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THE UNIVERSITY OF ALBERTA

ENVIRONMENTAL ALTERATION AND NATURAL REVEGETATION AT DISCOVERY MINE, NORTHWEST TERRITORIES, CANADA

by

KENNETH GEORGE TAYLOR

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA
SPRING, 1976


1400S
1200S
ROUND LAKE
200W
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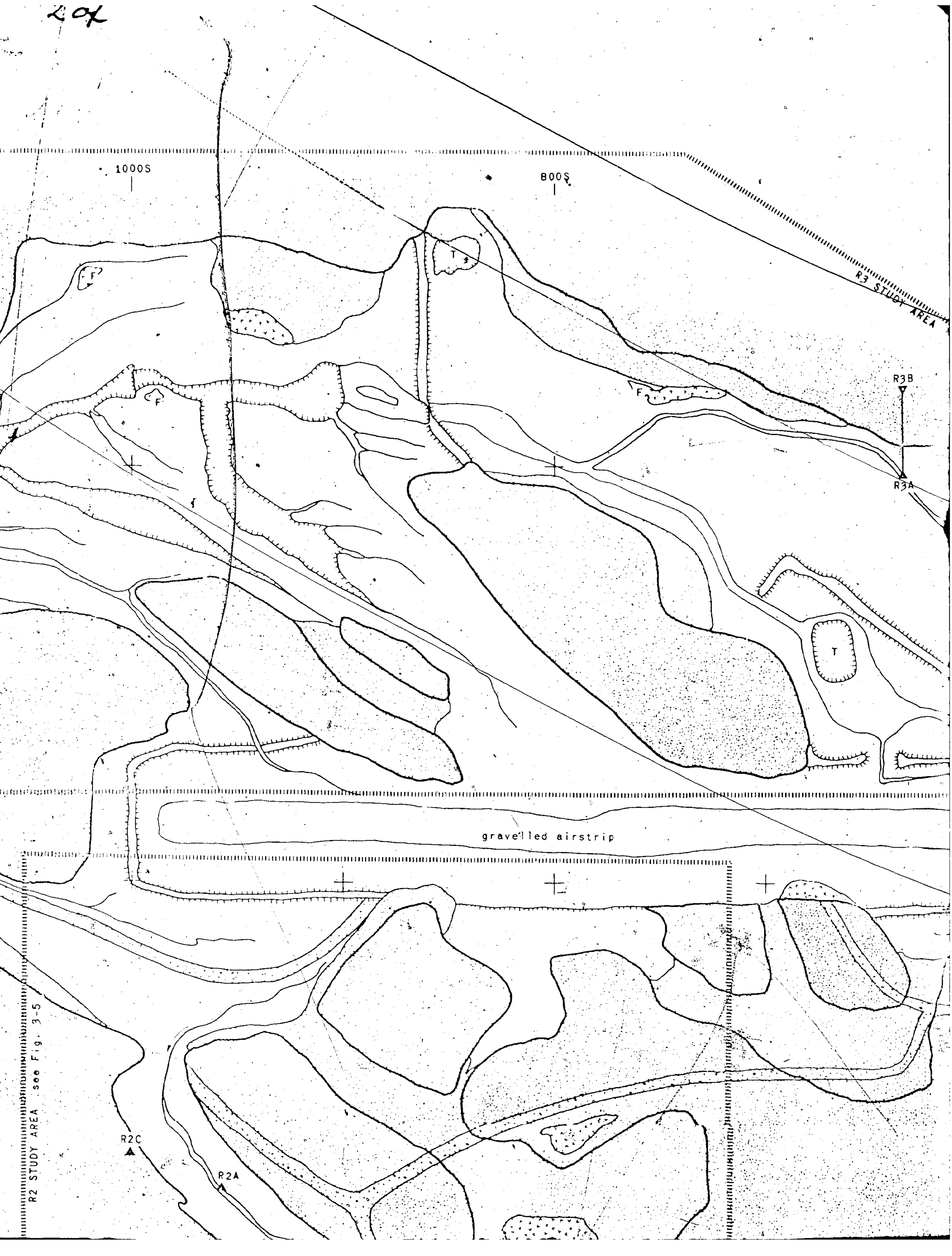
R3C
R3D
baseline
1400S
1200S
R3 STUDY AREA (see Fig. 3-6
DY AREA (see Fig. 3-5



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800S
R3 STUDY AREA
R3B
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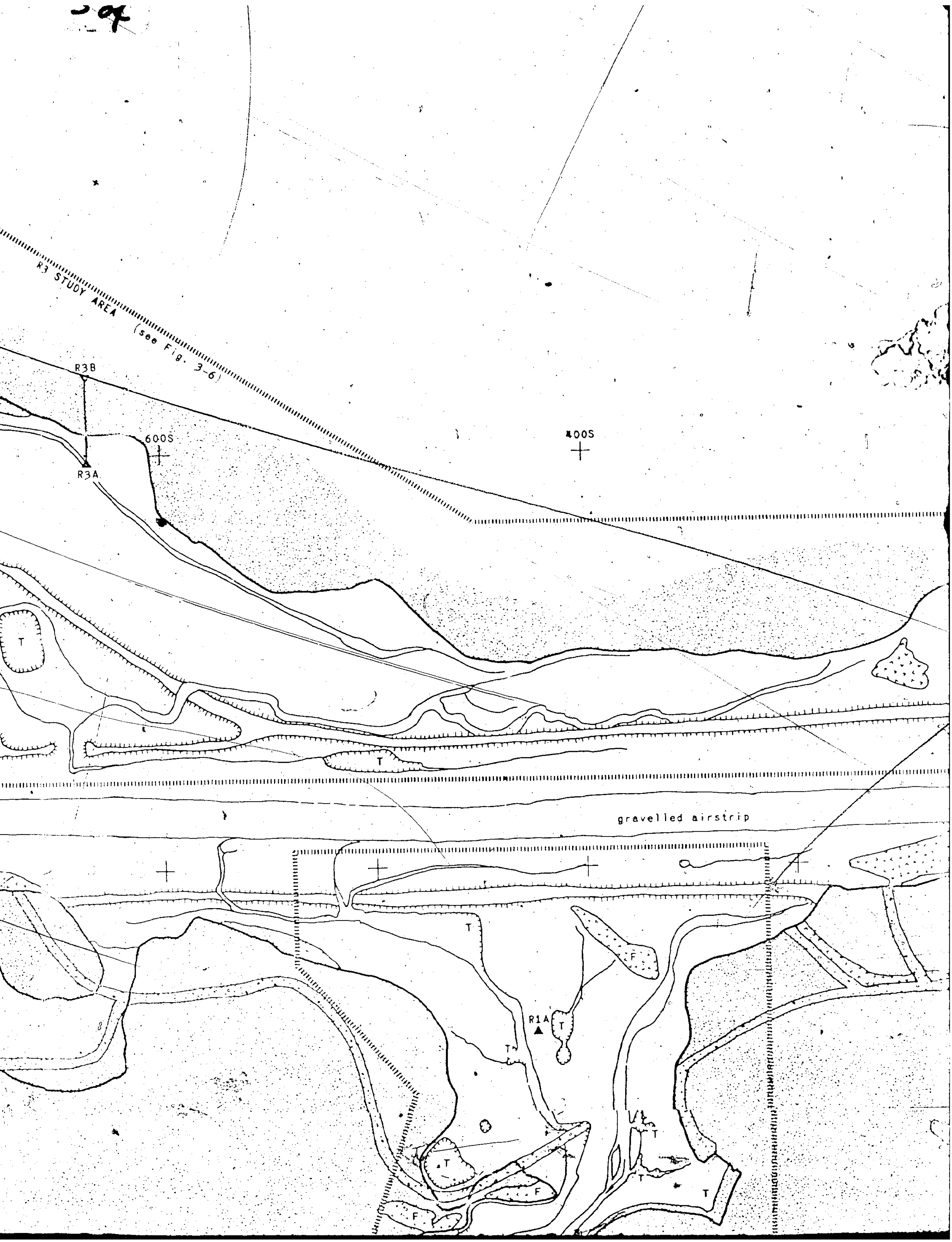
gravelled airstrip
R2C
R2A
R2 STUDY AREA see Fig. 3-5



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(see Fig. 3-6)
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R3A
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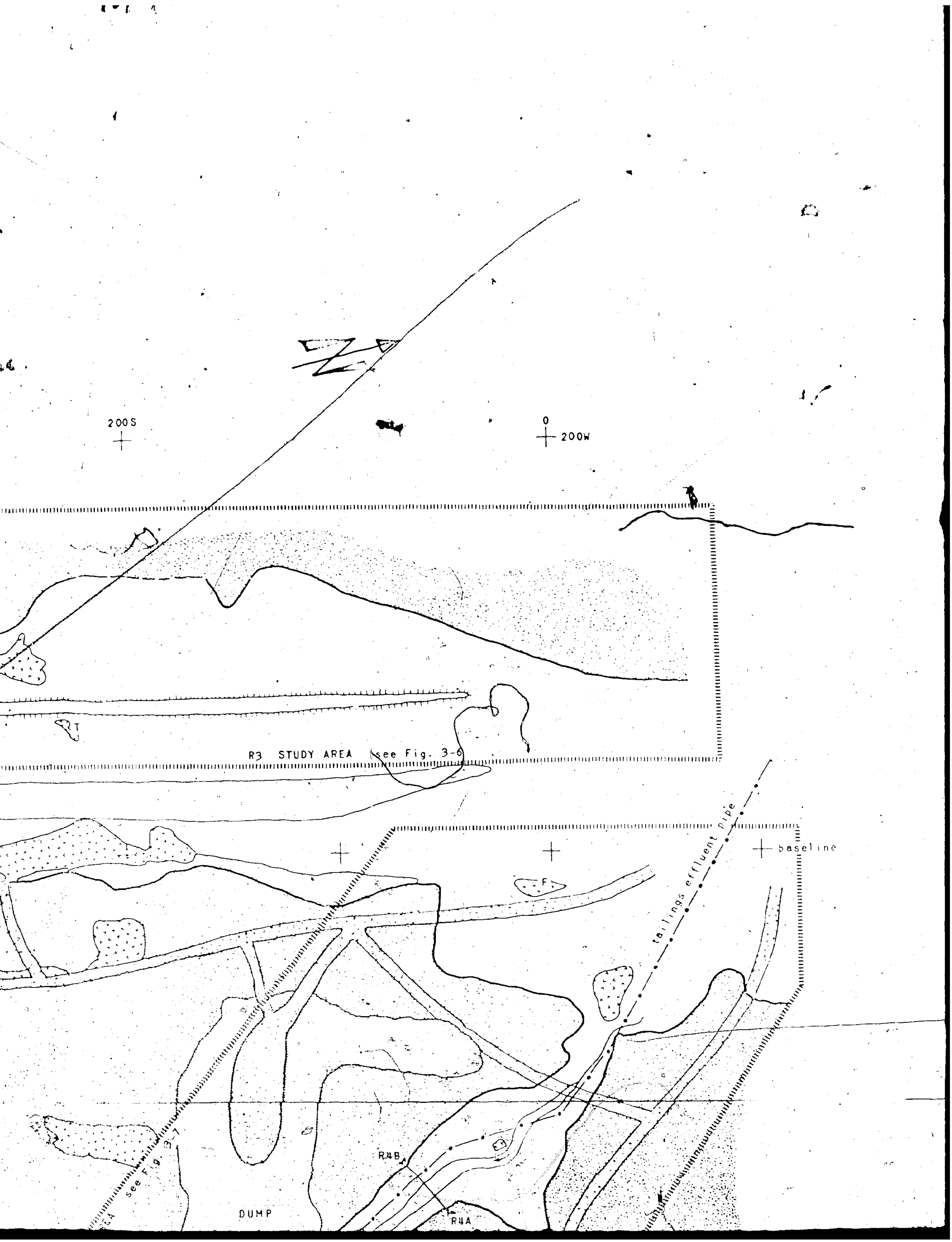
R1A



200S
0
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R3 STUDY AREA (see Fig. 3-6
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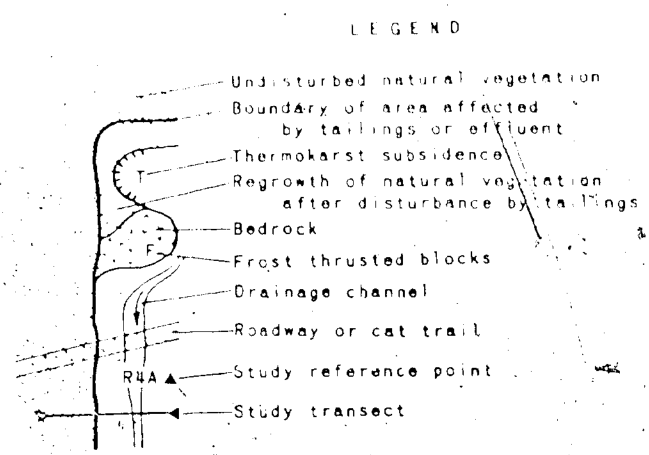
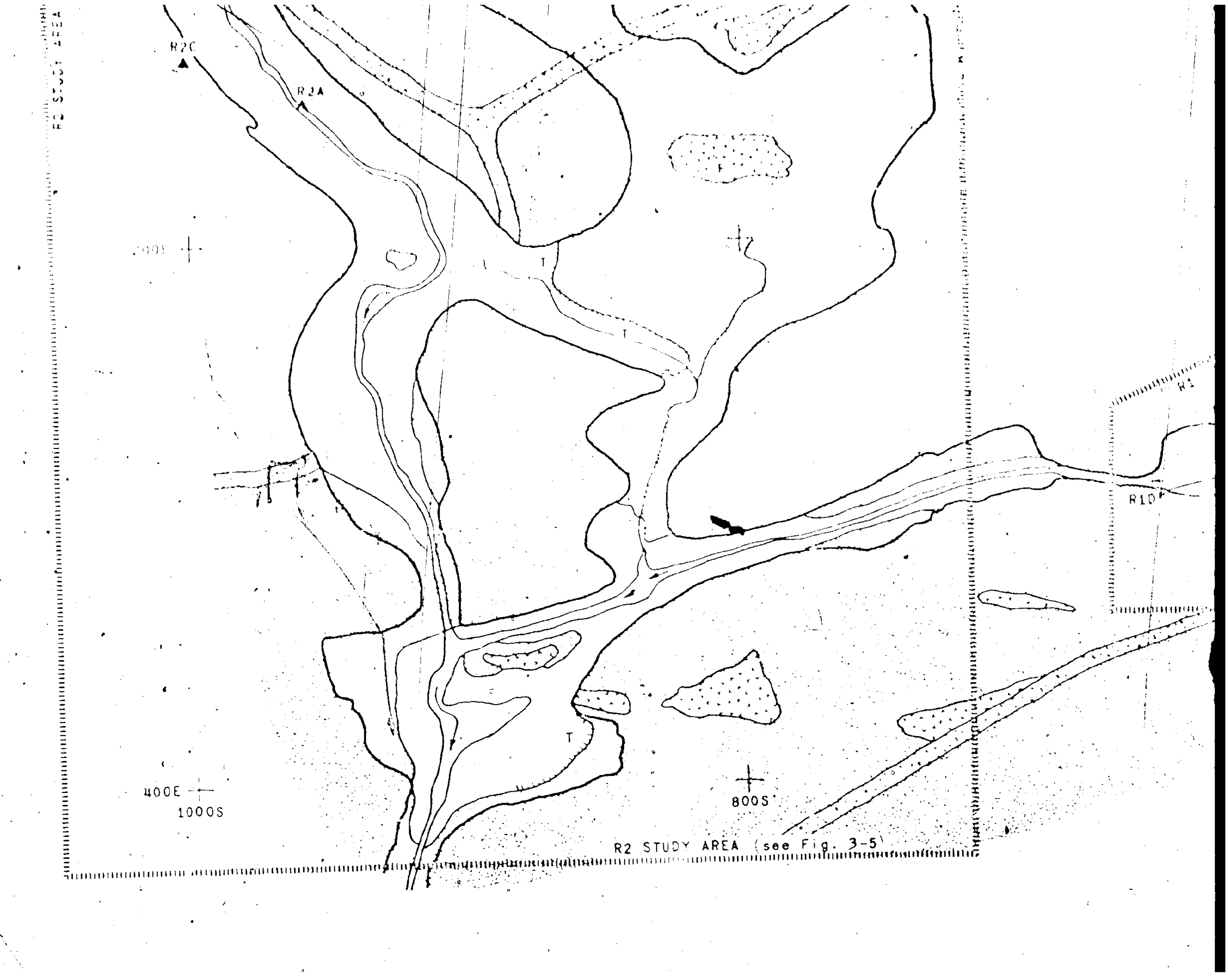
F
baseline
tailings effluent pipe
see Fig. 3-7
R4B
R4A
DUMP

5 of 1

R2B ▲


LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
T
F
R4A


R2 STUDY AREA
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400E
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R2 STUDY AREA (see Fig. 3-5)

