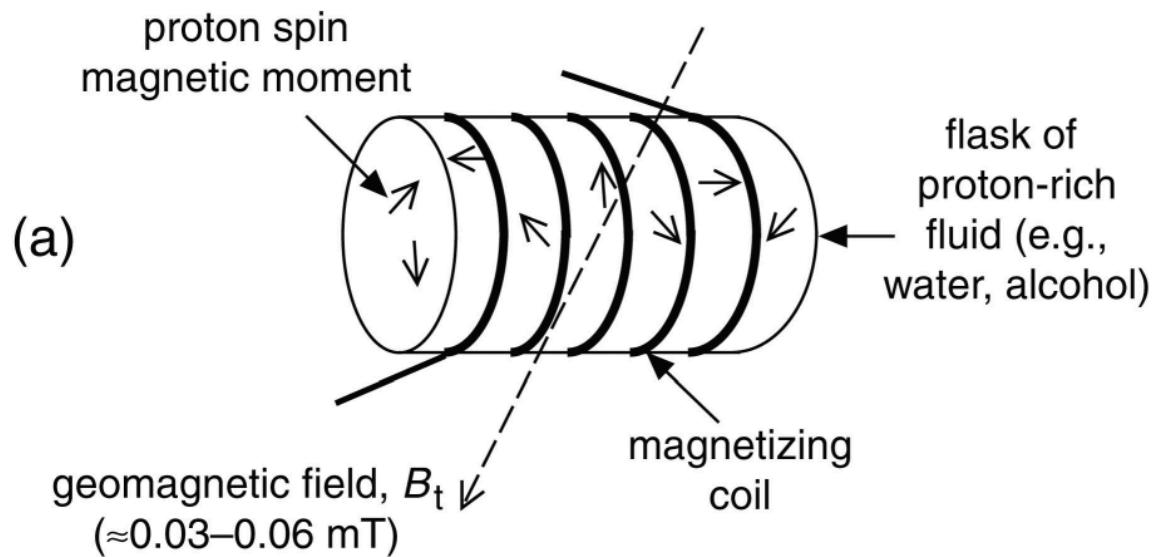
- Kernspin-Moment
- äußeres Magnetfeld: Drehmoment
- Präzession mit Frequenz

$$\omega = \gamma_p |B|$$

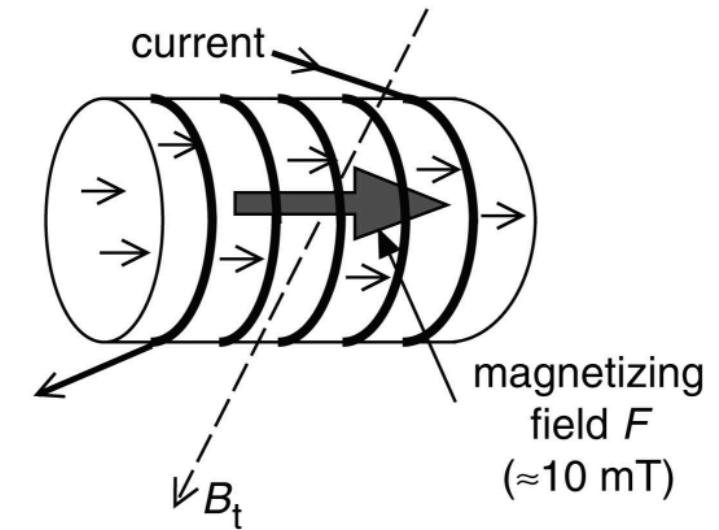
- gyromagnetisches Verhältnis
 $\gamma_p = 2.67513e8$

Kernpräzessionsmagnetometer (KPM)

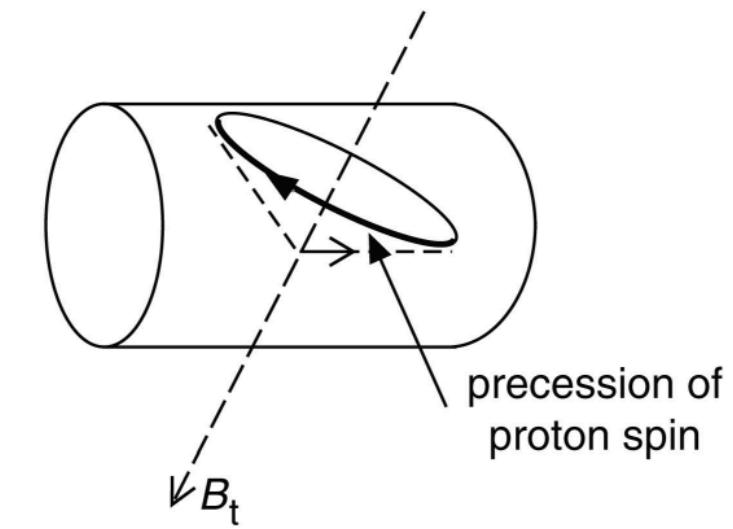
- $30\text{-}60\mu\text{T} \Rightarrow 1.2\text{-}2.5\text{kHz}$
- Spule magnetisiert Behälter
- Abschalten führt zu Präzession
- Frequenz-Messung: $\delta B=0.1\text{nT}$



(b)



(c)

