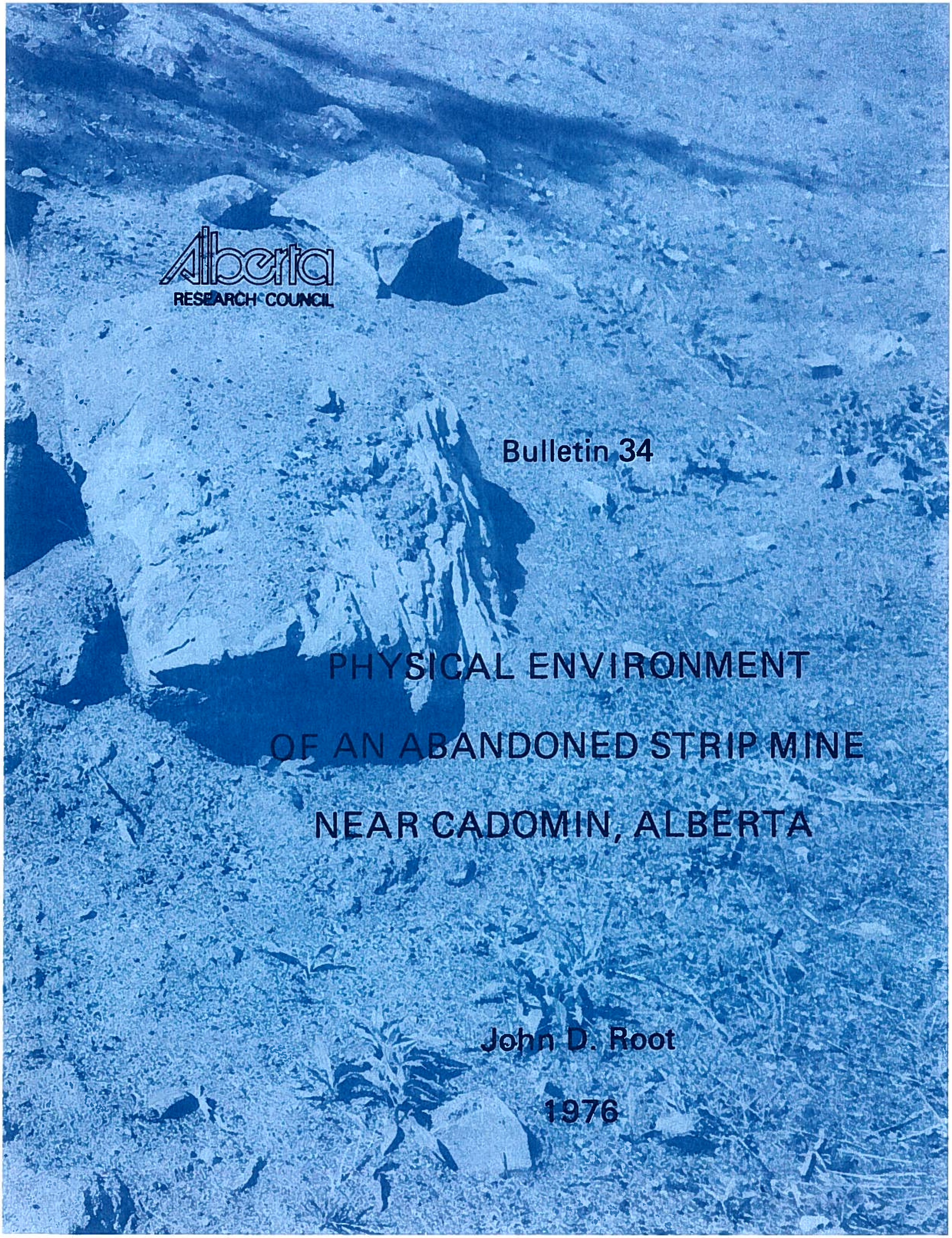

Alberta
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Bulletin 34

PHYSICAL ENVIRONMENT OF AN ABANDONED STRIP MINE NEAR CADOMIN, ALBERTA

John D. Root

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PHYSICAL ENVIRONMENT OF AN ABANDONED STRIP MINE NEAR CADOMIN, ALBERTA

ABSTRACT

An investigation of revegetation at an abandoned coal strip mine near Cadomin, Alberta, shows that soil moisture deficiency and wind are major factors inhibiting plant growth on disturbed ground in this area. High winds in fall and winter months act to reduce soil moisture, inhibit seed lodgment, remove fine particles, and abrade vegetation. Suggested remedial measures include erection of snow fences, compaction of spoil piles, mixing of organic matter with spoil, and roughening of spoil surfaces after compaction. Shelter belts should be left standing during the mining phase.

Geological observations at the minesite included weathering rates and groundwater analysis. Spoil weathers rapidly by physical processes; chemical weathering in the 20 years that have elapsed since abandonment is not significant. On spoil pile slopes, fine materials move downward rapidly and continuously, while the piles themselves are stable. Infiltration is high, runoff low. Groundwater quality is high and apparently little affected by passage through spoil.

These findings may be applicable generally in the Rocky Mountain Foothills of Alberta and British Columbia, wherever coal is extracted from the Luscar Formation or its equivalents, and where chinook (foehn) winds are frequent.

INTRODUCTION

An estimated 32,000 acres of the Alberta Foothills will be strip mined for coal over the next 20 years. This estimate excludes land used for access roads, service facilities, townsites, and coal exploration activities; thus, a significant area will require reclamation if it is to be restored to a state approximating its former condition. Reclamation involves restoring the disturbed area to its original topography, ensuring stable slopes, and revegetating exposed surfaces to prevent erosion. Although the restoration of disturbed land to stable, if not the original, contours is ordinarily a simple matter of earthmoving, revegetation is more difficult; at present (1973), the long-term success of revegetation procedures in the Alberta Foothills remains to be determined.

As a step toward establishing such methods, the author investigated and determined the geologic and microclimatic conditions controlling the distribution and amount of natural revegetation at an abandoned coal strip mine southeast of Cadomin, Alberta.

Study Area Location and Access

The study area is situated in the Foothills physiographic region of west-central Alberta at 53°01′ north latitude and 117°18′ west longitude (Fig. 1). Located 1 mile (1.6 km) southeast of the town of Cadomin, which is accessible from Hinton (30 miles, or 48 km, to the north) via Luscar and from Edson (70 miles, or 112 km to the northeast) via Highway 47, the minesite is reached from Cadomin by a bridge, owned by Inland Cement Industries Company Limited of Edmonton, crossing the McLeod River.

Physical Environment of the Cadomin Region

The study area lies at approximately 5500 feet (1675 m) above sea level, just below treeline at the eastern edge of the Rocky Mountains, just east of the geologic foothills-front ranges boundary on the northeast flank of the Nikanassin Range. Summits in this range attain elevations of 8000 feet (2438 m), while topographic relief within the study area is approximately 2900 feet (900 m). The

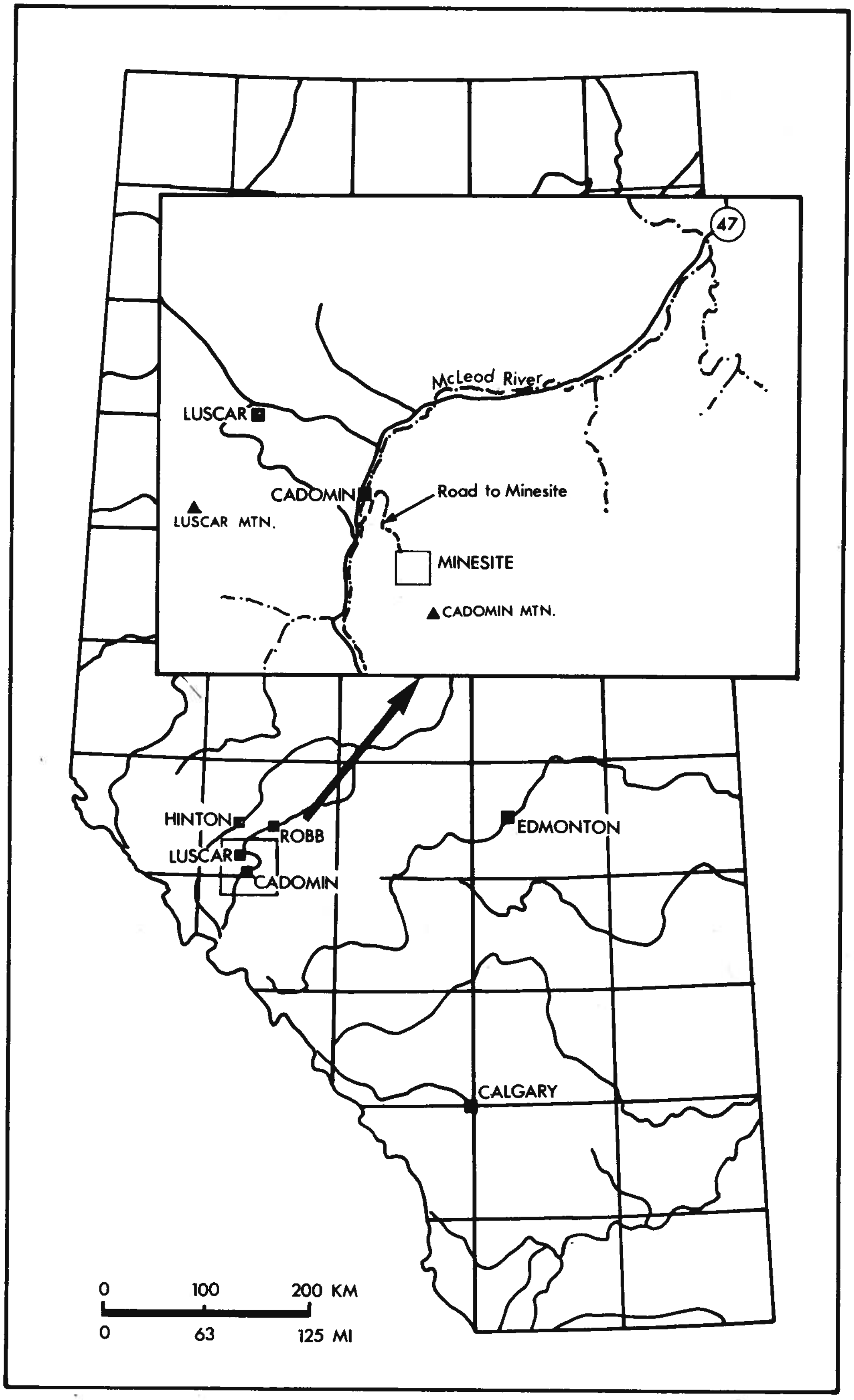

FIGURE 1. Location of the study area.

Nikanassin Range, which extends 18 miles (30 km) to the northwest and 17 miles (27 km) to the southeast from Cadomin, presents a considerable barrier to the easterly flow of Pacific air. The McLeod River flows east through a gap in the range at an elevation of 5000 feet (1525 m); the rapid flow of air through this gap gives rise to very high winds in the Cadomin area, only a few miles east.

Drainage in the Study Area

The study area is drained by Watson Creek, which flows to the east, and "Cadomin" Creek, which flows to the northwest; both streams are small but permanent and both flow into the McLeod River. Neither passes directly through the minesite.

Climate

The climate of the region is classified as subarctic or Dfc in the Köppen system of climatic classification. The letter D signifies a humid microthermal climate with cold winters and short cool summers, the mean temperature of the coldest month below -3^{O}C and the mean temperature of the warmest month above 10^{O}C. The letter f signifies precipitation throughout the year. The letter c signifies cool, short summers with only one to three months in which the mean temperature is above 10^{O}C (Atlas of Canada, 1957). The climate varies considerably throughout the region because of the rugged topography, large local relief, and varied exposure to wind. During the winter months air moving eastward over the Rockies periodically descends rapidly and warms adiabatically, creating a warm chinook wind accompanied by high temperatures, rapid removal of snow cover, and dessication of vegetation.

Soils

Soils of the region are complex and dependent on parent material and elevation. The study area was not glaciated during the Late Wisconsin; the soils have developed directly from weathered bedrock. The dominant soils of the control area are described as Lithic Orthic Grey Luvisols with Lithic Degraded Eutric Brunisols significant (Dumanski, *et al.*, 1972). In general, the soils are medium- to fine-textured, light olive brown to yellowish brown, stony, and have a thin (¾ - 3 inch, or 2 - 8 cm) organic Ah horizon.

Regional Vegetation

Vegetation in the region is classified as Lodgepole pine — white spruce — Engelmann spruce (*Pinus contorta* var. *latifolia* — *Picea glauca* — *Picea engelmannii*) (Atlas of Alberta, 1969).

The vegetation in the control area is mainly Engelmann spruce and white spruce with some lodgepole pine, balsam poplar (*Populus balsamifera*) and alder (*Alnus crispa*). The tree cover is scattered and stunted.

Description of the Minesite and Control Area

The study area consists of the 350 acres disturbed by mining and 300 acres of undisturbed surrounding land (Plate 1). Disturbed land is referred to as the "minesite" and undisturbed land surrounding the minesite is referred to as the "control area."

Minesite

The minesite consists of a large main pit, an upper smaller pit, and the overburden material that was dumped downslope from these two pits, consisting of broken rock strata, soil, and vegetation removed to gain access to the coal seams. With the exception of an adit of unknown length at the west end of the main pit, stripping was the only method used. The flat-topped and steep-sided lobes of overburden are referred to here as "spoil piles."

The main pit is in the shape of an elongated teardrop, is 2600 feet (793 m) long, 200 feet (61 m) deep at the wide east end and is less than 50 feet (15 m) deep at the narrow west end. The walls are very steep: at the west end, the south wall is vertical, while the south wall at the east end slopes at 55 degrees. The north wall of the main pit has a series of stepped cliffs along its length; in profile, it is not as steep overall as the south wall.

The upper pit is smaller and shallower, with gentler walls than the main pit. It is long and narrow, widening abruptly at the west end. The dimensions are: 800 feet (240 m) long, 200 feet (60 m) wide and 90 feet (27 m) deep.

The spoil piles from the main pit form an extensive flat-topped, steep-sided, tiered benchland at the lower east end of the minesite. Rolling topography with two isolated spoil piles extends between these spoil piles and the west end, where one long spoil pile is present. The spoil piles from the upper pit are smaller but are close to the upper edge of the south wall of the main pit.

