4

Declining Industrial Emissions, Improving Air Quality, and Reduced Damage to Vegetation

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During the century of mining and smelting activity in the Sudbury basin, more than 100 million tonnes of sulfur dioxide and tens of thousands of tonnes of copper, nickel, and iron have been released into the atmosphere (Ontario/Canada Task Force 1982). In the early 1960s, Sudbury's copper/nickel smelting complex represented one of the largest point sources of sulfur dioxide in the world (Summers and Whelpdale 1976), contributing approximately 4% of the global emissions (Freedman 1989). During this peak period, Sudbury emissions of sulfur dioxide approached current-day emissions from the whole of the United Kingdom (Table 4.1).

Environmental improvements in the Sudbury area during recent decades illustrate the importance of controlling the release of pollutants into the atmosphere. In the middle part of this century, when the regional and global nature of air pollution was not well understood, dispersing pollutants through tall stacks was considered an acceptable solution to a local environmental problem. In later years, it was recognized that discharging pollutants high into the atmosphere was simply creating problems elsewhere.

This chapter describes progress in reducing air pollutants from the Sudbury smelters. Attention is focused on two main pollutants: sulfur dioxide and metal particulates. Oxides of nitrogen, the other major precursors of acidic deposition, are released in relatively small amounts from the Sudbury smelters.

Recognition of the Problem

In Ontario, the Canadian province with the largest population, more than 95% of the sulfur dioxide emissions are from large point sources, predominantly smelters and electrical power plants. Of these, the nickel and copper smelters of Inco Limited and Falconbridge Limited in the Sudbury area contribute slightly more than half of the provincial and approximately 20% of the Canadian emissions (Table 4.1).

The damaging effects of smelter fumes on gardens, forests, and other vegetation were well known at the turn of the century (Barlow 1907; Haywood 1907), but early government response to public complaints appears to have been designed to protect the industry rather than people and ecosystems. Government legislation passed in 1915 provided that all patents issued to settlers of land within a defined area include a clause exempting mining companies from liability due to smoke damage. In 1921, The Damages by Sulphur Fumes Arbitration Act was passed to facilitate the settlement of claims of damage to agricultural crops and other vegetation. This act was repealed and replaced with a similar one in 1924, which led to the hiring of a claims arbitrator in 1925.

Table 4.1. Sulfur dioxide emissions from Sudbury smelters relative to total emissions from selected countries

	Total emissions (1000s of tonnes)	Year
Sudbury		
present	216	1994[a]
recent	700	1988[a]
historical	2560	1960[a]
(Comparison of 1986–1988)		
United States	20,700	1988[b]
China	20,000	1987[c]
Soviet Union[d]	9270	1988[e]
Eastern Germany	4365	1988[e]
Canada	3800	1988[f]
Poland	3760	1988[e]
United Kingdom	3400	1988[e]
India	3070	1987[c]
Spain	2925	1983[e]
Czechoslovakia	2520	1988[e]
Italy	2133	1986[e]
France	1368	1987[e]
Western Germany	1350	1988[e]
Netherlands	260	1988[e]
Sweden	198	1987[e]
Switzerland	67	1988[e]
Norway	67	1988[e]

[a] Unpublished data for Inco Limited plus Falconbridge Ltd.
[b] U.S. EPA 1990.
[c] Kato and Akimoto 1992.
[d] European part of the former Soviet Union.
[e] French 1990.
[f] OECD 1991.

As production of nickel increased, spurred on by increased demand during the two world wars, so, too, did the air pollution problems (Katz 1954; Dreisinger 1955; see Chapter 2). The mining companies took some important initiatives to reduce sulfur dioxide emissions through process improvements (e.g., rejection of high sulfur pyrrhotite components of ore before smelting, development of oxygen flash-furnace smelting, and the capture of sulfur for marketable byproducts such as sulfuric acid and liquid sulfur dioxide) (see Chapter 21). However, continuing fumigation problems within nearby urban and rural areas and the mounting scientific evidence of extensive damage to area forests (Dreisinger and McGovern 1964; Linzon 1971) demanded more stringent controls.

First Control Orders

The provincial government of Ontario finally responded to these concerns by imposing annual limits on smelter sulfur dioxide emissions, with the first control orders issued against Sudbury mining companies in 1969 and 1970. This control program was solely directed at improving local air quality. It did not address the contribution of Sudbury sulfur dioxide emissions to worldwide acid precipitation. Thus, the 381-m "Superstack," the world's tallest smokestack, was constructed at the Copper Cliff smelter of Inco Limited and began operating on August 21, 1972 (Fig. 4.1). Inco's Coniston smelter and Falconbridge's iron ore sintering plant (Fig. 4.2) were closed that same year, with the result that total emissions also declined after 1972.

