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William L. Griffin, Mathieu Chassé

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## Nickel

William L. Griffin<sup>1</sup> and Mathieu Chassé<sup>2</sup>

<sup>1</sup>Earth and Planetary Sciences, Macquarie University, North Ryde, NSW, Australia

<sup>2</sup>Institut de minéralogie, de physique des matériaux et de cosmochimie (IMPMC), Sorbonne universités – UPMC Université Paris 06, Paris, France

### Element Data

*Atomic symbol:* Ni

*Atomic number:* 28

*Atomic weight:* 58.69

*Isotopes and abundances:* <sup>58</sup>Ni 68.0769 %, <sup>60</sup>Ni 26.2231 %, <sup>61</sup>Ni 1.1399 %, <sup>62</sup>Ni 3.6345 %, <sup>64</sup>Ni 0.9256 %

*1 Atm melting point:* 1455 °C

*1 Atm boiling point:* 2913 °C

*Common valences:* 2+

*Ionic radii:* fourfold, 55 pm; fourfold square, 49 pm; fivefold, 0.63 pm; sixfold, 9 pm

*Pauling electronegativity:* 1.91

*First ionization energy:* 737.1 kJ/mol

*Chondritic (CI) abundance:* 1.091 %

*Silicate earth abundance:* 0.186 %

*Crustal abundance:* 47 ppm

*Seawater abundance:* ~2–10 nM/kg

*Core abundance:* ~5.2 %

## Properties

Nickel has an atomic number of 28, an atomic weight of 58.69, and a density of 8.9 g/cm<sup>3</sup>. It is a silvery metal that

melts at 1455 °C and boils at 2913 °C; it is magnetic, malleable, and ductile and conducts electricity ([www.rsc.org/periodic-table](http://www.rsc.org/periodic-table)).

Ni has five naturally occurring stable isotopes and up to 18 radioactive isotopes, all long extinct. Up to 0.4 permil difference in Ni-isotope composition is observed between coexisting kamacite and taenite in iron meteorites and is ascribed to diffusion during exsolution and cooling (Lazar et al., 2012). However, the isotopic composition of Ni in chondritic meteorites and Earth is probably identical within current analytical capabilities (Lazar et al., 2012). Significant fractionation of Ni isotopes can occur in low-temperature processes such as lateritic weathering of ultramafic rocks; progressive weathering leads to isotopically lighter soils ( $\Delta^{60}\text{Ni}_{\text{Soil-Bedrock}} = -0.47 \text{ ‰}$ ) (Ratié et al., 2015).

Ni is a transition element, with the electronic configuration [Ar]3d<sup>8</sup>4s<sup>2</sup>; consequently it shows both siderophile (iron-loving) and lithophile (silicate-loving) behavior. In the crust and upper mantle, it normally occurs as Ni<sup>2+</sup>, whereas in the Earth's core, it is alloyed with iron.

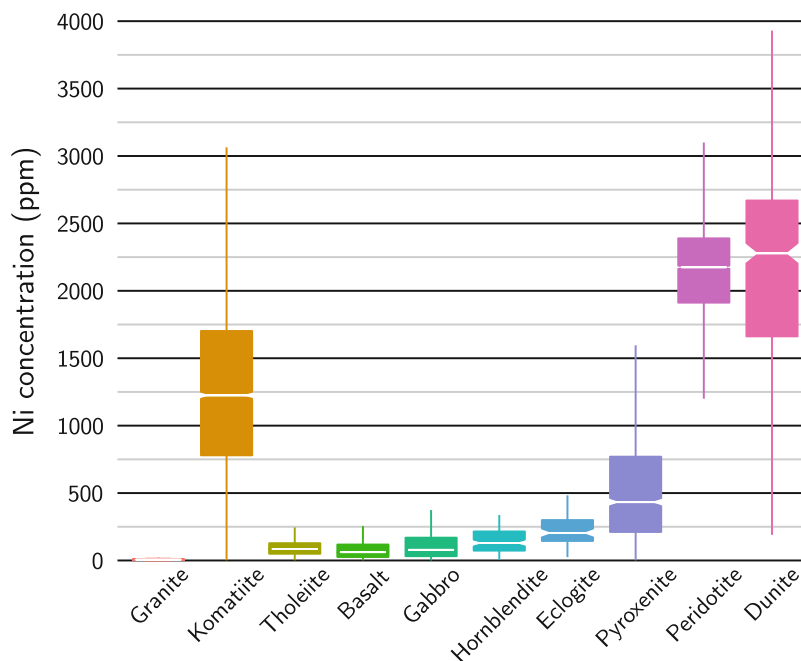
## History and Use

Nickel (Ni) was first isolated from NiAs (niccolite) and named by A. F. Cronstedt in 1751. The name derives from the Saxon “nickel,” a malicious sprite (“Kupfernickel”) who prevented them from extracting copper from niccolite, which they had mistaken for chalcopyrite (CuFeS<sub>2</sub>). Its properties were determined by J.B. Richter in 1804.

