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Geologic Sources of Asbestos in Seattle's Tolt Reservoir

Abstract

Water from Seattle's South Fork Tolt Reservoir contains chrysotile and amphibole asbestos fibers, derived from natural sources. Using optical petrographic techniques, X-ray diffraction, and scanning electron microscopy, we identified the geologic source of these asbestiform minerals within the watershed. No asbestos was found in the bedrock underlying the watershed, while both chrysotile and amphibole fibers were found in sediments transported by Puget-lobe glacial processes. These materials, widely distributed throughout the lower watershed, would be difficult to separate from the reservoir sediments. The probable source of this asbestos is in pods of ultramafic rock occurring north of the watershed. Because asbestos is contained in widespread Puget-lobe glacial materials, it may be naturally distributed in other watersheds in the Puget Sound area.

Introduction

Located in the Cascade Mountains of Washington, about 50 km east of Seattle, the South Fork Tolt Reservoir provides approximately one-third of Seattle's water supply. In 1975, the U.S. Environmental Protection Agency (EPA), while studying asbestos contamination in water supplies, discovered that the Tolt Reservoir contained asbestos fibers. Reservoir waters contained both chrysotile (up to 1.6 X 10^6 fibers/liter) and amphibole (up to 1.9 X 10^6 fibers/liter) asbestos fibers with lesser amounts commonly found in tributary streams. However, a point source could not be determined for either type of asbestos, indicating widespread distribution within the watershed (Kirmeyer 1979; Millete et al. 1979).

Many studies have demonstrated a link between airborne asbestos fibers and the increased incidence of asbestosis and various cancers in humans (c.f. Kane 1993). Although gastrointestinal cancer has been linked to occupational asbestos exposure, no definitive data on the effects of drinking asbestos appears to exist for either animals or humans (U.S. EPA 1980; Polissar et al. 1984). Nevertheless, the Seattle Water Department, with a grant from the U.S. EPA, developed methods of filtering asbestos fibers from the water supply (Kirmeyer 1979).

Asbestos appears to be widely distributed within the Tolt watershed and no significant human asbestos-polluting activities have affected the area. This indicates a natural source of asbestos contamination; determining this source could help minimize reservoir water contamination. We conducted a study to determine the natural geologic source of asbestos within the watershed. Asbestiform minerals occur only in specific rock types such as ultramafic rocks that have been metamorphosed and sheared (Deer et al. 1963a and b; Hodgson 1977; Whittaker 1979; Wicks 1979). We considered two possible sources of naturally occurring asbestos: one from bedrock in the watershed and another from glacial materials transported from outside the watershed by glacial and fluvial processes.

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Geologic Setting

The South Fork Tolt Reservoir occupies a steep-walled glacial valley which trends east-west and rises from about 500 m in elevation on the valley floor to 1500 m on the adjacent ridges. On the west end of the reservoir, late Pleistocene Puget-lobe glaciation formed a moraine near the present-day dam site. The rest of the watershed shows the effects of Pleistocene alpine glaciation.

Bedrock

There are three major bedrock groups within the South Fork Tolt Reservoir watershed (Figure 1) that have been described by Tabor et al. (1993). Pre-Tertiary melange rocks, composed of metagabbro, metadiabase, metatonalite and argillite, crop out in the center of the watershed. Over-