As described, the topography of the minesite is thus varied and rugged, consisting mainly of steep slopes and flat surfaces.

Control Area

The control area surrounds the minesite. To the west it comprises the uniform undisturbed slope of the mountainside; to the north of the minesite, the control area includes a steep-sided valley and a low ridge that separates the study area from the main valley below.

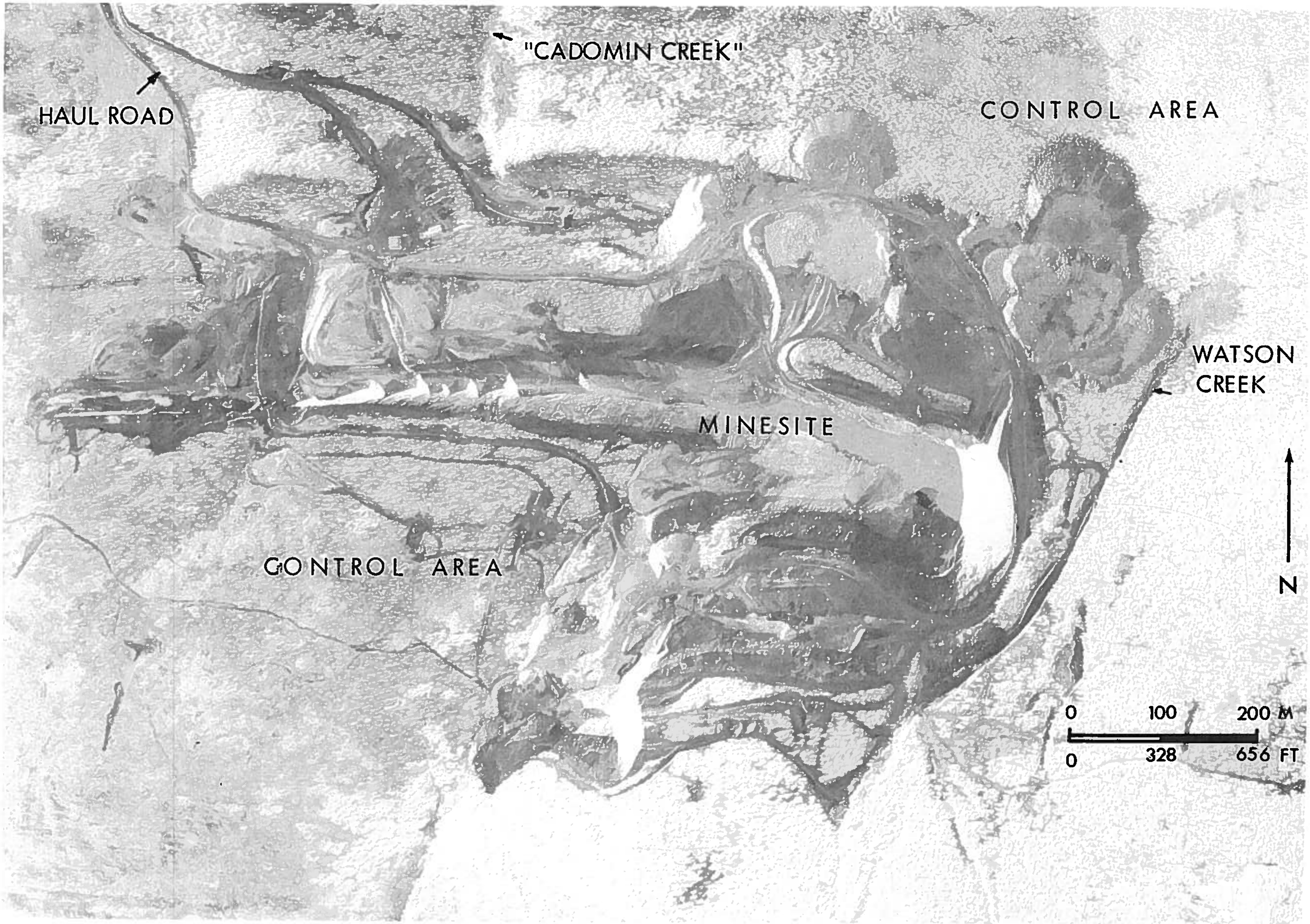

PLATE 1. Physical and cultural features of the study area, vertical aerial photograph.

Reclamation

Between the first stripping in the 1920s and closure of the mine in the 1950s, approximately 350 acres of land was disturbed by the mining operations. Apart from removing buildings, no effort was made to reclaim the area. Abandoned in this condition in 1952, the study area provides an opportunity to examine long-term natural revegetation, and potential slope stability and erosion problems.

Previous Work

Although voluminous literature is available on many aspects of disturbed land reclamation in the eastern United States and some parts of Europe, little is available on the reclamation in the Alberta Foothills. Peterson and Etter (1970) have summarized the literature related to disturbed land reclamation and research throughout the Rocky Mountain region of Alberta and conclude that there is a need to define the critical environmental factors which limit plant growth on disturbed sites.

To the writer's knowledge there has been little research conducted specifically on geologic and microclimatic conditions associated with disturbed land in the Alberta Foothills. However, geomorphic investigations of strip mining in the foothills and mountains of southern Alberta and southeastern British Columbia provide some information about weathering and erosion at the minesites.

Harrison (1972) examined thirteen surface mines in the Crowsnest Pass — Elk Valley area of Alberta and British Columbia and noted the aspect, profile, stability, associated deposits, composition, active geomorphic processes, and vegetation of each. His preliminary findings concur with those reported by Root (1972). Harrison reports that:

(i) Slopes greater than 30 degrees are rarely revegetated naturally and the downslope creep of surface material is rapid.

(ii) Downslope creep is not sufficiently rapid to regrade steep slopes in an acceptable period of time.

(iii) "Infiltration on most spoil is sufficiently high that run-off is available to form rills and gullies. The exception is where areas of drainage accumulation occur uphill from the spoil. Slope regrading by running water is therefore not an important process." *Sic*; the word "little" must be inserted between "that" and "run-off" for the first sentence to read correctly.

(iv) Softer rock types break down rapidly by physical weathering, and mineralogical and chemical changes at the surface are minimal.

(v) Water ponded uphill from a slope tends to result in slope failure.

Unpublished information received from T. Dillon of the University of Calgary in 1972 is applicable to the present study. Dillon studied seed germination and the associated microclimatic conditions for two small, isolated plots on spoil piles at an active minesite at Luscar, 7 miles (11.2 km) north of the study area. Half of the area in each of the two plots was compacted with a bulldozer and the other half was left uncompacted. A variety of seeds (mainly grasses), an adhesive, and a fibrous mulch were applied with a hydroseeder to each of the two plots. Dillon made detailed observations on the germination and growth of the seeds and measured incoming solar radiation, wind speed, temperature, and humidity at 1 foot (30 cm) above the ground surface; as well, surface temperature was monitored and soil temperatures taken at 0.4 and 2 inches (1 and 5 cm) below the surface. Sequential infrared photography was used to determine the moisture stress[1] of individual plants. Dillon concluded that:

(i) Plant growth was limited to small depressions.

(ii) Optimal growth of the plants was limited by lack of moisture.

(iii) Plant growth was better on compacted spoil material than on noncompacted spoil material.

Donald (1969, p. 32) observed the opposite in the Crowsnest area, where "Studies have shown that spoil provides a better growing medium if it is left where it falls, without compaction and with a minimum of contouring and reshaping."

All of the foregoing must be considered in the light of a statement by Berkowitz (1969, p. 42), in a discussion of surface mining in the Alberta Foothills: "At high elevations, where natural plant cover is either absent or scanty and stunted by climate and a rocky (almost soilless) substrate, reclamation in the commonly accepted sense is clearly impossible."

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[1]Moisture stress is defined as a condition of water shortage indicated by physiological responses of the plant.

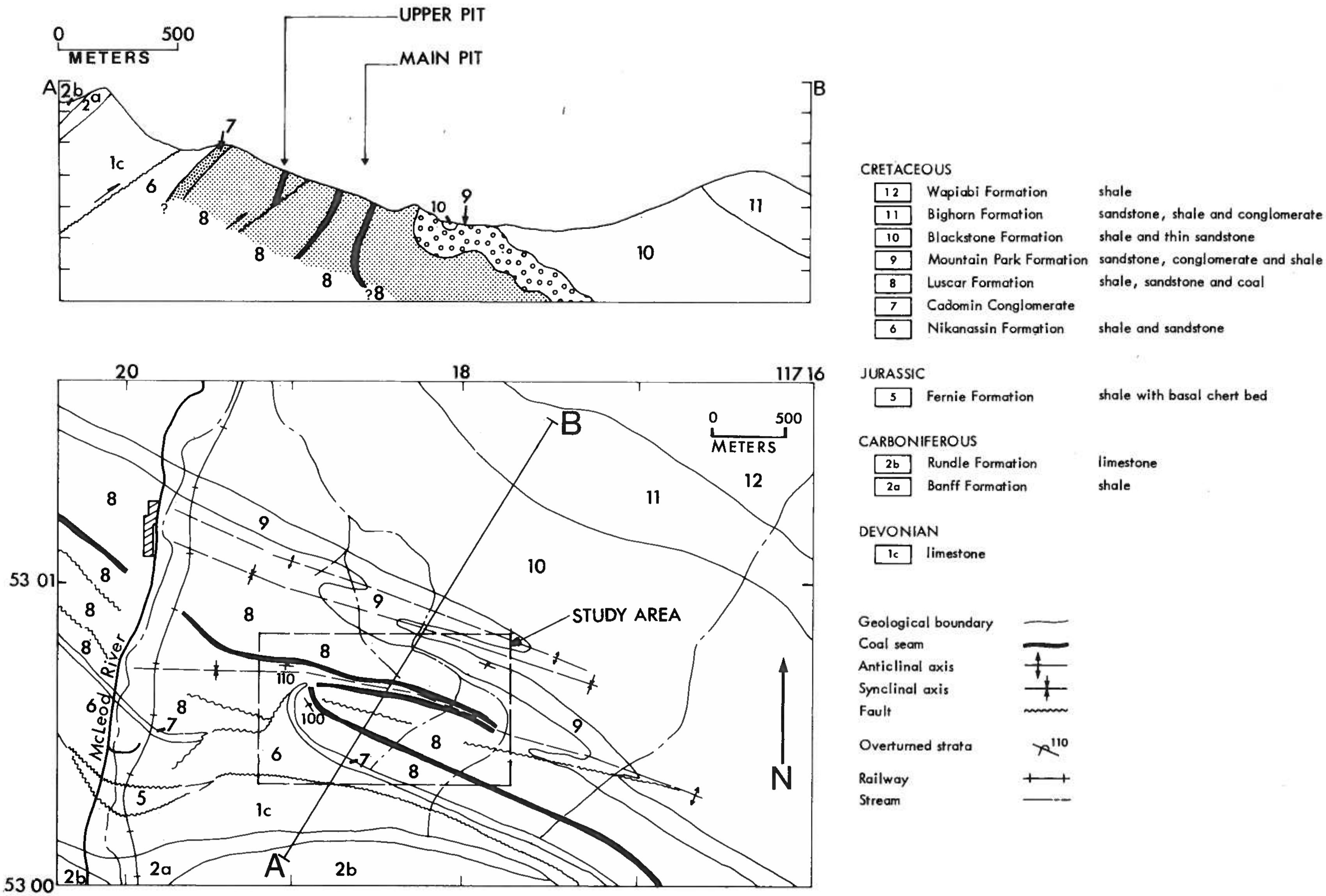

FIGURE 2. Bedrock geology and cross section of the study area. (after Mackay, 1929).

Method of Study

Five microclimatic stations were established in the study area in June of 1972, and continuous records kept of air temperature and humidity. Soil temperature, surface temperature, air temperature profiles, and precipitation were recorded periodically until September 1972. A plane-table topographic survey of the minesite was made, and the vegetation mapped. Water samples for chemical analysis were taken of surface runoff above the minesite, lake water and spring discharge within the minesite, and spring discharge below the minesite. Samples of spoil and wind-blown material were also taken. A snow survey was made over the study area in March and May of 1972, and January of 1973.

Acknowledgments

Sincere thanks are offered to Professor R. W. Longley, whose exacting demands, enthusiasm and critical eye have taught me so much.

I am indebted to Dr. L. A. Bayrock of Bayrock and Reimchen Surficial Geology Ltd. for the recognition, encouragement and support he has given me over the past few years and to Dr. G. B. Mellon[2], former Head of the Geology Division of the Alberta Research Council, who has given much practical advice and guidance. The good offices of Dr. R. Green, Chief of the Earth Sciences Branch of the Alberta Research Council, are also much appreciated.

My wife Judy identified the plants present in the study area, typed the manuscript, and helped me in innumerable ways.

Mr. Tom Dillon provided useful data on the Luscar minesite and much fruitful discussion.

Alberta Research Council funded the field work and Mr. Gerry Lobb and Mr. Conrad Kathol provided excellent field assistance. Mr. Pfanmuller of Inland Cement Industries Co. Ltd. generously allowed the use of the company's bridge across the McLeod River at Cadomin.

The Atmospheric Services Branch of Environment Canada, the Atmospheric Sciences Division and the Geology Division of the Alberta Research Council, and the Division of Meteorology, University of Alberta, provided various instruments for the study.

GEOLOGIC FACTORS

The geology of the study area is summarized in figure 2. All coal extracted from the study area came from the upper beds of the Luscar Formation (MacKay, 1929, 1930), which is a predominantly nonmarine sequence of soft grey sandstone and dark grey shale.

The Luscar Formation is underlain by a resistant chert and quartz-pebble conglomerate (Cadomin Formation) and overlain by a coarse green sandstone and green shale with lenses of pebble conglomerate (Mountain Park Formation) (Mellon, 1966). All three formations are Early Cretaceous in age.

The coal-bearing upper Luscar beds may be traced as far south as Ram River and as far north as northeastern British Columbia; because lithologic, stratigraphic and structural relationships are generally similar throughout these coalfields, it is likely that geologic factors in revegetation are similar to those of the study area.

Bedrock immediately adjacent to the coal seams is removed during the course of surface coal extraction; thus, spoil piles in the study area are mostly Luscar Formation material, with minor surficial constituents. The spoil is characterized by large to fine, broken, angular fragments of grey, medium-grained, crossbedded sandstone that contain various amounts of feldspar and volcanic rock fragments; shale and siltstone, ironstone, conglomerate and coal are also present. The proportions of these constituents vary considerably from spoil pile to spoil pile; average proportions are shown in table 1.