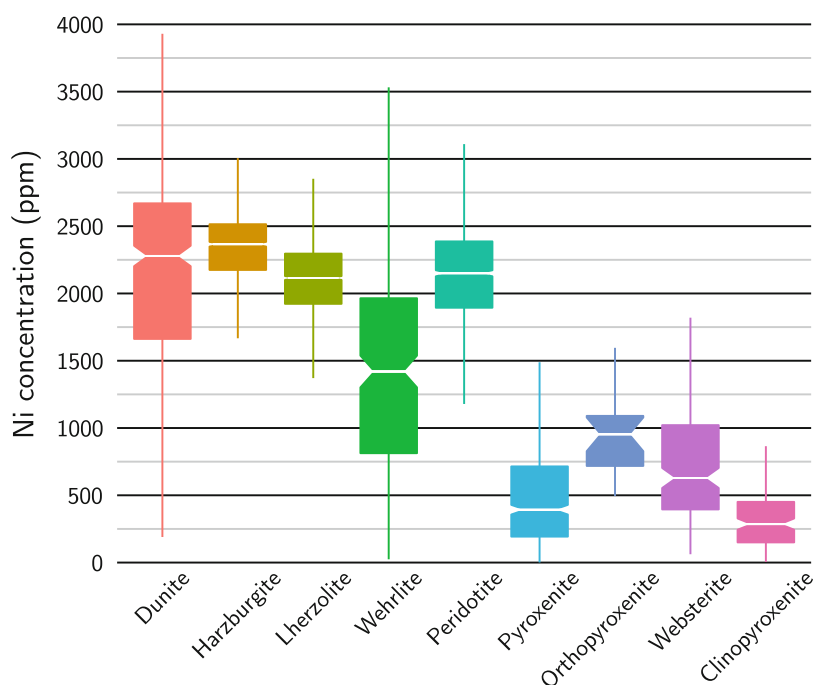
The main use of Ni (ca 65 %) is for the production of stainless steel, with demand increasing by ca 5 %/annum (International Nickel Study Group; [www.insg.org](http://www.insg.org)). It is also used in the production of nonferrous alloys or so-called “superalloys” which show better resistance to corrosion and are widely used in jet engines and turbines. Smaller proportions are used in various surface treatments such as electroplating and as hydrogenation catalysts.

**Nickel,**

**Figure 1** Distribution of Ni concentration in various lithotypes (Data from GEOROC, Sarbas and Nohl (2008); 18,359 analyses). The boxes represent the first and third quartiles of the data distribution. The horizontal line represents the median, and the width of the adjacent notches shows the 95 % confidence interval about the median. The “whiskers” represent 1.5 x midrange (arithmetic mean of maximum and minimum values) beyond the first or third quartile

**Nickel,**

**Figure 2** Distribution of Ni concentration in various mantle-related lithotypes. (Data from GEOROC, Sarbas and Nohl (2008); 5,403 analyses.)

**Ores and Production**

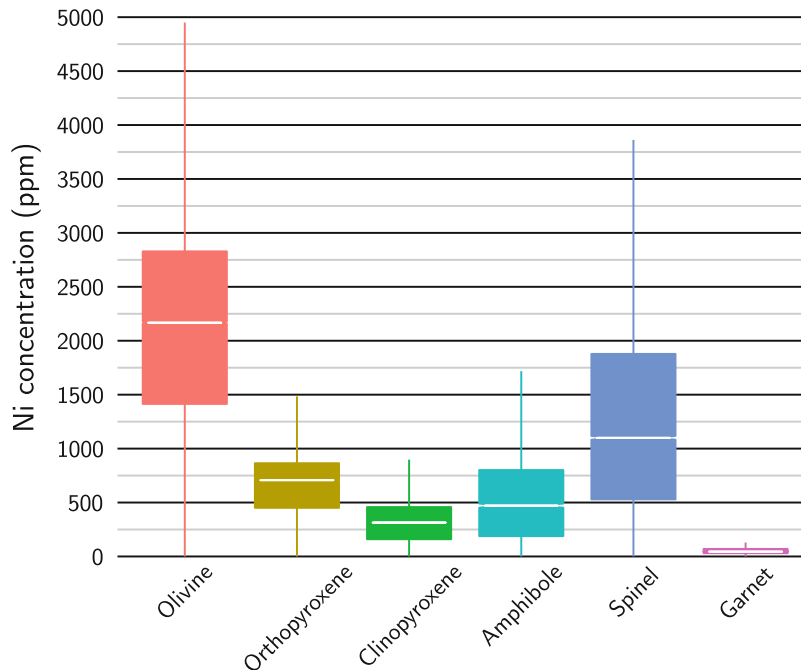
World usage of Ni amounts to between 1.8 and 2 million tonnes/year (2014–2015).