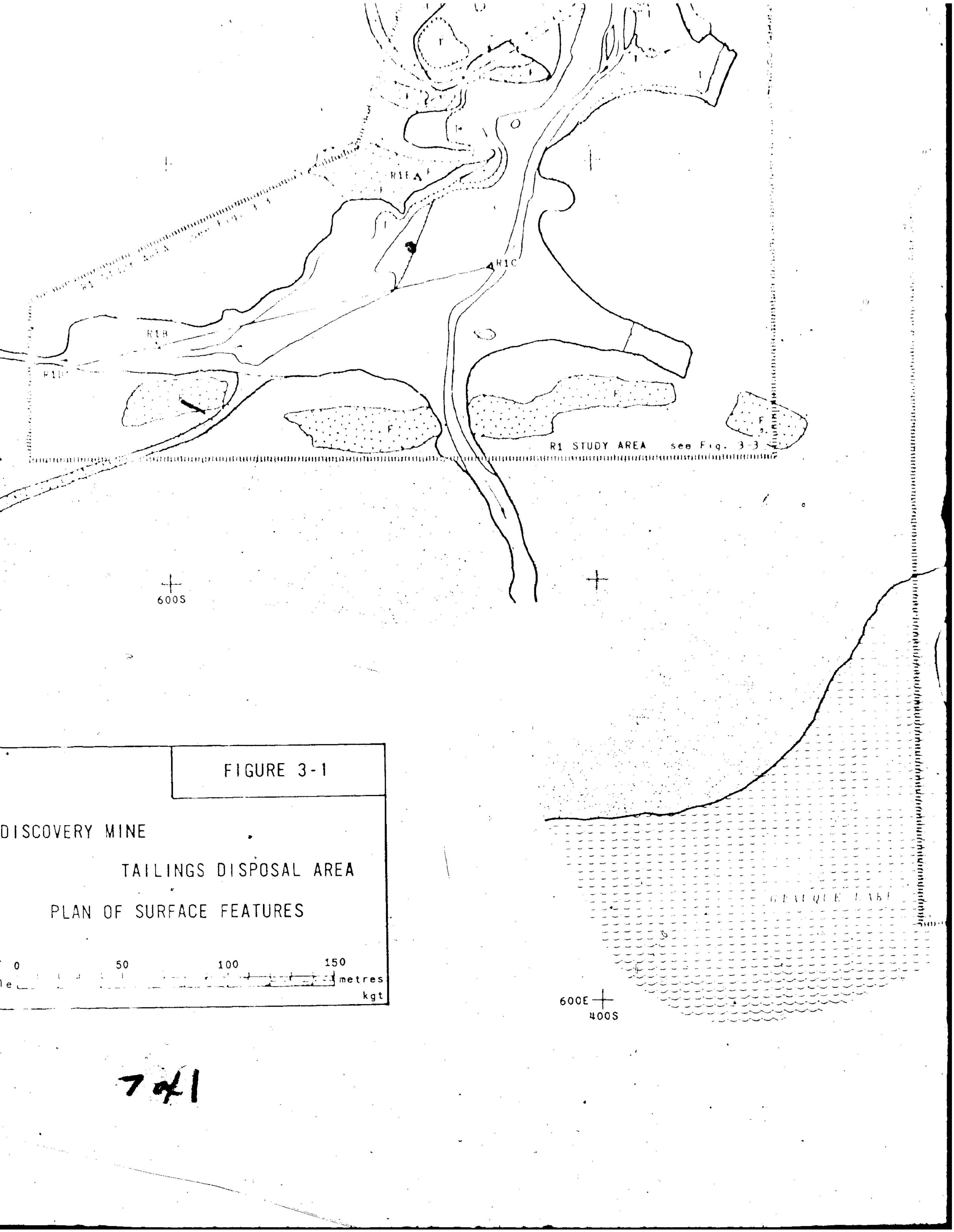


FIGURE 3-1

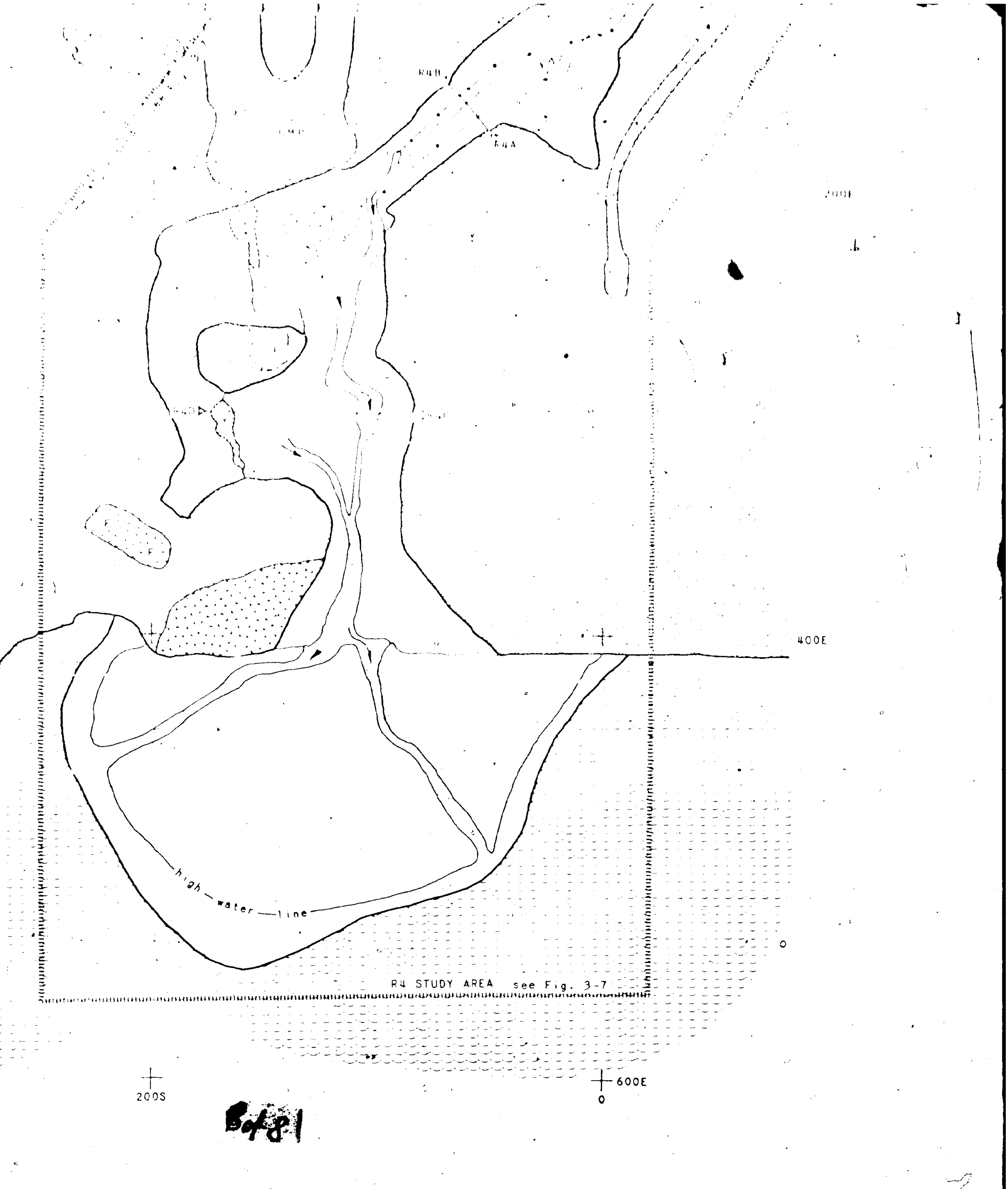
DISCOVERY MINE

TAILINGS DISPOSAL AREA

PLAN OF SURFACE FEATURES

0 50 100 150 metres

kgt



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600E
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....
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....
Dr. [illegible] W. [illegible]son

....
Dr. G. H. La Roi

Dated ....2[illegible] February 197[illegible]....

ABSTRACT

Discovery Gold Mine, 84 km north-northwest of Yellowknife, is situated in the forested portion of the Canadian Shield within the zone of discontinuous permafrost. During the 18 years of production, from 1950 to 1968, tailings from the mill were deposited over an area of approximately 41 ha. Much of the tailings were placed to create a foundation for an airstrip and a number of black spruce muskegs were in-filled during the process. The study investigates the environmental alterations caused by this mining operation and outlines the type and rate of recovery by vegetation. Botanical sampling and vegetation mapping indicate several stages of plant succession, although large sections of tailings remain barren and subject to erosion through thermo-karst, fluvial and wind processes. Factors favourable to plant succession include a stable ground surface, availability of runoff containing nutrients, and tailings deposits sufficiently thin that the roots of colonizing plants are able to reach the buried humus layer. The main factors inhibiting revegetation are a lack of plant nutrients, drought, and soil acidity and the associated metal toxicity. Recommendations are given on ways to assist natural revegetation at northern mine sites.

ACKNOWLEDGEMENTS

There are many people who have assisted me in various ways in the preparation of this study. I am grateful to the Boreal Institute for Northern Studies for financial assistance during the field season. I am indebted to Discovery Mines Limited for permission to initiate research at Discovery and for providing me with a house to live in. I fondly recall sharing coffee each evening with Tom Forrest (now deceased). For many years Tom single-handedly defended Discovery from marauding bears, ravens, and caribou. He always had a pot of coffee ready by the time any visitor walked up from the dock or in from the airstrip. I thank Tom for sharing with me the silence and beauty (and forest-fire smoke) of Discovery during the summer of '71.

Thanks are due to Roland Biber and CF-BVW for the rides to and from Yellowknife, and for the friendship that has grown since we first met on the airstrip. I thank Louise and Helen McGillivray for their help in carrying out the level survey and for the ride to Edmonton. Margaret Poulin provided considerable assistance in typing. Thanks are also due to Don Gill for his encouragement and comments on the text.

And finally, thanks go to my family and my many friends who have humoured me over the many years that this thesis has been in preparation. I am also indebted to my family for their support through my years of university education. And a special thanks to my wife, Rene, for her cheerful help in the many final tasks of print developing, proof-reading, and map-folding. I hope she will someday be rewarded by a midnight sunrise over Giauque Lake.

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CHAPTER I

INTRODUCTION

1.1 NORTHERN RESOURCE DEVELOPMENT

In recent years there has been increasing resource exploration and development in northern Canada. Coincident with this activity has been a dramatic increase in the level of public awareness of the potential for environmental damage which may result. Although past undertakings have resulted in only a moderate amount of disturbance in the North as a whole, modern technology enables man to have increasingly far-reaching effects. New modes of transport permit relatively easy access to even the most remote corners of the North. In addition, the growing demand for raw materials of all types will continue to trigger massive development projects in the years to come. However, many researchers agree that the northern environment is especially sensitive to disburbance, much more so than regions to the south. Such things as massive erosion following the disruption of the permafrost and the critical reliance of animals on certain plant or animal links in the food chain dictate that special care must be taken with all activities in the North. In addition, the harsh, cold climate greatly slows down and restricts normal biological processes so that natural recovery after disturbance is very slow.

All this points to a pressing need for knowledge about past and present environmental disturbance so that future development can be more responsibly planned. Many questions can't be answered. It is still not clear what changes can be expected in the natural balance of an area from either small or large scale land use. Those changes which are temporary must be differentiated from those which are permanent. There is a need to know the mechanics of, and the time required for, natural regeneration, so that this process may be assisted where necessary. Answers to these questions are required so that planners are able to decide what controls are needed on northern development, and what steps should be undertaken to remedy the undesirable effects of resource development. A study of the effects of past resource development activities is one of the most reliable ways to find the answers to these questions.

One such activity which has taken place in parts of the North for a number of years is mining, and undoubtedly this industry will continue as a major component of northern development. It is thus logical to look at past and present mining operations for answers to problems of environmental damage. To assess some of the effects of mining activity on the area surrounding a northern mine, Discovery Gold Mine,[1] north of Yellowknife, Northwest Territories, was chosen as a research area.

1.2 PURPOSE OF THE STUDY

The Discovery Mine is situated on the western shore of Giauque ("Jake-way") Lake, 85 km northeast of Yellowknife. Located at 63° 10'

1. The mining company has undergone several name changes. Incorporated in 1945 as Discovery Yellowknife Mines Limited, the name changed to Consolidated Discovery Yellowknife Mine in 1952. Since 1964 the name has been Discovery Mines Limited.

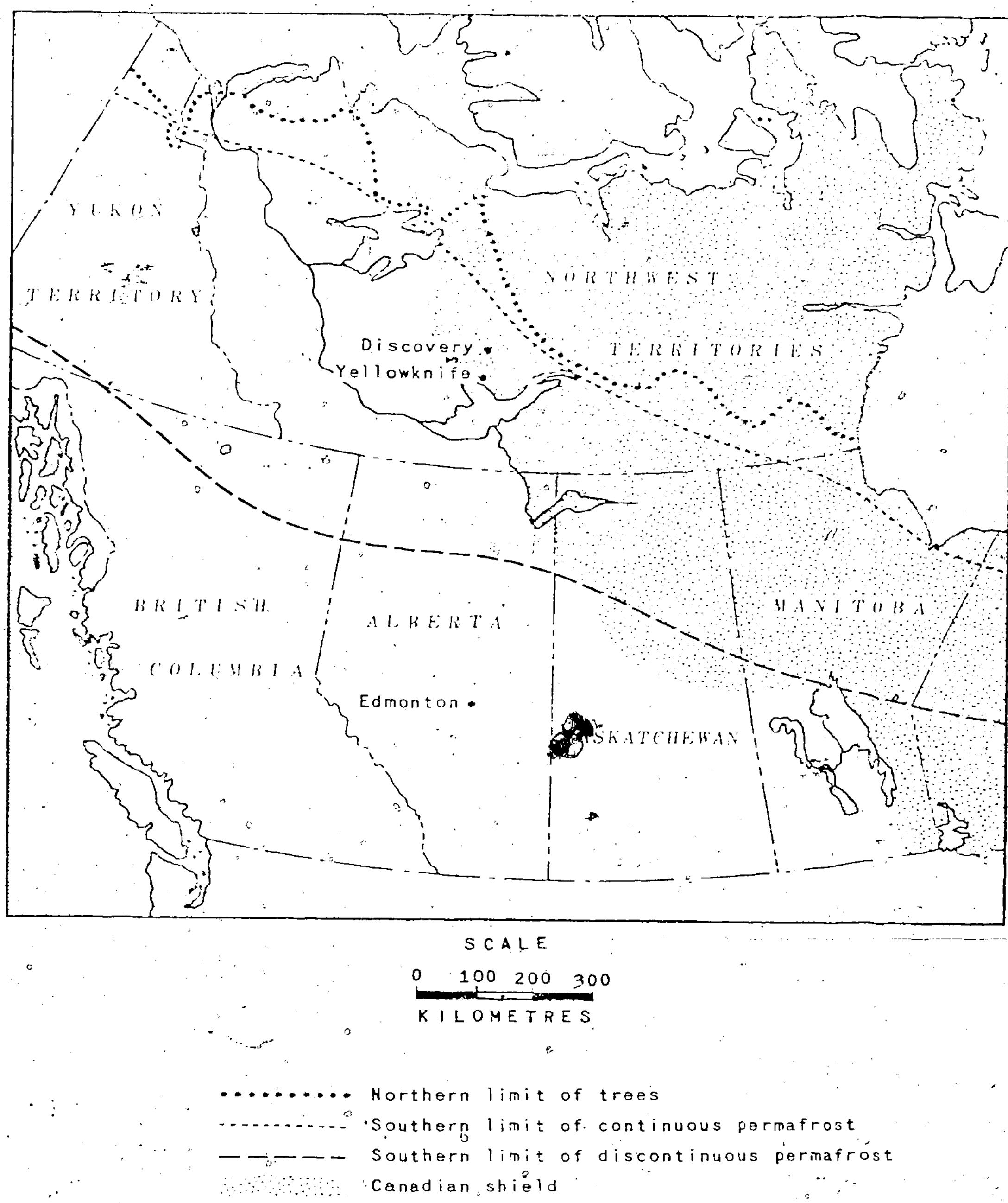
north and [illegible] west, Discovery [illegible] approximately [illegible] km [illegible] of the Arctic Circle and [illegible] km north of [illegible] Edmonton, Alberta [illegible]. It is located on the Canadian Shield within the zone of discontinuous permafrost (Brown [illegible]) and within the Northwestern Transition Section of the Boreal Forest Region as outlined by Rowe ([illegible]). The location of the mine is thus representative of one of the largest developmental regions in Canada.

The study undertaken at Discovery was broad in scope, and attempted to describe all aspects of disturbance rather than concentrating on a limited number. Since the disposal of the mill tailings has been perhaps the most visible and extensive element of the disturbance, they and their revegetation through natural processes have been given special emphasis. One important aim of the research is that of providing a base for studying long term recovery processes at the mine site. It is with this in mind that the study area has been recommended as a permanent International Biological Programme site (Le Roi and Babb, 1974, p. 131). It is hoped that this study, and future studies at this location will contribute to our ability to plan northern development in a non-destructive way.

1.3 HISTORICAL BACKGROUND OF THE YELLOWKNIFE REGION

The Yellowknife region has achieved world fame for its gold production. Serious mining activity in the area began in 1935 when a strike was made close to where the city now stands. In the decade that followed, Yellowknife was the centre of a series of staking rushes which culminated in the development of six mines in the area. Yellowknife thus grew to be, for a time, the most notorious and exciting town in the North (Price 1967). Following intensive prospecting near Yellowknife, the

FIGURE 1-1 THE LOCATION OF DISCOVERY MINE



Sources—Brown, 1970: Figure 3.
Douglas, 1970: p. 12.
Rowe, 1972: pocket map.

search for gold shifted to the more rugged and isolated country to the north.

1.4 THE DEVELOPMENT OF DISCOVERY MINE

The gold showing which led to the establishment of the Discovery Mine was found by Fred Giauque and his Sons in the fall of 1944 (Byrne 1950). Upon their return to town the claims that they had staked were sold to a Toronto mining company, and by the following fall preliminary mapping and drilling had indicated a find of major proportions. A Yellowknife geologist and his family were able to obtain control and financed the development of what eventually became the richest gold mine in the country.

Early in 1947 a winter road from Yellowknife was established and by the end of the year a shaft had been sunk to a depth of 84 m. During 1949 a mill and small refinery were built and the Discovery Mine produced its first gold brick on 10 February 1950. By the time the mine ceased production in the spring of 1969, the shaft had reached a depth of over 1216 m and more than $36,000,000 in gold had been extracted (Fielder 1970).

The task of developing a mine at Discovery was not easy. Access to the area had always been and remains difficult. In the earliest days a journey by canoe or light plane was the only alternative. The development of the mine resulted in a winter road, subsidized by the Federal Government, which by 1960 accomodated transport trucks delivering freight directly from Edmonton. However, the airplane remained an important, and in summer, the only reasonable means of access. By 1957 an airstrip 1000 m long and 70 m wide, built on tailings from the mill (Plate 1-1),

Plate 1-1. Oblique view, from the northeast, of Discovery Mine and the tailings disposal area. The mine shaft, mill, and townsite are located at the near end of the airstrip. 25 June 1971 - 13h00. Photo by Don Gill.

could accomodate a Bristol aircraft with a payload of 6.5 t, thus enabling year-round freight transport.

During the eighteen years in which the mine operated, a sizeable community was established (Plate 1-2). The isolation and self-containment of this industrial community made it unique in the north (Discovery Women's Institute 1968). At its maximum development the community was made up of more than 50 buildings. Included were bunkhouses capable of accommodating a total of over 100 men, plus thirty single family residences. A school, post office, commissary, dispensary, laundry, and a recreation complex including a theatre, library, curling rink and outdoor hockey rink completed the facilities.

1.5 DISCOVERY MILLING PROCESS

Details of standard Canadian milling practice in gold mines are available elsewhere (Carter 1957, Hedly and Tobachnick 1958) as well as are descriptions of the process used at Discovery (Anderson 1952, Blaney 1957, Byrne 1950). However, a summary of the procedure is useful in understanding the end result, the tailings.

The Discovery ore contained a greater than usual percentage of free visible gold. Other mineralization occurred as sulphides of iron, mainly pyrrhotite and pyrite. The first step in the processing of the ore was crushing, which at Discovery meant passage through a jaw crusher set at one inch and then through a cone crusher. Crushing was completed through a two-stage ball mill with the resultant ore being 80 per cent minus 200 mesh (silt) size.

The next step was amalgamation, designed to recover the larger (sand size) gold particles. The ore was fed into a jig (a sort of vibrating basket) which shook the heavy gold particles to the bottom

Plate 1-2. View of Discovery from the northwest. The mine shaft and mill facilities are located in the centre of the photo. Housing for staff is situated in the left background and the right foreground. 21 July 1971 - 12h30.

where they were trapped by a mercury additive, from which the gold was later recovered. At Discovery some 66 per cent of the gold was recovered during this stage of the process.

The next stage was cyanidation. The finely ground ore was agitated for some 48 hours in a cyanide solution so that the remaining gold particles would be dissolved. This slurry was then pumped to a precipitator where zinc dust was used to precipitate the gold in solution. At Discovery 98 per cent of the gold was recovered by this stage.

In the milling process there were several additives which affected the chemical composition of the tailings. The mercury used in amalgamation had little effect since it was distilled for re-use. 3.2 kg (7 lb) of lime per ton (of ore) was added at the ball mill stage so that it became well mixed. It has been found that pyrrhotite decomposes very rapidly in the presence of cyanide, causing very high cyanide consumption. This reaction can be substantially reduced through the aeration of concentrates with a weak lime solution for a few hours prior to the addition of the cyanide. Sodium cyanide was added at the rate of 1.13 kg (2.5 lb) per ton of ore to maintain the concentration at the cyaniding stage. Only very small amounts of zinc dust were added.

In standard cyanidation practice the solution in the cyanidation circuit is maintained at pH 10-12 for best efficiency, and lime is added to maintain that value. The major reason for creating this very basic solution is that in more acid solutions sodium cyanide very quickly hydrolizes, giving off hydrogen cyanide, one of the most rapidly acting poisons known. The reaction may be shown as:

$$NaCn + H_2O \rightleftharpoons HCn + NaOH$$

The basic solution then prevents hydrolysis of the cyanide needed to extract the gold as well as safeguarding workmen.

The end product of the milling process, or tailings, consisted of finely ground rock, much of it being the mineral-bearing iron sulphides. This waste slurry was carried from the mill in wooden pipes to a dyked tailings pond close to the mill where the water could drain away, leaving the solids. The slurry flowing into the tailings ponds was then very basic, with a pH of approximately 10, enough to kill most plants. This fact and the fact that exposure of the tailings to weathering processes soon created a highly acid environment resulted in a number of restrictions on primary and secondary plant succession on the tailings. These restrictions are discussed more fully in section 5.1.

CHAPTER 2

THE GIAUQUE LAKE REGION

2.1 GEOLOGY

The bedrock of the Giauque Lake area is Precambrian in age. It consists almost entirely of finely to coarsely interbedded metamorphosed sedimentary formations. Interbanded with these rocks are small lenses of basic volcanic intrusions. All these rocks have been subjected to several periods of deformation and are now intensely folded and faulted. The main constituents of the bedrock are quartz, feldspar, biotite, and hornblende. A long thin band of plagioclase-hornblende gneiss contains the gold-bearing quartz veins of the mine. The compositions of the several veins differ, but in general they contain small amounts of pyrrhotite, pyrite, arsenopyrite, and chalcopyrite (less than three percent total) in addition to the gold (Tremblay 1952).

2.2 PHYSIOGRAPHY

The Giauque Lake region has physiographic features characteristic of much of northern Canada — vast expanses of lakes and partially tree-covered bedrock outcrops. Viewed from the air the area appears flat and almost featureless (Plate 2-1), yet on the ground it is seen to be quite rugged. Although relief generally is not pronounced, near the minesite it does reach as much as 52 m. Ridges of volcanic rocks and quartzite, having resisted glacial erosion, stand above the surrounding bedrock. These ridges as well as most of the bedrock formations trend northeast. Glaciation has resulted in an accentuation of the bedrock struct[illegible] a deepening of valleys and the rounding of ridge summits. Some pro[illegible]ys follow fault zones. For the most part the region

Plate 2-1. Except for the pattern of hundreds of lakes, the Canadian Shield near Discovery appears flat and featureless from the air. 18 July 1971 - 17h00.

has only a light cover of glacial deposits, although a large esker crosses Giauque Lake.

