Environmental geochemistry and ecological risk of vanadium pollution in Panzhihua mining and smelting area, Sichuan, China*

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Abstract Vanadium is a trace element widely distributed in the Earth’s crust. Naturally high levels of vanadium are recognized mainly in basic rocks and minerals, particularly in titaniferous magnetite. And the anthropogenic sources of vanadium include fossil fuel combustion and wastes including steel-industry slags. In the last few years, the authors have made investigations and assessments on the environmental geochemistry and ecological risk of vanadium in the Panzhihua mining and smelting area. In the study area, anthropogenic vanadium resulted from mining, extracting and smelting of V-Ti magnetite; vanadium pollution of topsoil and sediments occurs mainly in the mining and extracting area, smelting area, slag dumping area, tailing dam and coal mining area. In the soil, the chemical speciation of vanadium shows: insoluble residue > organically bound > Fe (amorphous) oxide-bound > Mn oxide-bound > soluble component. Vanadium pollution can cause potential harmful effects on ecological systems, and lead to animal poisoning and human disease. So vanadium pollution should be monitored on a regular basis in the Panzhihua area.

Key words vanadium; environmental geochemistry; ecological risk; Panzhihua area

1 Introduction

Vanadium (V) is a relatively abundant element which is widely distributed in nature; however, workable V deposits are very rare (World Health Organization, 2001). Vanadium is a trace element, which may be beneficial and possibly essential for human beings, but certainly essential for some living organisms (Crans et al., 2004). However, vanadium has aroused ever increasing interest in the past few decades because of its toxicological effects on human beings and animals (World Health Organization, 1990; Nriagu and Pacyna, 1998; Almedeida et al., 2001; Mukherjee et al., 2004), and of diverse sources of pollution and its dramatic role in constituting a major risk to the global environment in facing silent epidemics of metal poisoning (Nriagu and Pacyna, 1988).

Vanadium occurs in the minerals vanadinite, paratone, and carnotite. It account for about 0.01% of the total in the crust (Budavari et al., 1996) and was derived mainly from titaniferous magnetite containing 1.5%–2.5% vanadium pentoxide, which is mined in South Africa, Russia, and China (Health and Safe Executive, 2002). Smelting of iron ores produces a lot of vanadium slag that contains 12%–24% vanadium pentoxide, which is used for the production of vanadium metal (World Health Organization, 2001). Vanadium pentoxide is also produced by solvent extraction from uranium ores and by a salt roasting process from boiler residues or residues from elemental phosphate plants. Ferrovanadium can be obtained from vanadium pentoxides or vanadium slags in the alumino-thermic process (World Health Organization, 2001). All crude oils contain metallic impurities, including vanadium, which is present as an organometallic complex. The concentrations of vanadium in crude oils range from 3 to 260 mg/kg and in residual fuel oil, from 0.2 to 160 mg/kg (National Academy of Sciences, 1974). During the burning of fuel oils in boilers and furnaces, vanadium is left behind as vanadium pentoxide in solid residues, soot,
boiler scale, and fly ash. Vanadium is also present in coal, typically with the concentrations varying between 14 and 56 mg/kg (World Health Organization, 2001). The hard metal industry uses small amounts of vanadium carbide in the production of tungsten carbide tool bits. Vanadium pentoxide is used as the catalyst for a variety of gas-phase oxidation processes, particularly the conversion of sulfur dioxide to sulfur trioxide during the manufacture of sulfuric acid. The most frequently used vanadium pentoxide catalyst contains 4%-6% vanadium in the form of vanadium pentoxide on a silica base (World Health Organization, 2001). Vanadium pentoxide is also used in some pigments and inks used in the ceramics industry to impart a colour ranging from brown to green. Vanadium pentoxide can be used as a colouring agent to provide ultraviolet filtering properties in some glasses (World Health Organization, 2001).

Natural high levels of V are recognized primarily in basic rocks and minerals, particularly in titaniferous magnetite. However, the concentrations of anthropogenic V in the environment have increased significantly in recent years as the demand for V tends to increase in high-temperature industrial activities including steel-iron refining, electronics and dyeing, etc., though the major sources of V in the surface environment are the combustion of fossil fuels and resultant wastes (Lepp et al., 1995; Nriagu and Pirrone, 1998; Kabata-Pendias and Pendias, 2001). Since V is always present in these materials, its concentrations can be used as a tracer to monitor the degree of environmental pollution (Soldi et al., 1996).

Vanadium is a major trace metal in fossil fuels and the combustion of these materials provides a significant source of vanadium to the environment (Duce and Hoffman, 1976). These are the major environmental vanadium fluxes resulting from human activities; other sources are the products of coal combustion, leachates, and effluents from mining and milling of uranium and titanium ores (Nriagu and Pacyna, 1988; Hope, 1997).

Although high V concentrations in the surface environment would not pose an immediate treat to the global ecosystem, a high level of anthropogenic V can cause a local environmental hazard (Hope, 1994, 1997). During the last few decades, the facade of vanadium as a “slightly” toxic and carcinogenic element has been eventually ratified to an essential trace element with anti-diabetic and anti-carcinogenic properties (Mukherjee et al., 2004).

There are several publications on vanadium geochemistry in geological processes and its toxicity, but there are only a few studies that focus on the environmental geochemistry of V in surface environment and ecological risks. In this paper, we carried out environmental geochemical surveys; the objectives are: (1) to investigate vanadium pollution and (2) to assess ecological risk of vanadium in the study area.

2 Study area

The giant Panzhihua V-Ti magnetite [Fe(V,Ti)O4] deposit, located in the southern part of the NS-trending Panxi rift valley, along the Jinsha River (upstream of the Yangtze River) in Southwest China, provides 20% Fe, 64% V and 53% Ti supplies for China, and it is celebrated as the most famous base of V-Ti magnetite production in the world. Vanadium-titanium magnetite ores contain Fe, Ti, V, Si, Al, Ca, Mg, Na, K, O, S, Cu, Co, Ni, Ga and so on.

The mining camp includes 6 large-scale (Panzhihua, Baina, Taihe, Hongge, Xinjie and Badong) iron deposits hosted in basic-ultrabasic intrusions, numerous medium-sized coal, clay, dolomite, limestone deposits, and minor graphite, manganese and barite deposits. Production facilities include a large steel manufacturing mill and a steel rolling mill. The extensive mining and processing activities have exerted major environmental impacts (Ni Shijun et al., 2001; Teng Yanguo et al., 2000, 2001, 2002, 2003).

Mining activities have left huge uncovered slopes, large areas of dumping waste rocks and extensive tailings dams. 11.50 million tons of Fe ore are mined per year, and more than 680 million tons of excavated ore and gangue, and 220 million m³ of tailings have been deposited near the Jinsha River, thus creating severe threat of trace metal pollution both in the mining area and further down stream towards the Yangtze River (Ni Shijun et al., 2001; Teng Yanguo et al., 2000, 2001, 2002).

3 Methodology

We have carried out some environmental and geological investigations since 1997. Systematic sampling was conducted to collect topsoil samples in July 2000. Topsoil sampling was carried out under similar geochemical background, so it is convenient to analyze environmental impact on soil due to mining activities. The soil samples were dried and sieved to obtain the less than 0.063 mm fraction. The contents of vanadium in soil samples were measured by using of the ICP-MS method at the Institute of Geochemistry, Chinese Academy of Sciences. The analysis results are listed in Table 1. According to the method described by Berrow et al. (1978) and Micera and Sanna (1998), the chemical species of vanadium in the soil were analyzed, and the analysis results are listed in Table 2.