Nickel is mined almost entirely from two types of deposit, magmatic sulfides and lateritic horizons, developed through the weathering of ultramafic rocks, usually in tropical areas (e.g., New Caledonia, Venezuela, the Dominican Republic, Brazil, Madagascar, and eastern Australia). Magmatic sulfides occur in ultramafic lava flows (komatiites; Figure 1) in

Archean cratons, in large intrusions of layered gabbros, and in the Sudbury giant impact crater. In all of these, the major ore mineral is pentlandite  $(\text{Ni,Fe})_9\text{S}_8$ , but Ni also forms a range of other sulfides, arsenides, and antimonides. While magmatic sulfide ores are important resources, >70 % of the world's supply of Ni is mined from lateritic deposits. During weathering, Ni concentrates in Ni-bearing limonite (Fe oxyhydroxide) and garnierite (referring to a group of green Ni-bearing magnesium phyllosilicates including serpentine, talc, sepiolite, smectite, and chlorite) in the middle-

**Nickel,**

**Figure 3** Distribution of Ni concentration in various mantle-related minerals. (Data from GEOROC, Sarbas and Nohl (2008) and authors' unpublished data; 105,630 analyses.)



upper parts of the weathering profile, providing a resource that is easily mined and processed.

## Geochemistry

The cosmic abundance of Ni estimated from carbonaceous chondrites is 10,910 ppm (Palme et al., 2014); estimates for its abundance in Earth lie between 17,000 and 19,000 ppm. Most of this is concentrated in the Earth's core; analyses of iron meteorites suggest the core contains *ca* 5 wt% Ni (McDonough, 2014), leaving *ca* 1860 ppm in the mantle (Palme and O'Neill, 2014) and 47 ppm in the continental crust (Rudnick and Gao, 2014). Ni substitutes readily into the Mg-rich minerals of the mantle and is largely retained in the residue during partial melting. Ni concentrations in the crust are correspondingly quite low. The worldwide distribution of Ni in different rock types is shown in Figure 1; Figure 2 provides more detail on its distribution in mantle rocks. The variability shown in Figure 2 is easily understood in terms of the relative abundance of Ni in the important minerals of mantle rocks (Figure 3). This behavior is related to the charge and ionic radii of Ni. Under crustal and upper mantle conditions, the most common oxidation state of nickel is Ni(II). The effective ionic radius of Ni(II) depends on its coordination number ( $^{[4]}\text{Ni}$ , 0.55 Å;  $^{[4]}\text{Ni}$  square, 0.49 Å;  $^{[5]}\text{Ni}$ , 0.63 Å; and  $^{[6]}\text{Ni}$ , 0.69 Å). The identical charge and similarity in ionic radii between  $^{[6]}\text{Ni}$  and  $^{[6]}\text{Mg}$  allow significant substitution of Mg by Ni in olivine, the main Ni bearer among mantle-related minerals (Figure 3). In addition, these distributions reflect mineral-mineral partitioning. Ni can substitute for Mg but

not for Ca, which explains the higher Ni concentration in orthopyroxene compared to clinopyroxene (Figure 3). Ni substitution may also be favored in the Mg site of spinel, which is smaller than the Mg site of garnet.

The solubility of Ni in pure water is low ( $<2\text{ }\mu\text{g/L}$ ), but in the presence of dissolved organic compounds, it can form complexes that are soluble. In anoxic conditions, it precipitates in sulfide phases (NiS, pyrite). Atmospheric concentrations of Ni are dominated by anthropogenic pollution, principally from the burning of oil, and have increased by a factor of  $>500$  since the beginning of the Industrial Revolution (Pacyna and Pacyna, 2001). Contributions to atmospheric Ni from smelting operations account for *ca* 10 % of the total; they have declined in recent years due to better emission controls, but previously devastated large areas in the vicinity of smelters at, e.g., Sudbury in Canada and the Kola Peninsula in arctic Russia.