Table 1. Estimated Percentages of Lithologic Types in Spoil Piles

Bedrock Type	Proportion of Spoil (%)
Sandstone	50 - 75
Shale and siltstone	30 - 50
Coal	5 - 10
Ironstone	4 - 10
Conglomerate	1 - 2

[2]Now Deputy Minister for Alberta Energy and Natural Resources, Edmonton.

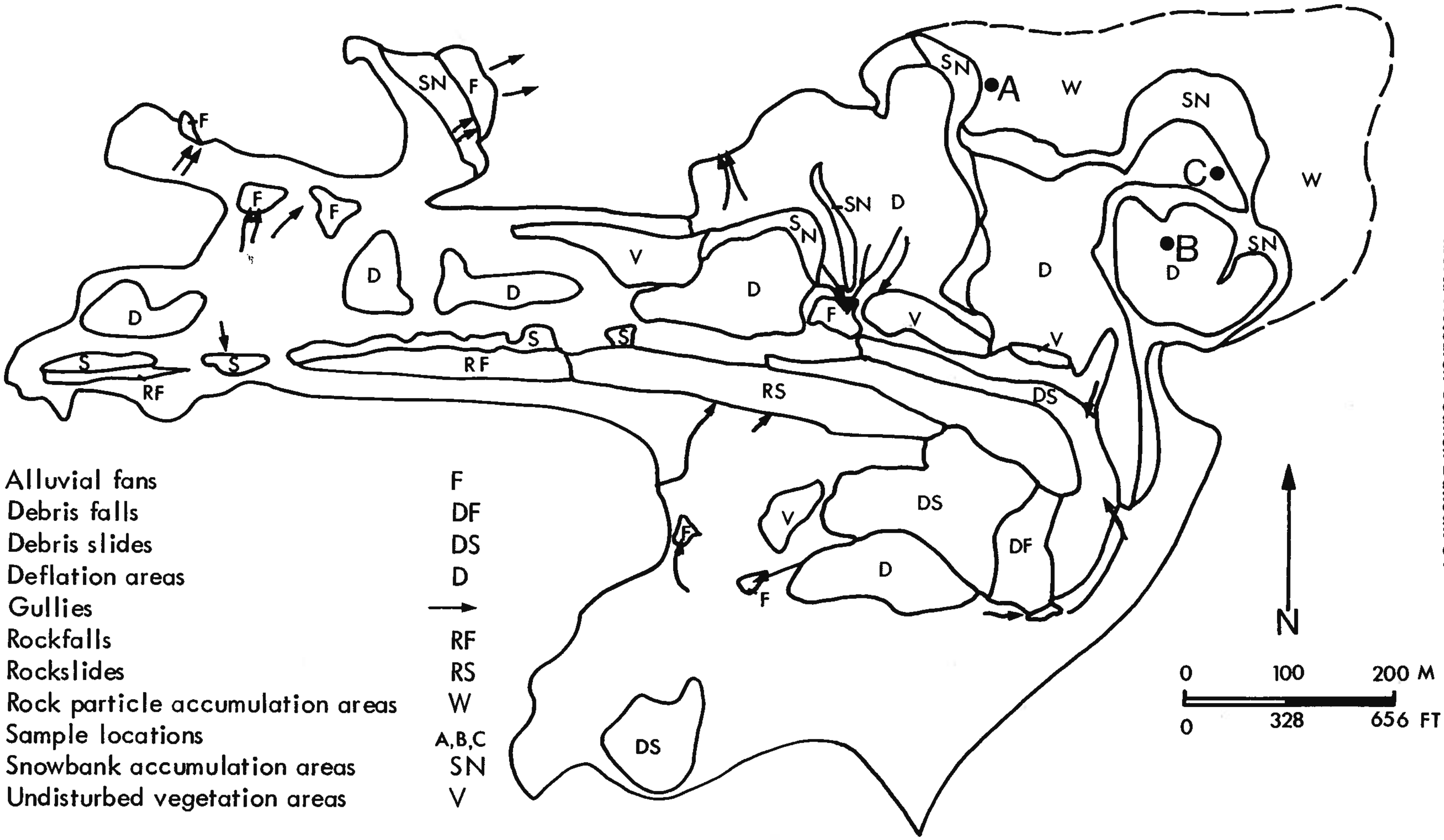

FIGURE 3. Mass wasting in the minesite.

PLATE 2. View looking east over main pit, showing inverted conical subsidence pits in foreground and steep highwalls.

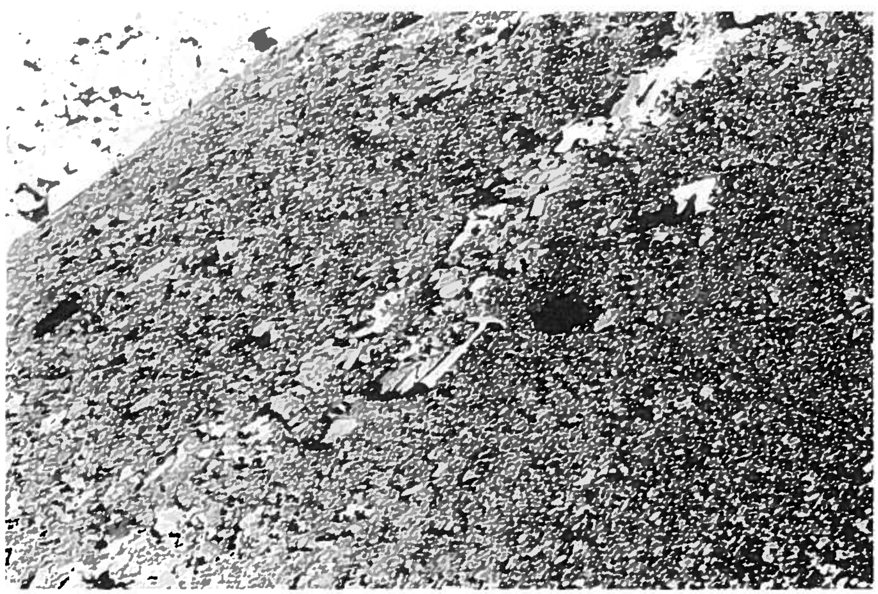

PLATE 3. Exfoliation weathering of sandstone and extension of debris downslope.

The mining process consisted of diverting the two creeks in the study area around the minesite, blasting the bedrock, removing the overburden and dumping it overslope and extracting the coal. As shown in the geologic section (Fig. 2), the seams were nearly vertical and considerable bedrock had to be cut back to maintain stable highwalls (Plate 2). The steep attitude of the seams controlled the economics of mining them: coal extraction was limited by the cost of cutting the bedrock walls back to stable conditions.

Weathering

Weathering processes at the surface of the minesite include frost wedging, abrasion by wind-borne particles, swelling and shrinking of clay minerals on wetting and drying, solution of the carbonate, kaolinite, and quartz cements found in the sandstones, and the release of overburden pressure after mining. In places protected from the wind, conical piles of loose sand derived from disintegration and exfoliation weathering of boulders may be observed. Also, weathered sand may be found extending downslope on spoil piles downslope from exposed boulders (Plate 3). At one location a sandstone boulder had a weathered rind of 4 inches (100 mm) and weathered rinds of ¾ inch (20 mm) or thicker were common (Plate 4). Because the material could not have been exposed for more than 40 years, the thickness of weathered rind indicates a rapid rate of weathering (0.02 to 0.2 inches, or .5 to 5 mm per year). This finding agrees with weathering rates of spoil materials at adjacent minesites near Luscar, 7 miles (11.2 km) north of the study area (R. Green, personal communication; T. Dillon, personal communication). Conglomerate bedrock and resistant sandstone units comprising most of the spoil break down into angular, blocky fragments (Plate 5). Fragments derived from thin ironstone beds in the Luscar Formation form almost perfect cubes, while more competent shales and siltstones form flaky elongated, irregular diamond shapes (Plates 6, 7).

Boulder-sized coal fragments up to 24 inches (60 cm) in diameter are found mixed with the surface materials, but most of the exposed coal has weathered to weak, flaky fragments 1 cm or smaller in size. The surfaces of many exposed shale boulders have weathered to acicular and small, platy fragments that may be dislodged and broken easily.

The blocky character of disintegrated spoil materials indicates that physical weathering is primarily responsible (Ollier, 1969, p. 17). The cold, dry climate and the short period of time elapsed since the materials were exposed to the atmosphere preclude significant chemical weathering. Insulating snow cover is removed from many places in the minesite by persistent high winds; this results in more frost shattering and abrasion by windblown particles than in the control area, which is sheltered from the wind by vegetation and retains fallen snow.

Mass Wasting

Mass wasting is defined as the downslope movement of rock particles under the influence of gravity but without the aid of any transportation medium; included in this term are rockfalls (free falls of rock), rockslides, debris falls (unconsolidated deposits), debris slides, subsidence, and soil and talus creep (Sharpe, 1960). All these types of mass wasting are found in the study area; their distribution is given in figure 3.

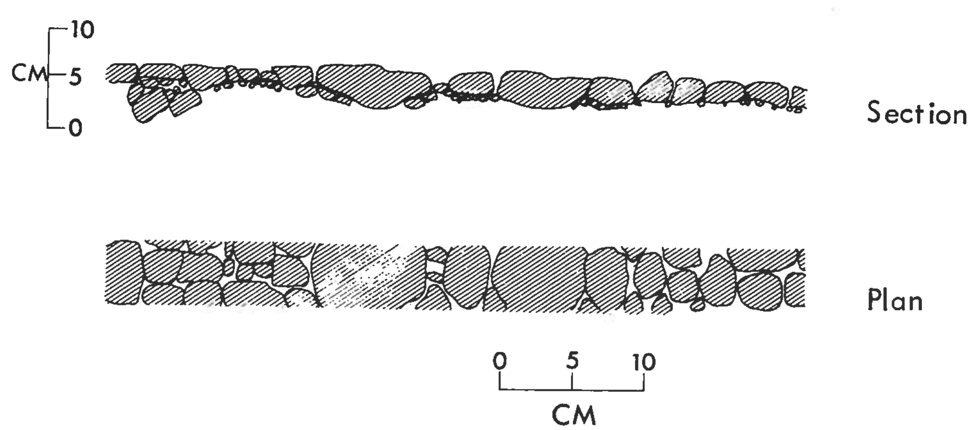

FIGURE 4. Deflation pavement in the minesite, illustrating removal of fine particles by wind.

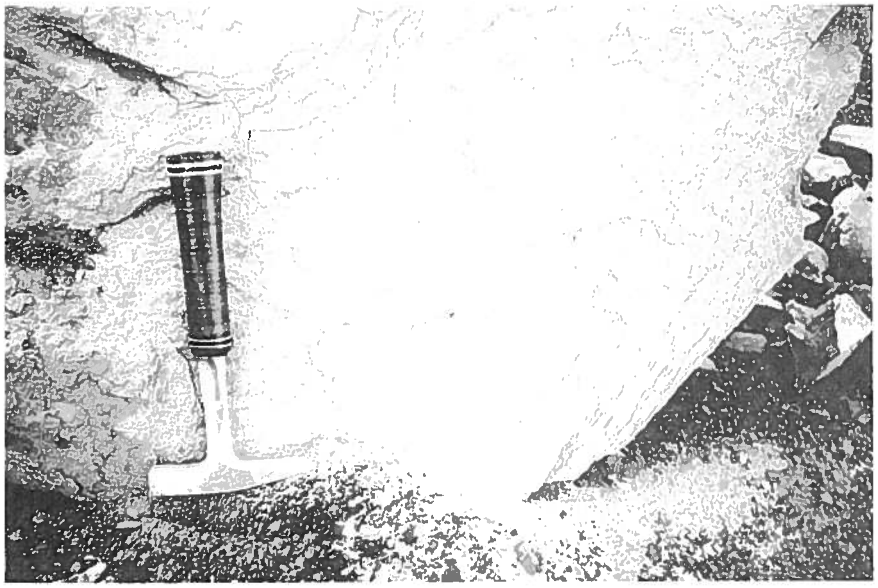

PLATE 4. Exfoliation weathering of kaolinite-cemented sandstone; weathered rind is about 5 cm thick.

PLATE 5. Characteristic appearance of weathered sandstone and conglomerate in spoil piles.

PLATE 6. Weathering of a block of shale capped with ironstone bed, showing characteristic fracture patterns.

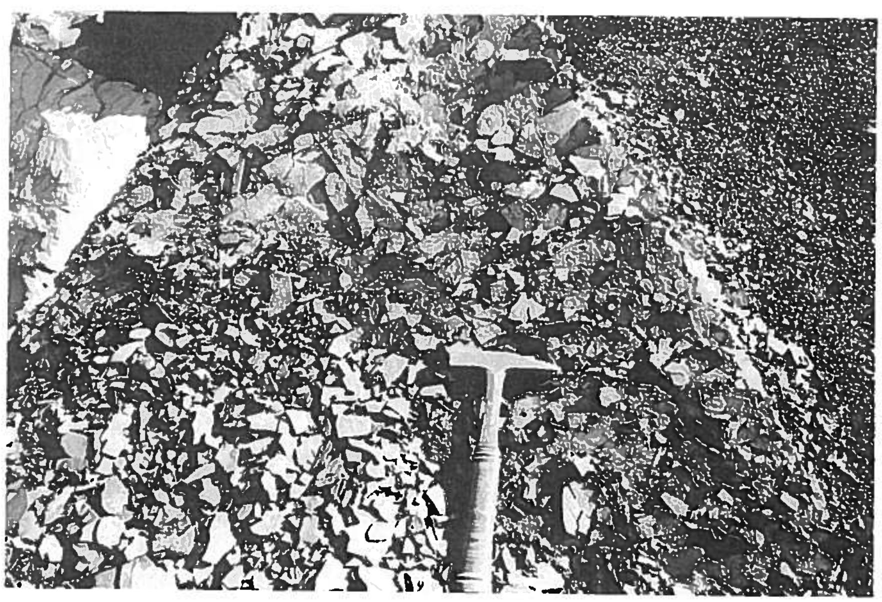

PLATE 7. Weathering of laminated silty sandstone, showing characteristic fracture pattern.

