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Curie Temperature

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Synonyms

Curie point

Definition

A rock containing magnetic minerals loses its permanent magnetism when heated up to a critical temperature, referred to as Curie temperature or Curie point, T_c. On the atomic level, below T_c, the magnetic moments are aligned in their respective domains, and even a weak external magnetic field results in a magnetization. As the temperature increases to T_c and above, fluctuations due to the increase in thermal energy destroy that alignment, and the rock becomes paramagnetic.

Magnetic Minerals and Curie Temperature

The most important magnetic rock-forming minerals are oxides of iron and titanium, and their compositions can be represented in the FeO-TiO_2-Fe_2O_3 ternary diagram. Among the three major solid-solution series identified in this system, the titanomagnetite series, $Fe_{3-x}Ti_xO_4$ (with $0 \leq x \leq 1$), plays a major role in controlling rock magnetism (Stacey 1992). Above 600 °C there is a continuous solid solution in the two-component series magnetite (Fe_3O_4) and ulvöspinel (Fe_2TiO_4), which upon cooling is restricted toward the end-members. Magnetite, the most abundant and strongly magnetic mineral, is of ferrimagnetic type, i.e., neighboring magnetic moments are aligned antiparallel, as in antiferromagnetism, but unequal numbers or strengths, thus giving a net magnetization.

There are many other magnetic minerals, but they are rare (iron sulfide), unstable (maghemite), or having a weak spontaneous magnetization due to the canting of its equal and nearly opposite atomic moments (canted antiferromagnetism), as hematite occurring in sedimentary rocks often in solid solution with ilmenite.

Variation of Curie temperature with titanium substitution in the titanomagnetite series is approximately given by $T_c = 580\ (1–1.26\ x)$. In pure magnetite, T_c is 575–585 °C, but titaniferous inclusions can reduce T_c, which approximates room temperature for $x = 0.77$ (Hunt et al. 1995). Saturation magnetization is also a function of temperature, and it disappears above T_c; at room temperature it decreases from 90 to 92 A $m^2\ kg^{-1}$ for $x = 0$ to about zero for $x = 0.8$. Because Ti^{4+} has no unpaired spins, the saturation magnetization decreases with increasing x (Alva-Valdivia and López-Loera 2011). The cell dimensions increase with increasing x. As a result of the increased cell dimension, there is a decrease in Curie temperature.

T_c undergoes a small increase with pressure. At the boundary between the crust and the mantle (or Moho), the T_c increase should be no more than a few degrees of the experimental values at normal pressure.

Geomagnetic Implications

There is a connection between the anomalies of geomagnetic field and the temperature-depth distribution, since rock magnetization is strongly affected by temperature variations. The rocks lose their magnetization at a depth where the temperature is greater than T_c and, consequently, their ability to generate detectable magnetic anomalies disappears. By transforming magnetic anomaly data into the Fourier domain and analyzing their spectra, it is possible to infer the depth of the magnetic layer bottom (MLBD), i.e., where magnetic rocks

H. K. Gupta (ed.), *Encyclopedia of Solid Earth Geophysics*, Encyclopedia of Earth Sciences Series,
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Curie Temperature, Table 1 Moho depth, depth and temperature of magnetic layer bottom, and geothermal flow of main tectonic units in Central and Southern Europe

Tectonic unit	Moho depth (km)	Magnetic layer bottom		Geothermal flow (mW m^{-2})
		Depth (km)	Temperature (°C)	
Variscan units (Central Europe, Corsica-Sardinia block)	29–33	29–33	540–580	60–70
Alpine units (Alps, Apennines, Molasse and Po basins)	25–50	22–28	500–600	50–80
Ligurian basin	17–24	20–24	570–650	80–100

are replaced with nonmagnetic material. Its comparison with information about thermal state of the Earth's crust can provide interpretation for both the magnetic source distribution and the Curie temperature.

Chiozzi et al. (2005) gave an example of MLBD determination and its relation with Moho depth, thermal structure, and geothermal flow in Central and Southern Europe (Table 1). MLBD corresponds to the Moho in the Variscan units, and the expected temperature is close to T_c of magnetite. Beneath the Alpine units, the magnetic layer bottom is shallower than the Moho and corresponds to temperature, as inferred from the geothermal flow, of 550 °C, indicating the presence of Ti. In the Ligurian basin, the temperature at the MLBD minimum depth is of 570 °C, hence compatible with the Curie point of magnetite. However, this depth is slightly larger than the Moho. Like observed in some oceanic regions (Counil et al. 1989), this might mean that the uppermost part of the mantle has magnetization.

Cross-References

- ► Earth's Structure, Continental Crust
- ► Geomagnetic Field, Global Pattern
- ► Geomagnetic Field, Theory
- ► Heat Flow, Continental
- ► Magnetic Domains
- ► Remnant Magnetism

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