2

Early History of Human Activities in the Sudbury Area and Ecological Damage to the Landscape

Keith Winterhalder

In contrast to the ancient events that formed the Sudbury Basin and its mineral deposits, its human history spans less than 10,000 years. As the Wisconsin glacier receded, a forest cover developed, and the area was settled by native groups. The events that led to Sudbury becoming one of the largest mining and smelting regions in the world (Fig. 2.1) are from a far briefer period of about 100 years. The environmental damage that occurred during this recent industrial period is the focus of this chapter. Other international examples of mining-related ecosystem damage are described in Box 2.1.

Sudbury lies in a vegetation zone referred to by Rowe (1959) as the Great Lakes-St. Lawrence Forest Region and is located on the margin of the northern Temagami section, once characterized by extensive stands of red and white pine (*Pinus resinosa* and *P. strobus*), and the southern Algonquin section, where white pine formed an admixture with tolerant hardwoods such as sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*). Although we do not know the exact nature of the vegetation that existed in the Sudbury area before disturbance, the huge white pine stumps now found on bare stony slopes (Fig. 2.2) and the vestiges of white cedar (*Thuja occidentalis*) that cover many acres of barren peat (Fig. 2.3) hint at a mosaic of pine forests on the slopes and cedar swamps in many of the depressions.

In 1824, the Hudson's Bay Company established a fur-trading post near what was later to become Sudbury, and the hunting and gathering life-style of the local Anishnabe people was modified to include commercial fur trapping. This, however, did not have a permanent effect on the local wildlife population. When the area was opened up to lumbering in 1872, the larger red and white pines were cut and floated down rivers to Georgian Bay and Lake Huron, then rafted to sawmills in the northern United States.

Lumber from the Sudbury area almost certainly played an important role in rebuilding Chicago after that city's devastating fire of 1871. Although the first European settlers in Sudbury would have found a forest that was partly cut-over, with regrowth of birches and poplars, in many areas some fair-sized trees must have remained, because the Sudbury parish came to be known as "Ste. Anne of the Pines."

By the turn of the century, black and white spruce (*Picea mariana* and *P. glauca*), balsam fir (*Abies balsamea*), and later jack pine (*Pinus banksiana*) were also being harvested, and more than 11,000 men were employed in the mills and in the bush around Sudbury. In the broader Sudbury area, lumbering continued to be the dominant industry as late as 1927, despite the emergence of the mining industry after 1886.

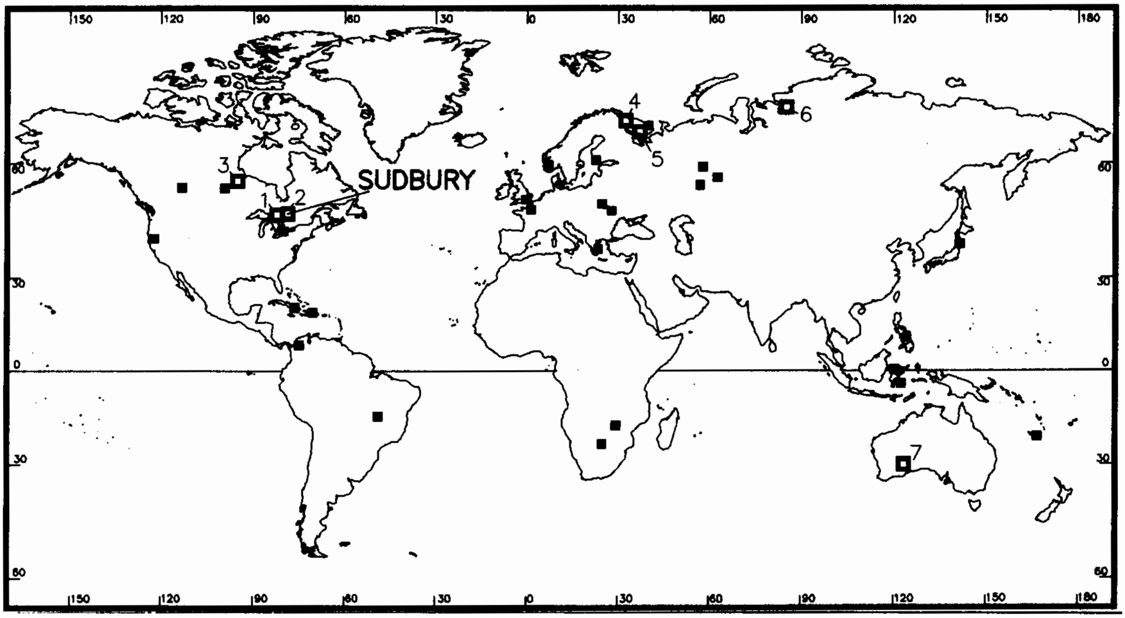


FIGURE 2.1. Worldwide location of nickel smelters and refineries. Numbers indicate the location of relatively large smelters (>30,000 tonnes of nickel per annum): (1) Inco Limited at Sudbury; (2) Falconbridge Limited at Sudbury; (3) Inco Limited at Thompson, Manitoba, Canada; (4) Pechenganikel Company (now Severonikel) at Nikel and Zapolyarny, Russia; (5) Severonikel Complex at Monchegorsk, Russia; (6) Severonikel Complex at Noril'sk, Russia; (7) Western Mining Company at Kalgoorlie, Western Australia.