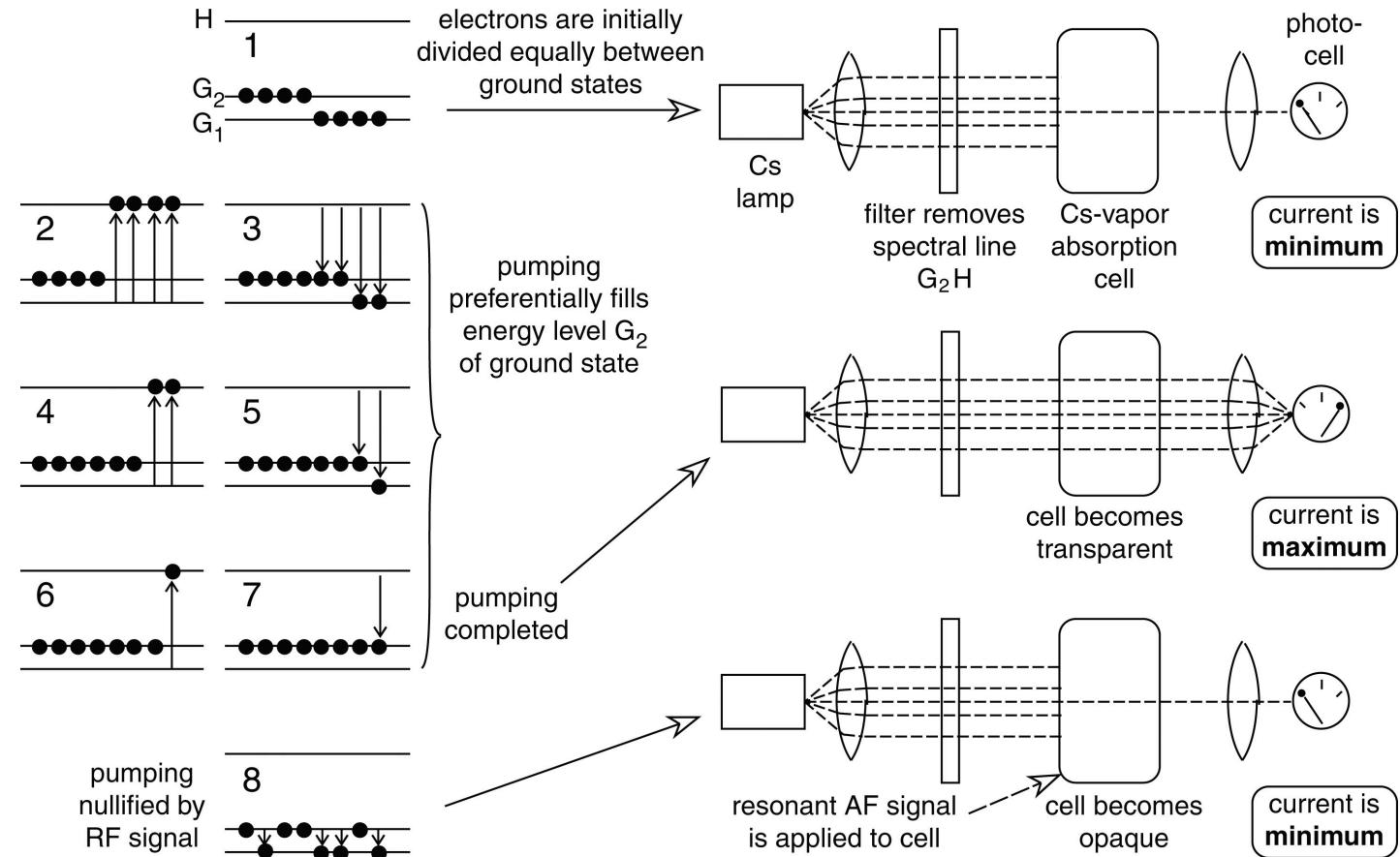


Kernpräzessionsmagnetometer (KPM)



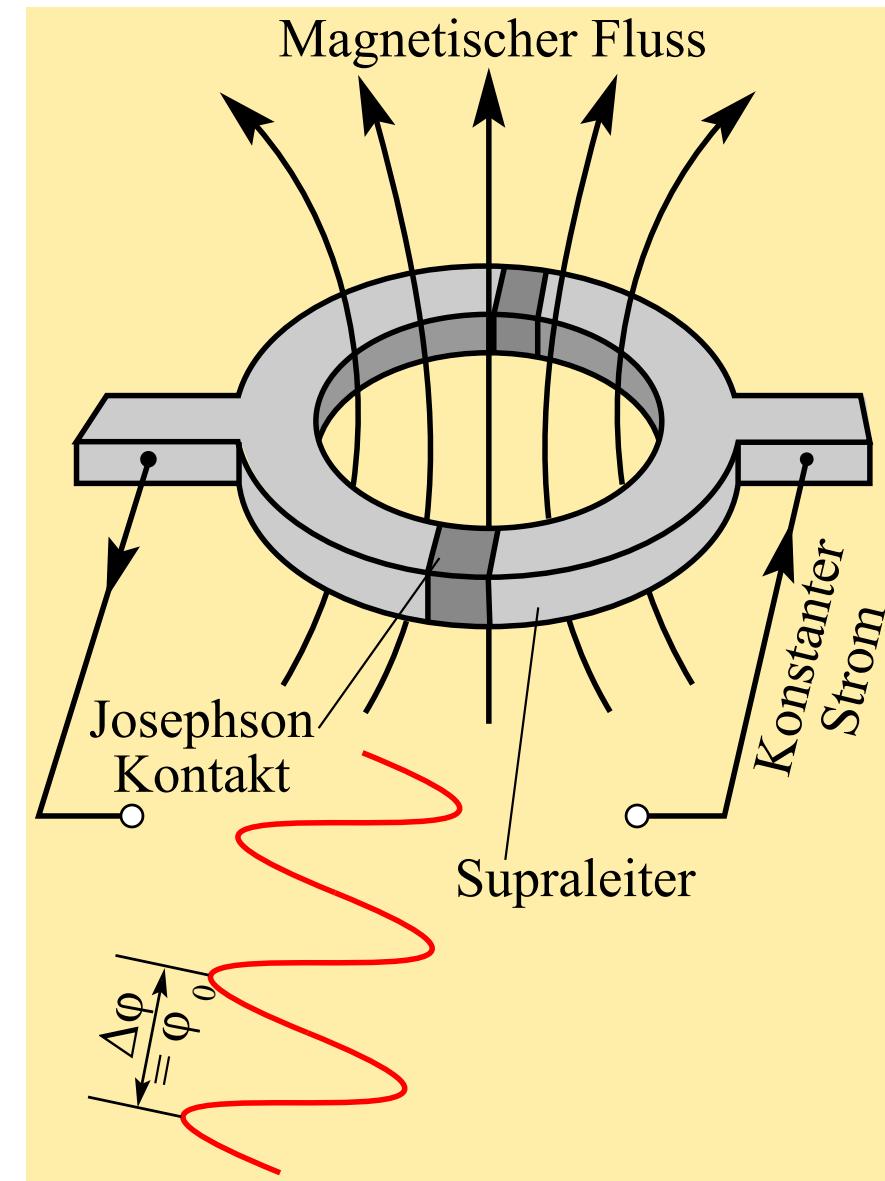
Optisch gepumpte Magnetometer (OPM)