Gullying

Gullies have developed where streamflow previously diverted around the minesite has flowed across spoil material. Gullies, once formed, tend to perpetuate themselves: the incised V-shape prevents snow removal by wind and the accumulation of snow releases a sustained flow when melting during the spring. The surface outlet for the upper lake (in the upper pit) is across a road that ponds it. Although the lake is rarely high enough to use this outlet, a large gully has developed immediately below.

The gullies themselves vary considerably in shape, but are typically very steep sided, relatively short, and broad — the characteristic shape for gullies in coarse-grained material.

These gullies provide an abundant and continuing source of easily transported material. Considering that runoff is rare, that much of the snowfall is removed and significant snowbanks do not accumulate, and that rainfall is intermittent, and usually light, the existence of gullies indicates that the spoil has a high potential for erosion.

Erosion and Deposition by Wind

The high winds that blow over the minesite are responsible for a rapid rate of aeolian erosion. Fine particles are uplifted and removed from the study area, while the larger particles are moved by saltation or rolled along until they lodge in snowdrifts or in vegetation. A layer of wind-blown particles 2.5 to 8 inches (7 to 20 cm) thick was found covering a snowbank on the east side of the scarp slope of a spoil pile in June (Plate 8) and many thinner layers were recorded in snowbanks during the snow surveys of March 1972 and January 1973.

Finely comminuted material is removed from the flat and rounded westerly exposed surfaces of the spoil piles, which have developed a deflation pavement (Fig. 4 and Plate 9). Pebble dunes have formed downwind (east) of large angular blocks (Fig. 5 and Plate 9). Particle sizes in one such dune ranged from 0.4 to 0.8 inches (1 to 2 cm) and one was measured at 1.75 inches (4.5 cm); during the snow surveys cobbles of coal up to 2.4 inches (6 cm) long were observed on top of snow, in places where the only means of transportation was by wind. Calculation of the wind velocity required to move fragments of this size (Bagnold, 1954, p. 101) indicates that a speed of 100 mph (160 kph) was attained at the minesite. This figure compares well with reported maximum winds of about 100 mph (160 kph) reported in the Cadomin area during the winter of 1972-73 (Edmonton Journal, 1973).

Figure 6 gives the calculated threshold wind velocity required to initiate movement of a particle over the ground surface based on grain size, lithology, and bulk density of the particle. From figure 6 and the range of sizes of

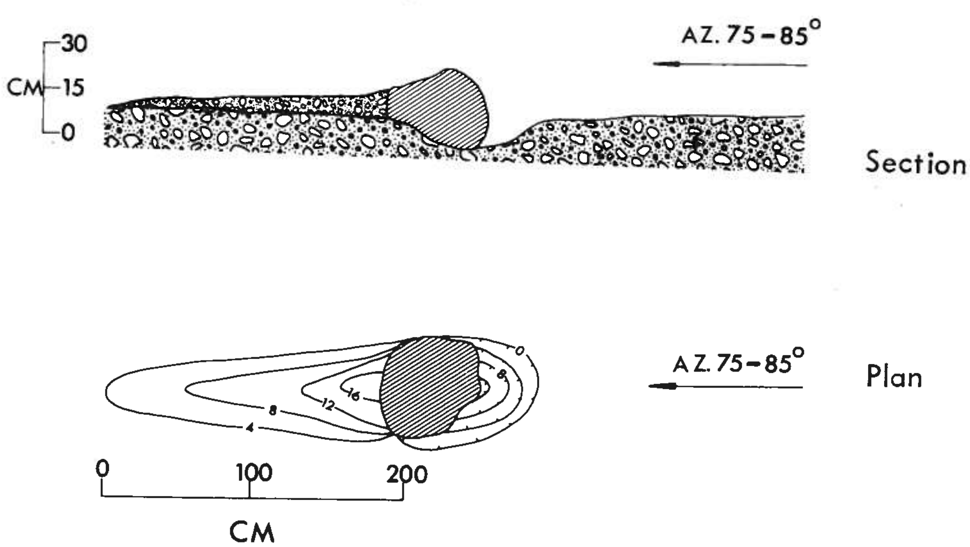

FIGURE 5. Plan and section of a pebble dune. Rock particles were removed from the upwind side of the boulder, transported and deposited on the lee side by wind.

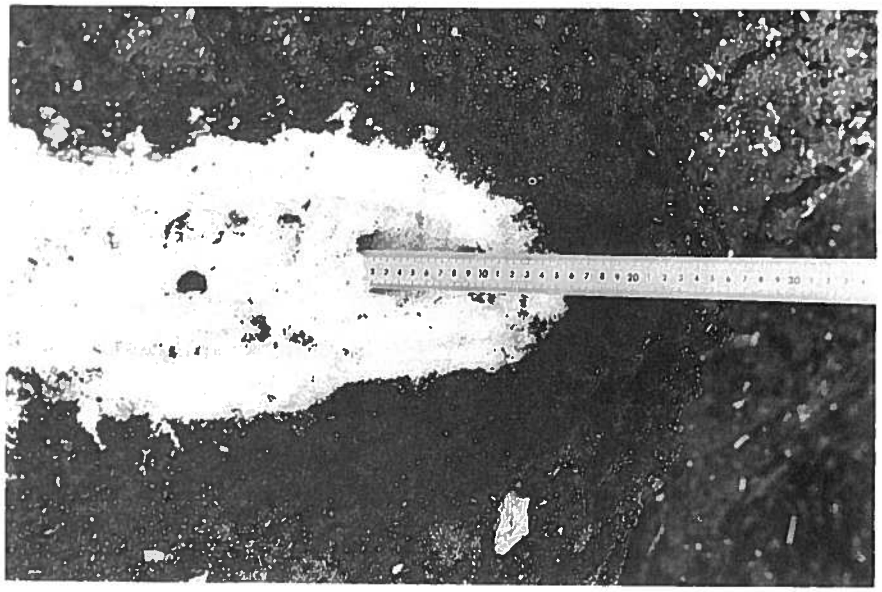

PLATE 8. Mantle (7 to 20 cm) of windblown rock particles from spoil piles accumulating on snow in the minesite. The large pebble at right center is sandstone (2.32 gm/cm^{-3} bulk density, 5 cm long). It would require a wind velocity of 140 kph to initiate movement.

PLATE 9. Deflation hollow under sandstone boulder, with pebble deflation pavement.

particles sampled in the minesite it is possible to estimate the wind speeds at 4 feet (1.3 m) above the ground surface that occur in the minesite. It should be noted that the higher values are associated with air streaming around boulders in front of the dunes to which the large pebbles were moved, and are not representative of wind speeds in open flat areas in the minesite.

In view of the large size of particles transported in the minesite during winter, and the agreement of theoretical and reported maximum winter wind speeds, high wind at the minesite is an important geomorphic agent and accounts for the deflation pavement and pebble dunes in the lee of boulders. The effect of this wind on moisture supply and vegetation is also important, and is discussed in the sections on Climatic Factors and Extent of Revegetation.

Groundwater

Numerous springs and seeps occur in the study area. A large spring below the minesite discharges year round and feeds the creek leading away from the study area (Plate 1). Flow from the smaller springs varies with the flow rate of the two small creeks mentioned earlier; spring flow rates reflect rainfall occurrences and spring melt.

Chemical Analysis of Water Samples

To detect changes in chemistry occurring when water passes through spoil material, samples were taken above the minesite and in the minesite at points where water issued from spoil piles. Locations of sample sites are shown in figure 7.

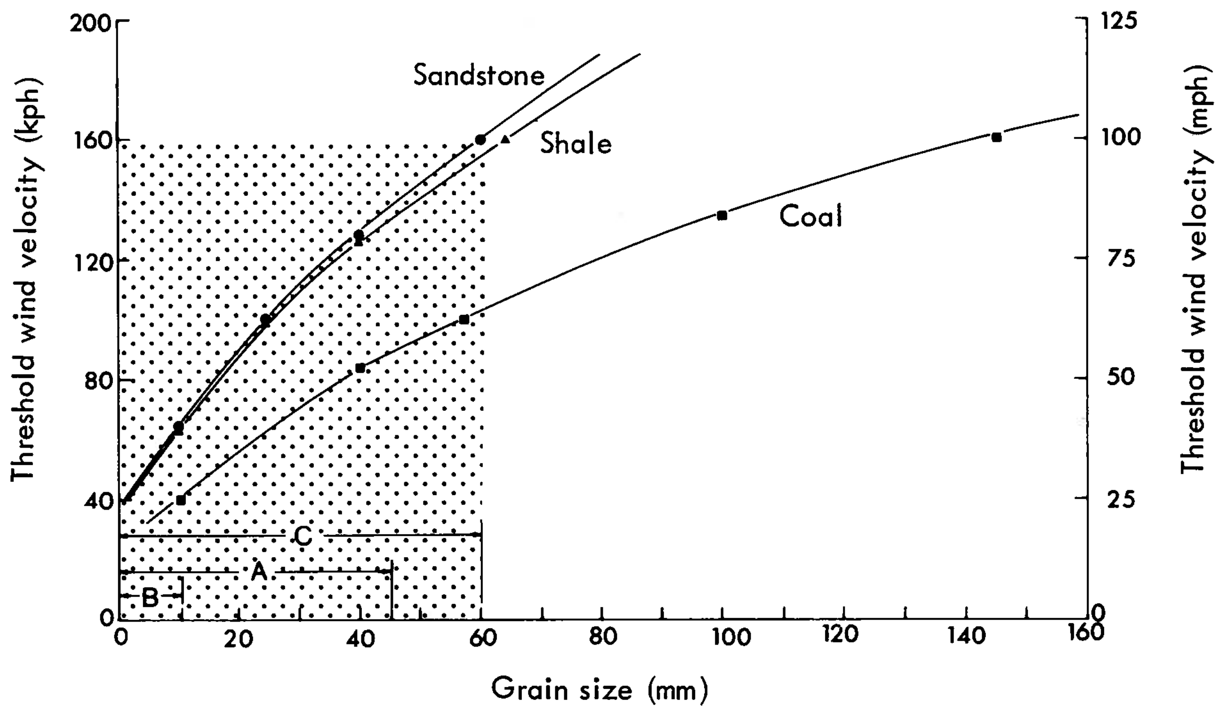

FIGURE 6. Wind velocity required to move spoil materials. Threshold velocity of wind at 1.3 m above ground surface for sandstone (bulk density 2.32 gm/cm^{-3}), shale (bulk density 2.20 gm/cm^{-3}) and coal (bulk density 0.97 gm/cm^{-3}) particles, and particle grain size: grain size range of samples A, B, and C collected in the minesite.

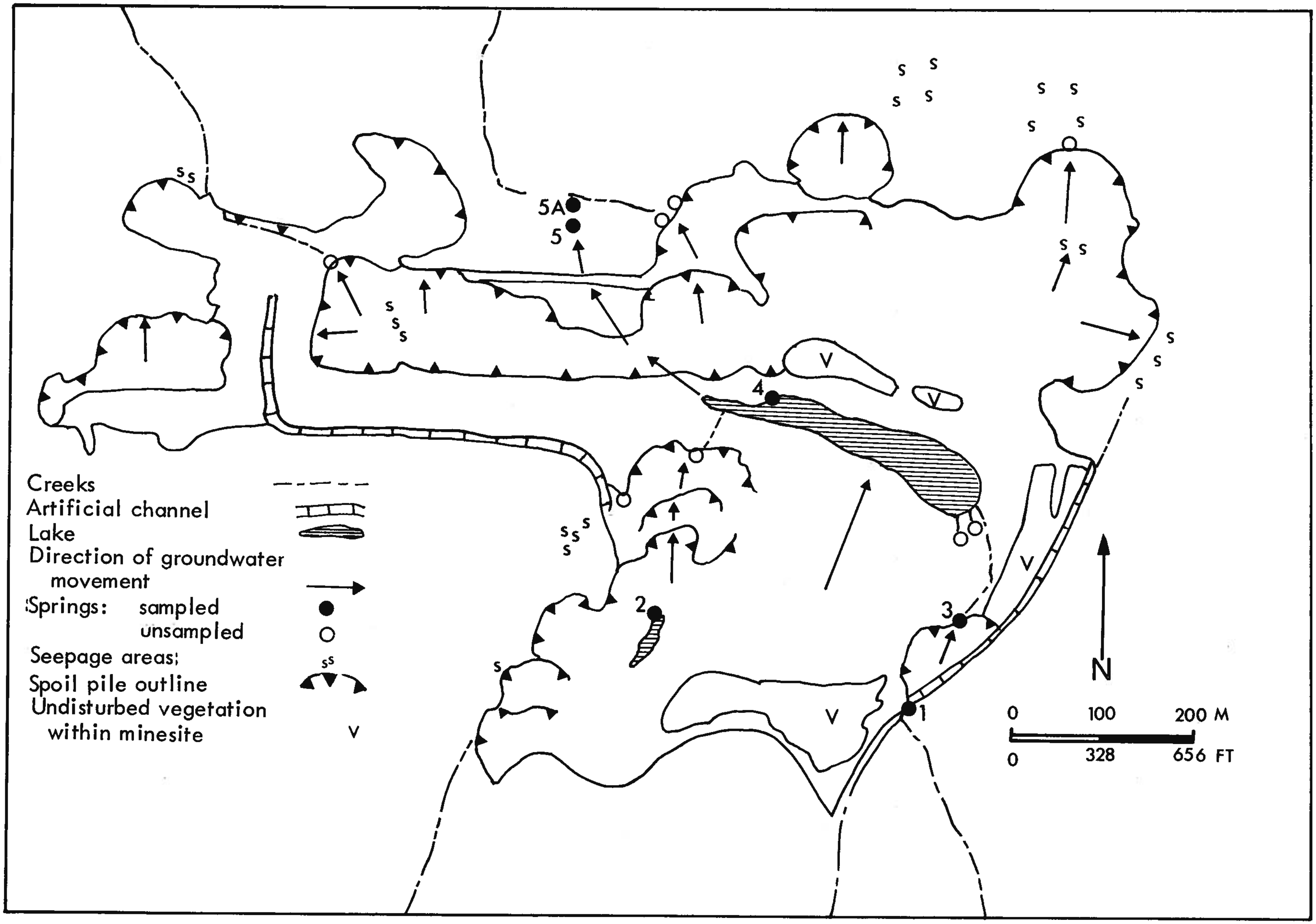

FIGURE 7. Surface water, drainage, groundwater movement and discharge, and locations of water samples taken for chemical analysis.

