

Introduction

Tellurium is a metalloid belonging to group 16 of the periodic table, which also includes O, S and Se. The element has an atomic number of 52, an atomic mass of 128, four oxidation states (-2, +2, +4 and +6) and eight naturally occurring isotopes (^{120}Te , ^{122}Te , ^{123}Te , ^{124}Te , ^{125}Te , ^{126}Te , ^{128}Te and ^{130}Te), of which ^{130}Te , ^{128}Te and ^{126}Te are the most abundant at 34.48%, 31.79% and 18.71% respectively of the total mass.

Tellurium is a rare element, present in the Earth's crust at an average concentration of only about $2 \mu\text{g kg}^{-1}$. Tellurium is a chalcophile element with lithophile tendencies, essentially being constrained to sulphide and low-temperature supergene minerals. Almost all Te minerals exist as tellurides, the most important being gold and silver tellurides, such as calaverite AuTe_2 , sylvanite $(\text{Au,Ag})\text{Te}_4$ and krennerite $(\text{Au,Ag})\text{Te}_2$, which form in mesothermal and epithermal precious metal vein deposits. There is only one example of a tellurium oxide mineral, tellurite TeO_2 (Sindeeva 1964). Similarly, there are few examples of tellurates, poughite $\text{Fe}_2(\text{TeO}_3)_2(\text{SO}_4) \cdot 3\text{H}_2\text{O}$ being the only confirmed mineral reported (Wedepohl 1978). Possible host minerals are pyrite, molybdenite, chalcopyrite, gold, silver and pentlandite, although in rock-forming silicate minerals Te generally falls below detectable levels. Tellurium has not been detected in pegmatites but occurs in hydrothermal sulphides and in skarn deposits.

Data for Te in magmatic rock types is very limited; Turekian and Wedepohl (1961) give an average concentration for all magmatic rocks of only $2 \mu\text{g kg}^{-1}$. Reimann and Caritat (1998) suggest levels between $1\text{--}6 \mu\text{g kg}^{-1}$ in igneous rocks and $2\text{--}9 \mu\text{g kg}^{-1}$ in sedimentary rocks. Greywacke and shale contain an average of $0.1\text{--}1 \text{mg kg}^{-1}$ Te (Wedepohl 1978). Pyrite and copper-molybdenum deposits generally contain the highest concentrations of Te. Vlassov (1964) reports Te concentrations from a pyrite deposit in the range $6\text{--}1350 \text{mg kg}^{-1}$ in pyrite and $9\text{--}6600 \text{mg kg}^{-1}$ in chalcopyrite. Whilst the ranges given for a copper-molybdenum deposit are notably lower, Vlassov (1966) reports $5\text{--}510 \text{mg kg}^{-1}$ Te in pyrite and only $5\text{--}20 \text{mg kg}^{-1}$ in chalcopyrite.

Ward *et al.* (1963) give an average Te concentration of 48mg kg^{-1} in manganese nodules from the Pacific.

During weathering Te may be oxidised to tellurites, which are slightly mobile and usually sorbed by Fe hydroxides. There has been no systematic investigation of Te in soil on the global scale, although it has a low mobility in various soil horizons (Kabata-Pendias 2001). Its average content in soil is cited by Jović (1999a) between 0.5 to 37mg kg^{-1} Te.

Tellurium is not stable as the free cation. Telluric acids $[\text{Te}(\text{OH})_4]$ are soluble in aqueous solution, although Te^{4+} gradually oxidises to Te^{6+} (Nolan *et al.* 1991) mainly as H_5TeO_6^- (Hein *et al.* 2003). It is likely that Te is scavenged by colloidal Fe and Mn oxyhydroxides, although Te is also abiotically and/or biologically methylated, which may increase its mobility in the aquatic environment. Early data estimated Te concentrations at about $10 \mu\text{g l}^{-1}$ in surface water (Wedepohl 1978), whereas more recent data suggest this was a significant overestimation. Hein *et al.* (2003) suggest that rivers may contain as little as $<5 \text{ng l}^{-1}$ and sea water even less.

In industry, Te is used to improve the machinability of copper and stainless steel, and its addition to lead decreases the corrosive action of sulphuric acid on Pb and improves its strength and hardness. It is used as a basic ingredient in blasting caps, and is added to cast iron for chill control. Tellurium is also used in ceramics and in the electronics industry as a semiconductor; bismuth telluride has been used in thermoelectric devices.

There is no known biological function for Te, but it may interact with Se to accumulate in bones (Reimann and de Caritat 1998). Some Te compounds are teratogenic, methylated Te is known to be toxic and tellurium hexafluoride (used in industry) is a severe irritant of the respiratory system in animals. Tellurium is not usually considered to be of concern to the environment because of its rarity.

Table 66 compares the median concentrations of Te in the FOREGS samples and in some reference datasets.

Table 66. Median concentrations of Te in the FOREGS samples and in some reference data sets.

Tellurium (Te)	Origin – Source	Number of samples	Size fraction mm	Extraction	Median mg kg⁻¹
Crust ¹⁾	Upper continental	n.a.	n.a.	Total	0.3
Subsoil	FOREGS	783	<2.0	Total (ICP-MS)	0.03
Topsoil	FOREGS	840	<2.0	Total (ICP-MS)	0.03
Soil ²⁾	World	n.a.	n.a.	Total	0.006
Water	FOREGS	807	Filtered <0.45 µm		<0.005 (µg l⁻¹)
Water ¹⁾	World	n.a.	n.a.		0.006

¹⁾Ivanov 1996, ²⁾Koljonen 1992.