The combination of increased dispersal of pollutants, reduced emissions, and the closure of obsolete plants led to dramatic improvements in air quality (Fig. 4.3). The concentration of sulfur dioxide in the Sudbury area dropped immediately by at least 50% after 1972. During the 1980s, the annual average concentration of sulfur dioxide remained fairly constant and well below the provincial objective of 0.020 ppm. There were also readily observed visual signs of the improving air quality. The occurrence of smoke and haze at the local airport, located 16 km northeast of Sudbury, declined sharply after the early 1970s (Fig. 4.4).

However, despite the reductions in annual average sulfur dioxide concentrations, severe short-term ground-level fumigations still occurred under certain climatic conditions. This continuing fumigation problem, together with mounting concern about the impacts of acidic deposition, led to further reductions in annual allowable emissions, starting in 1978, and required that the smelters curtail daily production/emissions under weather conditions that restricted the dispersal of the plumes. Under

FIGURE 4.1. Inco Limited Superstack (Sudbury Star Files) constructed in 1972 to reduce local impacts of industrial emissions. Technologies at Inco to reduce the quantity of pollutants released into the atmosphere are described in Chapter 21.

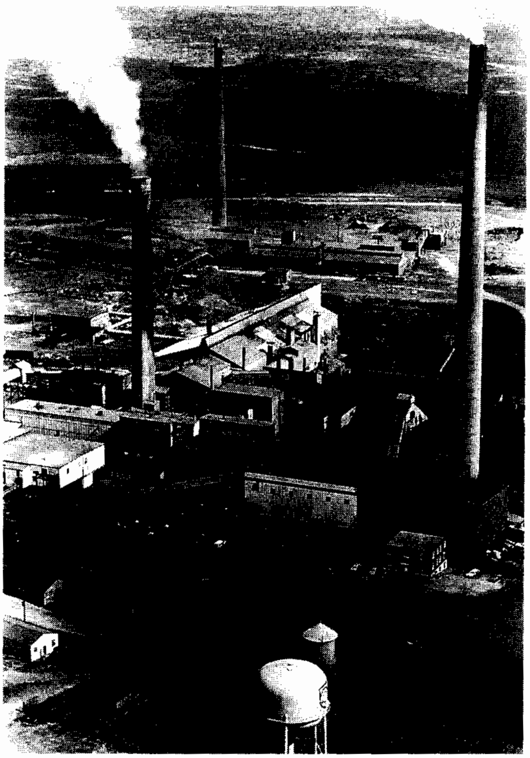


Figure 4.2. Falconbridge smelter (circa 1955). As part of the emissions abatement program, the pyrrhotite plant (center, rear) was closed in 1972. The sintering plant on the right was closed in 1978. Details of the abatement technology at Falconbridge Limited are provided in Appendix 4.1.

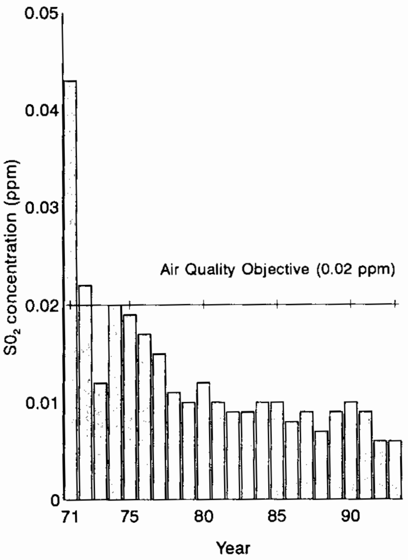


Figure 4.3. Annual average sulfur dioxide concentrations recorded at three sites in the Sudbury area over the period 1971–1993.

these requirements, production at the smelters is significantly reduced to avoid hourly sulfur dioxide ground-level concentrations greater than 0.50 ppm. These more-stringent requirements reduced the occurrence of ground-level fumigations but have still not eliminated them at all sites (Fig. 4.5).

A Regional and International Problem

The commissioning of the Superstack and the other changes to deal with what was perceived to be a local air pollution problem occurred in the same year that Sweden brought the transboundary problem of air pollution to the attention of the world. Sweden presented its case history of the impacts of atmospheric pollutants at the UN environment conference at Stockholm in 1972 (Anonymous 1972). By the mid- to late 1970s, North American scien-