- Absorptionszellen-,
“Cäsium-Magnetometer”
- quantenmechanischer
Zeemann-Effekt:
Aufspaltung von
Spektrallinien durch
Magnetfeld
- Präzessionsfrequenz des
Elektrons $\gamma_e = 1800\gamma_p$



SQUID-Magnetometer

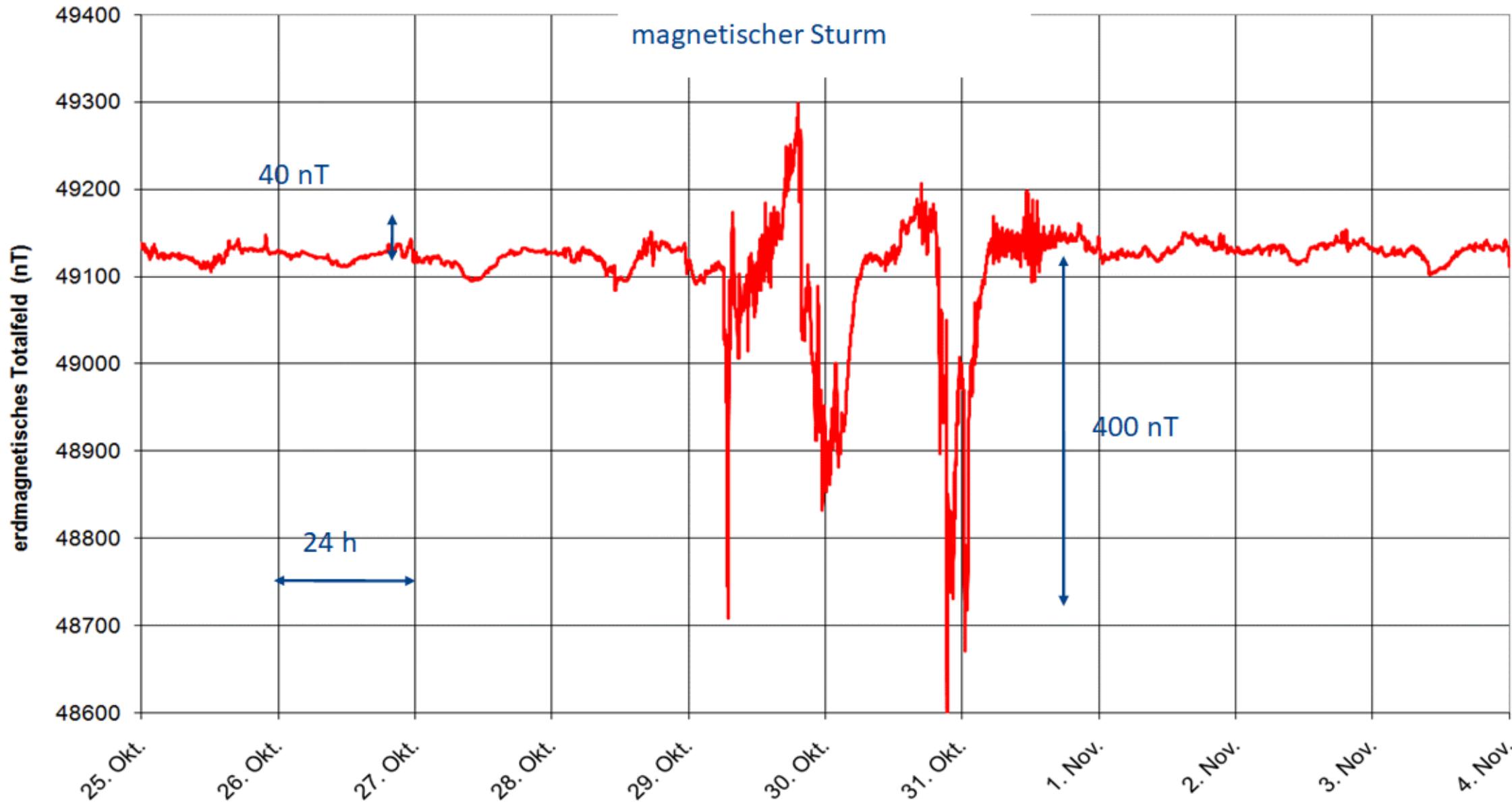
- supraleitender Ring aus Niob oder Keramik
- Elektronen-(Cooper)-Paare tunneln durch Barriere
- Magnetfluss gequantelt \Rightarrow periodische Spannungs-Kennlinie mit $T \propto B$
- extrem genau (1pT)
- Kühlung mit flüssigem Helium (-269°C, LTS) oder Stickstoff (-196°C, HTS)