Early logging practice, involving the selective removal of the larger red and white pine, made a minimal contribution to environmental degradation, because rapidly growing successional species such as white birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) would have colonized quickly. Even the less-selective logging that came later, for railroad ties and locomotive fuel and for pit timbers and pulpwood, should not have led to permanent denudation of the landscape. But events were to take a different direction in 1883 when surveyor William Ramsey accidentally routed the new Canadian Pacific Railway (C.P.R.) to the north of Bimitimigamasing Lake (now Ramsey Lake) rather than to the south. According to legend, it was C.P.R. blacksmith Tom Flanagan's discovery of a rusty stain on rocks near what became Murray Mine that initiated Sudbury's mining history (LeBourdais 1953; DeLestard 1967; Wallace and Thompson 1993).

The arrival of the railroad resulted in increased lumbering and a greater frequency of fire. Early accounts of Sudbury often spoke of blackened stumps and plentiful blueberries (Howey 1938), the blueberry plant being a very fire-tolerant species. The wood-burning locomotives must have contributed to the fire setting, and prospectors were said to have set fires to expose the bedrock under the duff cover. As logging became less selective, a greater proportion of the timber was removed, and the slash left behind created an ideal fuel for forest fires. Later, sulfur dioxide damage led to the death of leaves on the trees, creating tinder. Even today the blueberry patches, maintained to some extent by recurring fire, attract pickers who themselves often accidentally start new fires. As recently as the 1970s, a map of fire frequency for Ontario shows the Sudbury area as a record-setter.

Several different mining companies set up operations in Sudbury, but most of them only survived a few years (LeBourdais 1953). The Canadian Copper Company was the first successful one, beginning operations at Copper

Box 2.1. Selected Examples of Landscapes Denuded by the Effects of Smelter Fumes

Ducktown, Tennessee (Smith 1981)	Open-bed roasting and smelting of copper sulfide ore since 1850 has acidified the soil and created an almost totally barren landscape covering 2700 ha within the richly forested southern Appalachian Mountains.
Monchegorsk, Russia (Kryuchkov 1993)	Smelting of copper-nickel ore has given rise to 21,000 ha of barren land surrounded by 44,000 ha of dwarfed birch forest, in what was originally spruce-pine forest.
Palmerton, Pennsylvania (Jordan 1975)	Smelting of zinc ore in a narrow valley since 1898 has contaminated the naturally acid soil with zinc, cadmium, copper, and lead, giving rise to 485 ha of barren to sparsely vegetated land.
Queenstown, Tasmania (Blainey 1967)	Smelting of sulfide copper ore in this high rainfall area since 1896 has caused the denudation and erosion of the spectacular mountain peaks.
Smelterville, Idaho (Carter et al. 1977)	Smelting of sulfide ore in the Kellogg Valley since 1916 has led to the acidification and zinc, lead, and cadmium contamination of soil, resulting in extensive barren hillsides.
Trail, British Columbia (Archibold 1978)	Sulfide ore smelting since 1926 in the narrow valley of the Columbia River affected vegetation 25 km upstream and 95 km downstream into Washington State. Between Trail and the U.S. border, 17 km to the south, vegetation was almost totally eradicated.
Wawa, Ontario (Gordon and Gorham 1963)	Sulfur dioxide fumes emitted by an iron sintering plant since 1939 have damaged a narrow 37-km strip of vegetation, with complete denudation up to 8 km.

Cliff in 1885 and later being incorporated as part of the U.S.-based International Nickel Company (Inco) in 1902. The Mond Nickel Company, from Britain, began operations in 1900. It later amalgamated with Inco in 1929. Falconbridge Limited was incorporated and became the second largest company in 1928. For the past 65 years, Inco Limited and Falconbridge Limited have remained as the two companies with mining and smelting operations in the Sudbury Basin.

Roast Yards

During the early years of mining, ore was sent to other centers for smelting, but in 1888 the first roast yard and smelter were set up in Copper Cliff (LeBourdais 1953). During the first few years, nickel was looked on as a worthless and problematic contaminant in the copper ore, but in the 1890s, the Orford process was devised to separate the two metals (Boldt 1967). As the century drew to a close, the demand for nickel was boosted by the discovery of nickel-steel, which was used extensively for armorplate and in the Spanish-American War. The history of nickel production at Sudbury is shown in Figure 2.4.

Some of the early smelters used a portion of untreated or "green" ore, but historically, roasting was usually the first step in the processing of Sudbury's sulfide ore. The ore was heated in air to a temperature at which much of the sulfide was oxidized, and the sulfur was burned off as sulfur dioxide. In the early years of the Sudbury industry, crushed ore was piled on beds of cordwood in the open (Fig. 2.5), covered with the finer material to prevent open flames, and ignited. After a period during