## Biological Utilization and Toxicity

Ni is known to be toxic in high doses, but they are reached only in special situations. However, Ni contamination of groundwater can represent a hazard, especially in acidic conditions where it can be leached from soils (Nieminen et al., 2007).

Nickel is an important micronutrient in the oceans, and dissolved Ni is variably enriched (*ca* 10 nM/kg) in deeper waters and depleted (*ca* 2 nM/kg) in surface waters, following the pattern of other micronutrients such as Fe and Zn, as well as P and Si. This distribution suggests that diatoms actively

control the distribution of Ni in ocean waters (Twining et al., 2012). The methanogenic bacteria that dominated Archean life appear to have been addicted to Ni. It has been proposed that a decline in the Ni contents of banded iron formations late in the Archean reflects a decrease in the availability of Ni in ocean water. This “nickel famine” may have led to the rise of the cyanobacteria, and their production of oxygen led in turn to the Great Oxidation Event at the end of the Archean (Saito, 2009; Konhauser et al., 2009), allowing the evolution of multicellular life.

## Summary

Nickel shows a very diverse range of geochemical behavior, being both a siderophile and a lithophile element. It has been important to mankind since the Bronze Age and is a mainstay of modern industrial society. It also is an essential element in the biogeochemistry of the oceans.

## Cross-References

- [Earth's Mantle Geochemistry](#)
- [Iron Meteorites](#)
- [Lithophile Elements](#)
- [Ore Deposits](#)
- [Periodic Table](#)
- [Siderophile Elements](#)
- [Sulfide Minerals](#)
- [Transition Elements](#)

## References

- Konhauser, K. O., et al., 2009. Oceanic nickel depletion and a methanogen famine before the Great Oxidation Event. *Nature*, **458**, 750–753.
- Lazar, C., Young, E. D., and Manning, C. E., 2012. Experimental determination of equilibrium nickel isotope fractionation between metal and silicate from 500 °C to 950 °C. *Geochimica et Cosmochimica Acta*, **86**, 276–295.
- McDonough, W. F., 2014. 3.16 – Compositional model for the Earth's core A2. In Turekian, K. K., and Holland, H. D. (eds.), *Treatise on Geochemistry*, 2nd edn. Oxford: Elsevier, pp. 559–577.
- Nieminen, T. M., Ukonmaanaho, L., Rausch, N., and Shoty, W., 2007. Biogeochemistry of nickel and its release into the environment. *Metal Ions in Life Sciences*, **2**, 1–30.
- Pacyna, E. C., and Pacyna, J. M., 2001. An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide. *Environmental Reviews*, **9**, 269–298.
- Palme, H., and O'Neill, H. S. C., 2014. 3.1 – Cosmochemical estimates of mantle composition. In Turekian, K. K., and Holland, H. D. (eds.), *Treatise on Geochemistry*, 2nd edn. Oxford: Elsevier, pp. 1–39.
- Palme, H., Lodders, K., and Jones, A., 2014. 2.2 – Solar system abundances of the elements A2. In Holland, H. D., and Turekian, K. K. (eds.), *Treatise on Geochemistry*, 2nd edn. Oxford: Elsevier, pp. 15–36.
- Ratié, G., Jouvin, D., Garnier, J., Rouxel, O., Miska, S., Guimaraes, E., Cruz, V. L., Sivry, Y., Zelano, I., Montarges Pelletier, E., Thil, F., and Quantin, C., 2015. Nickel isotope fractionation during tropical weathering of ultramafic rocks. *Chemical Geology*, **402**, 68–76.
- Rudnick, R. L., and Gao, S., 2014. 4.1 – Composition of the continental crust. In Holland, H. D., and Turekian, K. K. (eds.), *Treatise on Geochemistry*, 2nd edn. Oxford: Elsevier, pp. 1–51.
- Saito, M., 2009. Less nickel for more oxygen. *Nature*, **458**, 714–715.
- Sarbas, M., and Nohl, U., 2008. The GEOROC database as part of a growing geoinformatics network. In *Geoinformatics Conference*, Postdam.
- Twining, B. S., Baines, S. B., Vogt, S., and Nelson, D. 2012. Role of diatoms in nickel biogeochemistry in the ocean. *Global Biogeochemical Cycles*, **26**, doi:10.1029/2011GB004233.