An unusual feature of the area is the presence of huge frost-thrust blocks of bedrock, some of which are shown in Plate 2-2. These blocks may reach dimensions of 10 to 20 m, depending on the jointing planes of the bedrock. Many of the crevices left by the thrust blocks make excellent natural wells and indicate the presence, in some locations, of a subsurface drainage system.

2.3 CLIMATE

The climate of the region is continental, with long, cold winters and short, warm summers. The meteorological station closest to Discovery is Yellowknife Hydro, 60 km to the southwest (Fig. 2-1) and data for this station can be taken as approximating conditions found at Discovery. The mean annual temperature is -6.1^{o}C (20.9^{o}F). Temperature by month is presented in Fig. 2-2. Mean annual rainfall at Yellowknife airport is 15.8 cm (6.24 inches), mean annual snowfall is 108.7 cm (42.8 inches), and mean annual total precipitation is 26.7 cm (10.5 inches). Precipitation by month is shown in Fig. 2-3. The ~~prevailing winds in the region are from the east and northwest in~~ winter, and from the east and south in summer. Winds are generally light, averaging 4.6 m/s (10.2 m.p.h.).

The minesite is approximately 80 km southwest of the southern limit of continuous permafrost (Fig. 1-1) and thus falls in the zone of discontinuous permafrost. Local occurrences of permafrost are found throughout the area, most commonly in sphagnum bogs and on some north-facing slopes. The depth of the active layer in such locations in the

Plate 2-2. Frost-thrust slabs of bedrock, common in the vicinity of Discovery Mine, provide impressive evidence of frost action. The slabs are located at 500S-200E on the study grid. 15 July 1971 - 14h00.

FIGURE 2-1 DISCOVERY MINE IN RELATION TO YELLOWKNIFE

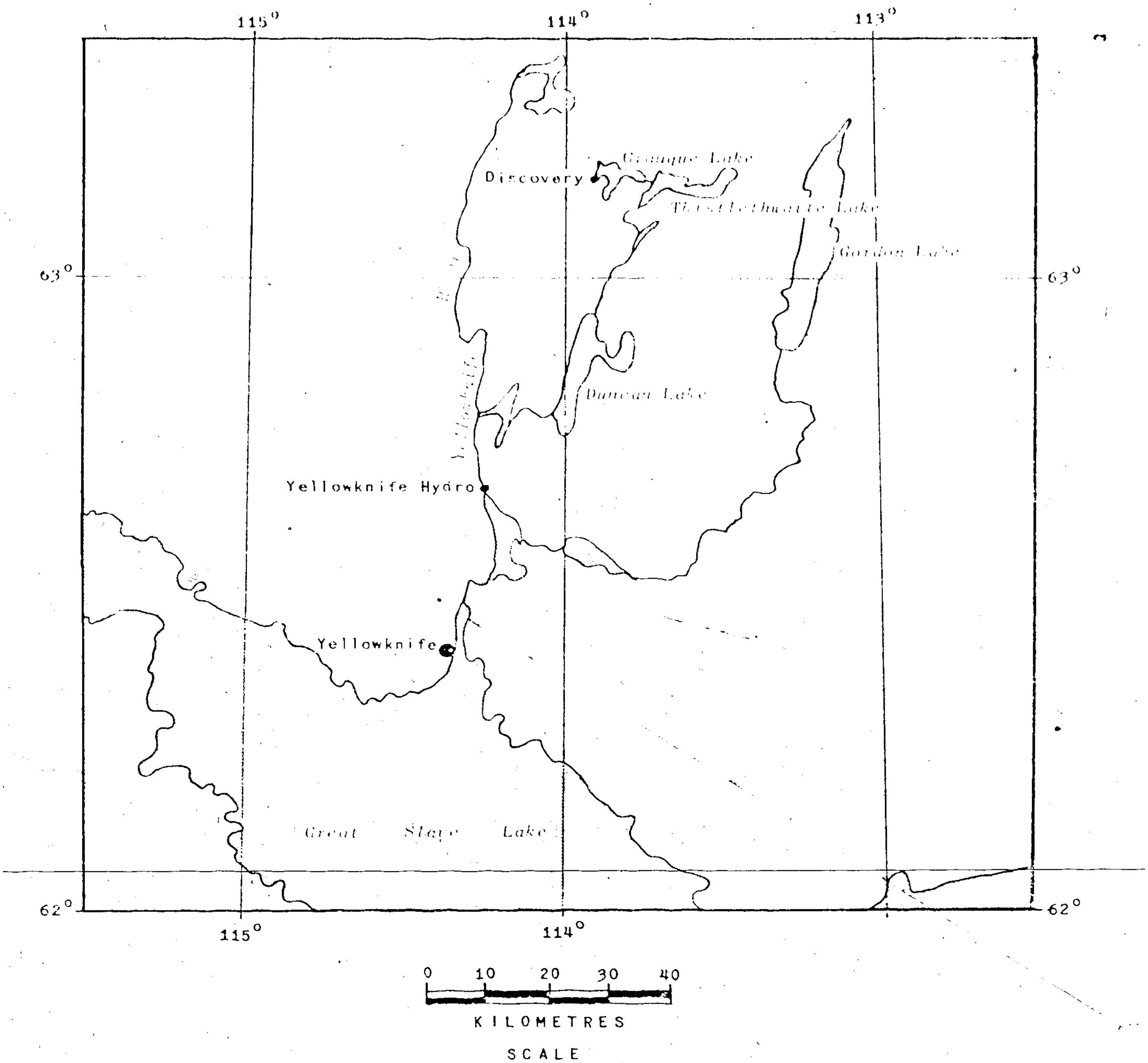
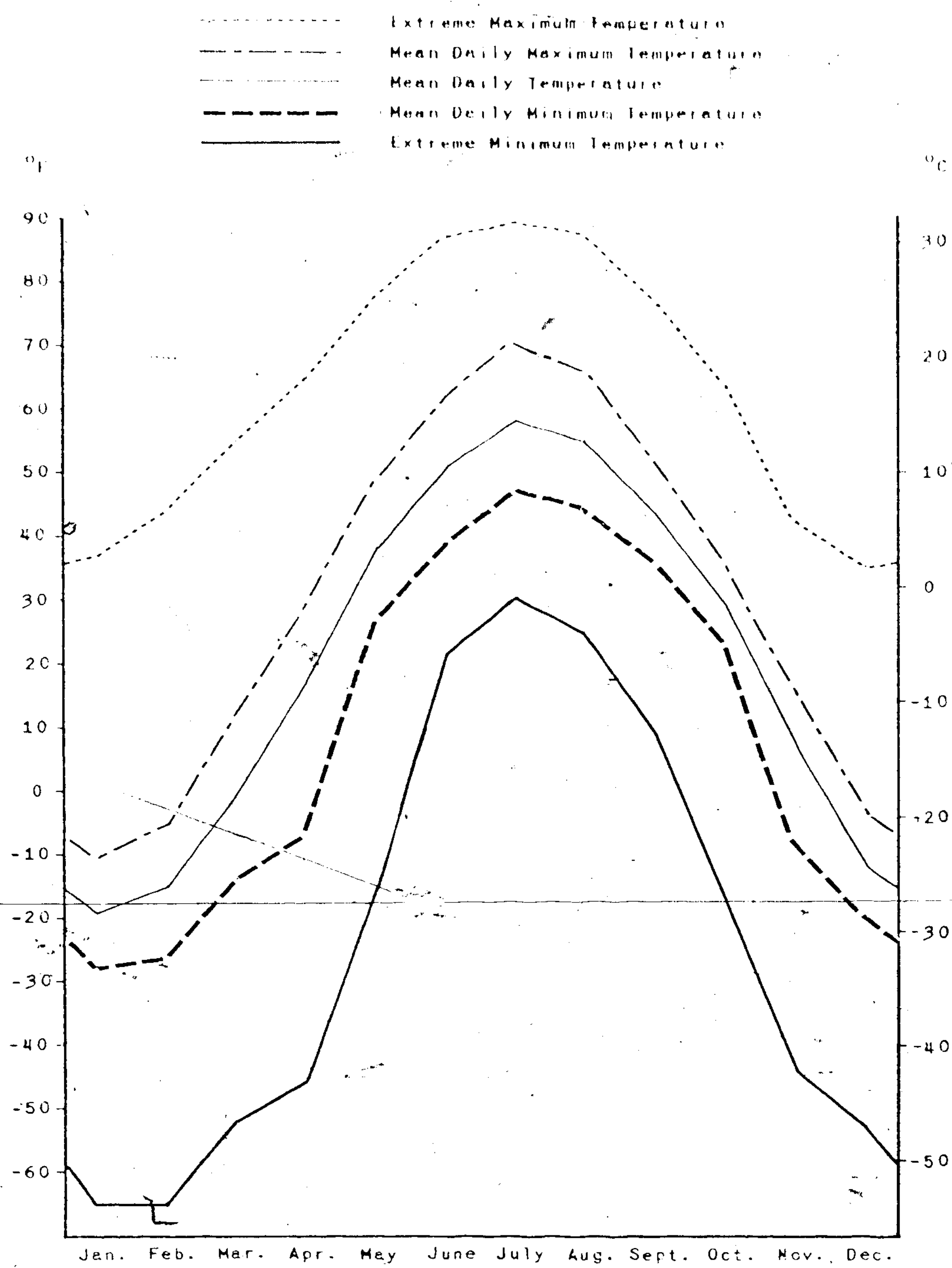
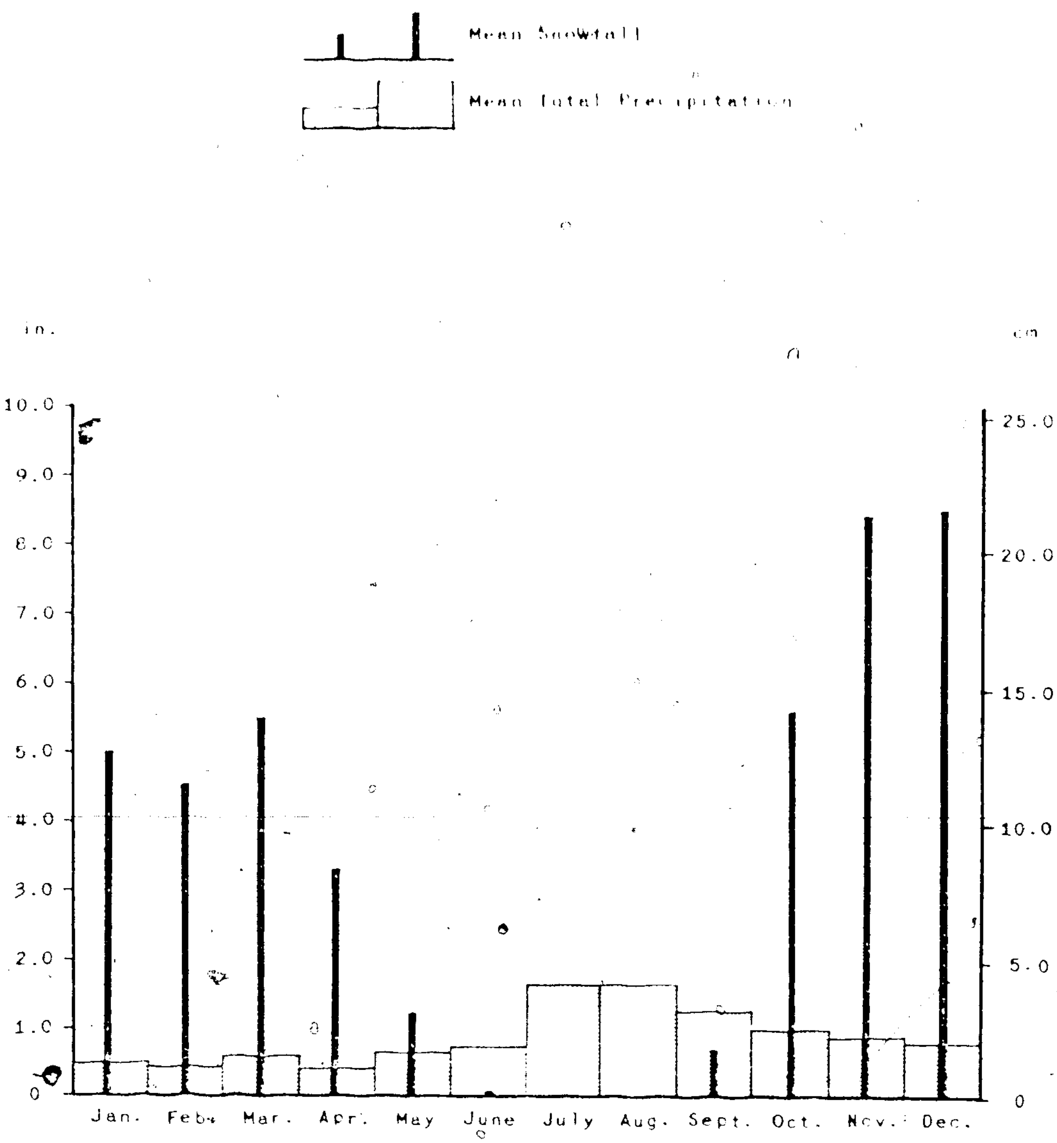


FIGURE 2-2. TEMPERATURE BY MONTH (YELLOWKNIFE HYDRO)



Source—Canada, Department of Transport, *Temperature and Precipitation Tables for the North—Y.T. and N.W.T.*, Toronto, 1967, p. 19.

FIGURE 2.3 PRECIPITATION BY MONTH (YELLOWKNIFE HYDRO)



Source — Canada, Department of Transport, *Temperature and Precipitation Tables for the North—Y.T. and N.W.T.*, Toronto, 1967, p. 19.

vicinity of Discovery Mine was as little as 15-20 cm in August 1971.

2.4 REGIONAL VEGETATION

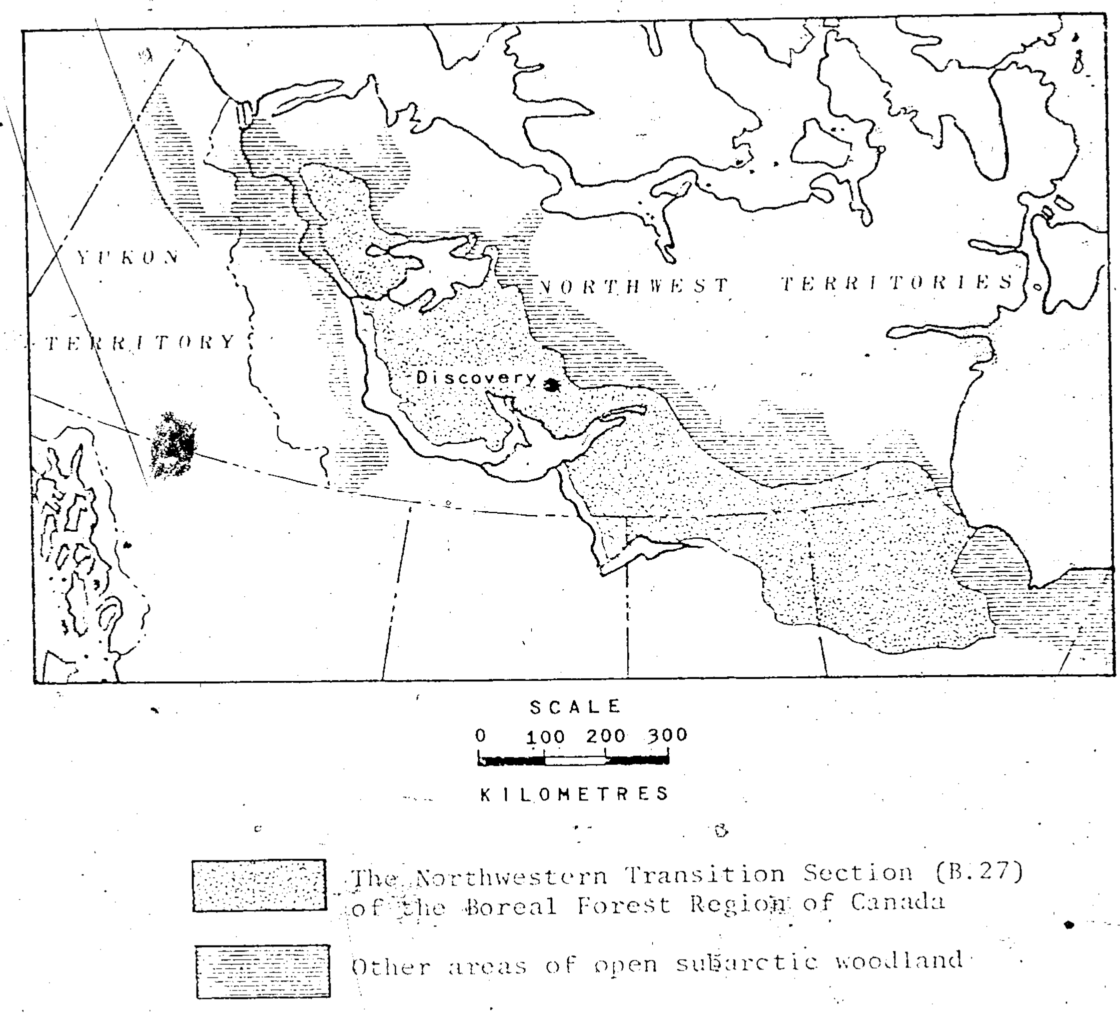
Discovery Gold Mine is situated in the Northwestern Transition Section of the Boreal Forest Region (Fig. 2-4). This large area is described by Rowe (1972, p. 55):

> "In this forest fringe fronting the tundra unfavourable climatic conditions, thin soils and frequent fires have combined to reduce the distribution, abundance and size of the tree species. Areas of bog, muskeg and barren rock are intermixed with open stands of dwarfed trees, although on local patches of sheltered, deep, frost-free soil the density and height growth of forest patches can be surprisingly good. Characteristic of the park-like coniferous stands on upland sites is a ground cover of light-coloured, foliose lichens. The most abundant tree on all sites is black spruce, and with it on the well-drained soils grows white spruce. Other accompanying species are white birch and tamarack, the latter of increased importance in the more northerly parts of the Section. Jack pine is only common in the southern part, especially on sandy soils and uplands. Stunted trembling aspen and balsam poplar extend well toward the northern boundary. Balsam fir is not present; a contrast to its commonness in comparable Sections on the east side of Hudson Bay.

There have been a number of useful plant ecology studies in areas of the Boreal Forest similar to the Discovery region. In 1962 Ritchie summarized a series of studies carried out in northern Manitoba. Larsen (1965) described the vegetation of the Ennadai Lake region, and in 1971 further described that of the Fort Reliance area. Maini (1966) worked in the vicinity of Small Tree Lake, N.W.T., just north of the Saskatchewan border. In 1966 Argus published a forest classification for the northeast corner of Saskatchewan.

In addition, a number of reference works are useful. These

FIGURE 2-4 THE BOREAL FOREST REGION IN WESTERN CANADA



Source—Rowe, 1972: pocket map.

include Moss (1959), *Flora of Alberta;* Porsild (1964), *Illustrated Flora of the Canadian Arctic Archipelago;* Cunningham (1958), *Forest Flora of Canada;* and Porsild and Cody (1968), *Checklist of the Vascular Plants of the Continental Northwest Territories, Canada.* Reference was also made to a study by Scotter (1966) in the region immediately to the east of Giauque Lake.