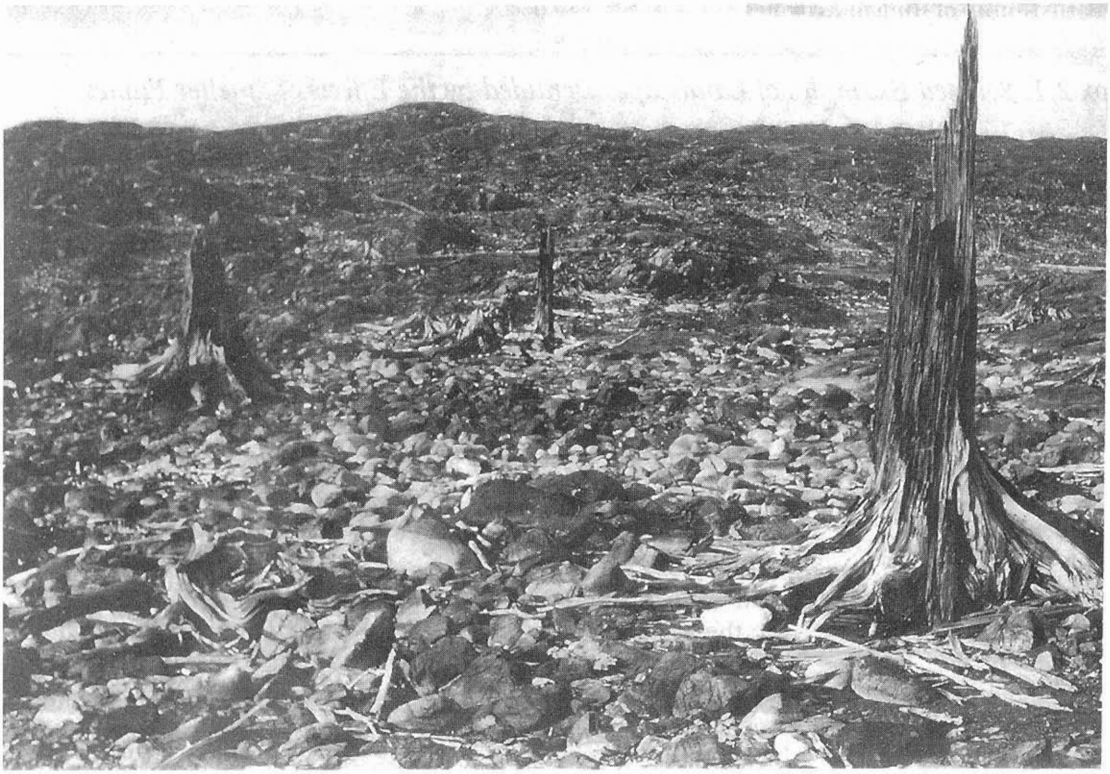


FIGURE 2.2. White pine stumps on a barren stony hillside, 3.2 km northeast of the Copper Cliff smelter.

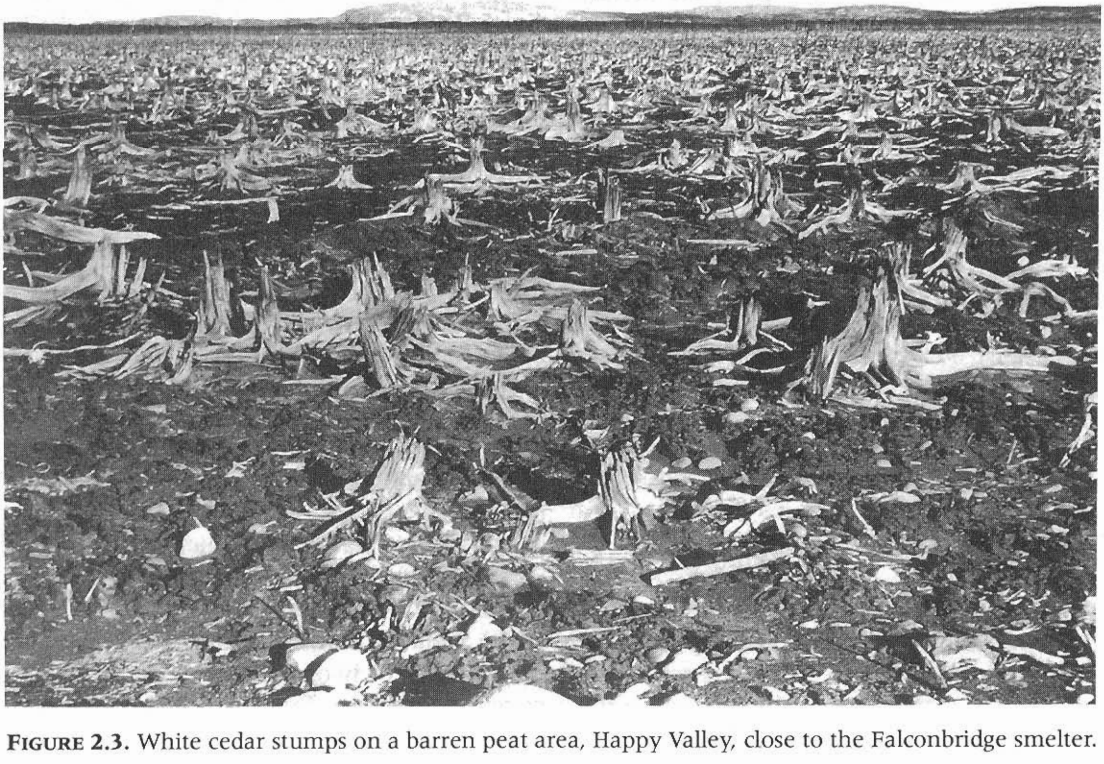


FIGURE 2.3. White cedar stumps on a barren peat area, Happy Valley, close to the Falconbridge smelter.