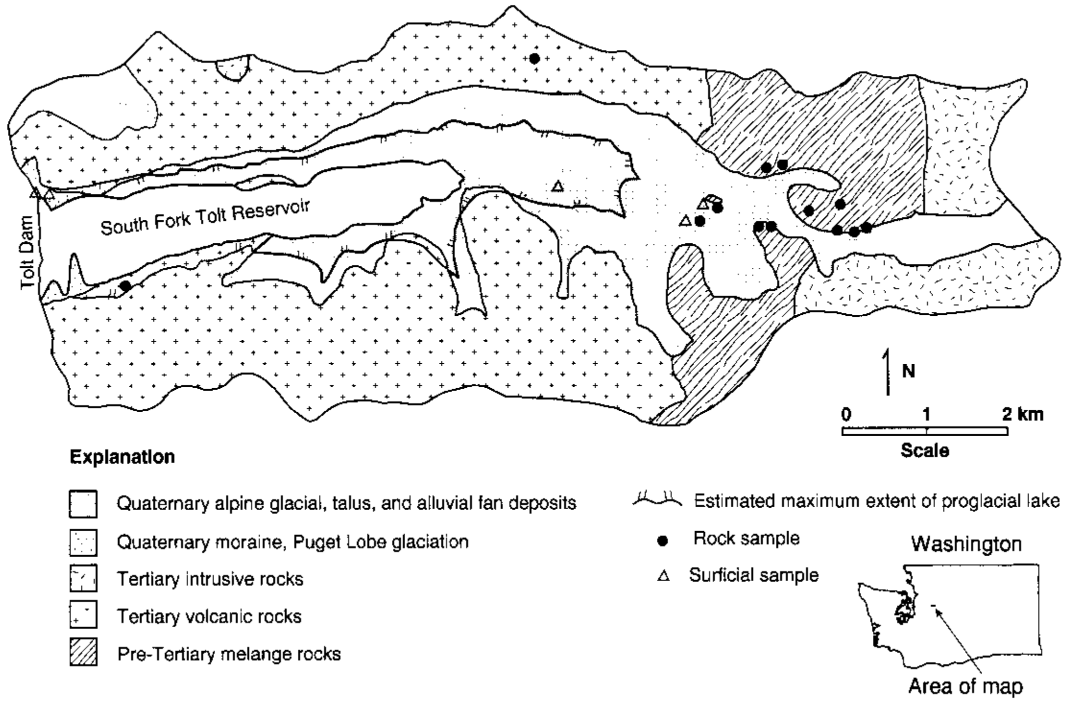

Figure 1. Geologic map of the South Fork Tolt Reservoir watershed showing sample locations. Geologic units adapted from Booth (1990) and Tabor et al. (1993); estimated extent of proglacial lake from Knoll (1967).

lying this group are Tertiary volcanic rocks, predominantly andesites, that are exposed in the western portion of the watershed and surround the reservoir. Intrusive rocks, tonalite and granodiorite from the Tertiary Snoqualmie batholith as well as gabbro, are found in the eastern portion of the watershed. The melange rocks are the only group likely to contain asbestiform minerals. Small ultramafic pods of serpentinized peridotite have been found by Tabor et al. (1993) in melange rocks east of the Tolt watershed (Figure 2). Within the watershed, however, no ultramafic rocks were mapped by Tabor et al. (1993) and none were found during our field investigations.

Glacial history

The history, distribution, and composition of alpine and Puget-lobe drift are described in detail by Knoll (1967) and Booth (1990) and are summarized briefly here. Alpine glaciation in the South Fork of the Tolt reached its maximum extent during the Evans Creek stade of the Fraser Glaciation, before the Vashon Puget-lobe advance. From a probable source in the eastern edge of the watershed, alpine glaciation reached as far west as a bedrock lip near the site of the present-day dam. The broad pass between the eastern edge of the Tolt watershed and the Money Creek drainage was probably occupied by glacial ice, and the ice flow divide may have been east of the present topographic divide.

During the Vashon stade, the Puget lobe of the Cordilleran ice sheet blocked the South Fork Tolt Valley at the rangefront, causing the river to pond eastward behind the glacier. At the ice margin, near the site of the Tolt Dam, glacial drift formed a moraine and meltwater flowed into the proglacial lake. According to Knoll (1967), this lake reached an altitude of at least 600 m, slightly higher than the present-day reservoir level (Figure 1).

Alpine drift

Alpine drift within the South Fork Tolt Valley consists of till, outwash, and glaciolacustrine clays. Alpine till, preserved in tributary stream valleys, extends from the eastern portion of the watershed to near the Tolt Dam. Alpine-derived glaciolacustrine deposits are interbedded with Vashon