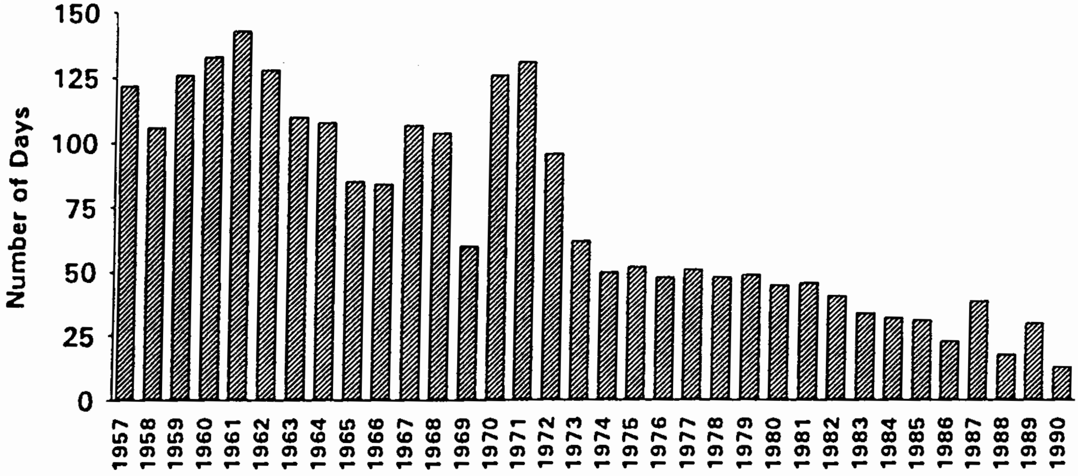


Figure 4.4. Changes in the recorded instance of smoke or haze at the Sudbury airport weather station, 1957–1990 (courtesy of R. Pitblado).

tists were rapidly accumulating evidence that air pollution was a regional rather than a local problem. The words *acid rain* and the chemical reactions that were involved in the transformation of emissions from automobiles and factories to acid precipitation quickly became "common knowledge."

SO_2 (sulfur dioxide)	+	H_2O (water)	→	H_2SO_4 (sulfuric acid)
NO_x (nitrogen oxide)	+	H_2O (water)	→	HNO_3 (nitric acid)

From extensive monitoring studies conducted during the 1970s, large point sources of sulfur dioxide, such as the smelters of Sudbury, were shown to be contributing to air pollution problems (e.g., acidified lakes) far from the sources of the pollution. For example, computer models indicated that 19% and 5.5%, respectively, of the total sulfur deposition in the Muskoka (central Ontario) and Nova Scotia areas originated from Sudbury (Ontario/Canada Task Force 1982). Within the Sudbury area itself, dry deposition and fallout of metal particulate were primarily of local origins, but even the Sudbury area was subject to substantial inputs of acid pollutants from far away (Jeffries 1984).

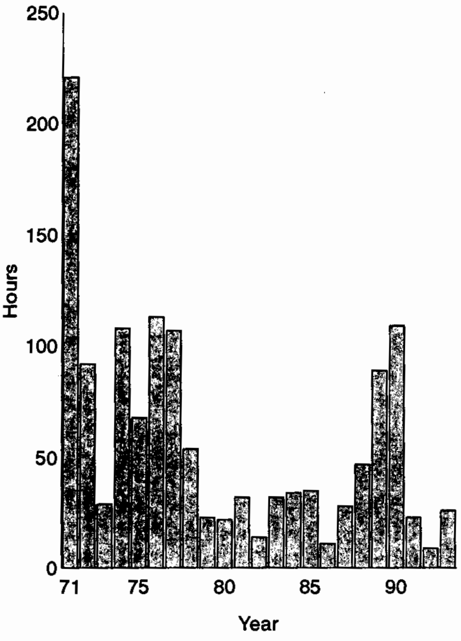


Figure 4.5. Frequency of short-term sulfur dioxide fumigations with an hourly average in excess of 0.50 ppm at Ontario Ministry of the Environment monitoring stations, 1971–1993.

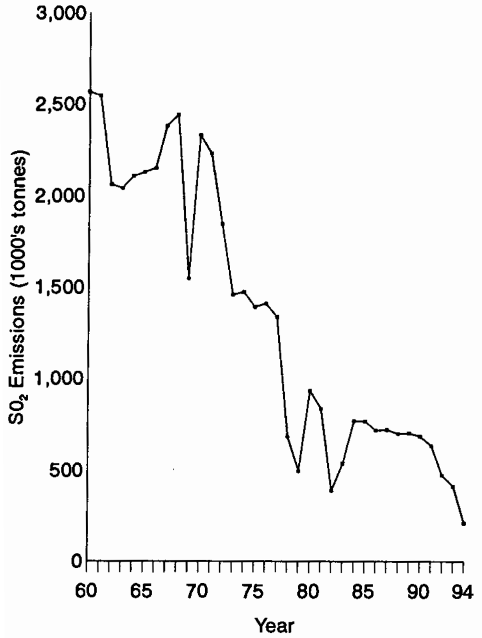


Figure 4.6. Sulfur dioxide emissions for the Sudbury area (1960–1994). In addition to legislated changes, labor strikes (1969, 1978, 1979) and periods of reduced nickel production (1982, 1983, 1994) contributed to the decline in sulfur dioxide emissions.

From modeling studies, it has been estimated that approximately 80% of the wet (snow and rain) deposition of acid in the Sudbury area originated from industrial areas in the United States and southern Ontario (Chan et al. 1984; Lusis et al. 1986).