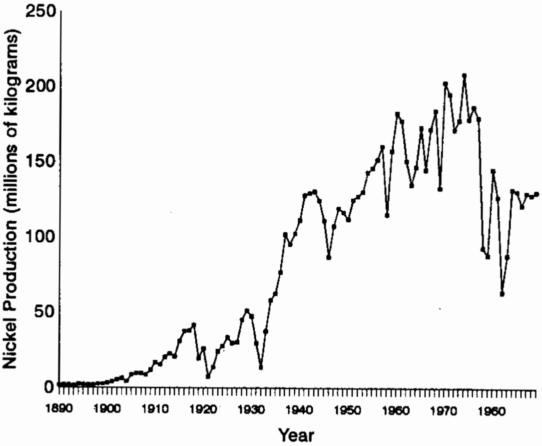


FIGURE 2.4. Annual nickel production from Sudbury smelters. (Data from Ontario Ministry of Natural Resources and the Ontario Ministry of Northern Development and Mines.)

which heat was provided by the burning wood, the ore itself began to burn (Boldt 1967). After burning for 2 months or more, the ore was loaded into rail cars and transported to furnaces for smelting and conversion. In the vicinity of the roast yards, even the smallest timber was removed as fuel, and between 1913 and 1916, the Mond Nickel Company removed nearly all the woody vegetation and tree stumps from the Coniston area to provide fuel for the roasting process (Watson and Richardson 1972). Laroche et al. (1979) estimated that more than 3.3 million m^3 of wood was consumed in the 11 roast yards that were in use during 1888–1929.

Most of the roast yards were located in close proximity to the nine smelters (Fig. 2.6) that operated at various times and locations throughout the area. In 1916, most of the smaller roast yards were replaced by a very large (2286 m long by 52 m wide) and highly mechanized yard, the O'Donnell roast yard, some distance west of Sudbury, to move this source of human discomfort farther from the main population centers. Open-bed roasting was not abandoned until 1929, even though this practice had long since been replaced in Norway because of the damage it had caused there (Peck 1980). In the latter years of heap-roasting at Coniston, the Mond Nickel Company followed the Norwegian example by not operating its roast beds in the summer (Peck 1978), thereby reducing damage to crops and other vegetation (Wallace and Thompson 1993).

Laroche et al. (1979) estimated that the roast beds released an estimated 10 million tonnes of sulfur dioxide. The dense sulfur dioxide fumes, emitted at ground level, killed plants and acidified soils in their path. Indeed, there was once a widely held hypothesis that the extensive destruction of vegetation and the presence of toxic soils in the Sudbury area are mainly the result of early open-bed roasting activities. It seems, however, that the effects of the roast yards were neither as severe nor as permanent as expected; the widespread poisoning of the soil was caused by the smelter fumes, which contained copper and nickel particles as well as sulfur dioxide. The slow-burning roast beds emitted mainly sulfur dioxide, which had a less permanent effect on surrounding soils. Turcotte (1981) showed that the Victoria Mine roast bed, which was distant from smelter activity, had done little to contaminate the surrounding landscape with metals, except in the immediate vicinity of the roast yard, and that vegetation had shown excellent recovery (see Fig. 2.5). The Coniston roast yard, in contrast, is still surrounded by barren metal-contaminated soils (see Fig. 2.5) but only because of its proximity to the Coniston smelter, a source of copper and nickel particulates. Struik (1974) studied a series of air photographs that showed the changes occurring in the vicinity of the O'Donnell roast yard (see Fig. 2.5), which was isolated from smelting activities, after its closure in 1929. By 1946, there was patchy cover by shrubs, whereas by 1959 pioneer trees

FIGURE 2.5. Roast yards in the Sudbury area. (*Upper left*) A 1920 view of the O'Donnell roast yard, showing wood and ore piled before ignition. The O'Donnell (*center left*) and circa 1901 Victoria Mine (*upper right*) roast yards during the roasting process. The Victoria Mine roast yard in 1979 (*center right*) and the O'Donnell yard in 1994 (*lower left*), showing the recovery of vegetation to the edge. (*Lower right*) A 1979 picture of the Coniston roastbed, that operated from 1913 to 1918, set in a landscape that is still almost completely barren. (Photos courtesy of Inco Archives, W. McIlveen and E. Snucins.)

such as poplars and birches had begun to colonize, again in a patchy manner. By 1973, a mosaic of forest cover had developed, but still with intermittent openings. Recent pictures of the site are included in Plate 2 (following page 182) and Figure 2.5.

Extent of Damage

On April 20, 1944, representatives of government and industry met to discuss the smelter emission problem and the forest damages allegedly caused by sulfur dioxide in the Sud-

FIGURE 2.6. Historical pictures of Sudbury smelters. (*Upper left*) A 1900 picture of the Canadian Copper Company's west smelter at Copper Cliff. (*Upper right*) The British-American Nickel Company smelter that operated sporadically at the Murray Mine site between 1917 and 1924. (*Center left*) The Victoria Mine smelter, built by the Mond Nickel Company in 1901, and operated until 1913. (*Center right*) A 1928 view of the Coniston smelter, built by the Mond Company in 1913. This smelter was taken over by Inco Limited in 1928 and operated until 1972. (*Lower left*) A circa 1973 picture of the Falconbridge Limited smelter. (*Lower right*) Inco's Copper Cliff Smelter in 1960.(Photos courtesy of Inco Archives and Falconbridge Limited.)

bury area. Studies were initiated on meteorology, atmospheric sulfur dioxide levels, the sulfur content of conifer foliage, lichen distribution, and forest damage. These studies were conducted during the summers of 1942–1944 when the smelters were in high production because of the war effort and thus may be considered peak conditions for industrial pollutants during the first half-century of smelting operations in Sudbury. The sulfur dioxide study used staff in fire towers and aircraft to determine the dispersal pattern of sulfur dioxide from the smelters. These personal observations demonstrated that smoke from Sudbury smelters could be seen from fire towers at least 120 km away, and the smell of sulfur extended at least 60 km (Murray and Haddow 1945).