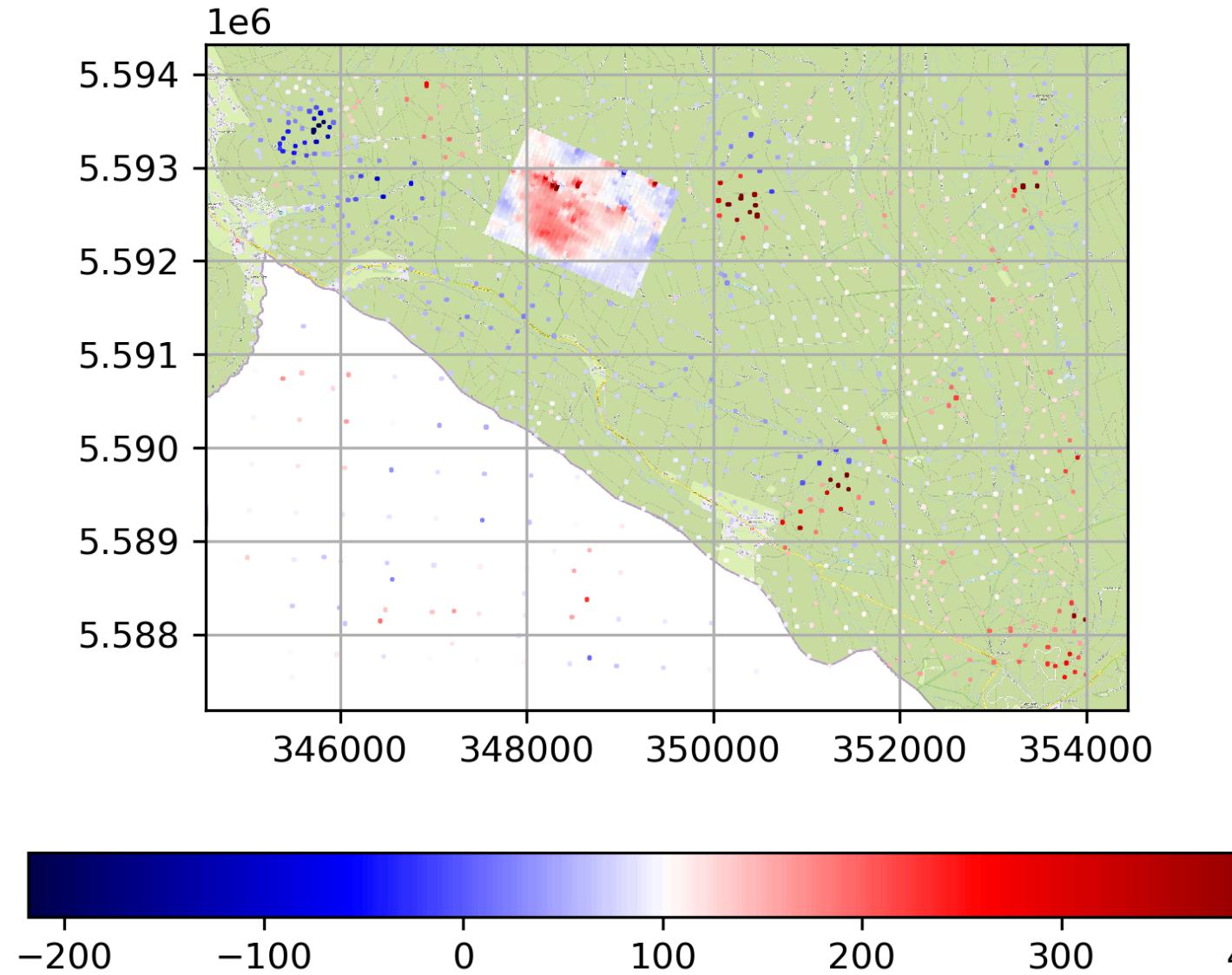
Geomagnetik

- Zeitliche Variationen
- Magnetfeld-Karten
- Beispiele Erzexploration und Landminen
-