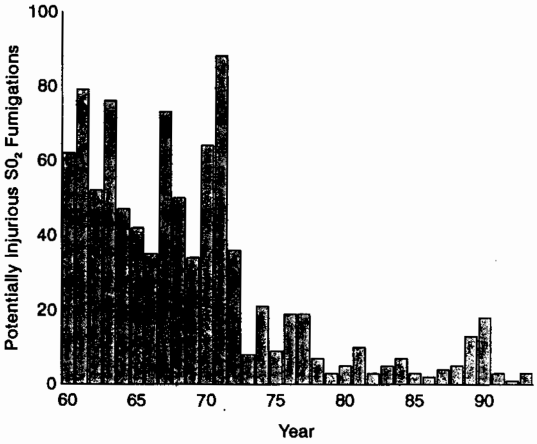
New provincial and national emission control legislation was needed to address this international problem. In 1985, the Ontario government established a control program called the Countdown Acid Rain Program to meet nationally and provincially negotiated reduction objectives for eastern Canada (Ontario Ministry of the Environment 1985). Under this program, the annual legal limit for Sudbury area sulfur dioxide emissions was set at 365,000 tonnes, to be achieved by 1994. This would bring the annual emission of sulfur dioxide down to about 14% of the highest emission year: 2.56 million tons in 1960 (Fig. 4.6).

Declining Industrial Emissions

Historical trends in emissions of sulfur dioxide in Fig. 4.6 illustrate the magnitude of the Sudbury area sources and the success of control programs. Both mining companies were able to achieve the 1994 limit. In fact, because of additional reductions due to extended shutdowns and some initial problems with one of the new furnaces at Inco Limited, the 1994 total of 216,000 tonnes was well below the required level.

In addition to regulating sulfur dioxide, the control orders have resulted in lower emissions of suspended particulates and trace metals in the Sudbury area. During 1973–1981, approximately 15,000 tonnes of particulate matter were released into the atmosphere each year (Ontario Ministry of the Environment 1982; Ozvacic 1982). These emissions included approximately 1800 tonnes of iron, 700 tonnes of copper, 500 tonnes of nickel, 200 tonnes of lead, and 100 tonnes of arsenic on an annual basis (Ozvacic 1982). Average levels of suspended particulates at two sites in the city of Sudbury ranged from 50 to more than 80 μg/m^3 during the early 1970s (Potvin and Balsillie 1976, 1978). By the late 1980s, these annual averages had dropped to less than about 30 μg/m^3, well below the provincial objective of 60 μg/m^3 (Dobrin and Potvin 1992). Among trace ele-

Figure 4.7. Frequency of potentially injurious sulfur dioxide fumigations in the Sudbury area, 1960–1993. The occurrence of potentially injurious fumigation events is calculated from the measured duration and concentration of sulfur dioxide at ground-level monitoring stations. Some international examples of the damaging effects of air pollutin on buildings, statues, and rock surfaces are provided in Box 4.1



ments, nickel is probably the most suitable indicator of temporal trends. In 1971, the mean concentration of nickel in air samples at a site 4 km east of the Copper Cliff smelter was 0.37 $\mu g/m^3$; after abatement efforts of 1972, concentrations immediately dropped by at least 50%. Additional reductions followed ongoing abatement activities and by the mid- to late 1980s, annual average concentrations of nickel at the monitoring station were in the order of 0.05 $\mu g/m^3$ (Dobrin and Potvin 1992). By 1995, it is projected that total emission of particulate matter will be approximately 1500 tonnes/year, equal to approximately 10% of the levels in the early 1970s.

Terrestrial Effects

Direct Damage to Vegetation and Acidification of Soils

Sulfur dioxide causes direct damage to vegetation (Katz et al. 1939; Linzon 1978). The severity of damage depends on the fumigation dosage and frequency, as well as the species tolerance. Damage can range from discoloration of leaves and needles to reduced growth rate and mortality of plants (Linzon 1978). Some observable damage to plants includes terminal necrosis on white pine (*Pinus strobus*) foliage and interveinal necrosis on leaves of white birch (*Betula papyrifera*) (see Plates 5 and 6, following page 182). Excellent color photographs of sulfur dioxide symptoms are also available in Malhotra and Blauel (1980) and Skelly et al. (1987).

During the period before the major emission reductions, many cases of vegetation injury associated with severe fumigations, sometimes up to 80 km from the Sudbury smelters, were documented (McCallum 1944–1964; Dreisinger 1952–1971). The size of area where sensitive species such as white pine were affected with severe-to-moderate injury covered more than 1800 km^2, with an additional 4000 km^2 of sporadic injury (Linzon 1978). These direct effects of air pollution, common in the 1960s, were largely eliminated by the control programs of the 1970s and 1980s.

The dramatic decline since 1971 in the number of potentially injurious fumigation events (Tebbins and Hutchinson 1961; Dreisinger and McGovern 1970) provides a quantitative measure of the improving conditions for vegetation in the Sudbury area (Fig. 4.7). Another valuable indicator of the improving conditions for plants are the lichens, which have recolonized much of the Sudbury area in recent decades. Lichens are useful monitors because they are particularly sensitive to air pollution (see Chapter 6).