The first report on vegetation damage (Murray and Haddow 1945) indicated that "severe burns" of tree foliage had occurred as far away as 35 km to the northeast, 20 km to the north, and 20 km to the south of the smelters. The question of chronic effects was also addressed, and a lichen study indicated that only crustose lichens and *Stereocaulon* were to be found within the most highly polluted area, although *Parmelia physodes* and *P. saxatilis* could be found near the edge of this zone. At a greater distance from the smelters, where effects of atmospheric pollution were less severe, it was possible to find more-sensitive lichen species, such as *Parmelia conspersa* and caribou lichen, *Cladonia rangiferina*. The author of the lichen study, R.F. Cain, suggested that other factors including frequency of fires might have interacted with the fumigation in bringing about this distribution pattern. The use of lichen distribution in tracing change in atmospheric quality is further discussed in Chapter 6.

A similar pattern with respect to higher plants was noted by Linzon (1958, 1971), who made observations on the extreme sensitivity of white pine to sulfur dioxide in the area and detected increased mortality and decreased growth of white pine as far as 40 km northeast of ore smelters. Gorham and Gordon (1960 a,b) reported the absence of white pine and velvetleaf blueberry (*Vaccinium myrtilloides*) within 24 km of the smelter and a sharp drop in species numbers 6.4 km from the smelter. Later, Freedman and Hutchinson (1980b) found that south-southeast of the Copper Cliff smelter, the number of forest floor species peaked at 15–20 km from the smelter, whereas the number of tree species continued to increase up to a distance of 30 km.

H. Struik, a forester with Ontario Ministry of Natural Resources (then Ontario Department of Lands and Forests), produced the first direct measure of the extent of vegetation damage throughout the Sudbury area. He examined air photographs and mapped areas that he referred to as "zones of site and vegetational stability" (Struik 1973). The earliest photographs (1946) revealed a large area of vegetation damage around the three major smelters at Copper Cliff, Coniston, and Falconbridge. This damaged area appeared to expand slightly in subsequent photographs in 1959 and in a composite of pictures for 1970 and 1973. From the maps that Struik produced for the early 1970s, the period just before major pollution reductions began (see Chapter 4), the zones of damage can be measured and summarized into two categories: (1) barren areas around the three smelters that had a total surface area of about 17,000 ha, and (2) a large surrounding semibarren area of approximately 72,000 ha (Fig. 2.7).

Denuded Landscape—The Result of Many Interacting Factors

Soil erosion began with logging and intensified as plant litter was destroyed by fire and as plant cover was killed in the vicinity of roast beds and smelters. Then, as the soil became poisoned and plant cover disappeared completely, erosion continued virtually unchecked. Much of the soil cover from the hillsides was washed into the valleys and often into the creeks and rivers. The only restraining feature, and a valuable one in many areas, was the coarse material in the glacial till. The stony and boulder-strewn slopes that we see today (see Fig. 2.2) result from the removal of fine material from the surface. Fortunately, however, the till was deep enough in some areas