2.4.1 FOREST COMMUNITIES

It is difficult to classify the vegetation of the study region into community groupings since factors such as soil, drainage and aspect cause many local differences (Plate 2-3). However, since it is desirable to characterize the vegetation to aid the description of the study area, a classification system is outlined below. The system was developed with reference to all the studies cited above but follows Argus (1966) most closely. The communities are listed below:

A) *Picea mariana* - sphagnum bog

B) *Picea mariana* - feathermoss woodland

C) *Picea mariana* - *Ledum groenlandicum* woodland

D) *Picea mariana* - lichen woodland

E) *Pinus banksiana* - lichen woodland

F) *Picea glauca* - lichen woodland

A) *Picea mariana* - sphagnum bog

The most common community occurs in numerous poorly-drained depressions. The dominant tree is *Picea mariana* with *Larix laricina* somewhat less common. Although the trees (especially *P. mariana*) may be quite closely spaced, the forest is generally open. The shrub layer consists of *Ledum groenlandicum*, patches of *Betula glandulosa*, and

Plate 2-3. These photos show the extensive intermixing of forest types in the vicinity of Discovery Mine. The upper right photo illustrates a small patch of *Pinus banksiana* - lichen woodland surrounded by *Picea mariana* - *Ledum groenlandicum* woodland. Nearby a thermometer shelter is located in the midst of a *Picea mariana* - sphagnum bog (upper left photo).

upper photos - 15 July 1971 - 13h00
lower photo - 21 July 1971 - 12h30

frequent occurrences of *Vaccinium vitis-idaea* and *V. uliginosum*. *Arctostaphylos rubra*, *Myrica gale*, *Rubus chamaemorus*, *Salix myrtillifolia*, *Shepherdia canadensis* and *Empetrum nigrum* are also present throughout the bog but in less representation. *Pyrola virens* and *Oxycoccus microcarpus* are found locally as well. A cover of *Equisetum sylvaticum* varies from nearly complete to a few scattered individuals. The moss cover consists primarily of hummocks of *Sphagnum capillaceum* var. *tenellum* together with *S. capillaceum*, *S. girgensohnii*, *S. magellanicum*, and *S. squarrosum* in wet depressions. Other mosses present include *Aulacomnium palustre*, *A. turgidum*, *Dicranum undulatum*, *Polytrichum commune* and *P. juniperinum* var. *gracilis*.

Some of the bogs in the area have well-developed clay frost boils, often devoid of vegetation. These boils cause a relief of 0.5 - 1 m on the bog surface. The tops of less active boils support the lichens *Cetraria nivalis*, *Cladina arbuscula*, *C. mitis*, *Cladonia amaurocraea*, *C. cornuta*, *C. deformis*, *C. uncialis* and *Peltigera aphthosa*.

B) *Picea mariana* - feathermoss woodland

An excellent example of this community is found on the southwest shore of Brien Lake, approximately 1.5 km west of Discovery. The dominant tree is *Picea mariana*, standing to 10 m high with an average dbh (diameter at breast height) of 10.2 cm. The trees are very closely spaced, resulting in a thick closed crown. Scattered throughout the woods are dead *Betula papyrifera*, up to 8.3 cm dbh. The reduced light on the forest floor has resulted in a sparse ground cover of mosses and lichens, although *Vaccinium vitis-idaea* is locally common. Most dominant (up to 80 per cent cover) is the feathermoss *Ptilium crista-castrensis* although

Hylocomium splendens, Aulacomnium turgidum and *Ptilidium ciliare* are also present. Predominant lichens are *Cladina rangiferina* and *C. alpestris* with a few occurrences of *Cladonia deformis* and *Nephroma arcticum*.

C) *Picea mariana - Ledum groenlandicum* woodland

Nearly pure stands of *Picea mariana* dominate the tree cover of this open forest type. *Betula papyrifera* is occasionally found, as well as *Alnus crispa*. *Ledum groenlandicum* grows abundantly in patches, with occasional small patches of *Vaccinium uliginosum* and *Viburnum edule*. Ground cover consists of abundant *Vaccinium vitis-idaea* and, commonly, patches of *Geocaulon lividum*, with occasional *Empetrum nigrum* and *Equisetum sylvaticum*. There is a fairly continuous cover of the lichens *Cladina alpestris, C. rangiferina* and *Cetraria nivalis*. *Cladonia cornuta, Cladina mitis* and *Peltigera aphthosa* are also present. The most common byrophyte is *Ptilidium ciliare* although *Aulacomnium turgidum* and *Sphagnum capillaceum* are also evident.

This community and the one following (D) are similar and commonly grade into each other. Depth of overburden and drainage are factors that appear to cause differences in the vegetation of these two community.

D) *Picea mariana* - lichen woodland

As with the previous class, nearly pure but open stands of *Picea mariana* dominate. Besides occasional appearances of *Alnus crispa* and *Betula papyrifera*, *Pinus banksiana* may also be found in drier situations. *Ledum groenlandicum* is found in isolated patches only, but *Vaccinium vitis-idaea, Empetrum nigrum* and *Lycopodium complanatum* are common.

The ground is covered with an almost continuous met of *Cladina alpestris*, *C. rangiferina*, *Cetraria nivalis* and to a minor extent *Peltigera aphthosa*. *Cladonia verticillata*, *C. uncialis*, *C. phyllophora*, *C. gracilis*, *C. amaurocrea*, *Peltigera malacea*, *Stereocaulon paschale* and *S. tomentosum* occur occasionally. A thin cover of mosses includes *Aulocomnium turgidum* and *Ptilidium ciliare*. Plate 2-4 illustrates this type of forest community.

E) *Pinus banksiana* - lichen woodland

This last major forest type is generally found on ridges where the widely spaced *Pinus banksiana* form an open woodland (Plate 2-5). In the many locations where there is little or no soil on the bedrock, trees are found rooted in crevices and slight depressions which catch small amounts of organics and moisture. Occasionally found with the pine are specimens of *Picea mariana*, *Betula papyrifera* and *Salix myrifolia*. The shrub *Juniperis communis* is abundant in certain situations. *Arctostaphylos uva-ursi* is common, as is *Empetrum nigrum*, while *Vaccinium vitis-idaea*, *Shepherdia canadensis*, *Ribes glandulosum*, *Rosa acicularis*, and *Lycopodium complanatum* occur infrequently, usually in small isolated patches. Common in small crevices on otherwise bare rock are small clumps of *Dryopteris fragrans* and *Saxifraga tricuspidata*. Both species are also found growing in small cushions in lichen which are scattered on the bedrock (Plate 2-6). These cushions consist primarily of *Cetraria nivalis* which has become established on bare bedrock, through trapping wind-blown plant matter and soil. Other lichens occasionally found are *Actinogyra muehlenbergii*, *Cetraria hepatizon*, *Cladonia amaurocreaea*, *C. cornuta*, *Parmelia separata*, and *Stereocaulon paschale*.

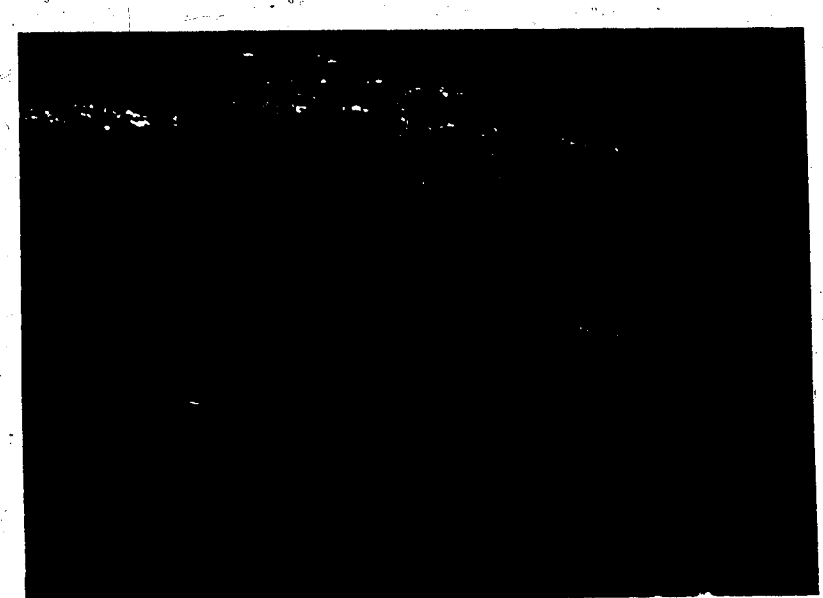


Plate 2-4. Typical forest cover in the vicinity of Discovery. The two main components visible in this photo are *Picea mariana* - lichen woodland (type D) and *Picea mariana* - sphagnum bog (type A). 18 July 1971 - 17h00.

Plate 2-5. *Pinus banksiana* - lichen woodland (type F) on a ridge south of Discovery. 30 June 1971 - 15h00.

Plate 2-6. Cushions of *Cetraria nivalis* which form on bare sections of bedrock. These cushions trap wind-blown plant matter and mineral material and are the first stage in soil formation at such locations. 19 August 1971 - 14h00.

The ridges on which these plants grow trend northeast-southwest and provide a good illustration of the effect of aspect at this latitude. The northwest-facing slopes usually host *Picea mariana-Ledum groenlandicum* woodland, but at the top of the ridge there is an abrupt transition to an open *Pinus banksiana*-lichen woodland. On one such ridge just to the southeast of the mine area, nearly twenty stunted specimens of *Populus tremuloides* were found on a sunny southeast-facing slope, the only occurrence of this species noted in the vicinity of Discovery.

F) *Picea glauca* - lichen woodland

This forest community occurs to only a minor extent in the study region and is found on the esker which crosses Giauque Lake. This open woodland is dominated by widely spaced *Picea glauca* (Plate 2-7). Very few specimens of *Picea mariana* were noted, but *Betula papyrifera* are slightly more common. *Ledum groenlandicum* provides a patchy shrub cover. Ground cover consists of *Vaccinium vitis-idaea, Arctostaphylos uva-ursi* and *Geocaulon lividum*. The large size of the trees (up to 30 cm dbh) and their age (up to 150 years) suggest that the esker provides a favourable habitat for *Picea glauca* as well as a sanctuary from forest fires.

2.4.2 LAKE MARGIN COMMUNITIES

The forest communities often extend to the water's edge. There are, however, some exceptions worthy of note. The shoreline along several small bays of Giauque Lake has a very heavy shrub cover of *Myrica gale* intermixed with *Ledum groenlandicum*. Also common in such situations is *Potentilla palustris*. *Salix planifolia, Vaccinium*

Plate 2-7. Open [illegible] - lichen woodland on an esker approximately 1.5 km east of the minesite. 30 June 1971 - 16h30.

[illegible] and [illegible] are also found.

Along the shore of [illegible] Lake, a lake too small for significant wave action, the littoral vegetation forms a complete border. [illegible] and [illegible] are common on seasonally submerged habitat. The former also grows in small shallow areas within the lake. Other species such as [illegible], [illegible] and [illegible] are also commonly found in the shallow water. [illegible] was noted occasionally. In the smaller ponds in the region, [illegible] is common.

CHAPTER 3

DESCRIPTION OF STUDY AREA

3.1 FIELD SEASON

The field season extended from 25 June to 30 August 1971. Access to the site was by charter float plane from Yellowknife. Accommodation was provided in one of the remaining mine houses through the courtesy of Discovery Mines Limited.

3.2 RESEARCH METHODOLOGY

As a result of the reconnaissance nature of the study, the first priority in the field work was to prepare a map of the mine site. Horizontal control was achieved by the use of a 50 m grid pattern on each side of a baseline established along the east limit of the airstrip. Station 2+00S[1] on the baseline was marked by a 20 cm steel spike driven into a crevice in a section of exposed bedrock. Station 10+00 was established approximately 2 m from the southeast corner of the embankment built from tailings to form a base for the airstrip. Stakes 1 m in length were driven into the ground at measured intervals

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1. In the survey terminology used here 'station' refers to a point established during the survey and marked with a stake driven into the ground for subsequent use as a reference point. The 2+00S indicates a point 200 m south of zero on such a reference survey line.

of 100 m along this baseline. Cross lines for the grid were then laid out using a compass and picket lines.[2] Grid points were established along the picket lines through pacing.

Features mapped include the extent of tailings deposition, and general surface features such as present drainage patterns, erosion by gullying, and evidence of thermokarst or frost action. In addition, plant growth on the tailings and the vegetative cover adjacent to the tailings were mapped, and representative plant specimens were collected and preserved for identification. A list of the specimens collected can be found in Appendix A.

Mapping of the tailings revealed that the total area could be subdivided into four major sub-areas, using criteria based primarily on the age of the tailings and the overall regeneration of vegetation. These study areas are designated R1, R2, R3 and R4. The R1 area is that in which regeneration processes have been operative for the longest time. The R4 area is the one most recently disturbed by tailings deposition.

Within these study areas certain sites were selected for more detailed investigation. A number of transects were established across

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2. The term 'picket line' is used to denote a method of extending a relatively accurate survey line through bush. Each new stake is placed so that it is exactly in line with the stakes (or pickets) previously established. Except when traversing narrow ridges, this method is more accurate than one using a hand-held compass only. With some practice pacing can be a fairly reliable method of establishing a grid pattern along picket lines. In the absence of an assistant it is the only realistic method of accomplishing such a survey.

representative sections of the study area. Wooden posts (approximately 8 cm in diameter and 1.5 m long) were driven into the ground at measured intervals. The vegetation found along each transect was mapped in detail. Soil pits were located along each transect in order to establish a profile of the tailings material and, where possible, the depth to the former ground surface. Samples of the tailings were collected from a number of pits for laboratory analysis. The methods of analysis used are described in Appendix B, page 184.

In addition several sites were selected for more detailed mapping. The larger scale used for these sites was based on a grid pattern of 5 or 25 m.

During the field season regular observations were made of several weather phenomena. They included temperature (daily high and low), precipitation, and relative humidity. Tables showing some of observations may be found in Appendix C, page 186.

3.3 OVERVIEW OF TAILINGS DISPOSAL AREA

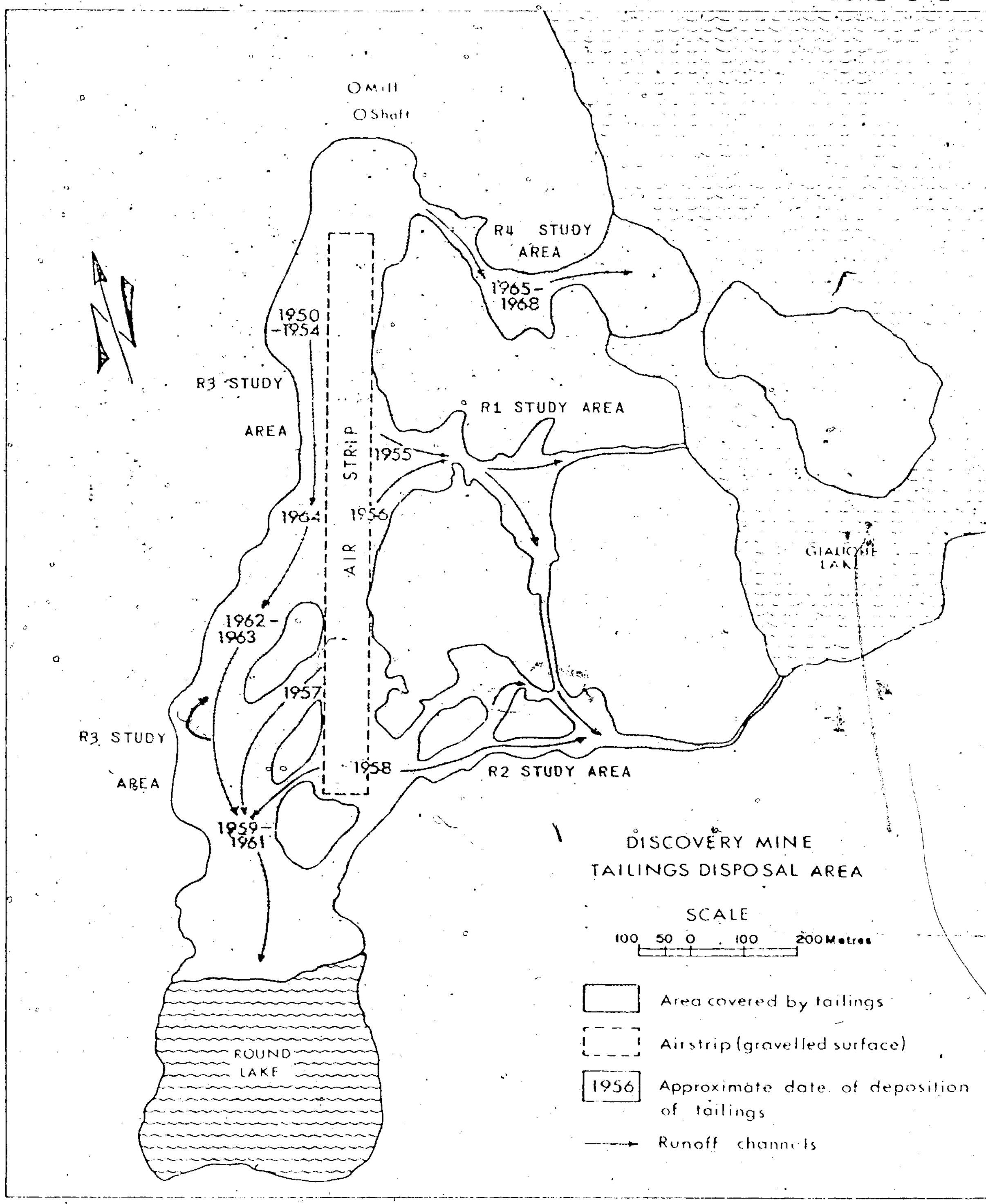
Figure 3-1 (pocket) is a plan of the surface features of the tailings disposal area. The stations along the baseline are denoted by a series of crosses immediately east of the airstrip. Additional gridline crosses are shown for a 200 m pattern. The grid lines may be identified by the numerals along the edges of the area mapped. Throughout the body of the thesis, specific locations will be designated through the use of grid coordinates. Thus, a coordinate such as 150S-50E indicates a location 150 m south of the baseline (zero on the baseline is located near the north end of the airstrip) and 50 m east of the baseline.[3]

The heavy line on the map indicates the extent of the area affected by tailings or effluent. Damage includes the selective or complete killing of the plant cover through drowning or other changes in the water table, changes in acidity, or through temporary and relatively light burial by tailings. The area lightly screened represents those locations in which some of the original vegetation has survived and is at present re-establishing itself. The unscreened area on the map, which includes most of the tailings disposal area, represents those sections in which the original vegetation cover was totally buried by tailings deposition. For the most part this area is now completely bare, although there are a few scattered patches of vegetation.

The central feature of the map is the airstrip. The base for this gravelled strip was created through the judicious disposal of tailings. Along the east side and at the south end, embankments or dykes composed of bulldozed overburden or tailings were used to contain the mill effluent and to allow the solids to settle out while the fluid drained away. While this base was being constructed, and through fluvial erosion since that time, a considerable amount of tailings solids has been carried into nearby low-lying areas, completely infilling several black spruce bogs. One result is that the whole of the tailings disposal area can be divided easily into four major sub-areas. Figure 3-2 indicates

3. Use of close control should enable future researchers at this proposed IBP research site to monitor changes at specific locations over time.

FIGURE 3-2


Mill
Shaft
R4 STUDY AREA
1965-1968
1950-1954
R3 STUDY AREA
AIR STRIP
R1 STUDY AREA
1955
1956
1964
1962-1963
1957
R3 STUDY AREA
1958
R2 STUDY AREA
1959-1961
ROUND LAKE
DISCOVERY MINE TAILINGS DISPOSAL AREA
SCALE
100 50 0 100 200 Metres
Area covered by tailings
Airstrip (gravelled surface)
1956 Approximate date of deposition of tailings
Runoff channels

the estimated date of deposition of the tailings, and the choice of study sub-areas.

3.4 THE R1 STUDY AREA

The R1 study area is formed by two large infilled bedrock depressions, which once contained *Picea mariana* - sphagnum bog (Plate 3-1). A considerable quantity of tailings has been deposited in this area, reaching a depth of over 1.7 m.

3.4.1 SURFACE DRAINAGE

Present drainage patterns at this site are shown in figure 3-1 (pocket). Two major drainage courses are shown, one flowing into Giauque Lake and the other flowing southward into a lowland portion of the R2 study area. In the case of the former, the channel is well marked near the airstrip while it is much less so near the lip of the hill. Only a small amount of tailings has been carried to the lake. The second, more southern, channel drains the middle portion of the airstrip and is quite incised, especially in the upper reaches near the airstrip. Where this course leaves the R1 area the drainage is through a small valley and there has been no channel development either in the valley, or in the tailings of the R1 area at the head of the valley. Though it appears that this has been and remains a major route for surface drainage, there is little evidence of significant transport of tailings down the valley to the R2 area.

Field observations indicate that in summer most of the runoff from rainfall soon infiltrates into the tailings. Although the summer of 1971 was dry, there were several heavy rainfalls, notably from thunderstorms on 11 and 17 August, in which there was 10.2 mm and 16.8 mm

Plate 3-1. Low oblique aerial view of the R1 study area from the east. 21 July 1971 - 12h30.

of precipitation respectively. Despite the large runoff area, namely the middle portion of the airstrip, at no time did the runoff flow farther than 100 m east of the baseline. One explanation for the marked channel erosion that occurs in the vicinity of the airstrip is that the packed, gravelled and oiled airstrip surface concentrates the runoff so that it has considerable erosive power when it first reaches the tailings. As this water infiltrates quickly into the tailings its erosive power is rapidly decreased.