In addition to the direct damage to exposed vegetation, the high emissions of sulfur from smelters also leads to the severe acidification of soils (reviewed in Chaudhry et al. 1982). Extremely acid soils were found in the vicinity of the Coniston smelter (Hutchinson and Whitby 1974; Hazlett et al. 1983). The pH values of surface soils up to 7.4 km from the Coniston smelter were generally less than 3.0, with values as low as 2.2. More extensive surveys between 1970 and 1979 at 70 sites in the Sudbury area demonstrated that soils were very acidic throughout much of the area surrounding the smelter, with an average pH of 4.1 (Negusanti and McIlveen 1990).

Trace Metal Accumulation in Soil and Vegetation

Although sulfur dioxide is generally recognized as the most important cause of vegetation damage in the Sudbury area, many researchers have studied and demonstrated the significance of the terrestrial effects of metals (Hutchinson and Whitby 1974; McGovern and Balsillie 1975; McIlveen and Balsillie 1978; Freedman and Hutchinson 1980; Negusanti and McIlveen 1990). These studies have shown that metal levels in soil (see Chapter 2) and vegetation decline with increasing distance from the smelters. Extremely high metal levels have been recorded in soil and vegetation in close proximity to Sudbury smelters. Nickel and copper at localized sites in surface soil near the Coniston smelter were determined to be as high as 12,300 μg/g and 9700 μg/g, respectively (Hazlett et al. 1983), but generally heavily contaminated sites have metal concentrations in the 200–500 μg/g range (Negusanti and McIlveen 1990).

There is very little conclusive information available regarding the changes in soil conditions that may have occurred after the major industrial abatement programs of the early 1970s. Gunderman and Hutchinson (1993) recently reported that the concentration of nickel and copper and the acidity of soils near the abandoned smelter at Coniston have declined substantially during the past 20 years. This pattern has also been observed from soil surveys conducted in the Sudbury area by Ontario Ministry of Environment scientists (Negusanti and McIlveen 1990). However, despite the apparent changes, the soils remain toxic to sensitive plant species (Gunderman and Hutchinson 1993), and it is difficult to determine what factors are responsible for the chemical changes. For example, the organic content of the soil also declined during the same period, suggesting that the surface soils are continuing to be eroded by wind and rain. Support for these findings was obtained from a recent extensive survey of Sudbury soils conducted by Dudka et al. (1994).

Monitoring of soil conditions and assessing the process of natural recovery represent important information needs. However, the structural instability of the soil and the extreme temporal and spatial variability in soil chemistry (Negusanti and McIlveen 1990) make this a challenging research area.

Other Air Pollution Problems

Particulate fallout, especially during smelter startups and shutdowns, has occasionally caused significant direct damage to vegetation and property (vehicles, patio decks, house sidings, etc.) at sites near the smelters (Ontario Ministry of Environment 1978). The injury symptom, referred to as "black spotting," is caused by particulate fallout consisting principally of nickel, copper, and iron sulfates. Leafy garden crops such as lettuce and cabbage, due to their large surface areas, have been observed to be very susceptible to fallout injury. Normal washing of affected garden produce was found to reduce metal levels well below those considered safe for normal consumption. Fallout damage to vegetation still occurs but appears to have been greatly reduced since the early 1980s.

Other air pollutants that have caused injury to vegetation on an episodic basis are sulfur trioxide and ground-level ozone (Negusanti and McIlveen 1990). Isolated atmospheric releases of sulfur trioxide resulting from malfunctions at the sulfuric acid plants have caused injury to sensitive species such as tomato, bean, and cucumber at downwind distances greater than 20 km.

Ground-level ozone, largely formed through the long-range transport of its precursors (oxides of nitrogen and reactive hydrocarbons) from southern industrial areas, has been reported to exceed the 1-hour provincial criterion of 80 ppb in the Sudbury area during the growing seasons (Potvin and Balsillie 1976; Dobrin and Potvin 1992). From 1975 to 1990, the criterion was exceeded during slightly more than 1000 hours, or on average about 63 hours per growing season. The injury noted in the Sudbury area has been minor and limited to species such as sweet corn, grape, potato, and Manitoba maple (Negusanti and McIlveen 1990).

Box 4.1. Fading Statues and Black Rocks

The corrosive effects of acid-forming air pollutants have created significant damage to buildings and statues throughout the world. The picture of the stone carvings in the front of the Confucian Temple in a suburb of Anshun, Guizhou Province, China, illustrates this damage. (Photo by Xiong Jilin.) Damage to the famous Taj Mahal, in India, is another example of this large-scale problem. Fortunately, recent pollution abatement programs in India appear to be effective at reducing or preventing further damage to the Taj.