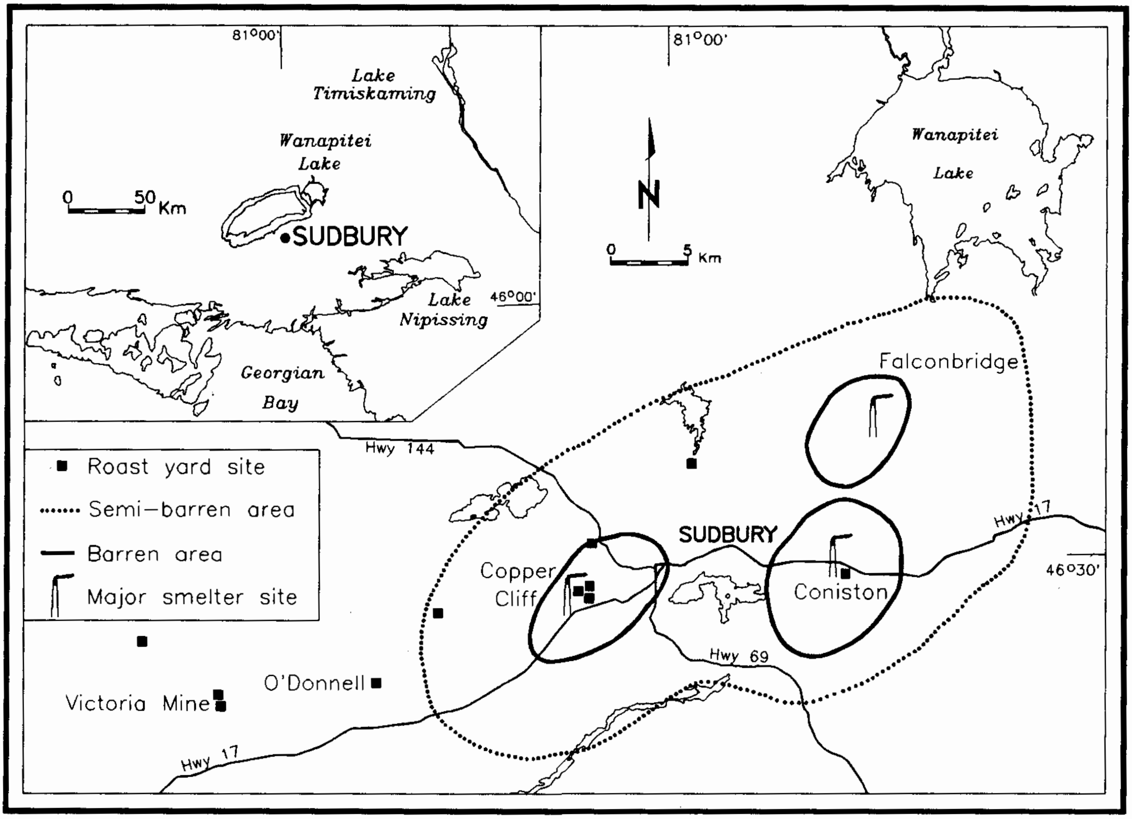


FIGURE 2.7. The location of the Sudbury Basin and the major sites of roasting and smelting activity and Struik's (1973) "zones of site and vegetational stability" based on air photographs.

that a soil base remained under the protection of the stones and boulders. Still, these boulder-covered slopes were not entirely stable, due to the effects of frost action, and each spring, there was some movement of coarse material and the consequent washing-out of fines. As humus-rich surface horizons were lost, so was their microflora.

Until relatively recently, it was assumed that vegetation damage in the Sudbury area was the direct result of sulfur dioxide impact. In the late 1960s, however, interest developed in acidification and metal contamination of the soils. Studies by a local group of ecologists and foresters (Winterhalder 1975) showed that soil acidity and concentrations of copper and nickel were highly elevated in soils near the smelters and could be directly correlated with 1953–1968 air pollution zones (Fig. 2.8), as could soil pH (Table 2.1). Other publications (Hutchinson and Whitby 1974; Freedman and Hutchinson 1980a; Hazlett et al. 1983) have identified the same pattern. In 1974, Whitby and Hutchinson showed that the soil from the Sudbury barrens was inhibitory to plant growth and that the toxic components were water-soluble, apparently including interacting ions of copper, nickel, aluminum (Winterhalder 1983), and at a lower level, cobalt.

The Sudbury landscape of today is the result of several environmental factors acting together over a period of almost a century: sulfur dioxide fumigations; metal deposition; intense logging; wild fires; water and wind erosion; and enhanced frost action (Winterhalder 1984). These environmental factors interacted one with the other. Figure 2.9 attempts to suggest some of the broader interactions that have occurred, including both positive and negative feedbacks.

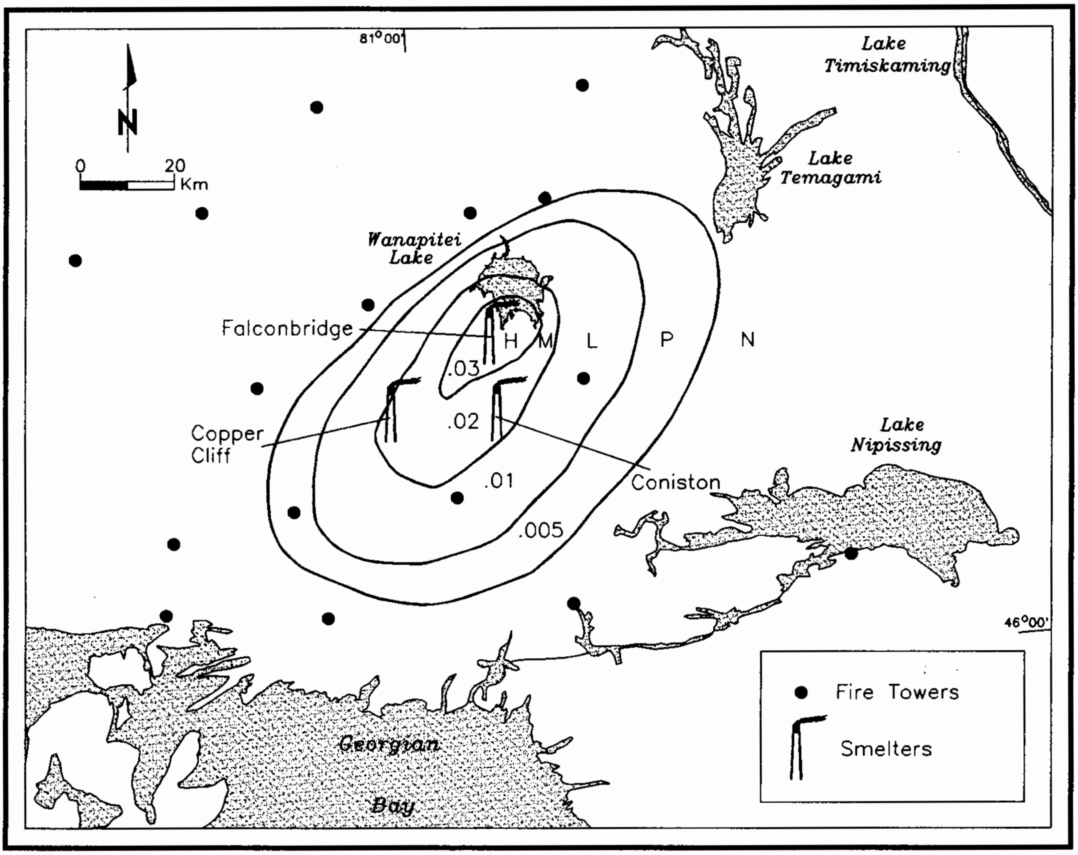


FIGURE 2.8 Mean sulfur dioxide concentrations used to categorize fumigation zones (1953–1968) (Dreisinger and McGovern 1971). The locations of fire towers from which sulfur smoke was frequently seen and smelled during 1939–1944 (Murray and Haddow 1945) are also indicated. See Table 2.1 for definition of zone categories.