3.4.2 THERMOKARST ACTIVITY

Figure 3-3 shows a number of depressions caused by thermokarst[4] activity. These areas, which in several places constitute a widening of the stream channel, provide places for sediment to settle during runoff, and for water to stand and seep underground. Water in these depressions disappeared within hours of the storms mentioned above, indicating a rapid infiltration rate.

The effects of thermokarst action are widespread throughout the R1 study area. Most notable is the depression shown at 410S-80E, which is approximately 1 m deep and has no outlet. A number of other depressions and cut banks are shown in Figure 3-3. Considering that tailings deposition in this area first began 15 to 20 years ago, it is surprising that thermokarst settling is still active. The degree of

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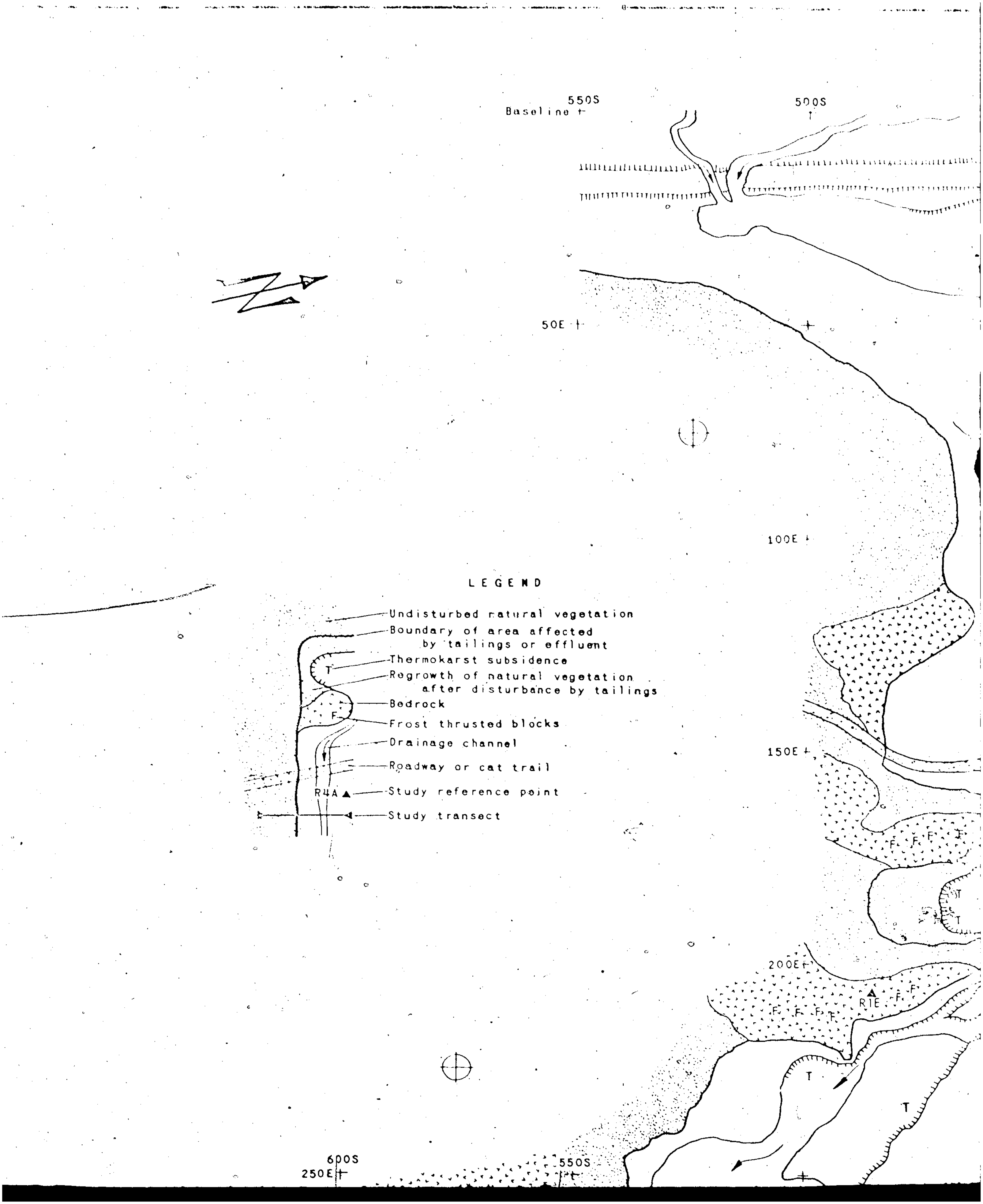
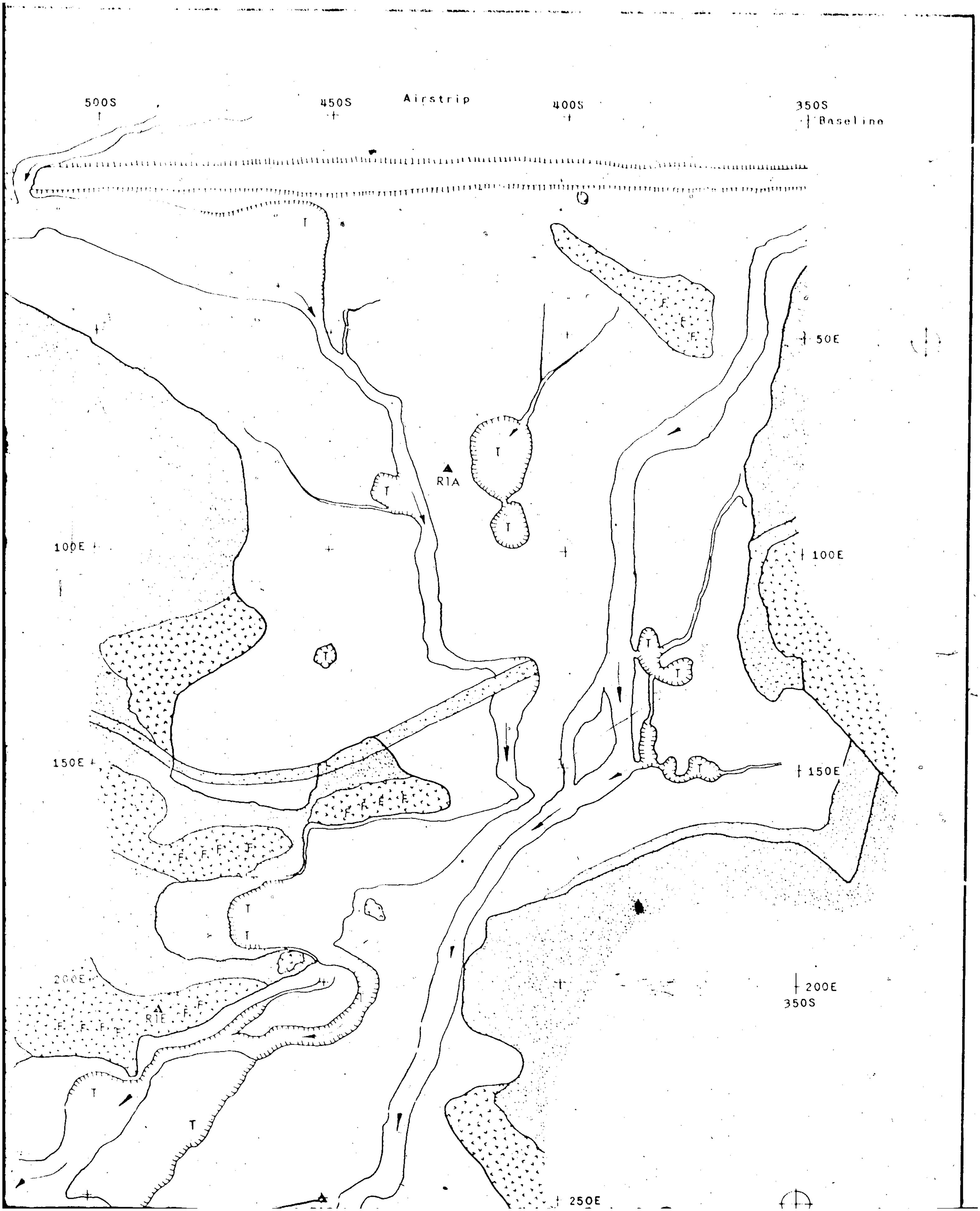
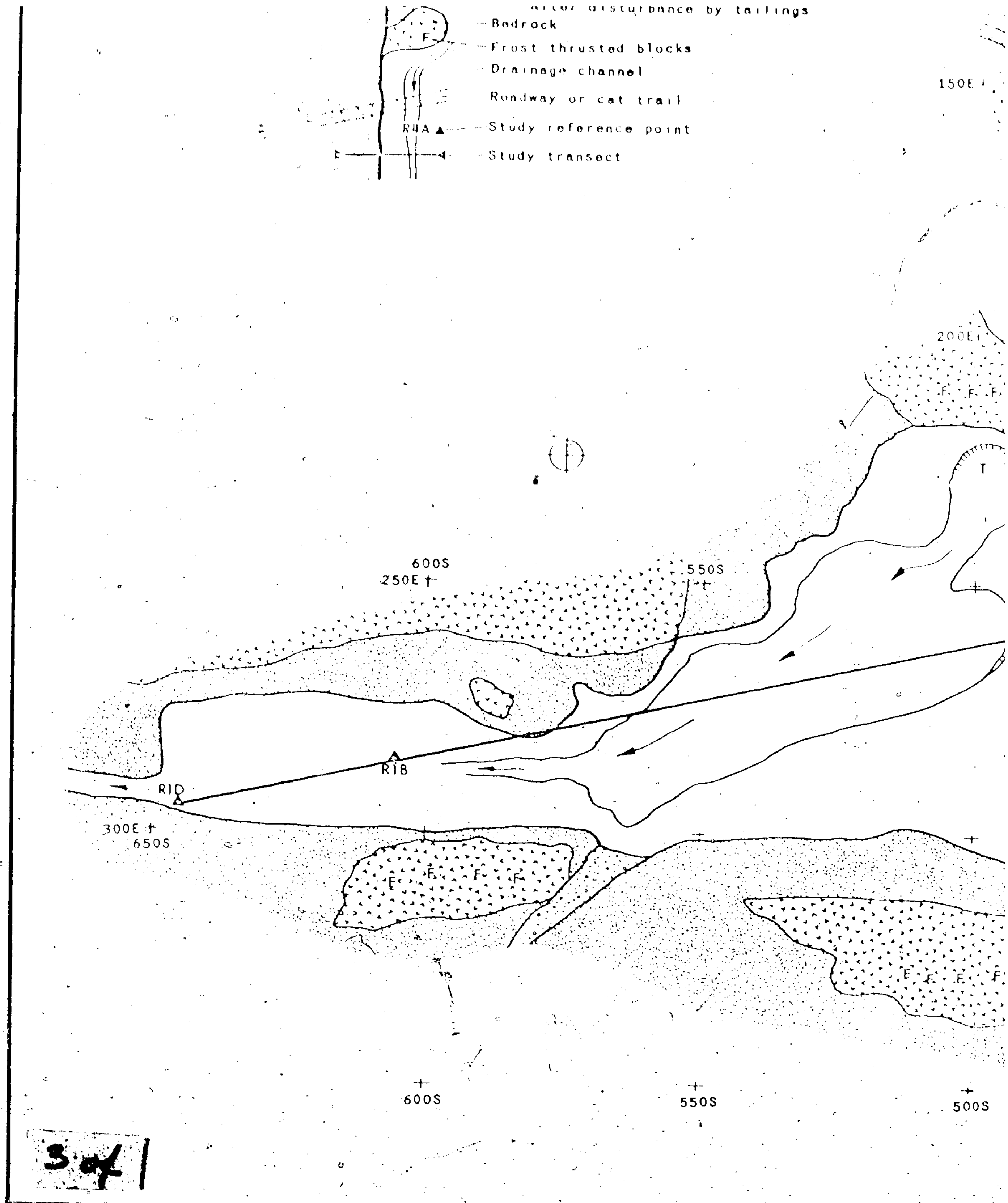
4. The term "thermokarst" is used to describe the features resulting from the melting of ground ice in permafrost regions. The principal effect of ground-ice melting is essentially collapse, which may give rise to surface pits and basins, funnel shaped sinks or dry valleys. A prerequisite for thermokarst activity is ground material with a high ice content. When a change in thermal equilibrium causes the ice to melt, and the resulting water evaporates or drains away, the decrease of volume may cause a collapse of the ground surface.



550S
Baseline
500S
50E
100E
150E
200E
600S
250E
550S
LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
R4A
R1E
T
F


Airstrip
500S
450S
400S
350S
Baseline
50E
100E
150E
200E
250E
350S
R1A
R1E
T
F


after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
R4A
Study reference point
Study transect
150E
200E
600S
250E
550S
R1B
R1D
300E
650S
600S
550S
500S
3 of 1

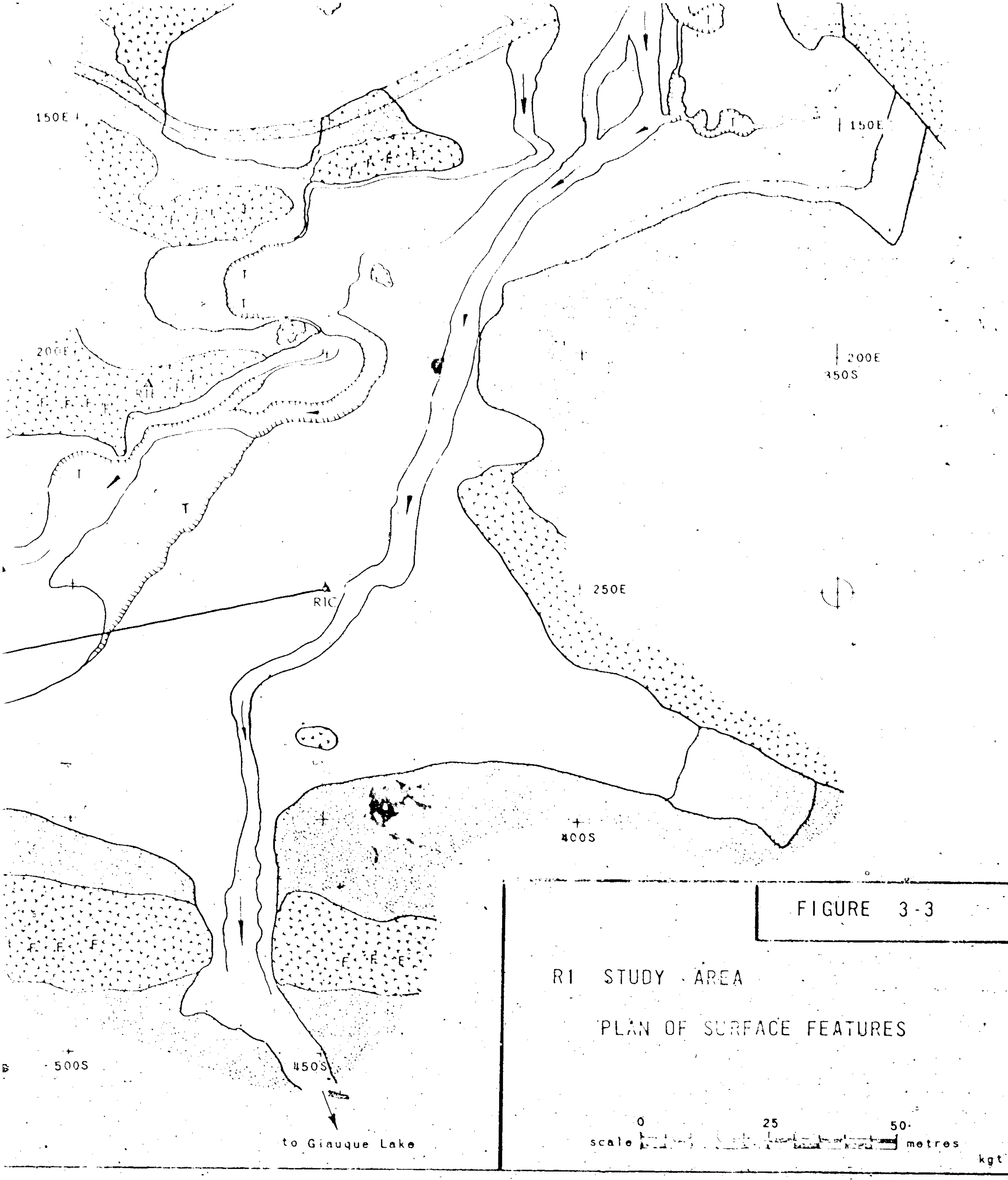


FIGURE 3-3

R1 STUDY AREA

PLAN OF SURFACE FEATURES

4 of 4

recent activity is difficult to determine but sediment which is obviously transported by runoff has filled only those depressions close to the airstrip.

The fact that thermokarst activity occurred within and under the tailings following deposition over bog terrain is not surprising. In the first place, in most areas of discontinuous permafrost, spruce bogs are thermally favoured sites for the maintenance of frozen ground. Such bogs are usually located in bedrock depressions which are receptacles for runoff and fine sediments washed from surrounding land. As a result, the fine mineral soil underlying such bogs has a high moisture content. On top of this mineral soil a layer of organic material forms, usually resulting from the accretion of sphagnum moss. Both layers have a high potential for absorbing and holding water. Once the moisture in these layers has frozen, there are several factors operative to maintain it in a frozen state (Brown, 1970: 24). During summer, with high temperatures and low humidity, the surface organic layer dries out and becomes an effective insulator against penetration of heat to subsurface frozen material. In the fall, with shorter days, decreased evaporation and increased precipitation, the moisture content and thermal conductivity of the organic layer increases, with a subsequent cooling of the ground. As a result such bogs have a lower mean annual ground temperature than adjacent non-organic locations. Trees growing in the bog, and to a lesser extent, shrubs, also assist in the maintenance of frozen ground. In summer, their branches intercept solar radiation, and the open nature of the trees in the bog facilitates the dispersion of heat by advection. Trees also intercept snowfall, decreasing the insulation of the ground during winter. [illegible] (19[illegible]) reports that permafrost extends to a depth of [illegible] m in the Discovery mine drift. The depth of the active layer (the surface zone which thaws each summer and refreezes in winter) was probed with a 6 mm diameter iron rod in a number of locations. This revealed that the depth of the active layer averaged 50 to 70 cm, but was as little as 15 cm during late summer (mid August) in some bogs.

Once tailings are deposited on such locations, the thermokarst process begins. The burial of the moss cover by tailings results in a decrease in ground surface albedo, and also destroys the insulation value of the surface layer. In time the shrub layer may die or be buried, and the spruce trees may also die. This caused the radiation-exchange surface to be lowered from the canopy to ground level, and there is a significantly greater transfer of heat into the ground. This results in a positive change in the thermal equilibrium. Gradually the moisture frozen in the subsurface layers of the bog thaws, the moisture evaporates or seeps out of the bog, and the decrease in volume results in a collapse of the surface of the tailings.

It is likely that some thermokarst settling may occur solely within the tailings. Under conditions of extreme cold experienced during the winter months, most of the tailings effluent freezes. This high ice content material is then buried under additional tailings deposits. The insulation afforded by the subsequent layers may then retard the thawing of the deeper material for several years. Later, during an unusually warm summer, if the thaw level penetrates deeper than is normal, thermokarst activity will occur.

Observations of thermokarst depressions in the RI study area revealed that settling was usually in the order of 1 m. Although the settling in the centre portions of the area is relative, an absolute measure of settling was observable at several locations along the edges of the study area. Plate 3-2 shows one such site where the lichen on the bedrock has been killed to a height of 1 m above the present level of nearby tailings (it is possible that it was the effluent rather than the tailings which reached this level). This value of 1 m was found at other locations within the study area. For example, at 470S-185E there is a distinct drop of 1 m in a small bog which has been only half covered with tailings (Plate 3-3). All the *Picea mariana* once growing in this bog have been killed. The small hummocks which made up the ground surface of the bog have lost virtually all of their lichen component, whereas *Ledum groenlandicum* and sphagnum mosses were growing satisfactorily. It appears that this regenerating section was subjected only to the water portion of the tailings effluent, which killed the lichens but not the mosses. In a number of locations, there is evidence to suggest that bogs which have been only partially covered by tailings are continuing to be infilled further as a result of thermokarst activity. In the operative process, the tailings/bog contact adjusts each summer to a new thermal equilibrium as tailings material moves into the thermokarst depression. As the thaw line advances into the bog, settling occurs, lowering the ground surface enough so that the tailings can infill, which causes a further retreat of the thaw line both horizontally and vertically, starting the cycle again.