An analysis of the samples shows that there is little difference in chemical and physical properties of the samples (Table 2). Total dissolved solids, total calcium carbonate hardness, total calcium carbonate alkalinity, pH, and chemical constituents of the water change little after passing through spoil material. All samples were pure enough to conform to drinking water standards in Alberta. It is not possible to determine whether the analysis shown represents groundwater quality immediately after mining, or whether the results indicate higher quality water after the flushing out of reactive minerals over the 20-year period since the mine was abandoned.

Summary

(1) The spoil materials at the surface weather extremely rapidly by physical processes, aided by mass wasting.
(2) Little evidence of chemical weathering was noted.
(3) Slopes of spoil piles are stable and are reduced only by the down-slope movement of fine-grained rock waste.
(4) Talus creep and frost creep are the dominant mass-wasting processes.
(5) Erosion by running water is minor, although spoil piles have a high erosion potential.
(6) Erosion and deposition by wind is significant, especially in winter.
(7) Water moving through spoil is only slightly altered chemically.

CLIMATIC FACTORS

Five instrument stations were established to record meteorologic and soil temperature data in the study area over a four-month period (June-September) in 1972. The stations were located in such a manner as to record differences in microclimate between the minesite and the control area, and to monitor variations within the minesite. Instrumentation at each station included a hygrothermograph, precipitation gauge, and thermocouple temperature probes at the surface and at 2, 8, 20 and 30 inches (5, 20, 50, and 75 cm) below the surface. At two of the five stations, thermocouples recorded air temperatures at 2, 8, 20 and 40 inches (5, 20, 50, and 100 cm) above the surface. Wind speed measurements were made periodically with a portable anemometer.

Temperature and Precipitation

Figure 8 shows the permanent recording climatological stations closest to the study area.

Table 3 gives basic climatic data for each of these stations, and for a control and a minesite station in the study area as well. The study area is at a higher elevation than the permanent weather stations, which accounts for the lower temperatures recorded in the study area. When adjusted for elevation differences, the temperatures are in closer accord.

Table 2. Chemical Analyses of Water Sampled in the Study Area

	Upper Lake	Upper East Creek	Upper East Spring	Main Lake	Large Spring Below Minesite	Large Spring Below Minesite	Alberta Potable Water Supply Chemical Limits
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 5A	
General							
Total dissolved solids	254	168	174	196	298	292	1000
Total hardness as $CaCO_3$	263	166	172	159	173	175	100
Total alkalinity ($CaCO_3$)	184	158	170	194	294	278	400
pH	8.2	8.1	8.2	8.1	8.2	7.9	4.5 -10
Major constituents							
Calcium (Ca^{++})	64.0	43.0	51.0	41.3	44.2	45.0	200
Magnesium (Mg^{++})	25.0	14.2	10.7	13.4	15.2	15.2	150
Sodium (Na^{+})	2.5	3.8	5.0	33.0	65.0	44.0	300
Potassium (K^{+})	0.4	0.0	0.0	0.8	0.8	0.8	300
Carbonate (CO_3^{--})	0.0	0.0	0.0	0.0	0.0	0.0	400
Bicarbonate (HCO_3^{-})	184.0	158.0	170.0	194.0	294.0	278.0	400
Sulfate (SO_4^{--})	71.0	14.0	7.0	15.0	20.0	17.7	250
Chloride (Cl^{-})	1.0	3.0	1.0	1.0	1.0	0.0	250
Nitrate (NO_3^{--})	0.6	0.5	0.6	0.6	0.7	0.4	10
Minor constituents							
Iron (Fe^{++})	0.05	0.07	0.05	0.08	0.07	0.07	--
Fluorine (F^{-})	0.15	0.24	0.11	0.20	0.32	0.32	1.5

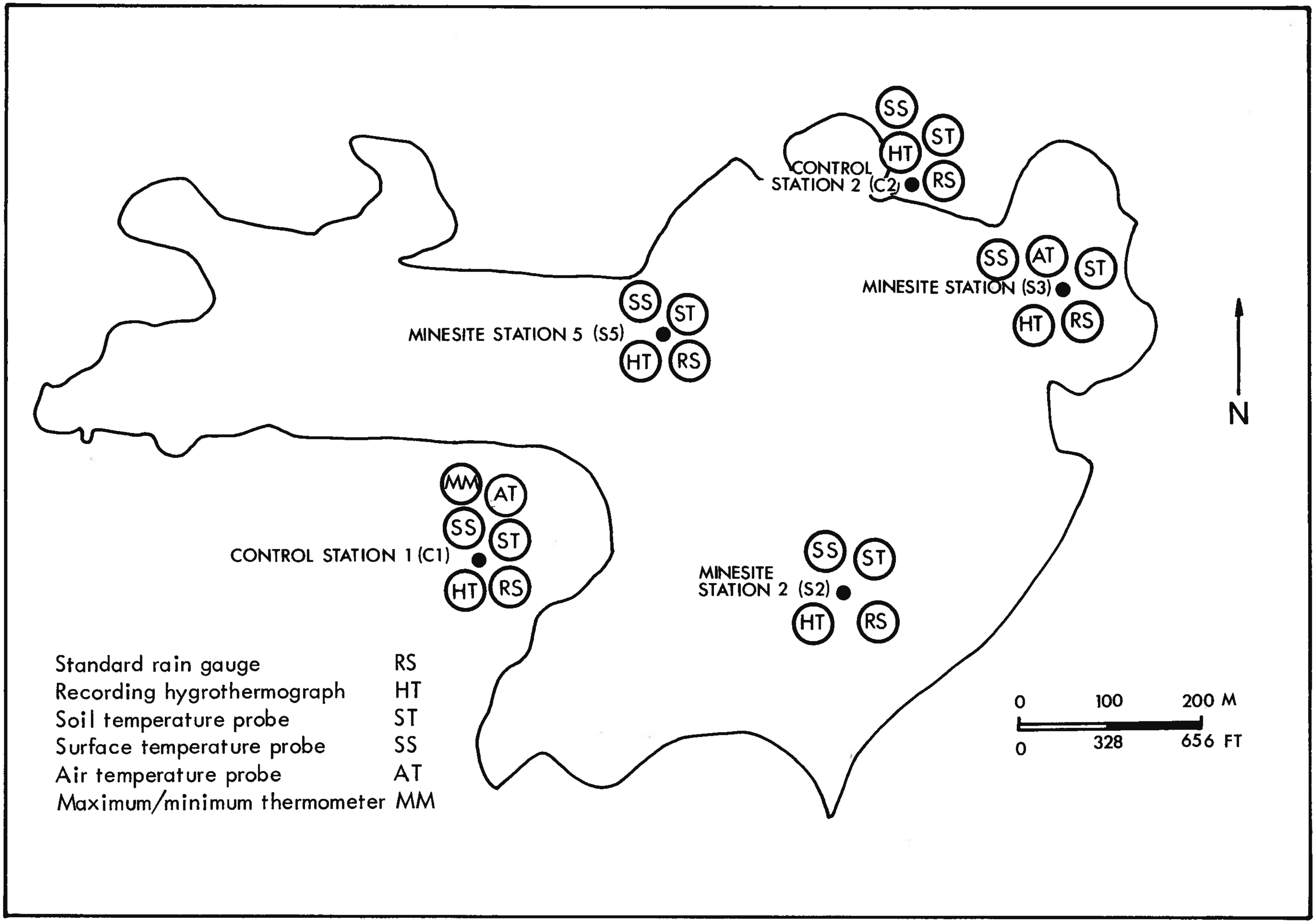

FIGURE 9. Microclimatic stations in the study area.

Generally the study area received more rainfall in June and July and less rainfall in August than the permanent weather stations, averaging to a figure that is considered to be normal for a typical summer. The long-term record of mean monthly temperatures recorded at Entrance shows that temperatures recorded in the study area were average for June and July, significantly above for August and significantly below average for September. Again, an average approximates the values expected in a typical summer.

Microclimatic Variation

Figure 9 shows the locations of the microclimatic stations in the study area; table 4 gives the monthly mean temperature, the monthly mean maximum, and monthly mean minimum recorded at the instrument stations during June-September, 1972. The monthly mean temperatures of the control stations are similar for June and July and differ only by 0.7° C for August. Monthly mean temperatures for minesite stations differ by up to 1.1° C and are generally higher than the control station monthly means. The mean monthly maximum temperatures for the minesite stations are consistently lower than those of the control area and the mean monthly minimum temperatures consistently higher. Generally then, the ambient air temperature in the minesite was warmer by 1° C than that of the control area, and the control area exhibits a greater range of monthly temperature than does the minesite.

Due to its dark coloration and sparse vegetation, the minesite has a lower albedo (reflectivity of solar radiation) than the control area. Thus, it might be anticipated that air temperatures within the minesite would be higher than the control area during the day and cooler than the control area during the night because of the greater absorption of heat at the surface in the minesite during the day and greater reradiation of heat at night. However, this is not the case.

Heat is transferred into and out of the soil by the movement of air, water, and water vapor so that soil with a high permeability will warm and cool more rapidly than soil with a low permeability. The rapid fluctuations in spoil temperatures compared to the control area, the lack of runoff and the coarse, angular spoil material indicate that the spoil materials are highly permeable and allow the rapid inflow and outflow of water, water vapor, and air.

Figure 10 compares air temperature in the control area with that in the minesite on two calm, sunny days and two windy, overcast days. On calm, sunny days the air temperature in the control area is warmer during the day and cooler during the night than in the minesite. On windy, overcast days the air temperature is slightly cooler in the control area during the day but the minesite is warmer throughout the night. The daily fluctuations of temperature are greater in the control area than in the minesite, contrary to what would be expected from a comparison of surface albedo.

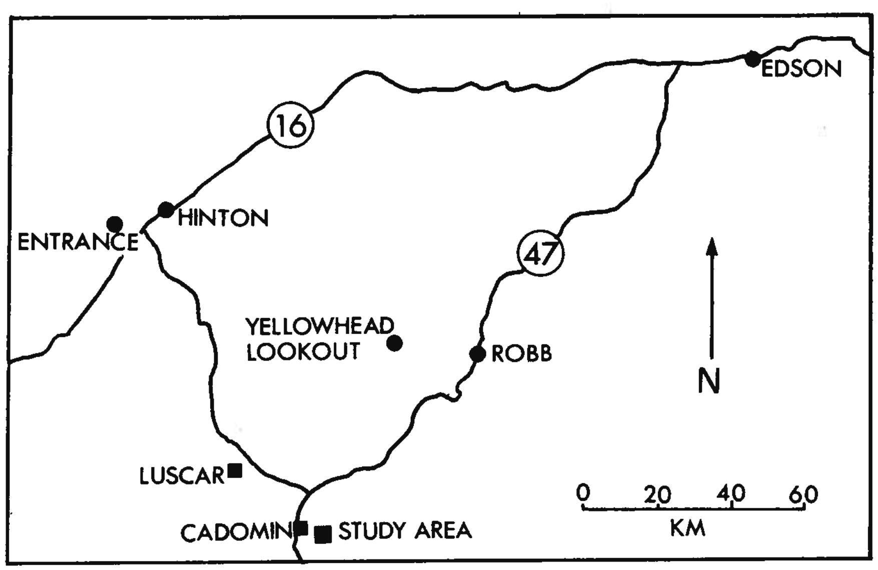

FIGURE 8. Permanent recording weather stations adjacent to the study area.

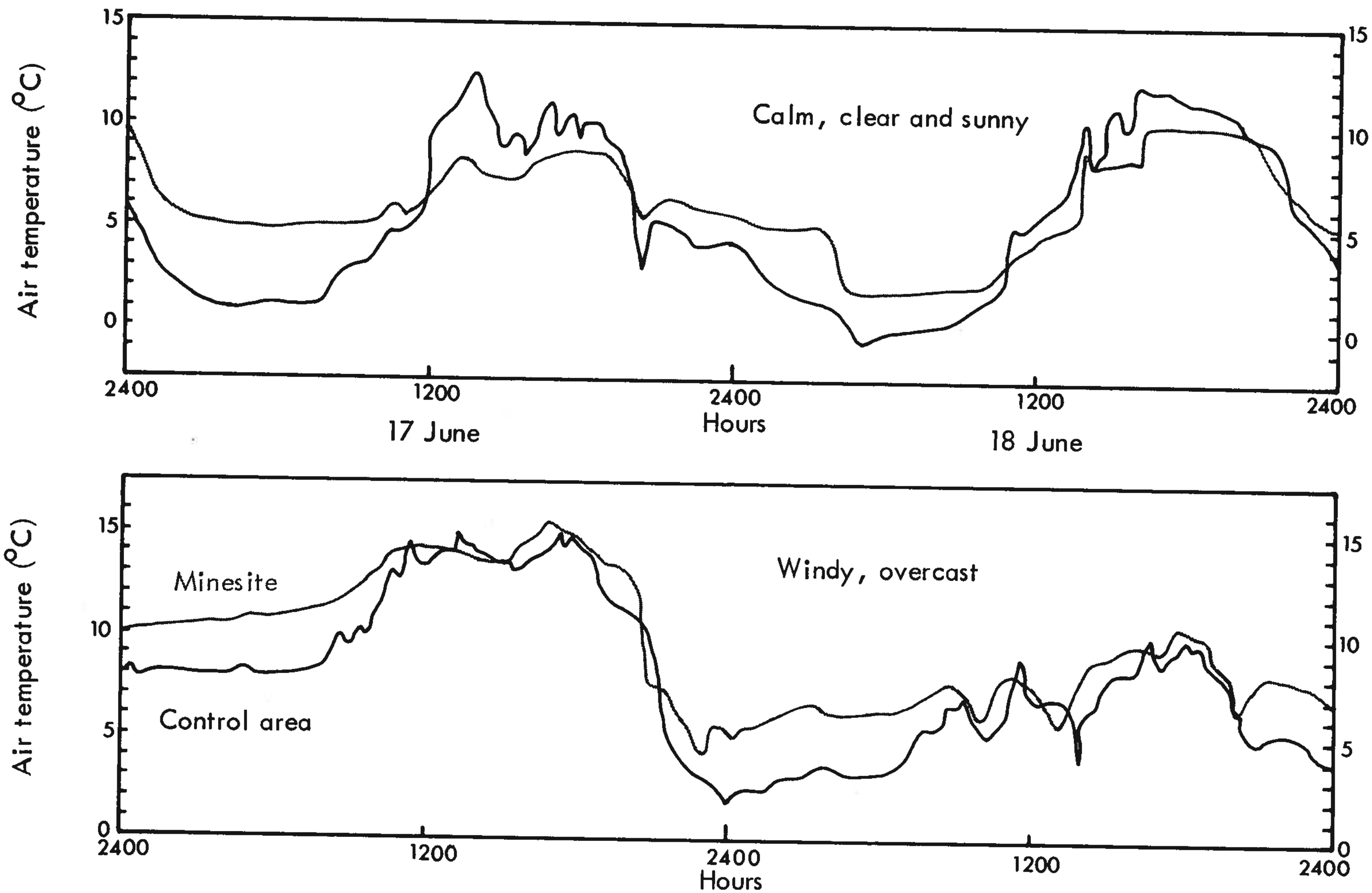

FIGURE 10. Diurnal temperature regime in the control area and minesite.