Magnetfeld-Variation



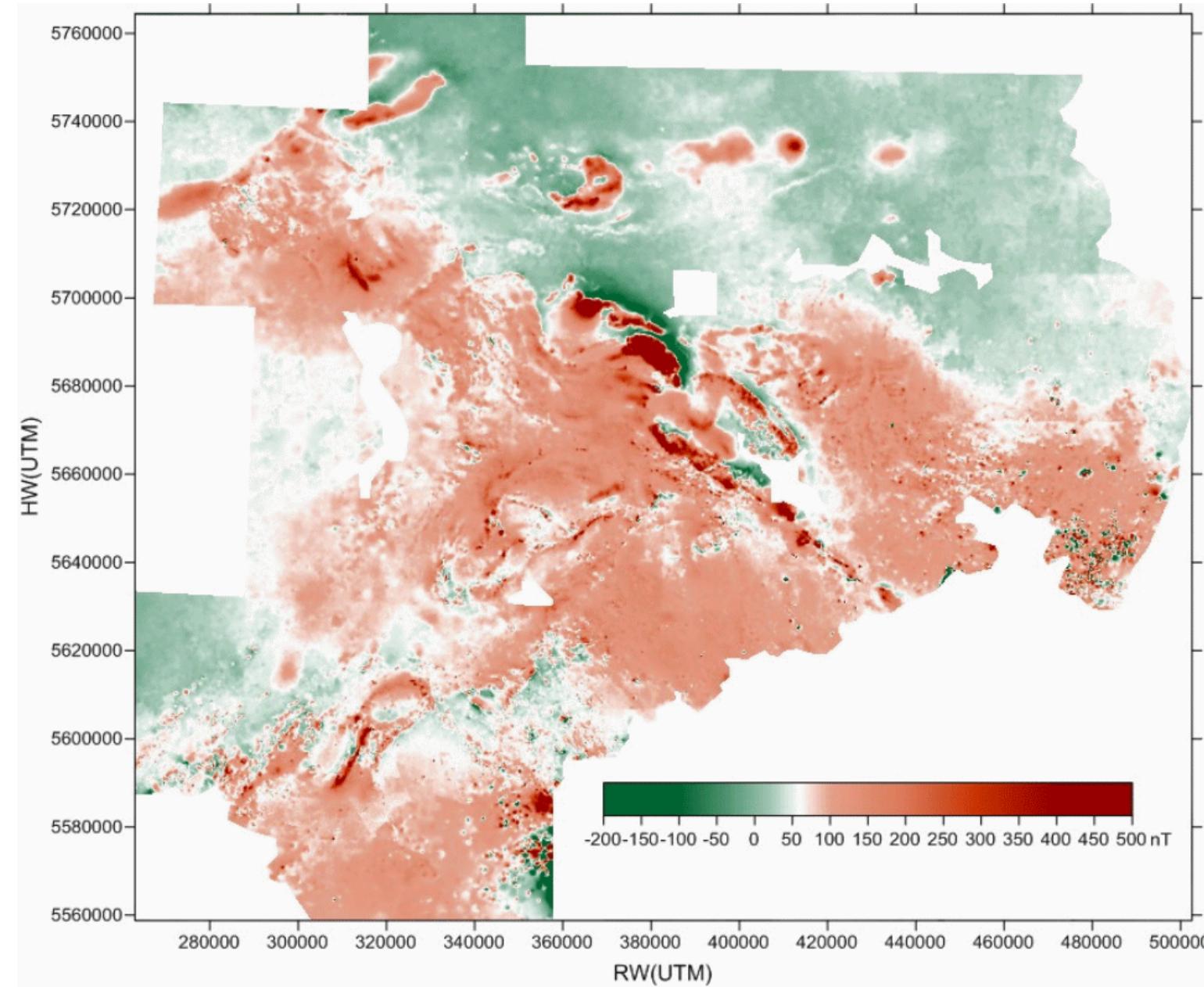
Magnetik-Datenlage



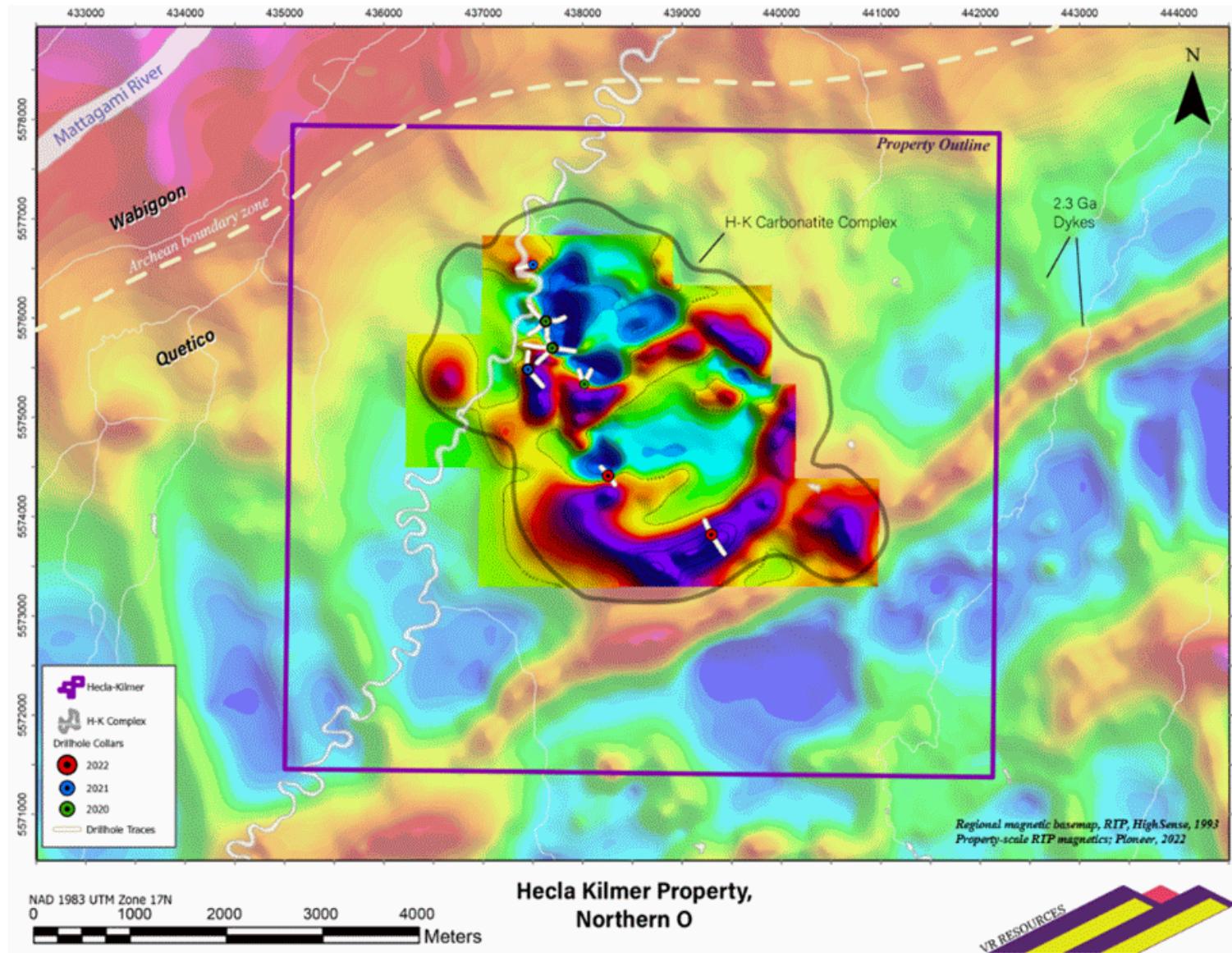
Punktdichte:

- Landesaufnahme (500-1000m)
- Verdichtung in Gebieten (100-200m)
- Detailuntersuchungen (1-50m)

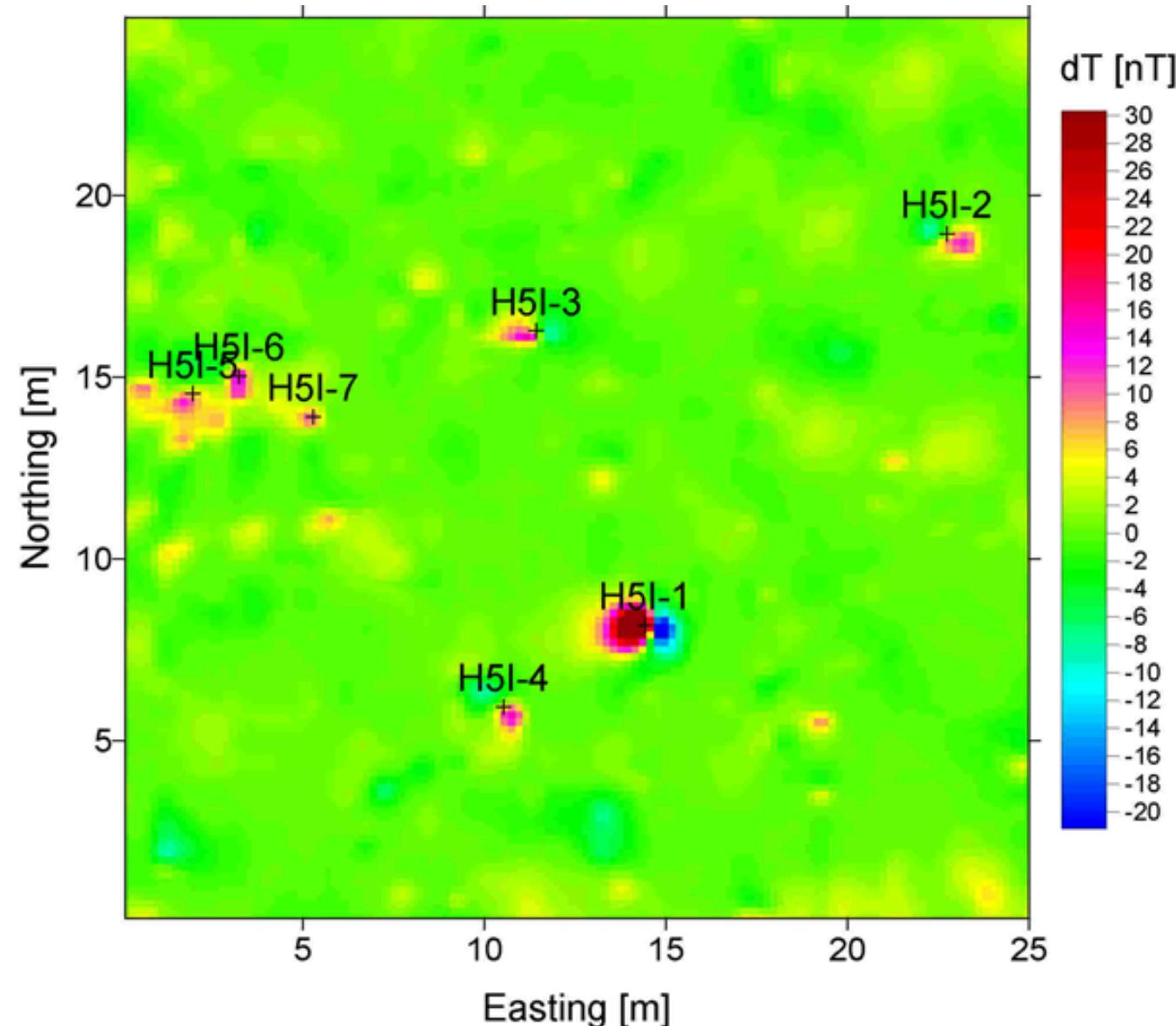
Magnetik-Karte von Sachsen



Mineral exploration with geomagnetics



Landmine and UXO search

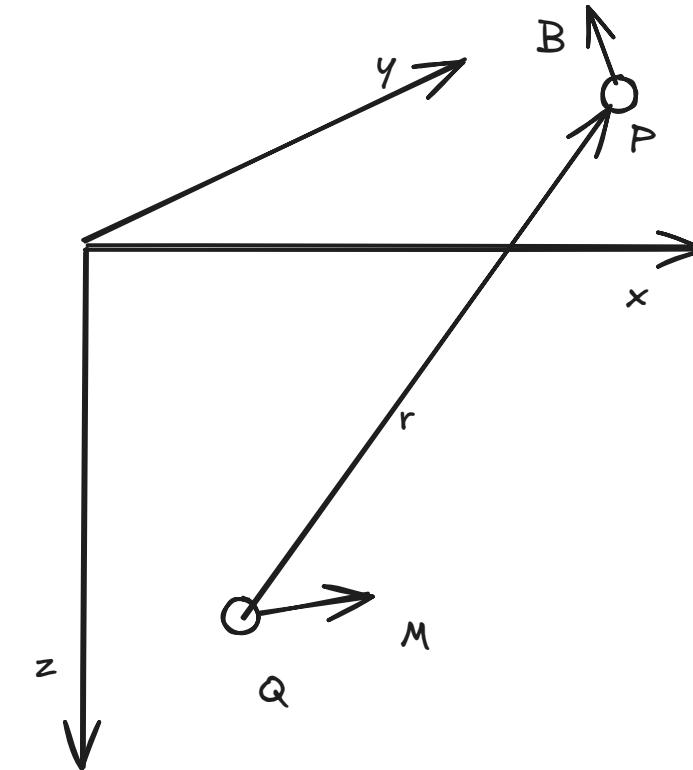


Modelling