In essence, the soil of the barrens is toxic to plants because of the interaction of its low pH (<4.0) with its copper and nickel contaminants, which can exceed 1000 ppm, respectively. At this pH, the contaminating copper and nickel (and possibly cobalt) become toxic. Aluminum is released from the clay minerals, augmenting soil toxicity. The toxic soil solution inhibits root growth, and seedlings are readily killed by drought or by frost heaving.

TABLE 2.1. Chemical characteristics of surface soils from the sulfur dioxide fumigation zones described by Dreisinger and McGovern (1971), as illustrated in Figure 2.8. Sampling was conducted in 1969 with 10 sites sampled in each zone.

Fumigation zone	Mean pH ± SD	Mean total copper (mg/kg ± SD)	Mean total nickel (mg/kg ± SD)
Heavy	3.8 ± 0.3	1250 ± 500	1930 ± 900
Moderate	4.3 ± 0.1	900 ± 300	750 ± 300
Light	4.7 ± 0.1	320 ± 80	400 ± 120
Perceptible	5.0 ± 0.2	200 ± 30	420 ± 120
None	5.0 ± 0.2	100 ± 20	200 ± 30

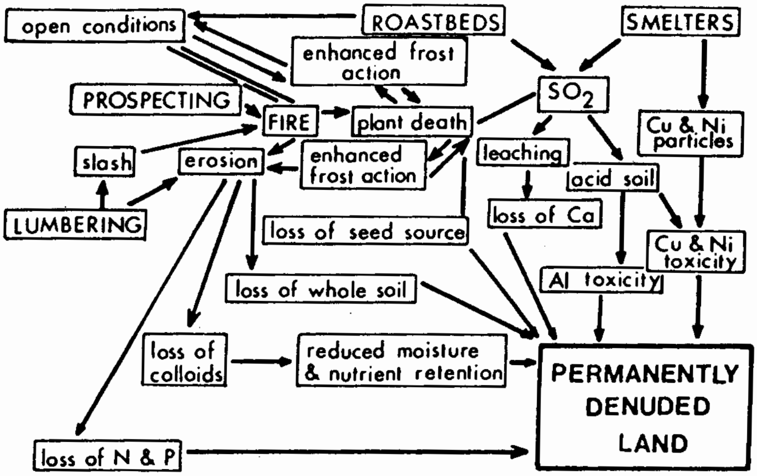


FIGURE 2.9. Simplified representation of some of the major factor interactions leading to the formation of barren land.

Although acidity and metal ions appear to play the major role in the soil degradation, the sulfur itself may also play its part. Some preliminary work (Hutchinson and Whitby 1976) suggests that the fundamental structure of the organic matter fraction of Sudbury soils has been changed by the high sulfur content, giving it a very strong metal-binding capacity.

Plant Communities of Sudbury's Altered Landscape

In 1981, Amiro and Courtin provided the first direct detailed and quantitative description of the vegetation surrounding the smelters today. They described nine different plant community types within the Sudbury area, three of which were confined to the industrially disturbed land. Pitblado and Amiro (1982) showed a similar pattern using remote sensing from a satellite, in which an estimate of the density of the vegetation present was obtained by measuring the ability of the landscape surface to emit radiation of different wavelengths.

The first of the Amiro and Courtin (1981) communities, referred to as "barren," broadly coincides with Struik's (1973) barren areas (see Fig. 2.7) and is characterized by a soil pH of 4.0 and less. In this zone, the degree of denudation was partly dependent on topography, being most severe on hilltops and steep slopes.

