

## Introduction

Scandium belongs to group 3 of the periodic table, along with Y, La and Ac. The element has an atomic number of 21, an atomic mass of 45, one oxidation state (+3) and one naturally occurring isotope ( $^{45}\text{Sc}$ ). Its geochemistry is quite distinct from the heavier group 3 members.

Scandium has a dispersed lithophile behaviour and rarely forms minerals in which it is a major constituent. The relatively large  $\text{Sc}^{3+}$  ionic radius (75 pm) often precludes favourable substitution for Al and Fe in rocks, although most of the Sc in the lithosphere is held in ferromagnesian minerals, especially Fe-rich pyroxenes in which  $\text{Sc}^{3+}$  does substitute for  $\text{Fe}^{3+}$ . In contrast, Sc levels are low in olivine as  $\text{Sc}^{3+}$  cannot substitute for  $\text{Fe}^{2+}$ . Some substitution of  $\text{Sc}^{3+}$  for Sn in cassiterite  $\text{SnO}_2$  has been noted, the charge balance being maintained by a coupled substitution with  $(\text{Nb},\text{Ta})^{5+}$ . Granite pegmatite often contains minerals enriched in Sc, such as beryl, garnet and Y minerals such as xenotime. Rare Sc minerals, such as thortveitite  $(\text{Sc},\text{Y})_2\text{Si}_2\text{O}_7$  and bazzite  $\text{Be}_3(\text{Sc},\text{Al})_2\text{Si}_6\text{O}_{18}$  (a beryl-like mineral), and Nb-Ta-Sc minerals also occur in such pegmatites. Carbonatite often contains enrichments of rare elements, such as lanthanides, and may include relatively high levels of Sc in such minerals as pyrochlore (a complex niobate) and baddeleyite  $\text{ZrO}_2$ .

The crustal abundance of Sc is quoted as 22  $\text{mg kg}^{-1}$  by Taylor (1964) and 25  $\text{mg kg}^{-1}$  by Fyfe (1999). Excluding olivine-rich rocks, such as dunite and peridotite, Sc levels in igneous rocks are usually inversely proportional to the  $\text{SiO}_2$  content. Thus, gabbro and basalt levels are generally 30–40  $\text{mg kg}^{-1}$ , andesite and dacite 10–30  $\text{mg kg}^{-1}$  and granite usually less than 10  $\text{mg kg}^{-1}$  Sc. Scandium is rare in hydrothermal sulphide mineralisation suites, typically only present at about 1–2  $\text{mg kg}^{-1}$ . Concentrations tend to be higher in high-temperature hydrothermal oxide mineralisation, with levels in minerals such as cassiterite and wolframite up to 0.2% and 0.4%  $\text{Sc}_2\text{O}_3$ , respectively. Scandium contents of sedimentary rocks are generally low; pure sandstone and limestone often contain <2  $\text{mg kg}^{-1}$  whereas argillaceous rocks are much higher, typically 10–30  $\text{mg kg}^{-1}$  Sc. Sedimentary ironstone and phosphatic shale tend to be enriched in Sc, probably because of the low solubility of

$\text{ScPO}_4$  (like  $\text{FePO}_4$ ,  $\text{AlPO}_4$ , etc.) and its capacity to co-precipitate with Fe hydroxides; they may contain up to a few hundred  $\text{mg kg}^{-1}$  Sc. Mielke (1979) cites levels of Sc in shale, sandstone and carbonate rocks as 13, 1, and 1  $\text{mg kg}^{-1}$  respectively. Residual deposits, such as impure bauxite and, especially, laterite and placer sands, may also be enriched in Sc with contents well above normal crustal levels. Laterite are particularly important in some humid tropical environments and often contain up to 100  $\text{mg kg}^{-1}$  Sc. Wedepohl (1978) reports that ash residues of some peat, coal, and crude oil carry significant amounts of Sc (5 to 1000  $\text{mg kg}^{-1}$ ). Therefore, environmental enrichment of Sc due to coal and oil combustion should be expected.

It is quite apparent that Sc is generally associated with siderophile elements, like Fe, Cr and Co, although elemental co-associations may vary depending on surficial environment.

In environmental systems, sorption by clay minerals and organic residues are the primary control on Sc solubility. The lowest concentrations in soil are reported for sandy and light organic soil, whereas somewhat higher amounts are found in soil derived from granitic and volcanic rocks (Kabata-Pendias 2001). Average Sc values in loess deposits are given by Kabata-Pendias (2001) as 5  $\text{mg kg}^{-1}$ , and by McLennan and Murray (1999) as 8  $\text{mg kg}^{-1}$ . On a global scale, mean Sc contents vary from 5 to 10  $\text{mg kg}^{-1}$  (Kabata-Pendias 2001).