Plate 3-2. Waterline on the bedrock in the vicinity of 475S-130E indicates that the tailings or effluent reached a height of nearly 1 m above the present surface of the tailings. Below the "waterline" the lichens once growing on the bedrock have been killed. The slightly darker depression in the centre of the photo, in which some plants are able to regenerate, suggests some settling in the area by thermokarst activity. 15 July 1971 - 14h00

Plate 3-3. View north from 470S-190E showing a small thermokarst depression in which *Equisetum arvense*, *E. sylvaticum*, and *Eriophorum angustifolium* are now growing. The floor of the depression, which consists of tailings, now lies 1 m below the level of the 'Ledum hummock' bog topography which originally existed and still occurs on adjacent land. 15 July 1974 - 14h00.

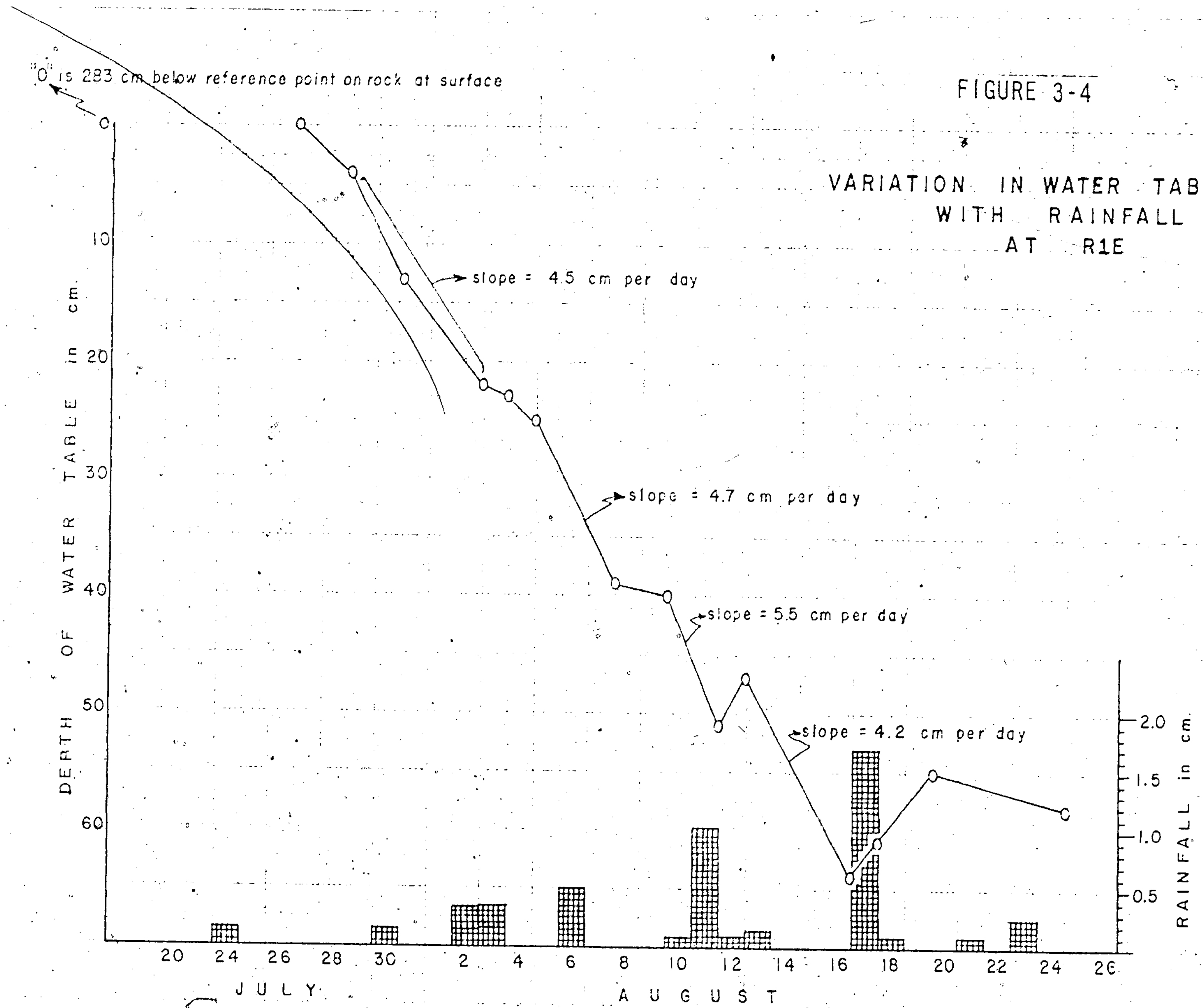
3.4.3 BEDROCK FRACTURES

The large size of frost-thrust blocks that are common in parts of the study area (Plate 2-2) indicates a deep fracture system in the bedrock. One such fracture zone (485S-205E, labelled RIE on figure 3-3) permitted observations of the water table. An open fracture extended to a depth of more than 8 m, and the water table was more than 2 m lower than the surface of nearby tailings deposits. Figure 3-4 shows the fluctuation of the water table, and the recorded rainfall, for part of the field season. Several interesting observations can be made from these data. First, it is notable that the slope of the change in the water table level is nearly constant, if one disregards the inputs from rainfall. Ground temperature measurements taken at Yellowknife indicate that in bedrock the rate of descent of the 0^{o} C isotherm is also uniform during much of the summer period (Brown, 1974, personal communication). This suggests that the level of the water table in the fracture is governed by the annual thawing of the active layer.

It is also notable that there is a rapid response of the water table to rainfall. Since the location of this fracture is approximately 200 m from the edge of a slope where drainage to a lower level can occur, and considering the quick recovery to the standard drop rate after a rainfall, it is thus likely that there is a relatively free underground movement of water through fractures in the bedrock. Although the contributory runoff area for the R1 study site is relatively large, only small amounts of water and even lesser amounts of tailings continue to flow over the lip of the hill. These observations thus verify the earlier statement that rapid infiltration of surface waters and free groundwater

FIGURE 3-4

VARIATION IN WATER TABLE
WITH RAINFALL
AT R1E



movement have prevented excessive surface erosion throughout most of the R1 area. From this it may be concluded that apart from the relatively minor instability caused by thermokarst processes, the surface morphology of the R1 study area should remain fairly stable, making the process of natural revegetation easier than might otherwise be the case.

3.5 THE R2 STUDY AREA

The R2 study area outlined in Figure 3-5 is somewhat smaller than the R1 area. The tailings deposits lie for the most part in a small glacial trough in the bedrock (Plate 3-4). Judging from the vegetation of nearby undisturbed sites, the original plant cover was a *Picea mariana* - sphagnum bog. The tailings have flowed over the lip of the hill, towards Giauque Lake, and at the base of the hill have infilled a corner of a large bog.

3.5.1 SURFACE DRAINAGE

The present drainage channel on the tailings surface is not well incised, but the amount of tailings in the vicinity of 940S-260E, as well as over the lip of the hill, at 900S-375E, indicates a considerable flow of water and tailings from the south end of the airstrip at some time in the past.

3.5.2 THERMOKARST

In the tailings-covered section from 100E to 200E some thermokarst settling has occurred. In the trough (near R2A) there is noticeably more subsidence at the centre than at the sides. Marks on dead tree trunks and on nearby bedrock indicate a former tailings level 70 cm above the present ground level. It is difficult to determine whether the ground level dropped to its present position through removal of

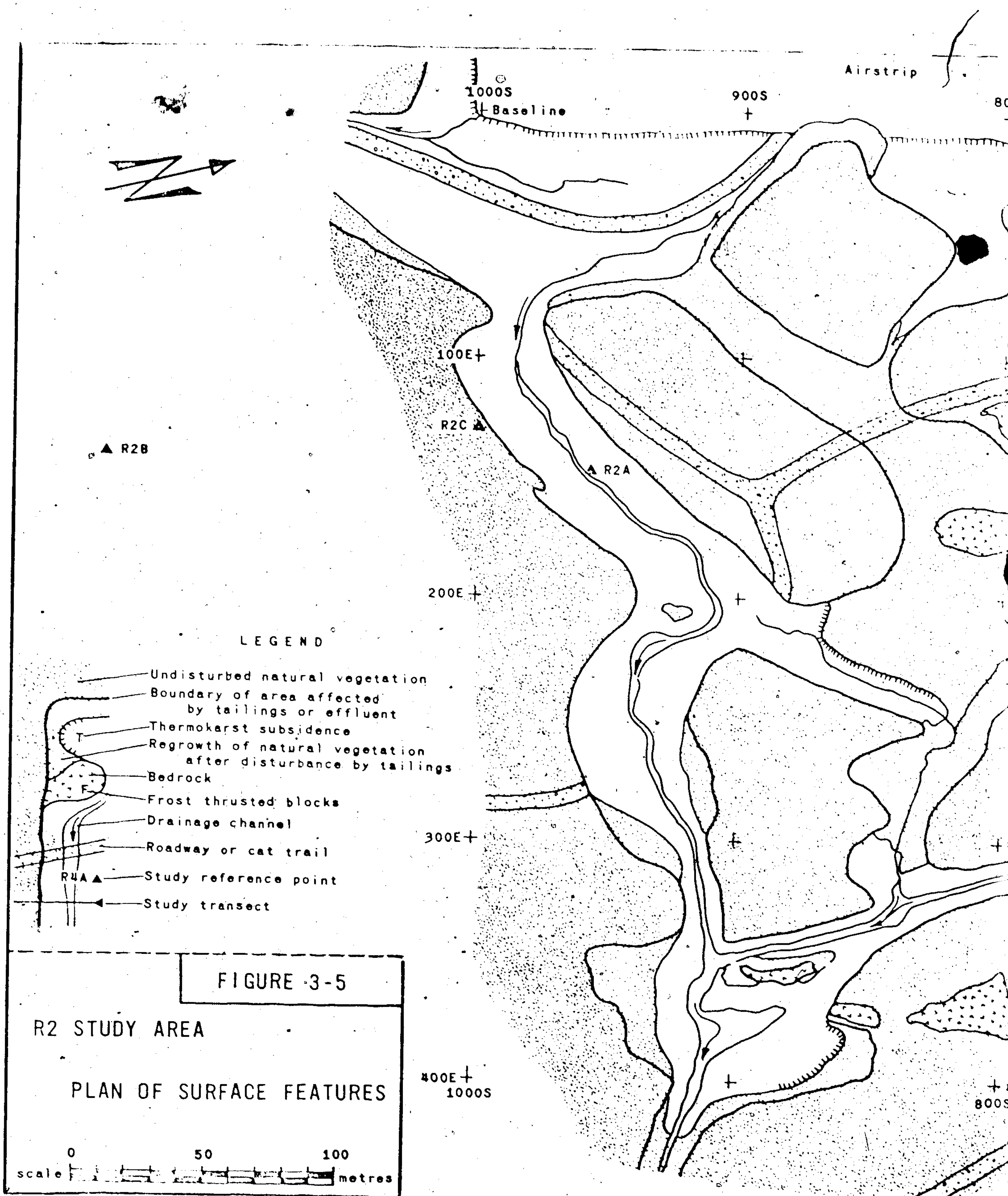


FIGURE 3-5

R2 STUDY AREA

PLAN OF SURFACE FEATURES

2of2

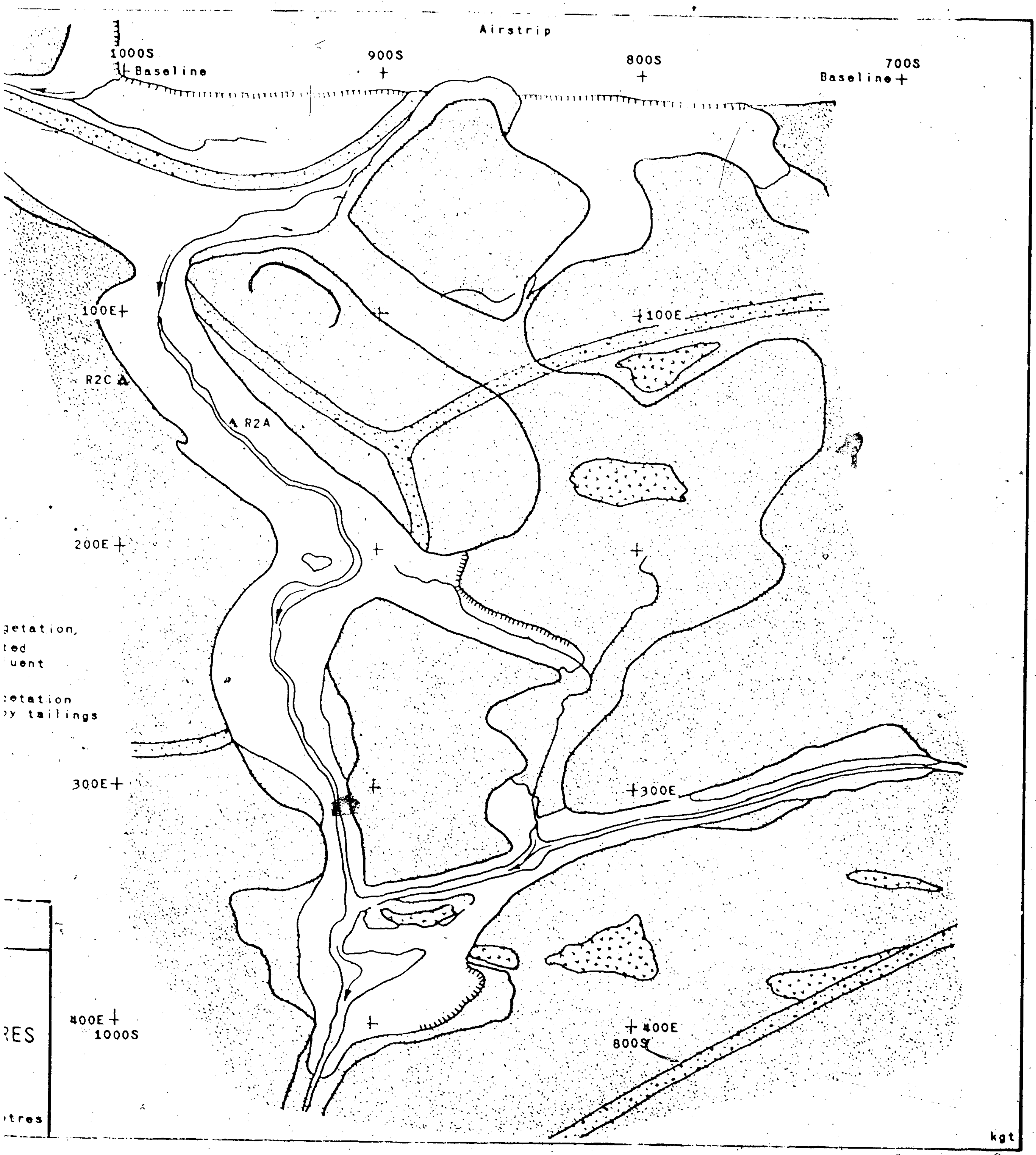

Airstrip
1000S
Baseline
900S
800S
700S
Baseline
100E
100E
R2C
R2A
200E
getation,
ted
uent
etation
y tailings
300E
300E
400E
1000S
400E
800S
RES
tres
kgt

Plate 3-4. The R2 area, situated in a glacial trough in the bedrock (see arrow), has directed tailings over the lip of the hill to a *Picea mariana-Larix laricina* bog in the lower right corner of the photo. 21 July 1971 - 12h00.

tailings by erosion or through thermokarst settling. It is likely that both have contributed.

Very noticeable settling has taken place in the vicinity of 860S-225E. At this location a small amount of tailings was deposited on a spruce bog. Water drainage from the tailings has had little or no effect on most of the bog, and the original plant cover appears undisturbed. However, along one edge of the bog, where the tailings were concentrated, settling of about 1 m took place (Plate 3-5).

The portion of the R2 study area in the vicinity of 880S-390E is located over the lip of the hill and about 20 m lower than sections closer to the airstrip. Tailings have been transported to a corner of a spruce bog, where settling of 0.8 - 1 m has taken place. The revegetation which has occurred in this area is described in section 4.2.1.

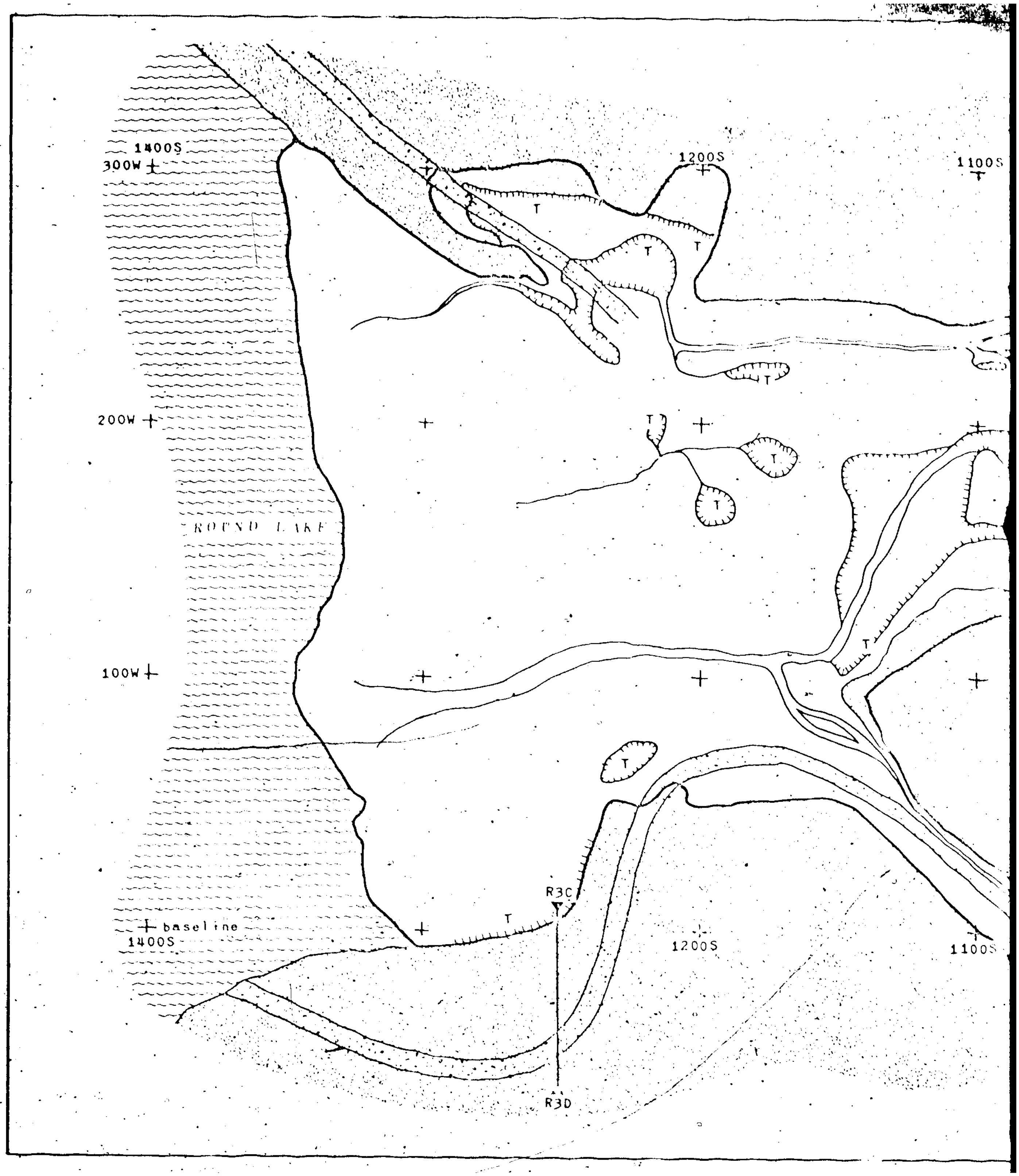
3.6 THE R3 STUDY AREA

R3 is the largest study area and is shown in figure 3-6. While the airstrip base was being created through tailings disposal, only small amounts of tailings were deposited at this site. However, water did drain from the settling ponds and followed the depression to reach Round Lake at the south end of the airstrip. Most tailings now present in this location were placed there after the completion of the airstrip, when the area became a prime disposal site. As a result the tailings have reached a considerable depth.