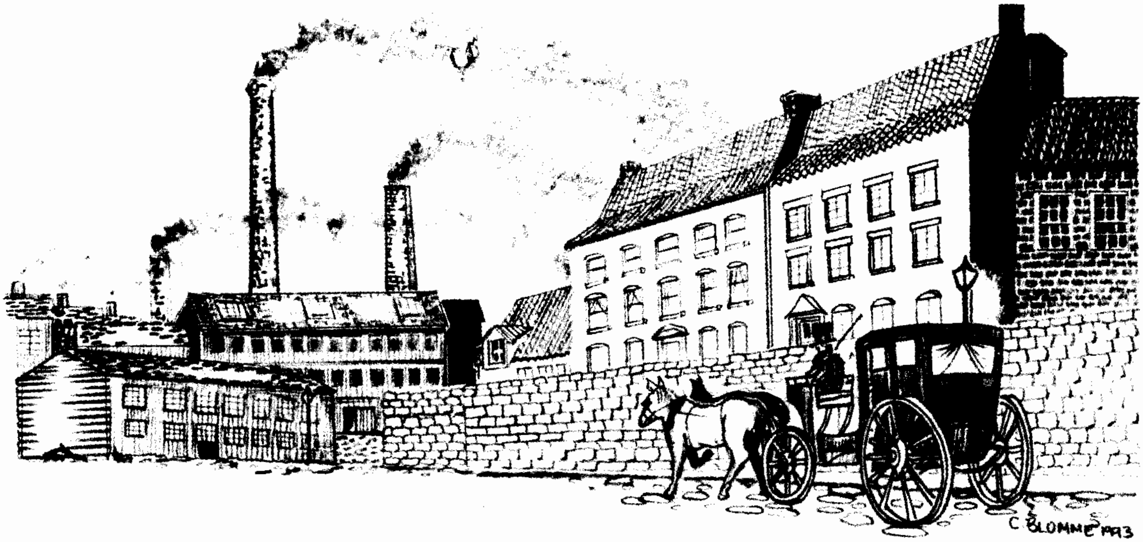
Highly depauperate relict trees, mostly red maple (*Acer rubrum*) but occasionally red oak (*Quercus borealis*) or American elm (*Ulmus americana*), are found on some of the barren rocky slopes. Relict shrub species include blueberry, red elderberry (*Sambucus pubens*), and witherod (*Viburnum cassinoides*). The moss *Pohlia nutans* can be found in seepage areas on north-facing slopes, and in moist depressions, tufted hair grass (*Deschampsia caespitosa*) often dominates, sometimes accompanied by patches of hair moss (*Polytrichum commune*). The relict red maples show a phenomenon best described as "regressive dieback," in which the foliage becomes reddened prematurely and the amount of living biomass produced each year gradually decreases, the plant being surrounded by dead limbs of various sizes. Even in low moist meadows with a surface cover of tufted hair grass, the red maples have the same appearance, suggesting that moisture is not the limiting factor.

Three of Amiro and Courtin's plant communities together make up the "semibarren" land more distant from the smelters. This area comprises an open woodland structure, with a sparse understory containing such acid- and fire-tolerant plants as blueberry, sweet fern (*Comptonia peregrina*), and bracken (*Pteridium aquilinum*) alternating with extensive bare areas. It is generally agreed that these stunted and depauperate woodlands, called by Amiro the "Birch Transition," "Maple Transition,"

FIGURE 2.10. Birch Transition community.

FIGURE 2.11. Red maple in a Maple Transition community, showing regressive dieback. The large birches exhibit premature marginal leaf chlorosis.

Box 2.2. The Term Acid Rain



Although we think of the term *acid rain* as modern, devised to describe a modern phenomenon, both the concept and the term are more than a century old. Robert Angus Smith began publishing on the chemistry of rain around the industrial city of Manchester, England, in 1852, and 20 years later he published a book entitled *Air and Rain: The Beginnings of a Chemical Climatology,* based on work in England, Scotland, and Germany. He not only used the term *acid rain,* but he demonstrated that precipitation chemistry is influenced by such factors as the combustion of coal, the decomposition of organic matter, wind trajectories, and the amount and frequency of precipitation. In addition to discussing procedures for the collection and analysis of precipitation, he described damage done to plants and materials by acid precipitation and recognized the atmospheric deposition of copper and other metals in industrial regions.

A century later, Eville Gorham began to further develop and integrate our understanding of the nature of acid precipitation and its effects on vegetation, soils, and surface waters in the United Kingdom and in Canada, but once again the work was largely ignored. A further step forward, which finally stimulated a scientific and public response, was taken by Svante Oden, a Swedish soil scientist. Oden managed to integrate chemical, limnological, and agricultural perspectives on acid precipitation, and he presented to the European scientific community a picture of long-range transport of atmospheric pollutants that had the potential to damage both aquatic and terrestrial environments. After a U.S. lecture tour by Oden in 1971 and his presentation at the 19th International Limnological Congress in Winnipeg, Manitoba, in 1974, scientific and public interest exploded in North America, and in 1975 the U.S. Forest Service sponsored the First International Symposium on Acid Precipitation and the Forest Ecosystem in Ohio.

A full historical perspective on acid precipitation can be found in Cowling (1982).

and "Red Oak" communities, respectively, are relict stands, a fact that is evident from the predominantly coppiced form of the component tree species. Both the Birch Transition (Fig. 2.10) and the Maple Transition contain white birch and red maple, the relative importance of each of the two species defining the community. Red maple shows the same regressive dieback in the woodlands as on the barrens (Fig. 2.11), whereas the white birch is characterized by a premature yellowing of the leaf margins in early summer, followed by the production of normal green leaves in late summer. The three communities tend to form a series related to soil drainage status, with the red oak community clearly at the well-drained end and, according to Amiro and Courtin (1981), Birch Transition at the moist end (a surprising fact in view of the normal preference of red maple for moist sites). The dynamics of these unique plant communities are described in more detail in Chapter 7.

Summary

Vegetation damage began with logging, fire, and roasting beds, but the decades of intensive fumigation from smelters caused most of the damage. The poisoning of soil by the addition of acid and toxic metals from smelter fumes created conditions that were unlikely to allow rapid natural recovery. Damage to the terrestrial ecosystem reached its peak during the 1960s, well before damage to lakes received attention. However, by the early 1970s, this emphasis changed when "acid rain" (Box 2.2) became a household word and the larger zone of ecological damage to surface water, described in the next chapter, became evident.

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