Concentrations of Sc in natural water are hence likely to be very low, probably <0.01  $\mu\text{g l}^{-1}$ . Scandium in natural water has some similarities with Al and Fe (Brookins 1988) but, unlike Fe, Sc exists in only the +3 oxidation state, and does not form a stable sulphide under normal conditions. Below pH 4, aqueous  $\text{Sc}^{3+}$  is nominally stable in pure solution, with hydrolysis to  $\text{ScOH}^{2+}$  between pH 4 and 7 and to insoluble  $\text{Sc}(\text{OH})_3$  between pH 7 and pH 11. Above pH 11, very rare in natural water, the amphoteric nature of  $\text{Sc}(\text{OH})_3$  is revealed and the scandate anion  $\text{Sc}(\text{OH})_4^-$  forms. River particulates contain on average 18  $\text{mg kg}^{-1}$  Sc (McLennan and Murray 1999).

The use of Sc in industry is increasing, particularly in alloy research and production, the

manufacture of catalysers and to polish glass. It can be found in many household appliances, including colour televisions, fluorescent lamps, energy-saving lamps and glasses.

Scandium is not known to be an essential element to either plants or animals and little is known about its toxicity. There is evidence that

Sc may cause damage to cell membranes of marine animals, including negative influences on reproduction and on the functions of the nervous system.

Table 58 compares the median concentrations of Sc in the FOREGS samples and in some reference datasets.

Table 58. Median concentrations of Sc in the FOREGS samples and in some reference data sets.

<b>Scandium (Sc)</b>	<b>Origin – Source</b>	<b>Number of samples</b>	<b>Size fraction mm</b>	<b>Extraction</b>	<b>Median mg kg<sup>-1</sup></b>
Crust <sup>1)</sup>	Upper continental	n.a.	n.a.	Total	14.0
<b>Subsoil</b>	<b>FOREGS</b>	<b>790</b>	<b>&lt;2.0</b>	<b>Total (ICP-MS)</b>	<b>9.19</b>
<b>Topsoil</b>	<b>FOREGS</b>	<b>843</b>	<b>&lt;2.0</b>	<b>Total (ICP-MS)</b>	<b>8.21</b>
Soil <sup>2)</sup>	World	n.a.	n.a.	Total	12

<sup>1)</sup>Rudnick & Gao 2004, <sup>2)</sup>Koljonen 1992.

### Sc in soil

Scandium has a median value of 9.19 mg kg<sup>-1</sup> in subsoil and 8.21 mg kg<sup>-1</sup> in topsoil; the range varies from <0.5 to 49.6 mg kg<sup>-1</sup> in subsoil and up to 54.1 mg kg<sup>-1</sup> in topsoil. The average ratio topsoil/subsoil is 0.894.

Low Sc values in subsoil (<5.70 mg kg<sup>-1</sup>) are observed in the glacial drift area from Poland to the Netherlands, much of the Baltic States, central Finland, southern Sweden, western Ireland, south-eastern calcareous Spain, and some smaller areas in Portugal, France and Hungary.

The Sc subsoil distribution map is similar to the iron map, and shows high values (>13.5 mg kg<sup>-1</sup>) in Variscan crystalline rocks of the Iberian Massif in western Spain, in the western Pyrenees (granitic rocks and shale), southern Portugal, Brittany in France (Fe-Sc anomaly clearly related to well known Ordovician oolitic stratabound iron ore), northern Italy from north of the Garda Lake to Tuscany (alkaline volcanics), Greece north of the Gulf of Corinth (lithological reasons including ophiolite, and different types of mineralisation), Croatia, Slovenia and southern Austria (karstic residual soil), eastern Slovakia (soil over volcanic rocks and Palaeogene flysch with ultramafic clasts), eastern Latvia, most of Norway, the ice divide area in northern Finland (weathered mica-

rich rock material), Wales, south-west England, and point anomalies in Scotland and northern Ireland (over the Antrim basalt). High Sc values can be correlated with crystalline rocks of intermediate to mafic or alkaline affiliation, including greenstone belts, and also karst with soil on carbonate rocks (Greece, Croatia and Slovenia). In northern Finland, iron ores are present.

In comparison to the Fe<sub>2</sub>O<sub>3</sub> map, the Sc subsoil map shows continuous high values in the Norwegian Caledonides, a stronger anomaly in southern Portugal, and a weaker anomaly in Italy.

The topsoil Sc map is very similar to the subsoil map, but with higher values in most of the Pyrenees, in Variscan western Spain and in the Sierra Nevada in southern Spain. On the other hand, the high subsoil values in Slovakia and Latvia disappear completely in the topsoil map.

The linear correlation coefficient Fe-Sc is 0.89 in subsoil and 0.92 in topsoil; with vanadium the correlation is also very strong: 0.91 for subsoil, and 0.91 for topsoil. The Sc topsoil distribution map is more similar to the Fe<sub>2</sub>O<sub>3</sub> topsoil map than to that of V.

Scandium also has a strong correlation (>0.6) with Co, Al, Ga, In, Cu, Ti and the heavy REEs.

### **Sc comparison between sample media**

The analytical values for Sc in stream and floodplain sediment have not been reported, because the analytical data did not pass the quality control checks. There are no Sc data available for

stream water, as the element was not part of the suite of analytical determinands. There is little difference between topsoil and subsoil distributions.