This contradiction is brought about by differences in thermal properties of surface materials. Soil temperature profiles show that the minesite responds more readily to insolation and air temperature changes than the control area, and that the soil temperature gradient in the minesite area is gentler than in the control area. Thus, the minesite is warmer than the control area at night because heat accumulated deep in the conductive spoil material during the day is released and warms the air. Cold air is not ponded in the minesite, whereas in the control area the vegetation tends to inhibit the mixing of warm air with cold air close to the surface. Hence the diurnal temperature regime shown in figure 10.

Wind Speed

Wind speeds measured periodically in the minesite correspond to measurements made by Dillon (personal communication, 1972) at a minesite at Luscar. In the study area at Luscar, wind speed within the minesite is consistently higher than in the surrounding area.

Potential Evapotranspiration

Combining wind, temperature, and precipitation data, daily values of potential evapotranspiration were calculated for the period June 12 to August 17 for each of the stations in the study area using Penman's (1963) and Christiansen's (1966) methods. Figure 11 shows the total potential evapotranspiration for each of the stations in the study area and indicates that the control stations have significantly lower potential evapotranspiration than the minesite stations. Surface albedo and wind speed are significantly different in the minesite and the control area. Further, air temperature at each station is not significantly different, while wind speed varies considerably. Thus, differences in potential evapotranspiration may be attributed to differences in surface albedo and wind speed. Of these two, wind speed is of far greater importance in evapotranspiration calculations.

Moisture Stress

Potential evapotranspiration is an index of the amount of moisture that is required for optimal plant growth and evaporation under various conditions of temperature, humidity and wind. Thus, if the values of cumulative potential evapotranspiration are compared with the amount of moisture supplied to the study area as precipitation, an indication of moisture stress is obtained. Figure 12 shows cumulative potential evapotranspiration and cumulative precipitation in the control area and minesite during the period June 12 to August 17, 1972. Where the cumulative precipitation curve is above the cumulative evapotranspiration curve, moisture for optimal plant growth is surplus; where the precipitation curve is below the evapotranspiration curve, moisture is deficient. Thus, from the figure it is apparent that a more pronounced moisture deficiency exists within the minesite. The period for which there is a moisture deficiency is also longer at minesite station 3 than at control station 1.

Table 3. Mean, Mean Minimum and Mean Maximum Monthly Temperatures of Permanent Recording Weather Stations, Control Station, and a Minesite Station.

	June 72			July 72			August 72			September 72		
Station	Min	M	Max	Min	M	Max	Min	M	Max	Min	M	Max
Entrance (1006 m)	3.8	11.2	18.5	5.6	12.6	19.5	5.8	15.4	24.9	-1.8	4.1	10.0
T_E	(-0.4)	(7.0)	(14.3)	(1.4)	(8.4)	(15.3)	(1.6)	(11.2)	(20.7)	(-6.0)	(-0.1)	(5.8)
Robb (1128 m)	4.0	11.8	17.5	4.7	11.7	18.7	6.8	14.7	22.7	-1.5	3.9	9.2
T_E	(0.5)	(7.3)	(14.0)	(1.2)	(8.2)	(15.2)	(3.3)	(11.2)	(19.2)	(-5.0)	(0.4)	(5.7)
Yellowhead L.O. (1372 m)	5.0	9.9	14.7	5.9	11.1	16.3	8.2	14.2	20.2	1.0*	6.8*	12.6*
T_E	(3.0)	(7.9)	(12.7)	(3.9)	(9.1)	(14.3)	(6.2)	(12.2)	(18.2)	(-1.0)	(4.8)	(10.6)
C_1 (1705 m)	2.8	7.2	11.6	4.4	9.5	14.5	7.4	13.4	19.5	-4.4	-0.6	3.2
S_3 (1704 m)	4.8	7.5	10.2	6.3	10.4	14.5	9.5	14.4	19.4	-3.1	0.4	3.8

*Period from September 1 to 19.

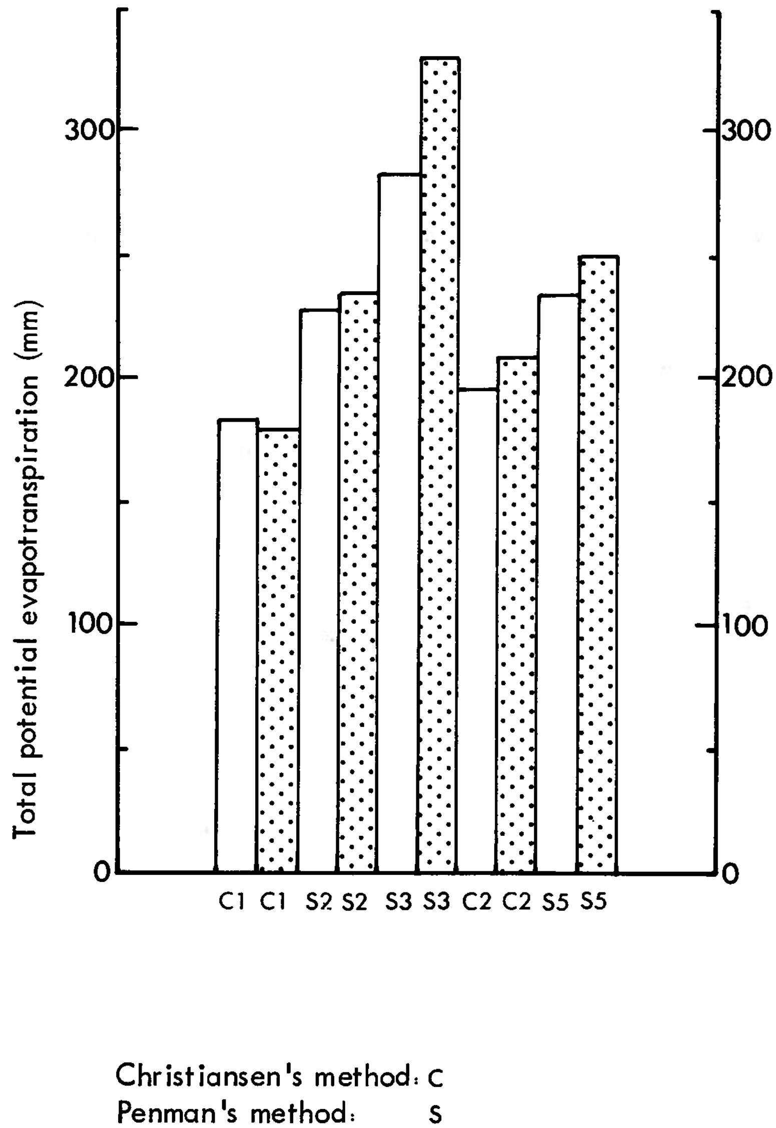

FIGURE 11. Total potential evapotranspiration for each of the stations in the study area.

Not all rainfall is retained at the surface for plant growth. No runoff was observed during the period June 12 to August 17 so that water loss from the soil was by percolation and evapotranspiration alone. The high permeability and low organic matter content of the spoil aids water loss by percolation.

Summary

(1) During the period of observation, climatic data recorded in the study area varied little from regional data, and fell within the limits for a normal summer.

(2) The difference between air temperature in the control area and in the minesite averages 1 to 3° C.

(3) Surface temperatures are generally higher in the minesite than in the control area and this can be attributed to the lower reflectivity of the minesite's surface and greater mixing of air close to the surface.

(4) The control area has a greater variation in temperature with a higher temperature than the minesite during mid-day and a cooler temperature than the minesite during the night.

(5) Soil temperatures in the minesite are generally higher than in the control area and are warmer at depth than in the control area. Soil temperatures in the minesite show that the soil at depth in the minesite warms and cools much more rapidly than the soil at depth in the control area.

(6) Factors in the high heat capacity of spoil include greater permeability and higher infiltration capacity of the spoil materials.

(7) Potential evapotranspiration is consistently higher in the minesite than in the control area.

(8) The albedo of the minesite and the control area are not sufficiently different to account for the large differences in potential evapotranspiration; wind speed is the controlling factor.

(9) The potential evapotranspiration exceeds the amount of moisture supplied by rainfall and a moisture deficiency was present for most of the study period.

EXTENT OF REVEGETATION

The distribution of plant communities in the study area and percentage of ground cover within each community are given in figure 13 (in pocket). Plants in the minesite are isolated, widely separated, and difficult to map. The communities identified give a semblance of local groupings with one or two plants as dominant species.

Table 5 lists plants identified in the control area and in undisturbed portions within the minesite; for comparison, table 6 lists plants found on spoil material in the minesite. Undisturbed vegetation in the minesite is similar to control area vegetation: continuous ground cover, with a large proportion of trees and shrubs. Vegetation in disturbed areas consists of isolated, individual plants or small plant mats, with occasional shrubs and deciduous trees. In general, plants within the minesite have the following characteristics:

(1) Low, prostrate, spreading, creeping, acaulescent (stemless), or caespitose (tufted).

(2) Matted with a dense growth of overlapping leaves.

(3) Perennial rootstocks, annual roots, rhizomes, large tap roots, dense fibrous root mats, and spreading and deep-penetrating roots.

(4) Vegetative reproduction common.

(5) Dying back to rootstocks or perennial stocks, reproduction by underground rhizomes.

(6) Growth only in places protected from the wind such as the lee sides of boulders and logs, and in depressions and hollows.

(7) Growth away from the prevailing wind; i.e., growth extends with wind direction.

(8) Adapted to rocky, gravelly, sandy, moisture deficient wind-swept habitats typical of high alpine regions.

(9) Frequently found at the break in slope at the base of spoil piles.

(10) Lack of vegetation on steep slopes of spoil piles.

Plants in both the control area and the minesite are abraded and gnarled by wind-borne particles of snow or rock (Plate 10). Areas showing marked abrasion are indicated in figure 13. All spoil materials except coal will support vegetation, but steep slopes limit plant growth by the rapid downslope movement of fine-grained frost-shattered material and inundation by wind-transported fine-grained rock debris. Figure 13 indicates that spoil pile slopes are practically devoid of vegetation. Vegetation on flat spoil surfaces is

Table 4. Mean, Mean Minimum, and Mean Maximum Monthly Temperatures in the Study Area

	June 72			July 72			August 72			September 72		
Station	Min	M	Max	Min	M	Max	Min	M	Max	Min	M	Max
C1	2.8	7.2	11.6	4.4	9.5	14.5	7.4	13.4	19.5	-4.4	-0.6	3.2
C2	3.6	7.3	11.0	5.2	9.5	13.7	8.6	14.1	19.6	–	–	–
S2	3.9	6.8	9.7	6.3	10.7	13.7	9.8	14.5	19.2	–	–	–
S3	4.8	7.5	10.2	6.3	10.5	14.5	9.5	14.4	19.4	-3.1	-0.4	3.8
S5	4.2	7.5	10.7	5.4	9.3	13.3	8.8	13.7	18.6	–	–	–

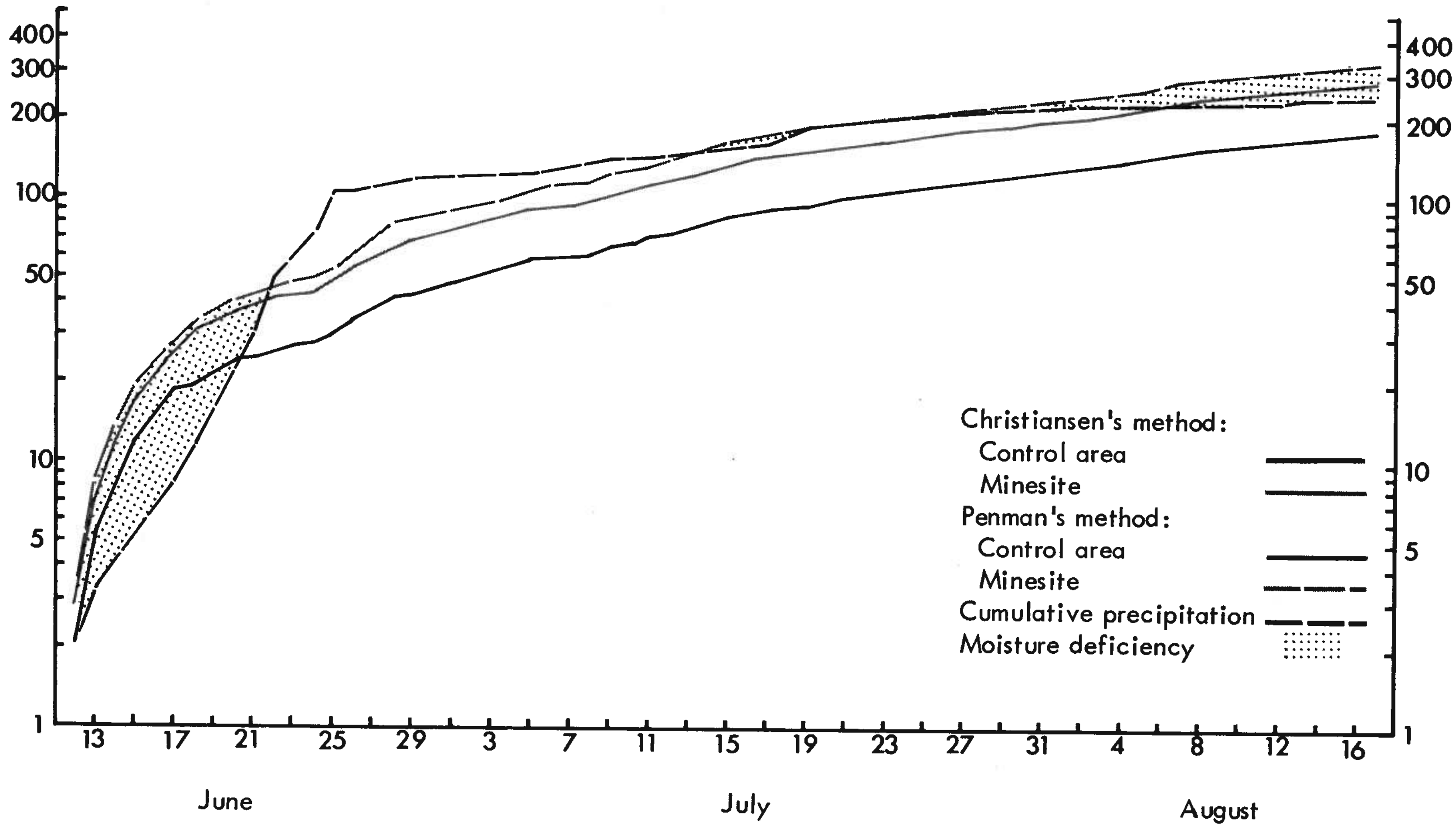

FIGURE 12. Cumulative potential evapotranspiration for control station 1 and minesite station 3.