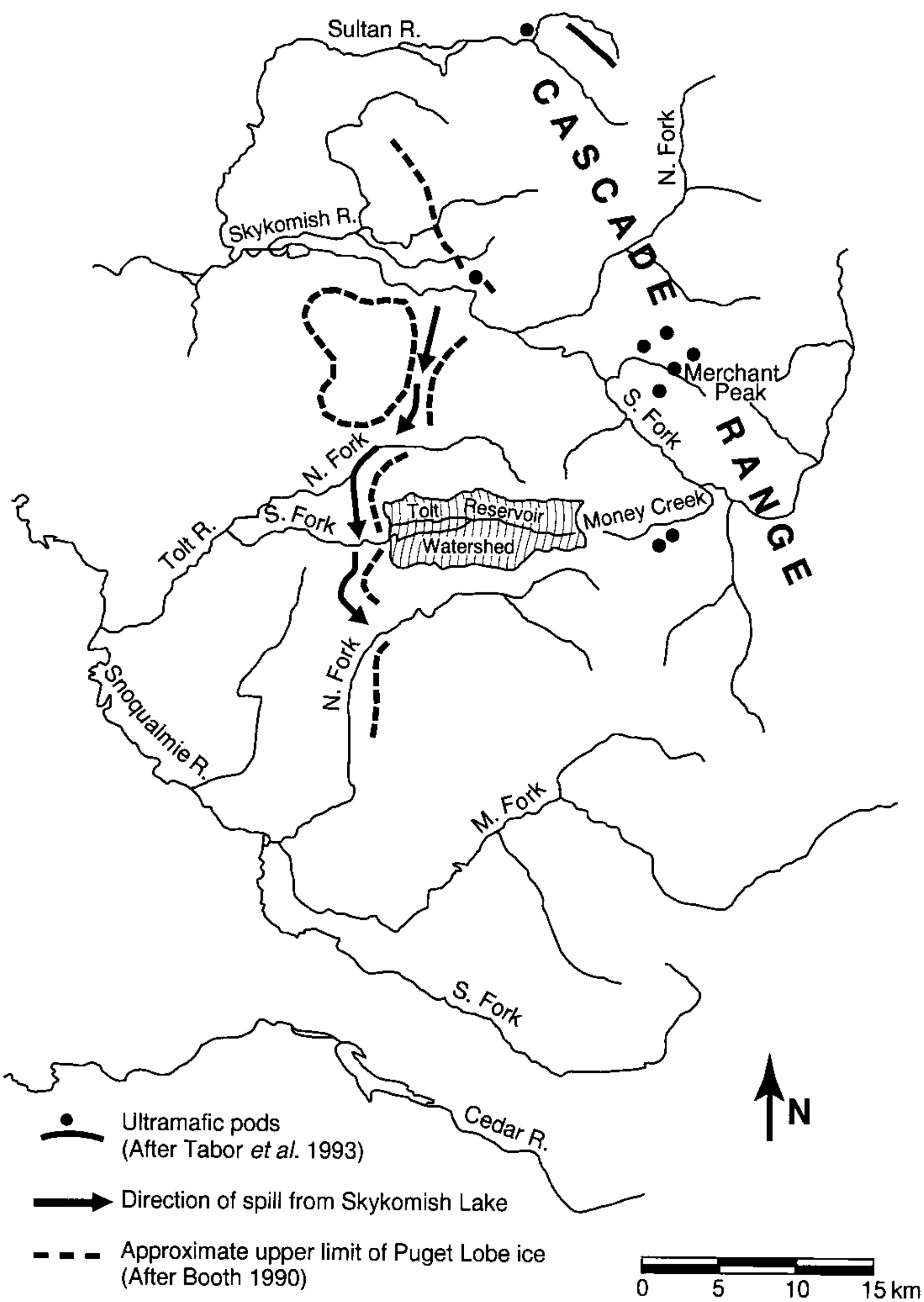

Figure 2. Mapped ultramafic pods, limits of Puget-lobe glaciation, and river drainages near the Tolt Reservoir. Arrows show direction of spill along rangefront from Skykomish Lake during Puget-lobe glaciation (after Booth 1990).

till on the moraine at the rangefront. Blue-gray silty clays overlie alpine till and are divided into two units by Knoll (1967). The lower clays are believed to be composed of proglacial lake sediments derived from alpine material, while the upper clays were deposited by meltwater from both alpine and Puget-lobe glaciers.

Puget-lobe drift

Vashon till from Puget-lobe glaciation occurs in the moraine at the mouth of the valley, along with outwash sands and gravels. The till, composed of rounded gravels set in a clayey sandy matrix, has been traced to an altitude of 700 m at the rangefront. Puget-lobe advance and recessional outwash are exposed southeast of the Tolt Dam. Glaciolacustrine material, partially derived from Puget-lobe glaciation, overlies alpine till near the east end of the reservoir (Knoll, 1967).