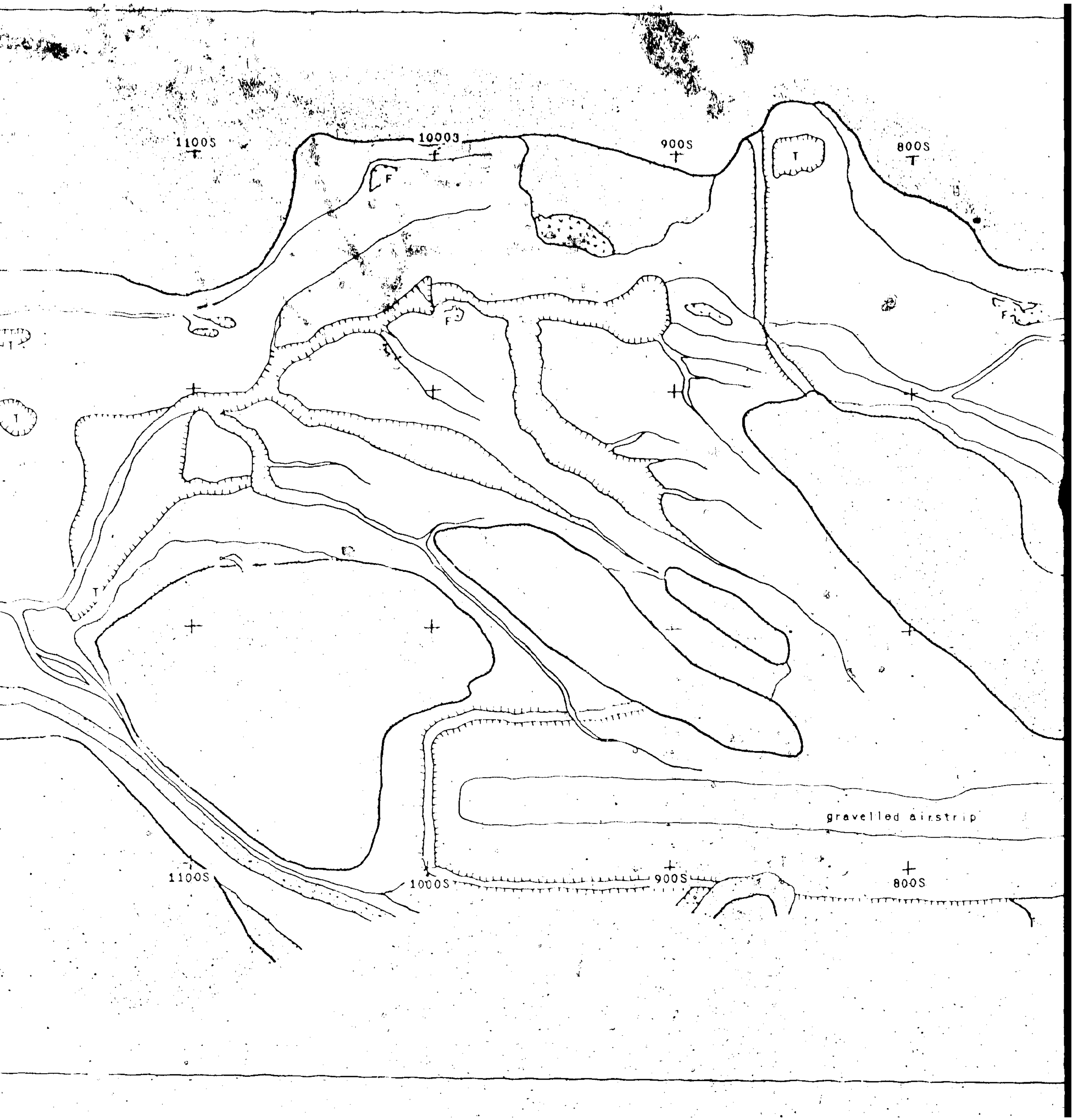
3.6.1 SURFACE DRAINAGE

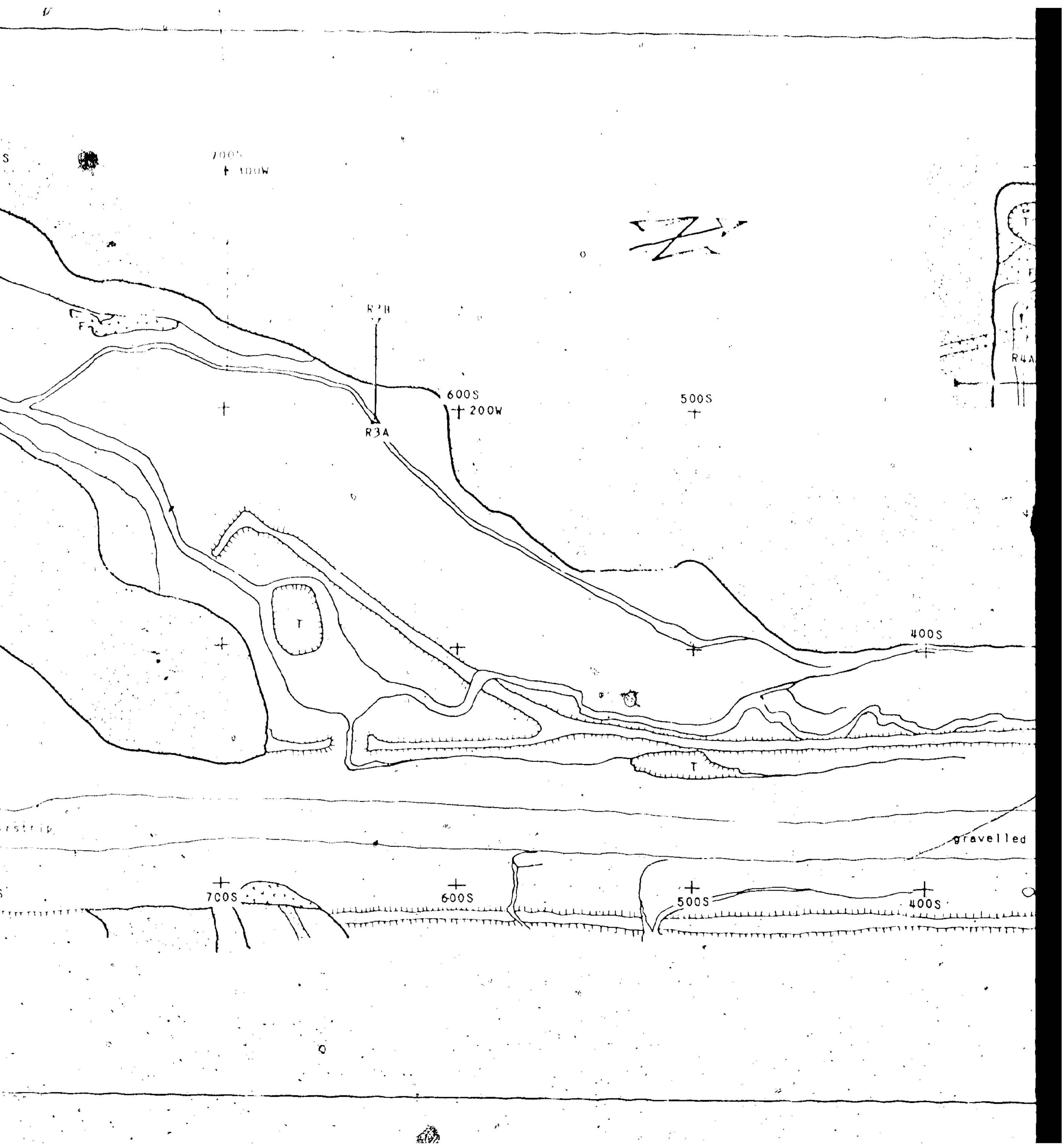
Runoff is actively modifying much of the surface at this location. Large gullies in the vicinity of 1000S-200W are up to 2 m deep and they are still eroding downward through the tailings (Plate 3-6).

Plate 3-5. The surface of the tailings-covered bog in the centre of the photo has sunk approximately 1 m below the surface of the undisturbed bog shown on the left. On the right is a bedrock knoll which restrains the flow of the tailings. The direction of the drainage is toward the background. 31 July 1971.- 14h00.



1400S
300W
1200S
1100S
T
200W
ROUND LAKE
100W
R3C
baseline
1400S
1200S
1100S
R3D


1100S
1000S
900S
800S
T
F
gravelled airstrip
1100S
1000S
900S
800S



700S
100W
N
R3B
R3A
600S
200W
500S
400S
T
F
R4A
gravelled
700S
600S
500S
400S

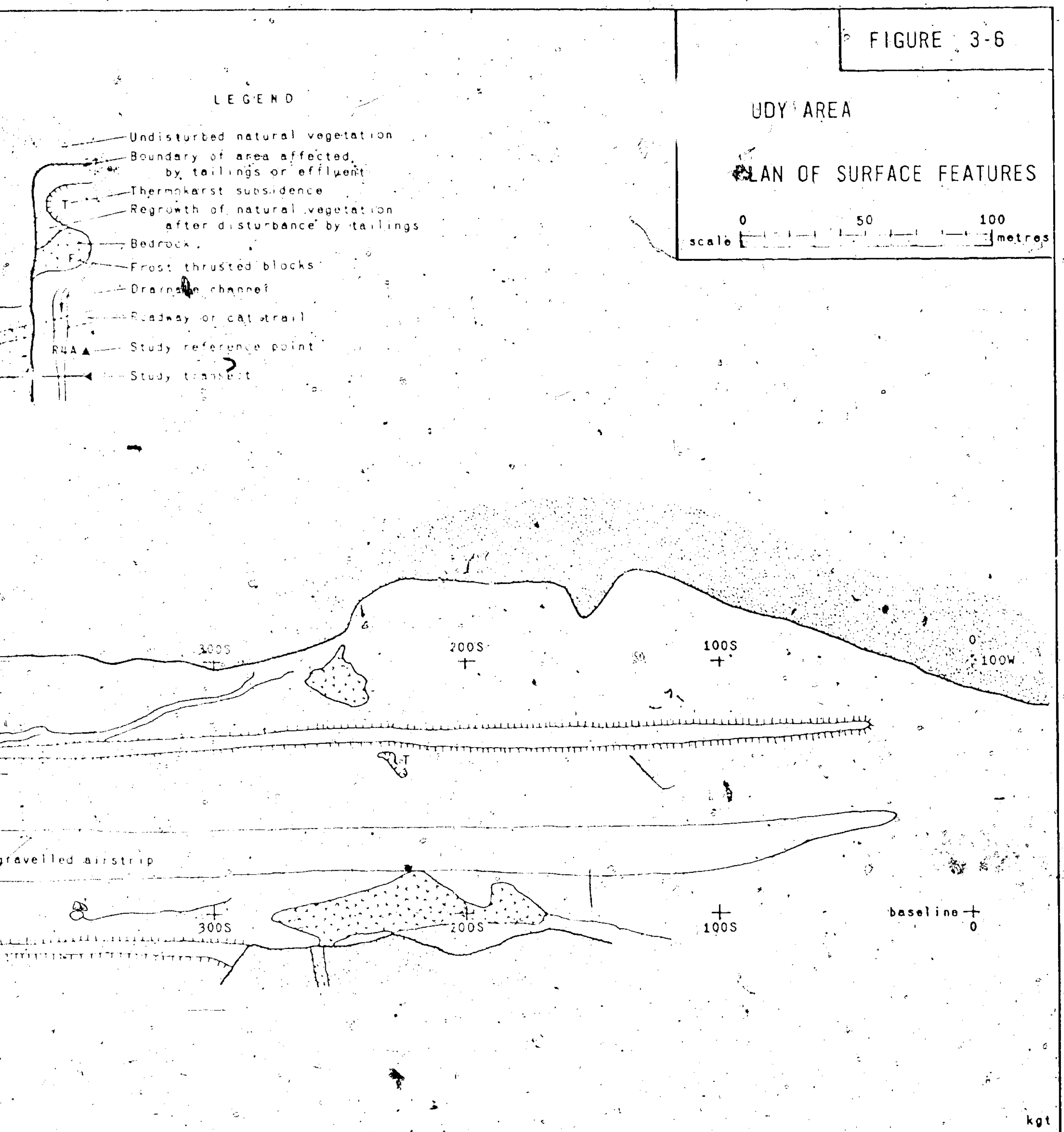


FIGURE 3-6
UDY AREA
PLAN OF SURFACE FEATURES
0
50
100
scale
metres
LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
R4A
300S
200S
100S
0
100W
gravelled airstrip
baseline
kgt

Plate 3-6. This oblique view of the southern portion of the R3 study area shows some of the gullies caused by erosion of tailings deposits. These gullies (right center) reach up to 2 m in depth. 21 July 1971 - 12h30.

Much of the eroded material has been transported to Round Lake to form a large delta projecting more than 100 m into the lake (Plate 3-7). In the higher (northern) part of the site, notably north from 850S-200W and along the west side of the airstrip, dykes (composed of bulldozed tailings) were constructed to contain the tailings. As a result the tailings level west of the middle portion of the airstrip is 1 to 2 m higher than the airstrip surface.

This difference in elevation has led to continuing erosional problems. Runoff from a poorly vegetated bedrock slope to the west has resulted in gullying and the transport of tailings material onto the airstrip. From 1962 onward, spring runoff caused sufficient erosion of these tailings that remedial measures were undertaken by Discovery Mines in an attempt to keep the tailings material off the gravelled surface of the airstrip (Discovery Mines Limited, weekly progress reports). In 1971 it was evident that without regular maintenance of the dyke beside the airstrip, the runoff from the slope between 200S and 500S would flow east across the airstrip, carrying with it considerable amounts of tailings. This process will eventually ruin the airstrip through the creation of a soft surface and the risk of engine damage from the resulting dust. In addition, the increased runoff will intensify the erosion already taking place on the eastern edge of the airstrip, where several gullies up to 60 cm deep are eroding headward toward the gravelled portion of the airstrip.

However, in 1971, the drainage channels existed as shown on Figure 3-6, flowing to the south and to Round Lake.[5] Between 600S and 800S erosion and gullying are minor, since base level is controlled by an

Plate 3-7. Tailings which are now being transported by runoff from former disposal areas are creating a large delta at the north end of Round Lake. 21 July 1971 - 12h30.

overburden muskeg dyke and a bedrock outcrop in the vicinity of 860S-220W. To the south of this dyke severe gullying is occurring. The base level for much of this section is Round Lake and the tailings surface in this area reaches 10 m above that. Although not all of the 10 m is erodable tailings, the gradient is such that considerable gullying will take place for years to come, and large quantities of eroded tailings will continue to infill Round Lake.

3.6.2 THERMOKARST

There are several active thermokarst features in this study area. One, on the surface of the airstrip, is in a location which began to receive tailings in 1950 (Plate 3-8). This suggests that thermokarst processes may remain active where there has been a cover of tailings for more than two decades. Shallow depressions at 500S-60W and 675S-120W also indicate continued thawing of the organic material below the tailings deposits. The latter depression is rather large in area so that only in times of peak runoff will water flow from the depression to Round Lake.[5]

There is little evidence of thermokarst in the section where there is active gullying (South of 800S). It is unlikely that bogs existed in this location to begin with, because of the slope and southerly aspect. However, there are a number of thermokarst depressions around the margins of Round Lake. The most recent (Plate 3-9), located at 1260S-245W where the tailings have buried a spruce bog, has collapsed 1 m. Several other shallow thermokarst depressions are evident in the

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5. Since this lake does not drain into Giauque Lake, the mill effluent could not contaminate the mine's water supply via this route.

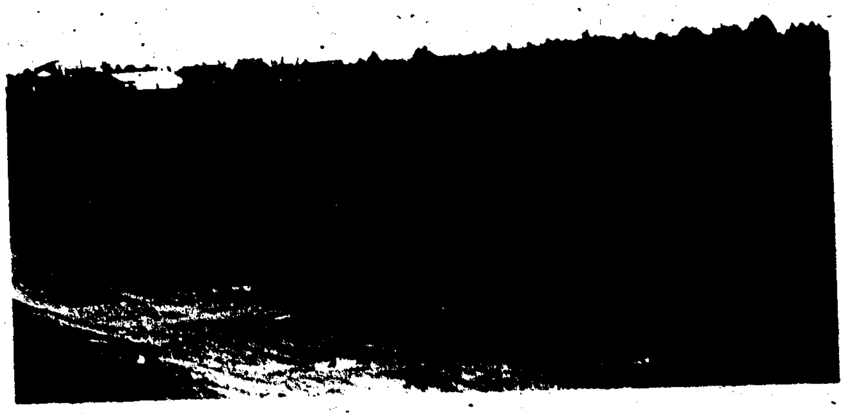


Plate 3-8. These thermokarst depressions, located at approximately 2258-60W, have occurred at the edge of the airstrip in a location where tailings were deposited beginning in 1950. 7 August 1971 - 09h30.

Plate 3-9. This recent 1 m deep thermokarst depression is located at a bog/tailings contact which was formerly near the shore of Round Lake. The geologist's hammer in the foreground gives scale. 3 August 1971 - 16h00.

delta portion of the study area. A minor winter road at [illegible] has also induced thermokarst settling where it passes from the tailings onto the bog surface. Other than the infiltration which occurs in the thermokarst depressions, most of the drainage in the area is surface and towards Round Lake.

There is little or no revegetation of the tailings in this area. What revegetation has occurred is found along the margins of the tailings or adjacent to frost-thrust rocks, or on overburden dyke material.

3.7 THE R1 STUDY AREA

The final study area is one which has most recently received tailings from the mill. It is located closer to the mill than the other areas, and was apparently chosen when it became apparent that the R4 site could receive no additional tailings without extensive damage to the airstrip. The site has two advantages for the disposal of mill tailings. Its proximity to the mill greatly reduced maintenance problems on the tailings disposal pipeline, especially in severe cold when there were constant problems with the line freezing. In addition the site is formed by a large gully which has a steep gradient to Giauque Lake, some 150 m below. Thus the area provides a virtually limitless disposal sink. Since efforts had previously been made to direct tailings away from Giauque Lake (and the domestic water supply), it is probable that disposal at this location was carried out with the knowledge that mine closure would occur in a matter of several years.

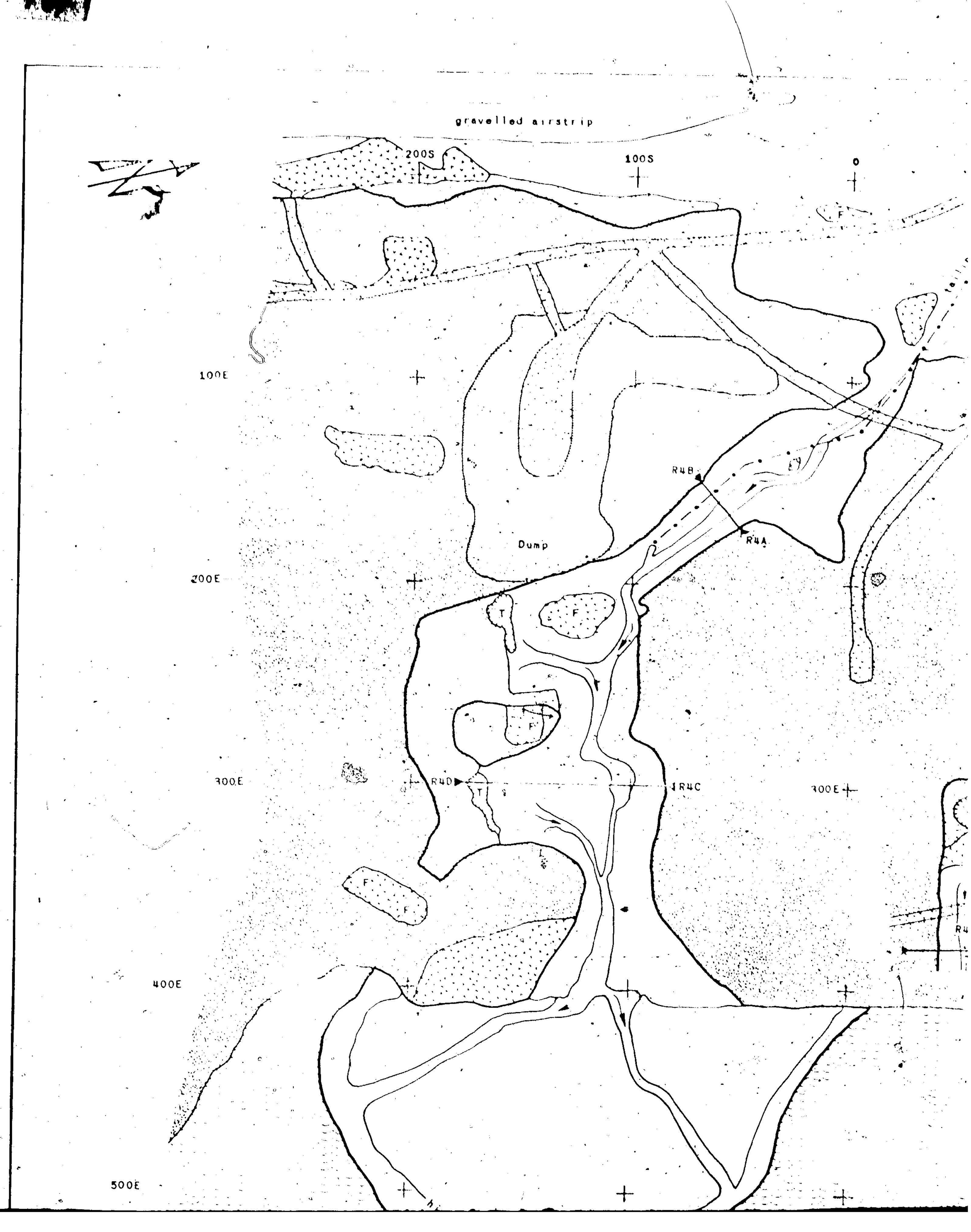
3.7.1 SURFACE DRAINAGE

Although most of the tailings flowed into the lake, some remained in a small depression to the east of the dump (Figure 3.7). This depression was formerly occupied by spruce bog, the northern half of which has been buried by tailings. The southern half is free of tailings but virtually all the [illegible] have been killed by mill effluent and/or by a rise in the water table caused by tailings disposal.