Table 5. Plants Found in Undisturbed Sites within the Minesite

Scientific Name	Common Name
Gramineae sp.	grass species
Arctostaphylos uva-ursi (L.) Spreng.	common bearberry, kinnikinnick
Arctostaphylos rubra (Rehder & Wils.) Fern.	alpine bearberry
Epilobium angustifolium L.	fireweed, great willow herb
Alnus sinuata (Regal) Rydb.	alder
Betula glandulosa Michx.	dwarf birch
Juniperus horizontalis Moench	creeping juniper
Rosa sp.	rose
Salix sp.	willow
Picea engelmannii Parry	Engelmann spruce
Picea glauca (Moench) Voss	white spruce
Pinus contorta Loudon var. *latifolia* Engelm.	lodgepole pine

Table 6. Plants Found Growing in the Minesite on Spoil Material

Scientific Name	Common Name
Achillea millefolium L.	common yarrow
Aster sp.	aster
Androsace chamaejasme Host	sweet-flowered androsace
Astragalus eucosmus Robins.	milk vetch
Botrychium minganense Victorin.	mingan grape-fern
Campanula rotundifolia L.	bluebell, harebell
Cirsium vulgare (Savi) Airy-Shaw	bull thistle
Crepis nana Richards.	hawksbeard
Delphinium glaucum S. Wats.	tall larkspur
Dryas drummondii Richards.	yellow dryad
Dryas integrifolia M. Vahl	white dryad
Epilobium angustifolium L.	fireweed, great willow herb
Epilobium latifolium L.	willow herb
Equisetum arvense L. or *E. sylvaticum* L.	horsetail, scouring rush
Galium boreale L.	northern bedstraw
Gentianella amarella (L.) Borner ssp. *acuta* (Michx.) J.M. Gillett	felwort
Haplopappus sp.	--
Heracleum lanatum Michx.	cow-parsnip
Leguminosae sp.	--
Lychnis apetala L.	campion
Mertensia paniculata (Ait.) G. Don	tall mertensia
Oxytropis campestris (L.) DC	late yellow loco-weed
Ranunculus acris L.	tall buttercup
Senecio canus Hook.	prairie groundsel
Solidago decumbens Greene	goldenrod
Taraxacum officinale Weber	common dandelion
Trifolium pratense L.	red clover
Trifolium repens L.	white clover, dutch clover
Zygadenus gramineus Rydb.	death camus
Alnus sinuata (Regel) Rydb.	alder
Potentilla fruticosa L.	shrubby cinquefoil
Juniperus communis L.	ground juniper
Rosa woodsii Lindl. and *R. acicularis* Lindl.	common wild rose and prickly rose
Rubus strigosus Michx.	wild red raspberry
Salix sp. (probably *S. scouleriana* Barratt)	willow
Populus balsamifera L.	balsam poplar
Lycoperdon perlatum Pers.	puffball

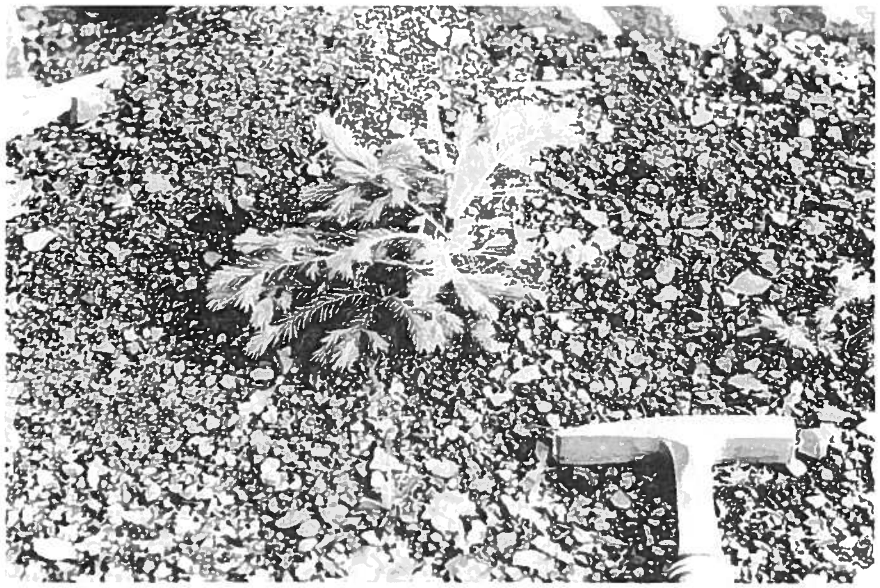

PLATE 10. Abraded young Engelmann spruce.

PLATE 11. Snow redistribution by wind.

subject to abrasion by wind-borne particles; as well, the deflation pavement created by removal of fine-grained rock particles is a poor substrate for germination. Where rock particles have accumulated below the minesite, the understory vegetation has been buried and growth retarded. On the positive side, groundwater in the minesite has a pH of about 8, is pure and supports relatively luxuriant vegetation at springs.

Variation in Snow Cover

Table 7 gives the depth and water equivalent of snow measured in the study area in March 1972; a comparison of the minesite and control area averages indicates a significent difference in moisture. This has been mapped in figure 14. Winter precipitation is the same in the minesite and in the control area, but snowfall in the minesite is considerably redistributed by wind (Plate 11), and lost, with consequent reduction in moisture. Large areas in the minesite do not retain snow cover and hence receive no soil moisture recharge from snowmelt. Snowdrifts within the minesite are covered between snowfalls by fine-grained dark-colored rock particles that reduce the albedo of the snow, promote the absorption of heat, and therefore promote ablation and melting of the snowpack. Thus the amount of moisture retained in the minesite from winter precipitation is significantly less than that retained in the control area.

Effects of Wind

The removal of snow cover allows vegetation on the minesite surface to be abraded by wind-borne particles of snow and rock, and desiccated by warm chinook winds. Plants in the minesite that die back to rootstocks have a better chance of survival under these conditions, and many species in the mintesite communities are of this type (Table 5).

Trees adjacent to the minesite have been damaged by windblown particles of snow and rock; many exhibit an asymmetric shape known as flagging, in which branches extend farther on the side of the tree protected from the prevailing wind (Plate 12). Some trees have been killed by wind-borne particles since mining operations ceased, have rotted at their bases and been blown down by strong westerly winds. The orientation of fallen trees and the orientation of flagging are remarkably consistent, aligned in the direction from which fine-grained rock particles are moved and deposited.

A number of dead flagged trees were cut and growth rings examined. The annual growth rings show a marked eccentricity, with the pith closer to the west-facing side of the tree. Three sections taken at different heights show a decrease in the eccentricity of the growth rings with increase in height, attributable to greater abrasion closer to the ground.

Table 7. Results of Snow Survey

Location of Snow Sampled		Depth of Snow (cm)	Water Equivalent (cm)	Density (%)	Comments
Control Area					
Haul road					
below minesite	(1)	78.0	15.70	20.1	Exposed; low vegetation
Near C1	(2)	147.0	33.50	22.8	Sheltered; in trees
Near C1	(3)	107.0	33.00	30.8	Sheltered; in trees
Near S2	(4)	12.5	2.06	16.5	Exposed; windswept
Near S2	(5)	38.3	7.56	19.8	Powdery snow; windswept
Minesite					
Near S3	(6)	20.3	1.75	8.7	Powdery snow; windswept
Near S3	(7)	129.0	34.80	27.0	Snowbank
Near S3	(8)	59.0	17.80	30.2	Snowbank
Near C2	(9)	48.0	10.20	21.3	Snowbank
Near C2	(10)	23.1	2.28	9.9	Powdery snow
Control					
Near C1	(11)	33.3	10.20	30.8	Sheltered; in trees
Minesite					
Near S3	(12)	0.0	0.0	0.0	Exposed; windswept

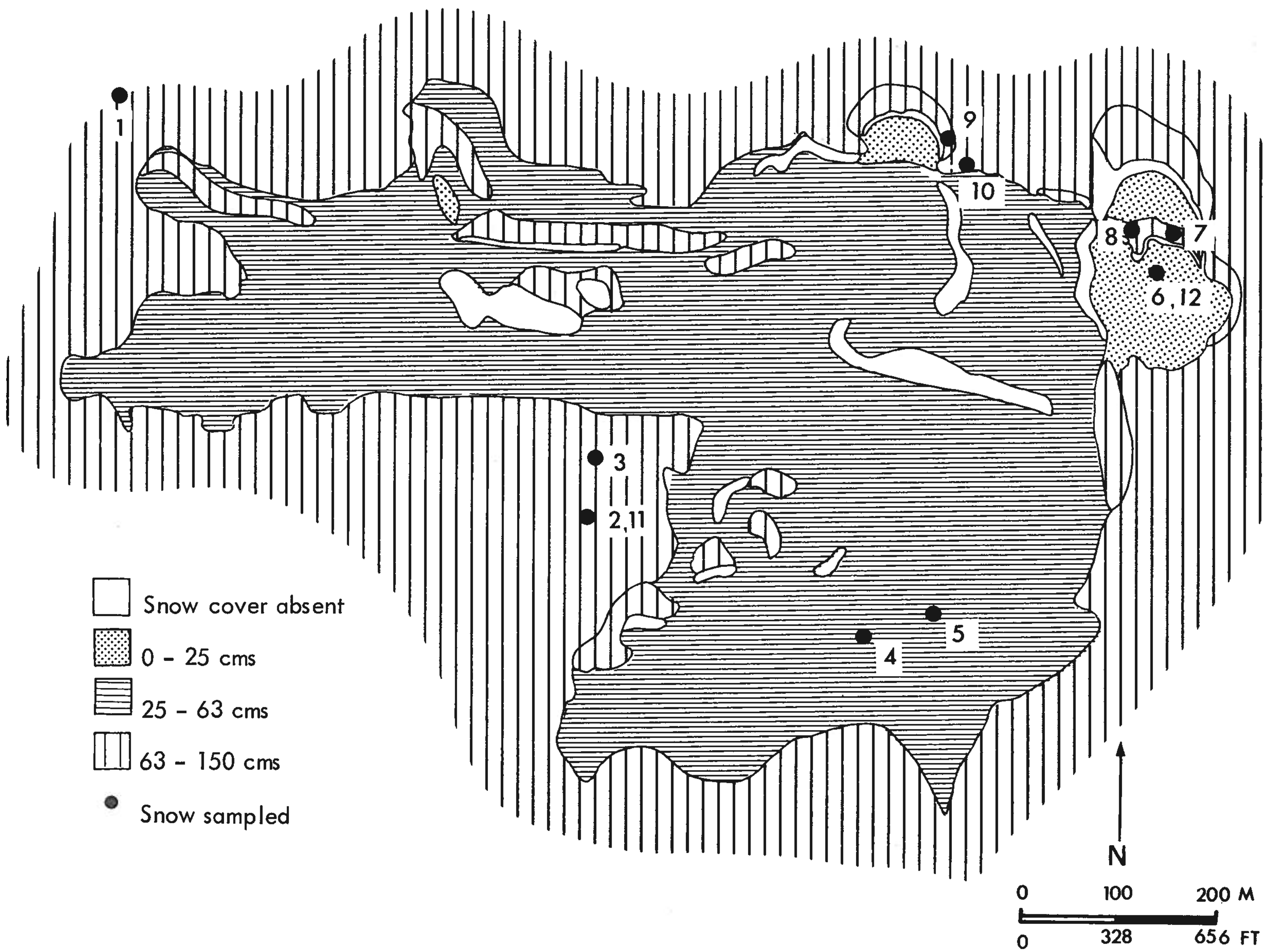

FIGURE 14. Distribution of snow cover in the study area, March 1972. Minesite had no snow cover, January 1973, whereas control area had 33 cm (10.2 cm water equivalent).

PLATE 12. Pebble deflation pavement, Engelmann spruce damaged by wind-blown particles, flagged trees.

PLATE 13. Displacement of screen support from vertical.

The vegetated pebble dune shown in figure 15 is oriented at 85 degrees (downwind azimuth), which is consistent with the orientation of flagging. Stems that extend above the dense *Salix* mat on such dunes during the summer are killed by abrasion and dessication during the winter. As a further testimony to the severity of winter winds in the study area, the three instrument stations in the minesite were displaced from 12 to 20 degrees from the vertical by storm winds (Plate 13) during the winter of 1972-73. The four 2 by 4 inch (5 by 10 cm) legs supporting each station were embedded in 3 feet (1 m) of minesite spoil; considerable force would be required to displace these stands from the vertical. A thick coat of white paint covering the stations at the beginning of the field season in June 1972 was intact at the end of September; but by January 1973 the paint at the base of the stations on the west-facing side had been removed by wind-blown rock particles and the west-facing sides were pitted and scarred by the impact of wind-blown rock particles (Plate 14).

These observations establish that winter storm winds in the study area from the west are violent, persistent, and damaging to plants.

Seed Distribution

Summer and fall winds are also persistent and strong, and have a considerable influence on seed distribution.