Te in soil

The median Te content is 0.030 mg kg⁻¹ in both subsoil and topsoil. About 25% of the samples are below the detection limit of 0.02 mg kg⁻¹. The maximum content is 1.63 mg kg⁻¹ Te in subsoil and 0.93 mg kg⁻¹ Te in topsoil. The average ratio topsoil/subsoil is 0.989.

In subsoil, low Te values (<0.02 mg kg⁻¹) occur over most of Sweden and Finland, the Baltic States, the glacial drift area from the Netherlands to Poland, part of Hungary and Austria, central Portugal and western Spain, and parts of northern England, eastern Scotland and northern Ireland.

High Te values in subsoil (>0.05 mg kg⁻¹) are found in Italy, Greece, in karstic soil of Slovenia and Croatia, the Pyrenees (Silurian black shale), the Poitou region (the strong association Sb-Ag-Te-Pb-Zn points to a blind mineralised area, see above), and an area from Asturias to northern Portugal (following structures which contain epithermal gold mineralisation). The Te anomalies in Greece and Slovenia-Croatia are generally in terra rossa and other soil types on carbonate rocks, and are related to pedogenesis of karstic soil and possibly to bauxite genesis. A

slightly elevated Te point value in north-eastern Greece is in the vicinity of Au mineralisation (Pangaeon). An outlier with 1.63 mg kg⁻¹ Te in western Austria is associated with gravel deposits in the nearby Tauern region, which frequently show enhanced Te and Se concentrations.

There is little difference between the Te distribution patterns of subsoil and topsoil, and this similarity is indicated by the average ratio topsoil/subsoil of 0.989. In south-western coastal Norway, high Te values in topsoil occur in an area where there is a smelter (Sauda Zn).

In topsoil, an outlier with 0.93 mg kg⁻¹ Te is present in the western Pyrenees in Spain, associated with black shale of the Silurian.

Tellurium in soil has a good positive correlation (>0.4) with Fe, Mn, Sc, V, In, Co, Ni, Zn, Cd, Cu, Y and some heavy REEs. This pattern, which is the same in subsoil and in topsoil, points to an association with fine-grained iron- and manganese-oxide phases, but also suggests enrichment in particular mineralising settings in association with intermediate intrusive rocks (porphyry copper type) and their metamorphic equivalents in crystalline massifs.

Te in stream water

Tellurium values in stream water range from <0.005 to 0.032 µg l⁻¹ (excluding three outliers up to 0.11 µg l⁻¹), with almost 60% of the data below the analytical limit of quantification. Distribution of tellurium is different from all other investigated elements. Concentrations tend to be higher in

alkaline stream water of the Mediterranean region, in which Te resembles As, Mo, Se, U and V.

Lowest Te values in stream water (<0.005 µg l⁻¹) occur throughout most of Fennoscandia on Precambrian Shield and Caledonian rocks, in Estonia, western and south-western Lithuania, in

most of Poland, parts of northern Germany and in Denmark on deposits of glacial drift from the Precambrian Shield. Low values extend over most of Caledonian and Variscan terrains, and about half of the surface of the sampled Alpine Orogen: eastern Slovakia, most of Hungary and Slovenia, all Croatia, central Austria, Switzerland and French Alps, north-eastern Italy, southern Italy and Corsica, over the Pyrenees, north Albania and central Greece. With so much of this data below the limit of detection, no reliable detailed interpretation is possible.

Enhanced Te concentrations in stream water ($>0.009 \mu\text{g l}^{-1}$) are found in south-western Finland and central Sweden on Precambrian Shield rocks, and in Latvia and north-east Lithuania, in north-east Germany on glacial drift of Precambrian Shield origin, in south-western Norway, north-east Scotland and northern England on Caledonides, and in western Czech Republic, south Germany, extreme northern and southern tips of France, on south-western tip of Portugal, in south-west Spain (related to the Iberian Pyrite Belt mineralisation) and on Sardinia (caused by base metal deposits), all on Variscan terrains (De Vos *et al.* 2005). High Te values are also found in Slovakia, eastern Austria, north and central Italy and Sicily, Baetics of southern Spain (associated with Fe-Cu mineralisation), north-east Spain (related to Cu-U disseminations in detrital sediments in the Ebro River basin, and evaporitic

calcareous sediments), north and south Greece, including Crete, all of the Alpidic region. The relatively high Te in north-east England is associated with both heavy industries in the surrounding areas, and could also be related to the underlying Durham Coalfield geology. The high Te area in central Macedonia and Thessaly in Greece is associated with gold and base metal mineralisation; in western Crete the stream drains Neogene sediments and Permian phyllite and schist, with Fe mineralisation (limonite, haematite, pyrolusite, alunite), and gypsum beds. An isolated high value in north-east France occurs in a similar context.

Owing to the small fraction of meaningful Te determinations, the following comparisons are on the level of mere indications. The tellurium distribution in the map is a combination of the patterns followed by the elements of the Major-ions stream water, those typical of the Sea influenced stream water, and inverse to the Mn-Fe stream water. The Major-ions stream water pattern is dominated by climate and only partly related to geology (Sardinia, Italy, Greece). The Sea influenced stream water may be responsible for enhanced concentrations along western coasts, and the inverse Mn-Fe stream water for the belt of low concentrations across central Europe, and for the high concentrations in south-east Spain and northern Greece.

Te comparison between sample media

The analytical data for Te in stream and floodplain sediments have not been reported, because the analytical results did not pass the quality control checks. There is little difference between topsoil and subsoil distributions. Almost half of the stream water Te data are less than the

limit of detection. It is, therefore, difficult to compare patterns between stream water and soil data, although areas of relatively high stream water Te tend not to correlate well with higher values in soils.