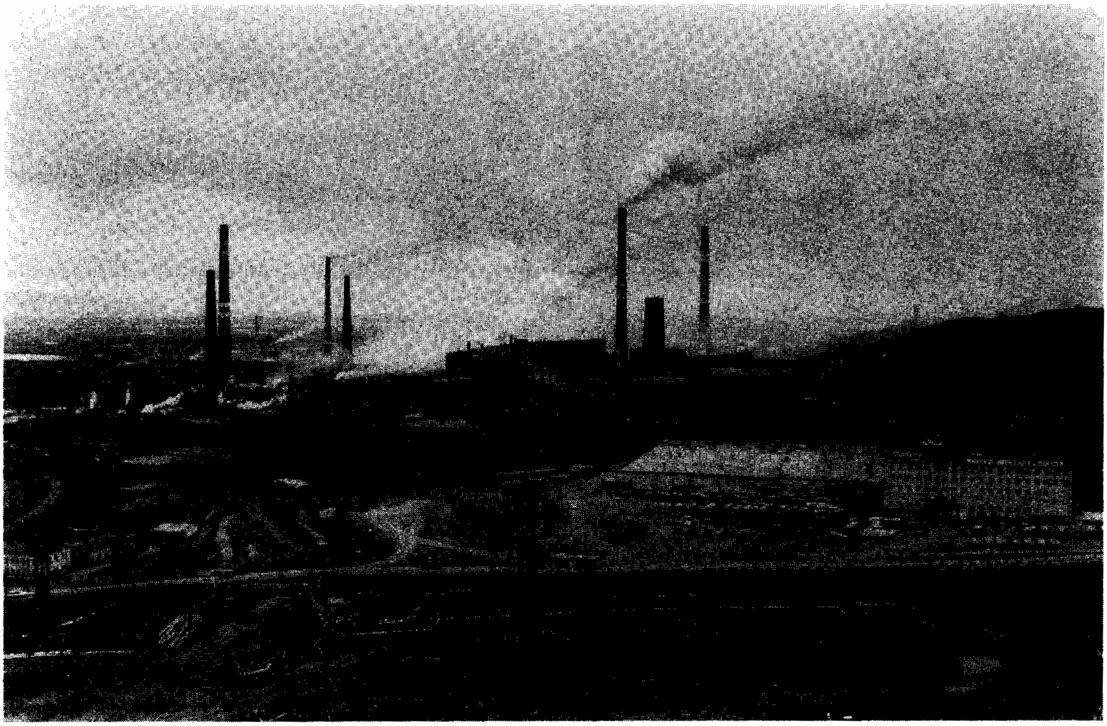
In Sudbury, the blackened rocks also bear witness to the severity of air pollution problems. The relative contribution of roast bed fumes, smelter emissions, or smoke from forest fires in creating this distinctive feature of the barren landscape is unknown, but the combined effects have created a substantial challenge for restoration efforts. The blackened surfaces create extremely hot and dry conditions in summer, microclimate conditions that exclude all but the hardiest of plant species.

Conclusions and Future Projections

As illustrated in later chapters, the reductions in industrial emissions have allowed the denuded Sudbury landscape to begin slowly to recover. Natural processes have begun to repair the damage inflicted since before the turn of the century. Improvements in air quality have also allowed highly successful artificial reclamation programs to speed up the recovery process (see Chapter 8). This is particularly evident in the successful re-establishment of white pine, which is among the most sensitive tree species to sulfur dioxide injury. With the influx of vegetation into the denuded areas from natural growth and colonization, as well as from the reclamation efforts, the organic content and pH of surface soil should increase; soil metals should then become less bioavailable and hence less toxic to plants.

The prospects for additional reductions in smelter emissions and further ecosystem recovery are promising. If anticipated progress in ore processing and smelting technology is realized (see Chapter 21), it will be possible to reduce annual sulfur dioxide emissions in the Sudbury area to less than 250,000 tonnes. Additional reductions in particulate and trace metal emissions would also occur, possibly resulting in an annual particulate emission level of about 1000 tonnes. However, there are still concerns about the frequency and intensity of local site-specific fumigations. Further improvements will be required in the daily produc-

Box 4.2. Noril'sk, the World's Largest Point Source of Sulfur Dioxide



Noril'sk, a city of 260,000 built during the Stalin era to harvest the vast mineral resources in central Siberia, is now considered one of the most polluted cities on earth (Saunders 1990; Peterson 1993). The current emissions of sulfur dioxide from the nickel, copper, and cobalt smelters and refineries are estimated to exceed 2.5 million tonnes/year (Saunders 1990). Located at approximately 300 km above the Arctic Circle, Noril'sk supplies roughly two-thirds of the total nickel production of Russia. At present, there is little information available on the effects of industrial emissions on the tundra ecosystems near Noril'sk. It has been estimated that air pollution has severely affected 10,000 km^2 of forests in Russia and other parts of the former Soviet Union (cited in Peterson 1993). (Photo of the nickel smelting complex in Noril'sk by D.J. Peterson in 1992.)

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tion/emission reduction program to reap the full benefits of continuing smelter sulfur dioxide abatement initiatives.