Figure 16 shows the range of seed flight against wind speed for four seed types found within the study area. The method is that employed by Geiger (1965, p. 47) to calculate the probable flight paths of seeds. Most of the herbs and forbs (herbs other than grasses) produce feathery pappi (appendages on the fruit), and the flight path of these seeds will be similar to the achenes (one-seeded fruits) of dandelion shown in figure 16. When the wind speed is greater

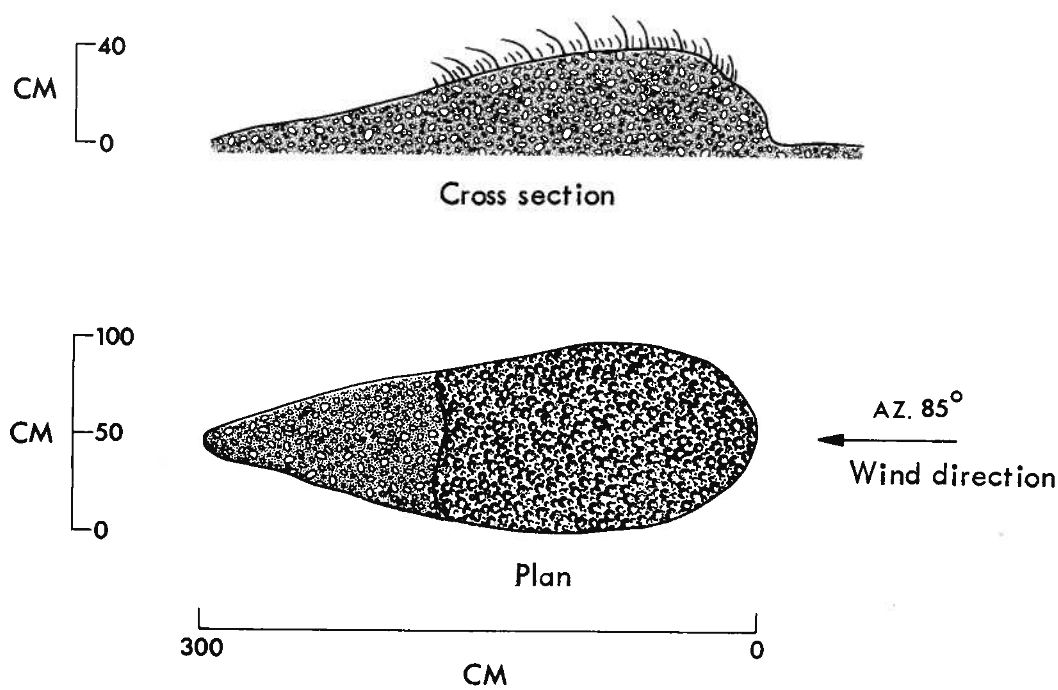

FIGURE 15. Schematic diagram of a typical partially vegetated pebble dune in the study area near control station 2. Vegetation is Salix *sp., which forms a dense mat close to the surface of the dune. Summer growth above the mat is killed off by abrasion and dessication during winter.*

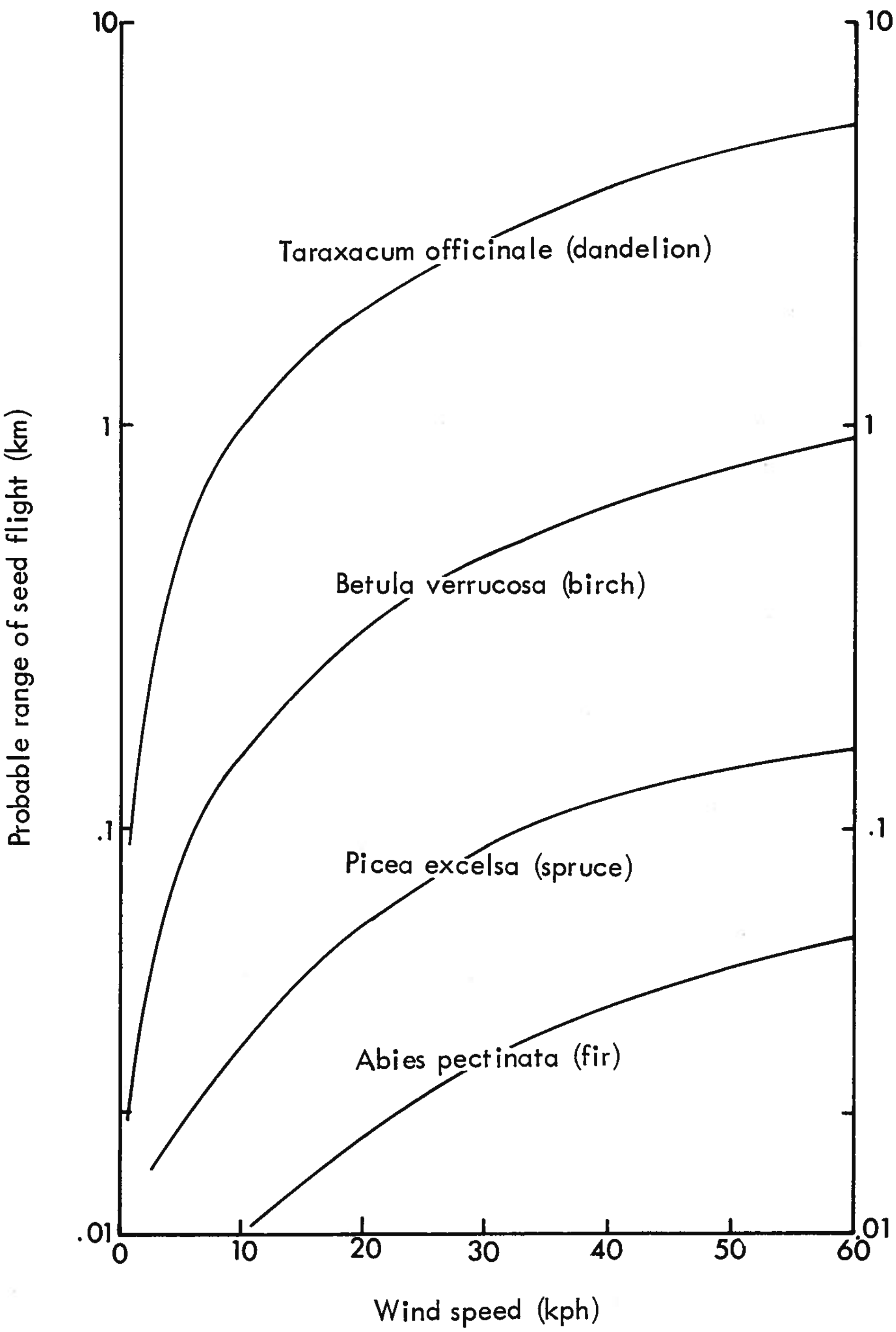

FIGURE 16. Probable range of seed flight for specific species at various wind speeds. Achenes of dandelion (Taraxacum officinale), *birch seed* (Betula verrucosa), *spruce seed* (Picea excelsa) *and fir seed* (Abies pectinata).

than 2 mph (3 kph), the probable range of seed flight exceeds the dimensions of the minesite. Therefore, seeds produced within the minesite will tend to be blown out of the minesite by relatively gentle winds. This does not preclude seeding from the control area to the west of the minesite, however.

Generally the vegetation cover increases from east to west in the minesite, which probably reflects lower wind speeds at the west end of the minesite and less removal of seeds from the area. At the east end of the minesite, where considerable fetch is available to the wind, higher winds are present and more seeds are removed from the minesite.

Seeds produced within the minesite with shorter probable ranges will fall within the minesite even at relatively high wind speeds. However, the pebble deflation pavement of the minesite presents fewer seed catchments than undisturbed vegetated ground of the control area, and seeds may be repeatedly uplifted and transported. This offsets the higher rate of seed fall. Thus, most seeds eventually lodge in places protected from the wind.

The azonal and isolated plant cover in the minesite reflects seed transport over the minesite, high winds, and moisture deficiency created primarily by high evapotranspiration and rapid percolation of soil water.

Infrared Indications of Moisture Stress

Healthy plants appear bright red on false-color reflection infrared film, while those under moisture stress (insufficient plant moisture) appear reddish-brown. One roll of this film was exposed on a day in August, photographing in some cases plants with adequate moisture supply (groundwater seepage and springs) and in other cases plants established on spoil materials. Plants with adequate moisture photographed bright pink; plants on spoil materials photographed light pink to pink-brown. Thus, moisture deficiency is indicated for plants growing on spoil materials.

Summary

(1) Generally, the vegetation in the minesite decreases from west to east. This may be attributed to greater wind fetch at the east end of the minesite, resulting in higher winds and higher evapotranspiration, greater removal of snow and fine-grained rock particles, and greater abrasion of adjacent vegetation.

(2) In the control areas, established vegetation shelters the ground surface from wind, preventing removal of snow, reducing potential evapotranspiration, and protecting young plants from abrasion by snow and rock particles.

CONCLUSIONS AND RECOMMENDATIONS

Comparing geological and climatic factors in revegetation of the minesite, it is apparent that the geology of the area favors plant growth, while the climate inhibits it. The minor extent of revegetation shows that climatic factors are dominant.

Spoils composed of mined bedrock materials will support vegetation, and groundwater — which is of excellent quality

PLATE 14. Abraded screen support.

— does not become significantly altered physically or chemically in passing through spoil. Yet the climate of the study area is such that potential evapotranspiration is high and soil moisture is low, especially in the minesite, during much of the growing season. These conditions retard plant growth on an otherwise suitable substrate.

Soil moisture deficiency and wind are the major growth-inhibiting agents in the minesite. Wind reduces soil moisture in summer and snow accumulation in winter, prevents seed lodgment in bare spots, removes fine spoil materials, and abrades vegetation in both the minesite and control area when charged with airborne rock particles.

To aid in the artificial revegetation of this and similar strip mines in the northern Alberta Foothills, it is recommended that measures be taken to reduce wind speeds over disturbed areas. After mining, reclamation could include compaction of spoil piles, erection of snow fences, incorporation of organic material into spoil, covering of rock debris spoils with stockpiled soil and surficial desposits, along with the usual backfilling, recontouring, and seeding. Care must be taken to avoid surface runoff, because of the high potential erodibility of the spoil. It is suggested that compacted spoil piles be roughened on the surface, to create suitable germination sites for seeds, to aid infiltration and reduce ground-level wind speeds.

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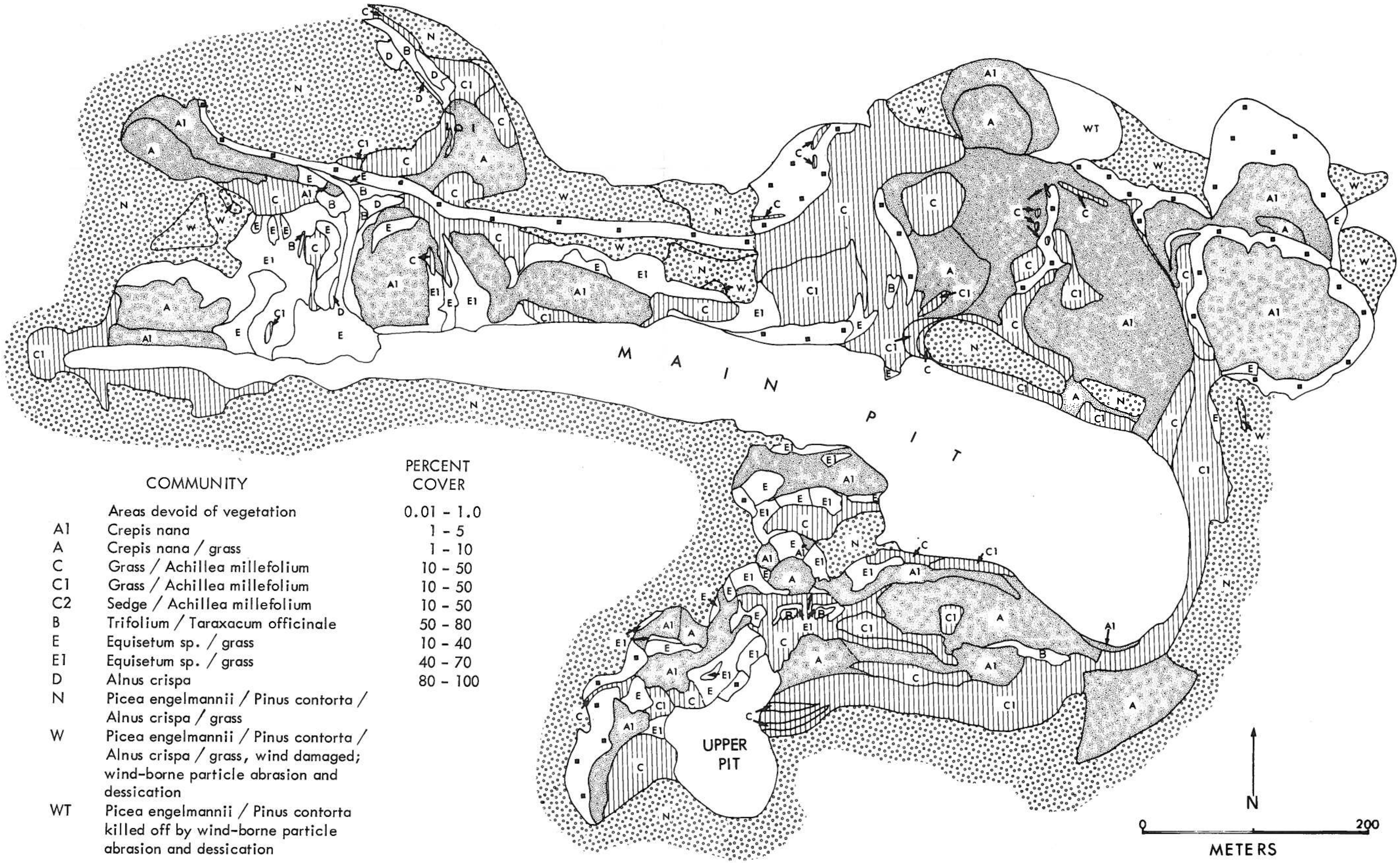

FIGURE 13: PLANT COMMUNITIES AND APPROXIMATE GROUND COVER PERCENTAGE IN THE MINESITE.