Analytical Procedures

We collected and analyzed twenty-three bedrock and exotic cobble samples and six glacial drift samples from the Tolt watershed (Figure 1). Our procedures were designed to verify the presence or absence of asbestos fibers in geologic materials; we did not precisely determine the quantity of fibers present. A complete description of the sampling information and analytical procedures can be found in Reid and Craven (1979).

For selected rock samples, we made and examined thin sections for asbestiform or related minerals. If a sample appeared to potentially contain asbestos, especially chrysotile, we also performed X-ray diffraction and electron microscope scans. We treated glacial deposit samples to remove organics and iron and then particle size separated them using the methods of Jackson (1969). We further separated the silt and clay fractions by density using heavy liquids. Chrysotile, at D ~ 2.55, separated with the light fraction (D < 2.58), while amphibole, at D = 3.0-3.3, separated with the heavy fraction (D > 2.92).

We examined select samples of these density fractions using powder X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. Specimens were usually scanned at between 2500 and 5000 X, with greater magnification used to positively identify morphological features and photograph fibers.

Morphological aspects can be very important in determining fiber mineralogy (Asher and Mcgrath 1976; Gravatt et al., 1978). A 3:1 or greater length to diameter ratio is commonly used to define asbestos fibers (U.S. Dept. of Health and Human Services 1980), although asbestiform fibers often have ratios 10:1 or greater. Chrysotile's fibrous form is created by magnesium octahedral and silica tetrahedral sheets rolled into hollow tubes or scrolls (Deer et al., 1963b; Yada 1967; Yada 1971). The edges of the rolled sheets often cause small fibers to have a characteristic groove running along their long axis. Amphiboles tend to form fibers having characteristic cleavage angles (Deer et al. 1963a; Whittaker 1979).

Results

Bedrock

We examined six samples of volcanics, five of metadiabase, four of metatonalite, and eight cobbles of various origins, including gabbros and granodiorites, with the petrographic microscope. We did not observe any asbestiform minerals in the thin sections, although many had stubby, prismatic amphiboles. We also X-rayed the light density fraction of nine samples; none yielded a pattern similar to chrysotile. In addition, we scanned the light density fraction from five specimens (two volcanics, three metadiabases) using the electron microscope and no fiber morphology was observed. We found no asbestos in the twenty-three rock samples examined.

Glacial drift

We performed XRD analysis on three clay and three silt-sized, light-density fractions from Vashon till, glaciolacustrine clay, and alpine till. The diffraction patterns obtained from these yielded indeterminate results. While the patterns closely resembled chrysotile, other minerals (most notably kaolinite) have similar patterns. SEM analysis later revealed the greatest proportion of these samples to be kaolinite-like plates. Under these circumstances, XRD could not confirm or deny the presence of chrysotile. Similar problems have been encountered by other workers (Mangia 1980). XRD detection limits for chyrostile or amphibole asbestos in mixtures with other minerals are in the 0.5 to 2 wt. % range (Guthrie 1993).

We scanned the light and heavy density fractions from both silt and clay sizes of six glacial drift samples using SEM methods. Specimens prepared from the Vashon moraine, outwash, and glaciolacustrine material showed the highest amounts of both chrysotile and amphibole fibers. Lesser amounts of chrysotile and amphibole asbestos fibers were found in alpine till from a location below 640 m in elevation. No asbestiform minerals were found in the upper alpine moraine material. All heavy density fractions also contained some non-asbestiform amphiboles.

Discussion

Distribution of asbestos within the watershed

In bedrock within the South Fork Tolt Reservoir watershed, we found no evidence of asbestos. However, all materials derived directly from the Puget-lobe glaciation that we examined contained both chrysotile and amphibole asbestos. Two "mixed" samples (alpine till below the Vashon-age lake level) also contained chrysotile and amphibole fibers, though in conspicuously lesser amounts than Vashon till, outwash, and glaciolacustrine sediments. In addition, chrysotile and amphibole asbestos streamwater concentrations reported by Kirmeyer (1979) indicate that tributaries in contact with Puget-lobe drift or glaciolacustrine sediments contain asbestos fibers. Of these tributaries, higher asbestos concentrations were found in those in the western portion of the watershed.