The magnetic field caused by a magnetization \vec{M} vector can be computed by (Blakely, 1995):

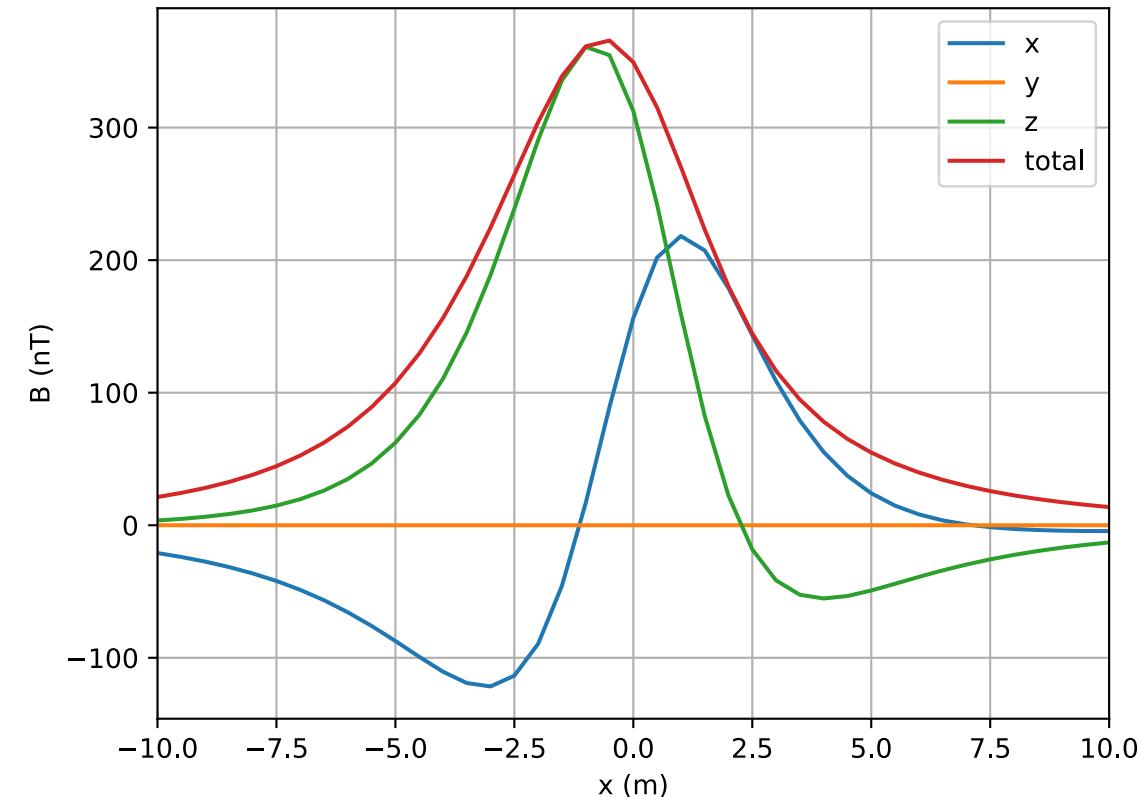
$$\vec{B}(\vec{r}) = \frac{\mu_0 M}{4\pi r^3} \left[3(\vec{M} \cdot \vec{r})\vec{r} - \vec{M} \right]$$

where $\vec{r} = \vec{r}_P - \vec{r}_Q$ is the space vector between the magnetic moment Q and the measuring point P.