Sudbury is not alone in its efforts to control emissions. Significant reductions in sulfur emissions and deposition have been achieved in several areas in North America and in parts of Europe (Hedin et al. 1987; Dillon et al. 1988; Wright and Hauhs 1991). However, in contrast, the conditions at the giant Noril'sk smelting complex (Box 4.2) and at other large Russian smelters are still very similar to historical conditions at Sudbury. Also, significant increases in sulfur dioxide emissions are expected in China and India where rapid industrial development is increasing the use of high sulfur coal (Galloway 1989).

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Appendix 4.1.
SO_2 Abatement at Falconbridge Sudbury Operations
(Mike Kozlowski, Falconbridge Limited)

Falconbridge's efforts to address the sulfur dioxide (SO_2) problem commenced in 1972 with the closure of a plant that had been used to burn sulfur and recover nickel from a pyrrhotite (Fe_7S_8) concentrate made at that time.

The biggest single reduction in SO_2 emissions was the result of building a new $300 million (in 1994 dollars) smelter in 1978. The dramatic reduction was due largely to the construction of a new acid plant that converts the SO_2 to sulfuric acid—a salable commodity.

The processing of ore at the present smelter at Falconbridge Ontario begins with slurry received from the Strathcona Mill (Fig. A4.1). The moisture content is adjusted and the concentrate, together with sand, is fed to two fluid bed roasters. Currently about 60% of the sulfur is eliminated (oxidized) in the roasters, and the resultant calcine/flux fed to two electric furnaces. An intermediate or "furnace" matte containing about 35% nickel is produced during electric smelting. This matte is processed in the converter aisle where more sulfur and iron are oxidized in conventional Peirce-Smith converters to yield a cast matte containing about 52% nickel for shipment to the company's refinery in Norway. The key change that has reduced SO_2 emissions is that off-gases from the roasters are tightly contained and therefore rich in SO_2—about 10%. This gas is suitable for treatment in the single-pass acid plant, whereas the gases from the old smelting process were too dilute to do this.

With the new smelter, most of the rest of the SO_2 is produced in the converter vessels, although the SO_2 from the electric furnaces and the acid plant tail gas make up a significant proportion. All three sources are vented to the atmosphere through the same 93-m stack. In addition to the annual SO_2 emission limits imposed by the control orders shown in Figure A4.2, there is a control order regarding the permissable concentration measured at ground level. Currently, this is 0.5 ppm, calculated on an hourly basis. Periods of high ground-level concentration are usually due to adverse weather conditions. The smelter uses a monitoring system and will shut down the converter aisle if an exceedance is anticipated. Complaints from nearby citizens are investigated immediately and appropriate action, including shutdown if necessary, is taken.

A continuing decline in emissions of SO_2 has occurred since the new smelter was built. The decline from 1988 to 1993 occurred even during a period of a 22% increase in nickel production. This recent continued decrease in SO_2 for each tonne of nickel produced was largely the result of recent changes at the Strathcona Mill and the mines. These changes have been directed at rejecting more of the pyrrhotite in ore and making greater quantities of copper concentrate for sale (thereby reducing the sulfur load to the smelter).

A new magnetic separator allowed more pyrrhotite to be passed to the pyrrhotite rejection circuit. Improvements in the rejection circuit further increased the amount of pyrrhotite removed. Unfortunately, these changes also led to an increase in the nickel lost in this circuit. In 1993, a recycle loop was added to the rejection circuit, which reduces these losses to traditional levels.

At the same time that these improvements in pyrrhotite rejection were being made, less pyrrhotite was being supplied in the ore from the mines. The combined effects were to decrease the pyrrhotite and increase the nickel content of concentrate going to the smelter. The high-grade concentrate allowed an increase in the electric furnace matte grade, which in turn led to a significant reduction in the amount of SO_2 produced per tonne of cast matte.