Within the watershed, asbestos fibers are distributed in glaciolacustrine sediments. This makes the extent of the Vashon-age proglacial lake a significant factor influencing the extent of asbestos distribution. Knoll (1967) found evidence that the lake reached an altitude greater than 600 m (Figure 1). Vashon till has been traced to an altitude of 700 m near the dam of the proglacial lake. In principle, the maximum possible lake level could be close to that altitude, although there is apparently no direct sedimentary or geomorphic evidence to support this. We found asbestos fibers in a sample of "mixed" alpine till taken from a streamcut at approximately 640 m elevation, suggesting that either previous continental glaciation or the proglacial lake level reached this elevation.

In the Tolt watershed there is little chance of physically isolating asbestos-bearing materials from the water supply because glaciolacustrine materials, partially derived from Puget-lobe glaciation, were used to seal the reservoir. Any activity that increases erosion and mass wasting of these widespread, unconsolidated materials within the watershed would likely increase waterborne asbestos.

Source area of asbestos

The bedrock source of the asbestos found in the Puget-lobe drift probably lies to the north of the Tolt watershed, in the North Cascades. The North Cascades contain widespread serpentinized ultramafic pods, some of which have asbestiform minerals (Misch 1966; Vhay 1966; Brown 1987; Tabor et al. 1993). North of the Tolt reservoir, the Pilchuck, Sultan, Stillaguamish, and Skagit Rivers all drain terranes of the North Cascades, and all contain asbestos from indigenous sources (D. Dethier, oral communication 1979). During the Vashon-age glaciation, asbestiform minerals probably reached the Puget lobe from sources in the Cascades by combined alpine glacial and fluvial processes. However, significant southward glacial transport of this material was probably minor. Most Puget-lobe drift only contains 5-15% clasts foreign to the local drainage (Booth 1990).

Within the South Fork Tolt watershed, no ultramafic rocks are known to crop out, although some may occur under surficial deposits. Tabor et al. (1993) mapped ultramafic rock occurrences about 5 km east of the watershed above Money Creek and about 10 km northeast of the watershed in the Merchant Peak area of the Skykomish River watershed (Figure 2). Alpine glacial transport of ultramafic materials from the Money Creek watershed over the broad pass into the eastern Tolt watershed is unlikely because the required ice flow divide would have been located in an area of the Money Creek drainage that is presently about 5 km east of and 400 m lower than the pass.

The most likely source of asbestos is the Skykomish watershed, with transport to the Tolt watershed by Puget-lobe glacial or glaciofluvial processes (Figure 2). During the complex recessional history of Vashon-age glaciation, water draining from north and east of the Skykomish valley was impounded in a lake occupying the

Skykomish valley (Booth 1990). This lake would have collected water and sediment from areas with known ultramafic pods such as the Merchant Peak area and the Sultan River basin to the north. During most of the Vashon-age glaciation, the only drainage from this lake spilled southward through a trough along the rangefront, eventually reaching the Snoqualmie watershed south of the Tolt (Figure 2). Subglacial and subaerial passageways in this trough provided some of the sediment found in recessional deposits downstream from the present day Tolt reservoir (Booth 1990). Flow from the Skykomish valley lake probably provided sediment, and with it asbestos, to the proglacial lake then occupying the South Fork Tolt reservoir site.

Regional significance

Asbestos-bearing ultramafic rocks in watersheds of the North Cascades may provide a naturally-occurring source of asbestiform minerals. In the South Fork Tolt Reservoir watershed, our results strongly indicate that both chrysotile and amphibole asbestos fibers were transported into the watershed by Puget-lobe glacial and glaciofluvial processes, and were not derived from any bedrock source within the watershed. The occurrence of asbestiform minerals in widespread Puget-lobe glacial materials has regional significance beyond the Tolt Reservoir watershed. For example, the north forks of the Tolt and Snoqualmie Rivers also were found to contain asbestos at the same time that asbestos was discovered in the Tolt Reservoir (Seattle Water Department, unpubl. data). In these watersheds, asbestos may also have been transported southward from the Skykomish drainage. Further south, the Cedar River, Seattle's other water source, contains only minor amounts of asbestos (J. Sceva, oral communication 1979). This watershed is not underlain by melange or ultramafic rocks (see mapping by Frizzell et al. 1984); moreover, it was not directly affected by drainage from the Skykomish valley. Thus, both the distribution of asbestos-bearing rocks and the distribution of Puget-lobe glacial materials influence the likelihood of natural asbestos minerals occurring in the waters or sediments of other watersheds in the Puget Sound area.

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