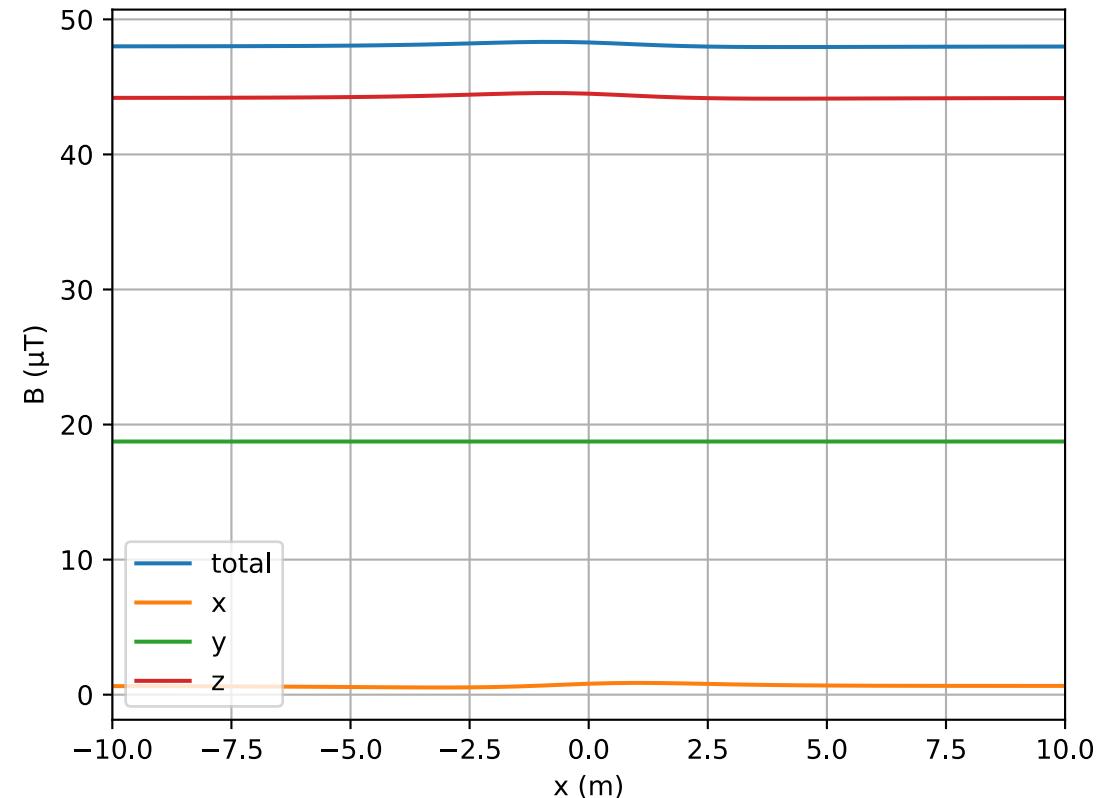
Beispiel - Anomalie

```
1 def magneticDipole(Q, M, P=None, x=None, y=...  
2     P = np.column_stack([x * np.cos(np.deg2rad(y)), ...  
3                           y + x * np.sin(np.deg2rad(y))])  
4     P == Q  
5     r = np.sqrt(np.sum(P**2, axis=1)) # distance  
6     M0 = np.linalg.norm(M)  
7     M = np.array(M, dtype=float) / M0 # unit vector  
8     R = P / np.reshape(r, [-1, 1]) # normed position  
9     fak = np.reshape(my0 * M0 / 4 / np.pi / r**3, [1, -1])  
10    return (np.reshape(R.dot(M), [-1, 1]) * fak)  
11  
12 M = np.array([-1, 0, 1]) * 100 # magnetization  
13 Q = [0, 0, -3] # location of the source  
14 x = np.arange(-10, 10.1, 0.5)  
15 B = magneticDipole(Q, M, x=x, z=1, alpha=0)  
16 ax.plot(x, np.linalg.norm(B, axis=1)*1e9, ...  
17 for i, t in enumerate("xyz"):  
18     ax.plot(x, B[:, i]*1e9, label=t)
```



Beispiel - Totalfeld

```
1 F = 48000 * 1e-9 # 48000 nT = 48µT
2 I = 67 # degrees
3 D = 2
4 Z = F * np.sin(np.deg2rad(I))
5 H = F * np.cos(np.deg2rad(I))
6 X = H * np.sin(np.deg2rad(D))
7 Y = H * np.cos(np.deg2rad(D))
8
9 Btotal = B + np.array([[X, Y, Z]]);
10 fig, ax = plt.subplots()
11 ax.plot(x, np.linalg.norm(Btotal,
12           axis=1)*1e9, label="total")
13 for i, t in enumerate("xyz"):
14     ax.plot(x, Btotal[:, i]*1e9, label=t)
```



Beispiel - Totalfeld-Anomalie

```
1 fig, ax = plt.subplots()
2 TFA = np.linalg.norm(Btotal, axis=1)-F
3 ax.plot(x, np.linalg.norm(B, axis=1)*1e9,
4         label="anomaly")
5 ax.plot(x, TFA*1e9, label="total")
6 ax.legend()
7 ax.grid()
8 ax.set_xlim(-10, 10)
9 ax.set_xlabel("x (m)")
10 ax.set_ylabel("B (nT)")
```