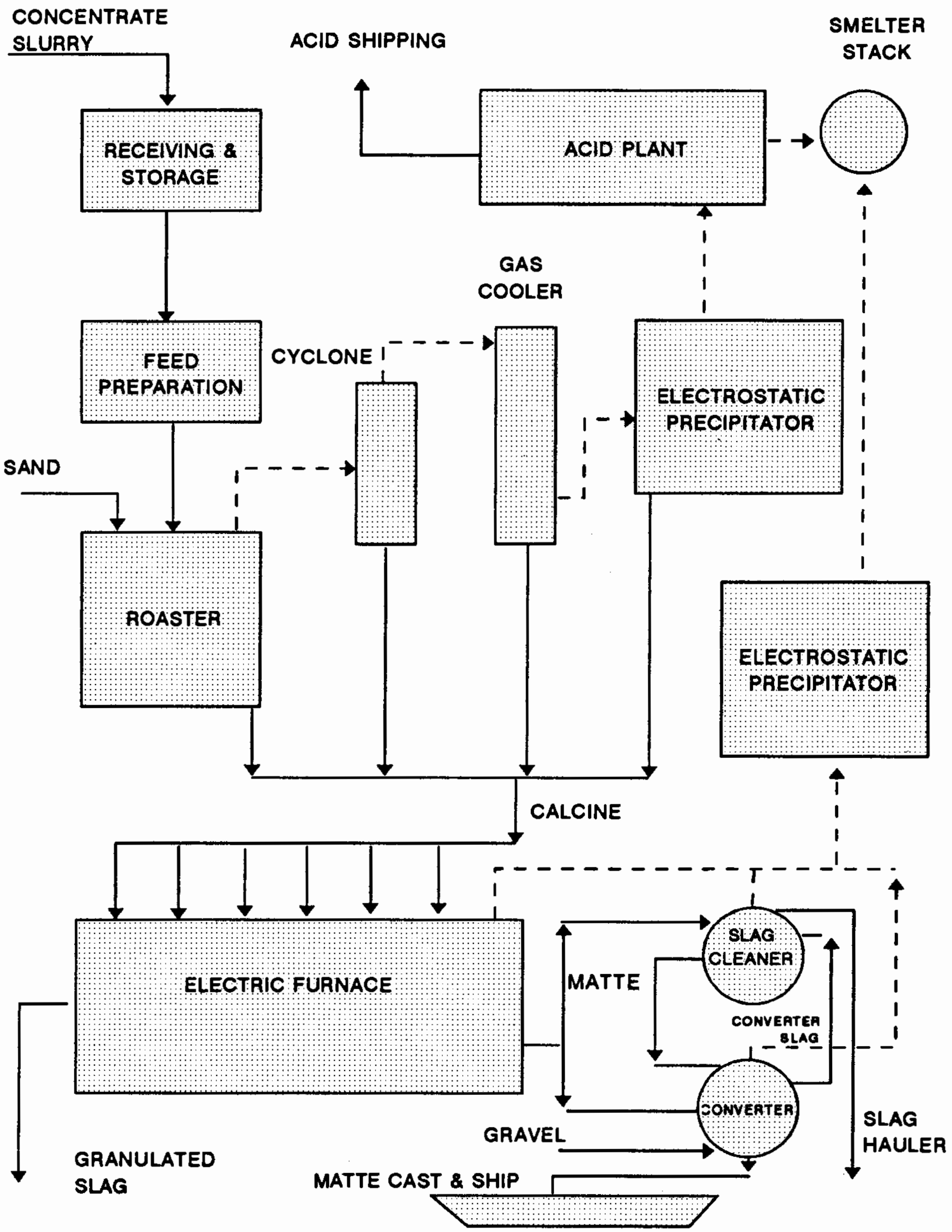


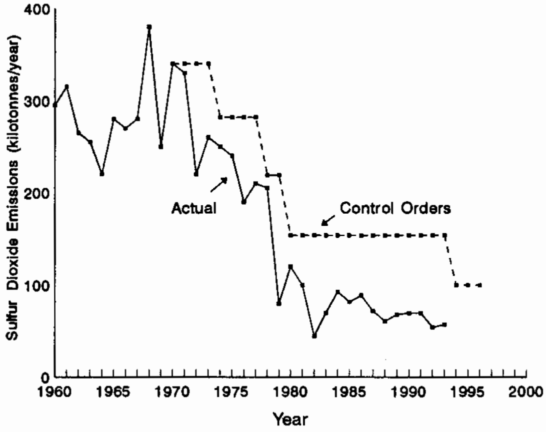
Figure A4.1.

Production of copper concentrate leads to nickel losses. To counteract this, several million dollars were spent on flotation columns and press filters in the Strathcona Mill. This had led to a valuable reduction in those losses.

Regulations and Future Developments

The Falconbridge Sudbury Operations has consistently stayed below government control orders. In addition to complying with the new

Figure A4.2. Changes in emissions of sulfur dioxide from the Falconbridge smelter. Note that the limit set for emissions in 1994 was required under Regulation 661/85.



100-ktonne order for 1994, Falconbridge has voluntarily committed to keep emissions below 75 ktonnes by 1998.

Future efforts in the mill will focus on increasing both pyrrhotite rejection and copper concentrate production, thus increasing the concentrate grade to the smelter. Some of the issues that the research and development work will need to address include:

1. increased complexity of the mill circuits and the need for reliable advanced process control
2. impoundment of pyrrhotite tailings to prevent acid run-off
3. increased sensitivity to the mine feed grade

In the smelter, more SO_2 will be captured for acid production by increasing the amount of sulfur burned off in the roaster. Engineering studies are needed to evaluate capacity shortcomings in the roasters and acid plant. Increasing the degree of roast has a negative impact on metal recoveries, which has to be counteracted by adding more reductant in the electric furnaces. This, in turn, has serious implications for furnace operations (bottom build-up, higher temperatures, increased off-gas volume), which require extensive research and development programs and additional capital expenditures.

Falconbridge has spent more than $40 million in the past 5 years on SO_2 abatement and continues to work on a long-term basis with all levels of government to reduce the environmental impact of its operations.