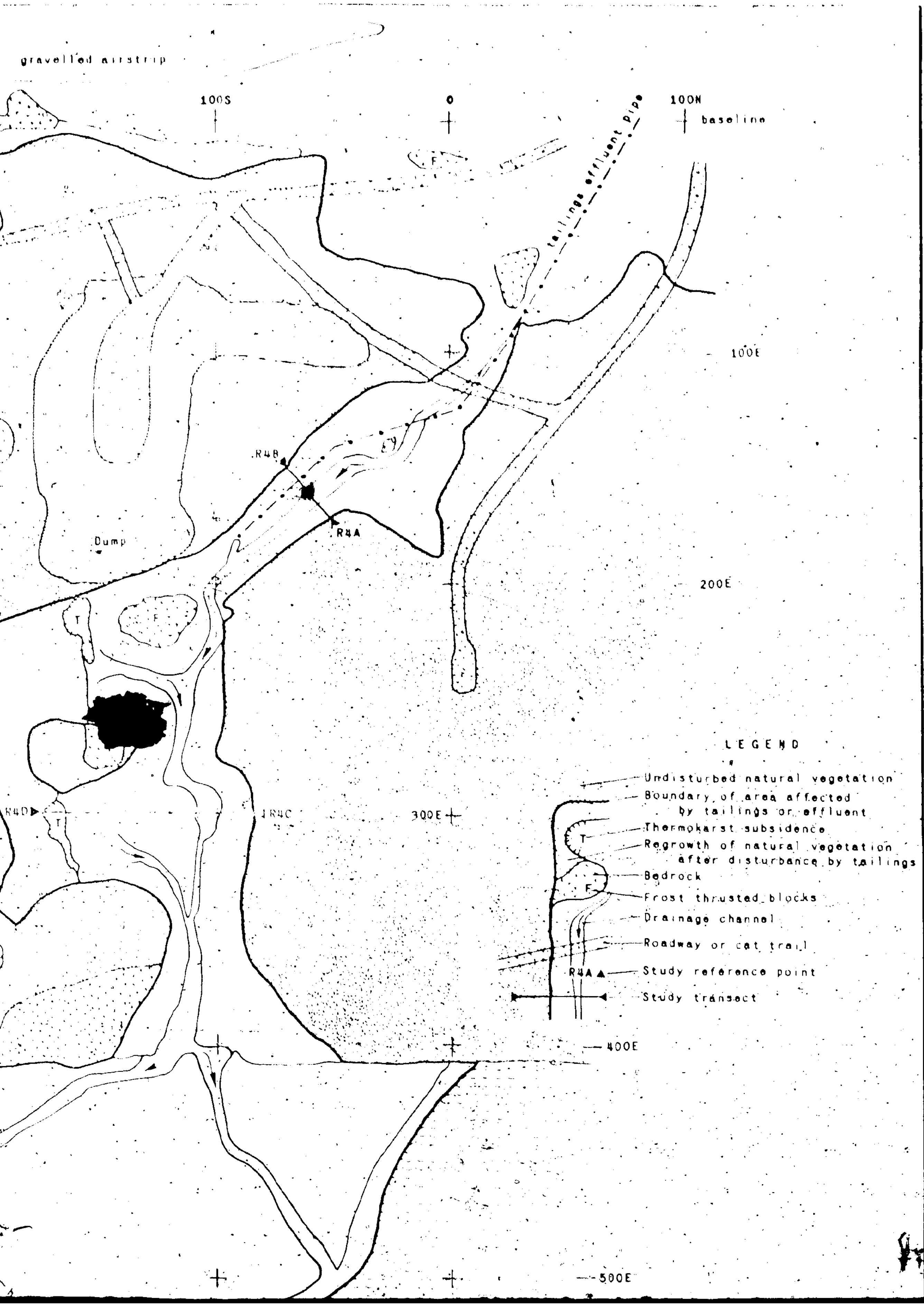
The slope down the hill to the lake is badly gullied, and is best described as a tangle of dead trees, shrubs, and tailings. Where the tailings enter the lake a delta, some 150 by 200 m, has been built up (Figure 3.7; Plate 3.10). Most of the delta surface is relatively stable but two channels up to 2 m deep have been cut by runoff from upslope. Wave action is eroding the north side of the delta, resulting in a wide shelf of shallow water (Plate 3.11). Some of the eroded material is being transported southward by littoral drift, and deposited between the delta and an island. This process may eventually extend the delta to the island. Since the water on the opposite (southeast) side of the island is very shallow, this blockage will undoubtedly decrease water circulation and alter the hydrologic nature of the bay.

3.7.2 THERMOKARST

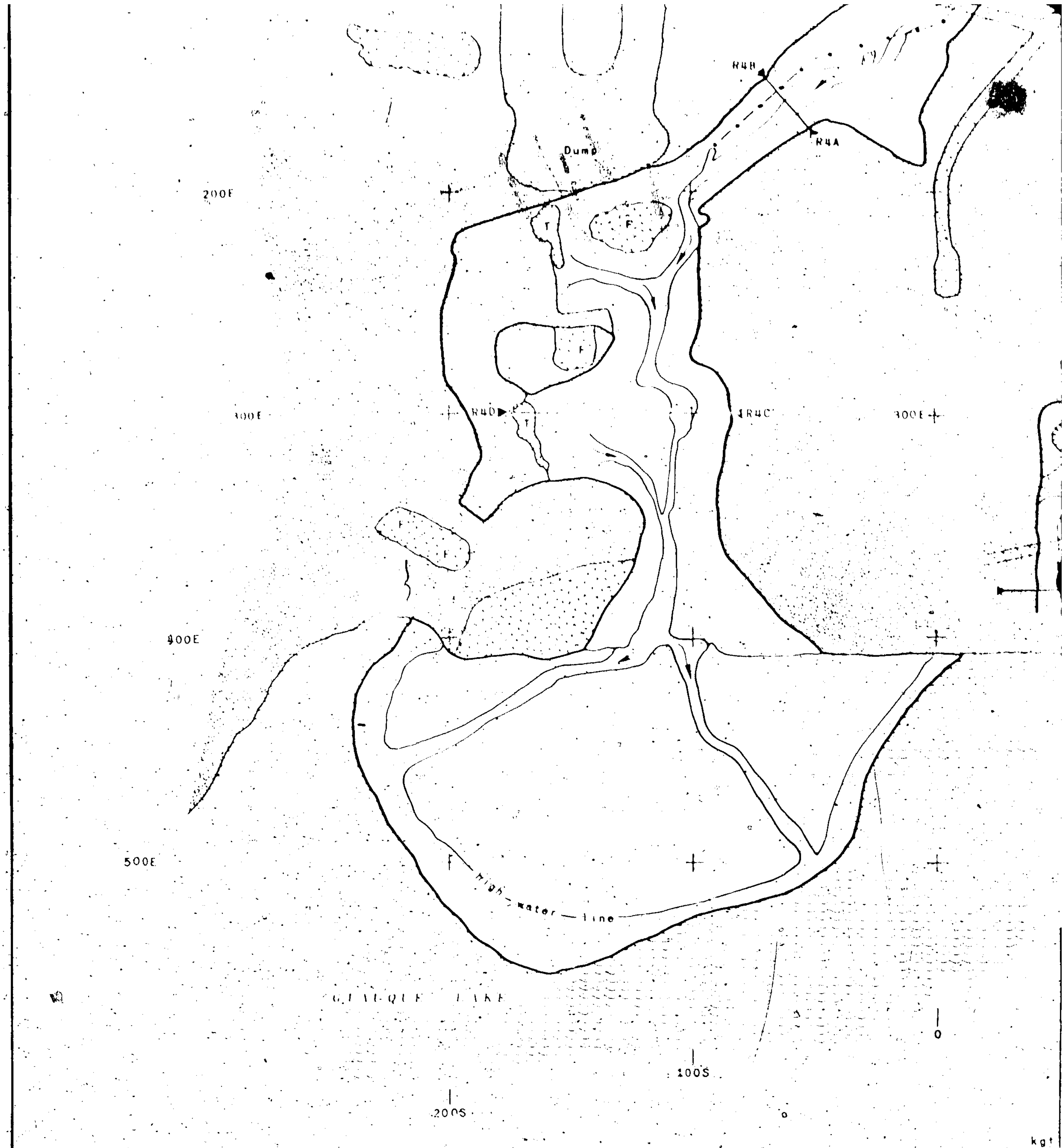
Some thermokarst settling has occurred in the upper (former bog) section, but most of it has been masked by continuing erosion. Neverthe-[illegible] settling at the centre of the bog, at the limit of tailings deposition, has been in the order of 40 cm. No evidence of thermokarst activity was


gravelled airstrip
200S
100S
0
100E
200E
300E
400E
500E
Dump
R4B
R4A
R4D
R4C
300E
F
T

2 of



gravelled airstrip
100S
0
100N
baseline
tailings effluent pipe
F
100E
R4B
R4A
Dump
200E
T
F
R4D
T
R4C
300E
400E
500E
LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect



Dump
R4B
R4A
200E
F
T
R4D
R4C
300E
300E
400E
500E
High-water line
LAKE
0
100S
200S
kgt

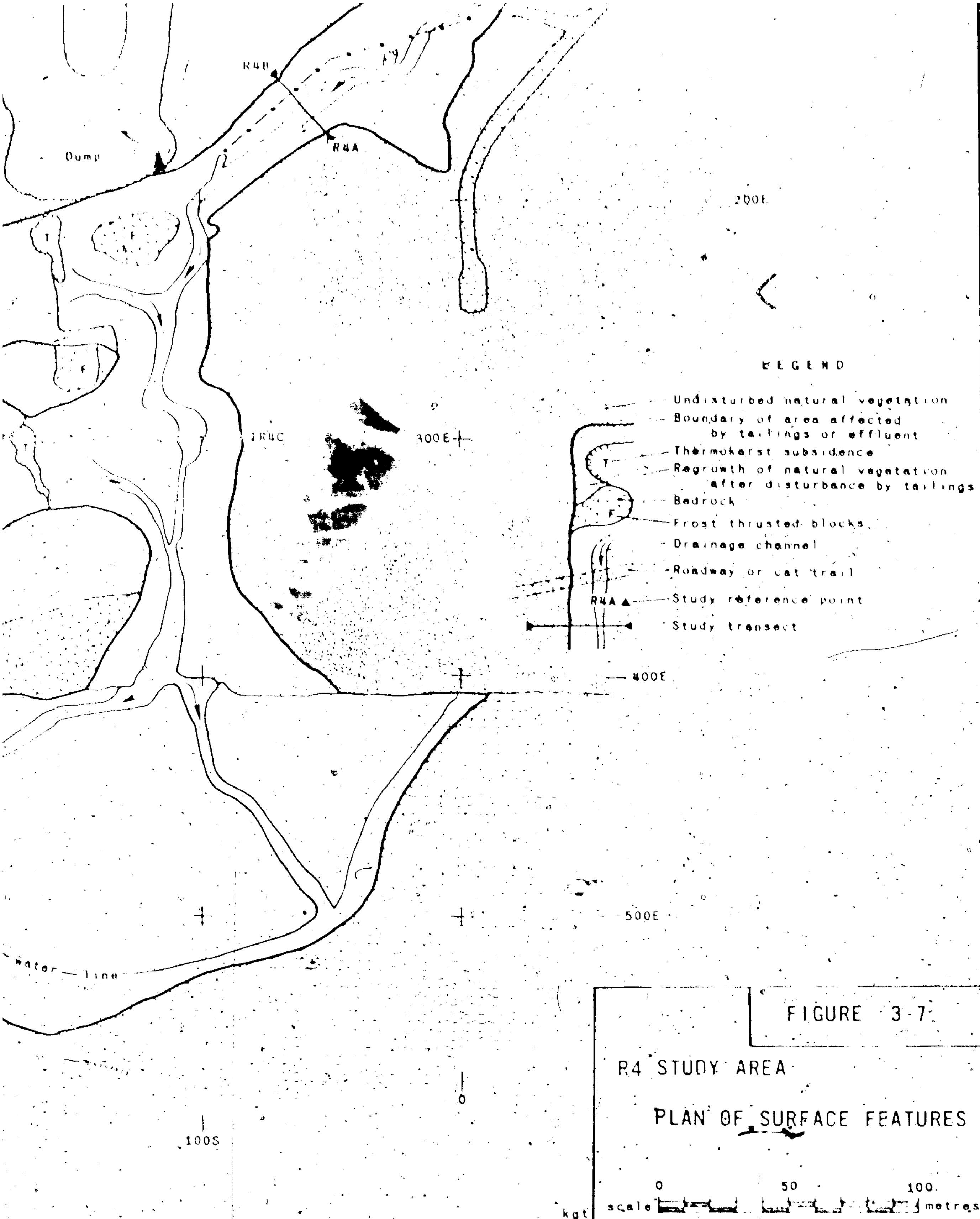


FIGURE 3-7

R4 STUDY AREA

PLAN OF SURFACE FEATURES

Plate 3-10. The most recent tailings disposal area consists of a gully leading to Giraque Lake where a delta, 150 by 200 m, has been formed. 21 July 1971 - 12h30.

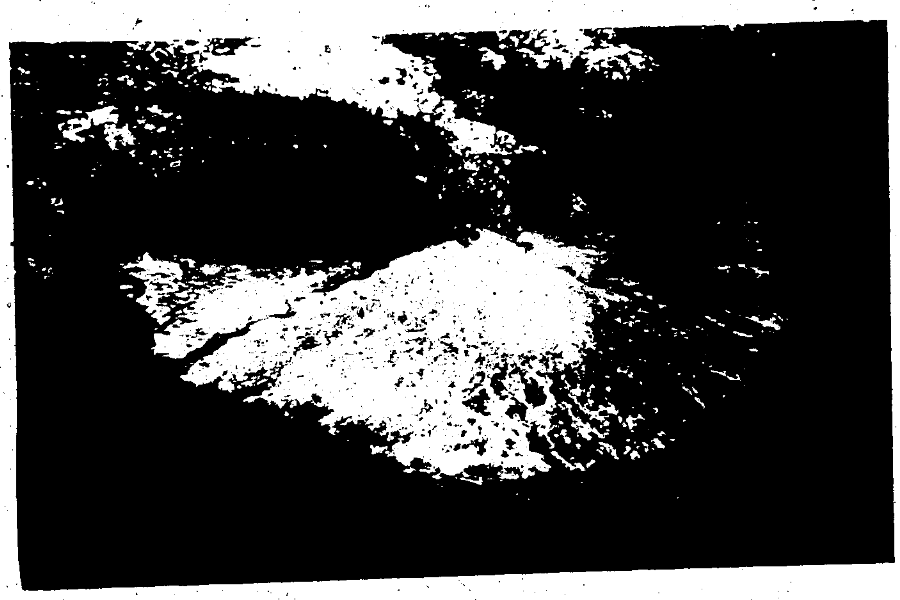


Plate 3-11. Tailings flowing down the gully have created this large delta into Giauque Lake. Runoff now bifurcates at the base of the hill and has incised two channels into the surface of the delta. 21 July 1971 - 12h30.

found on the delta extending into Ciaapis Lake.

Although there is no vegetation growing on the delta, plants are regenerating successfully on the upper section, primarily at sites with a thin cover of tailings.

CHAPTER 4

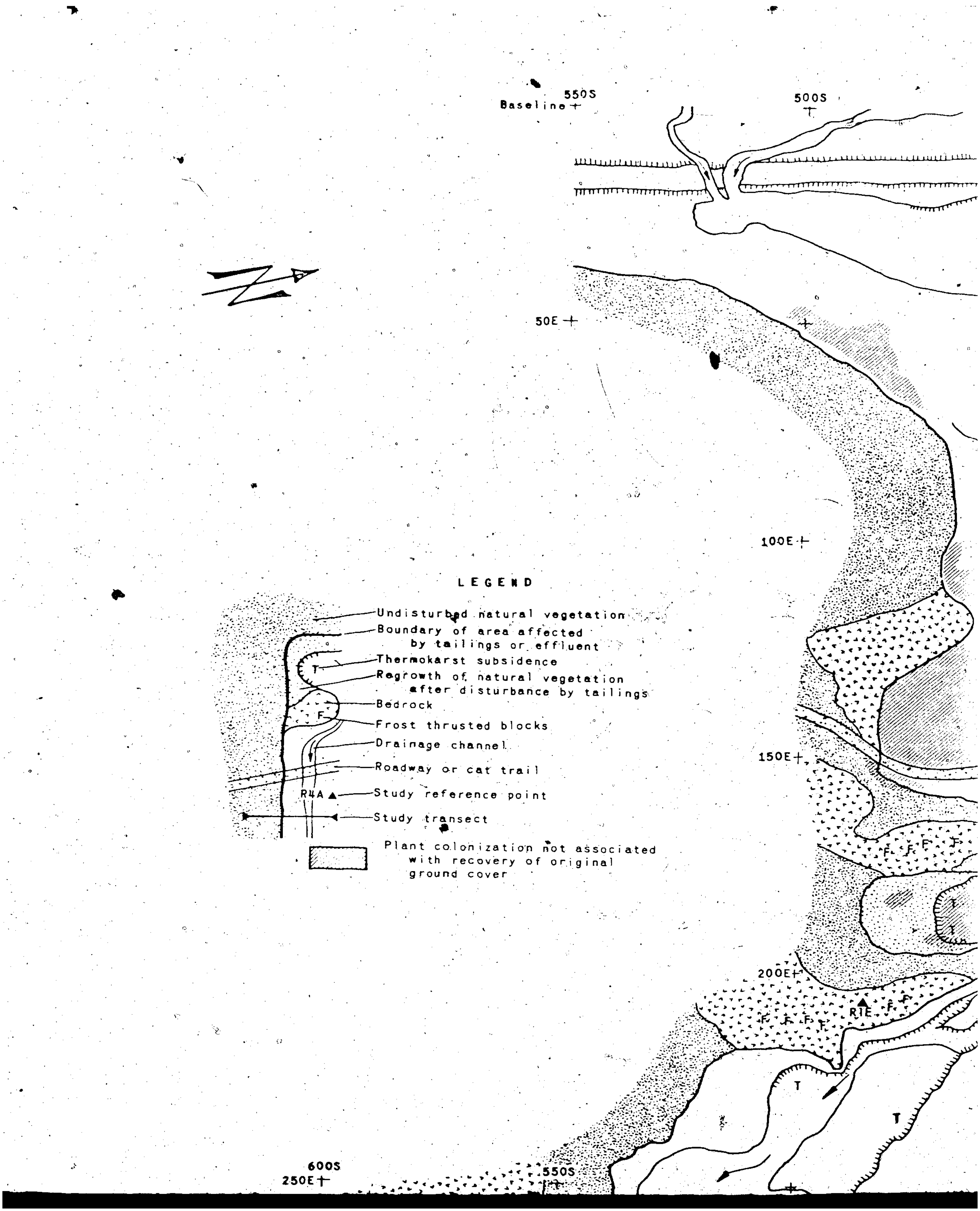
REVEGETATION

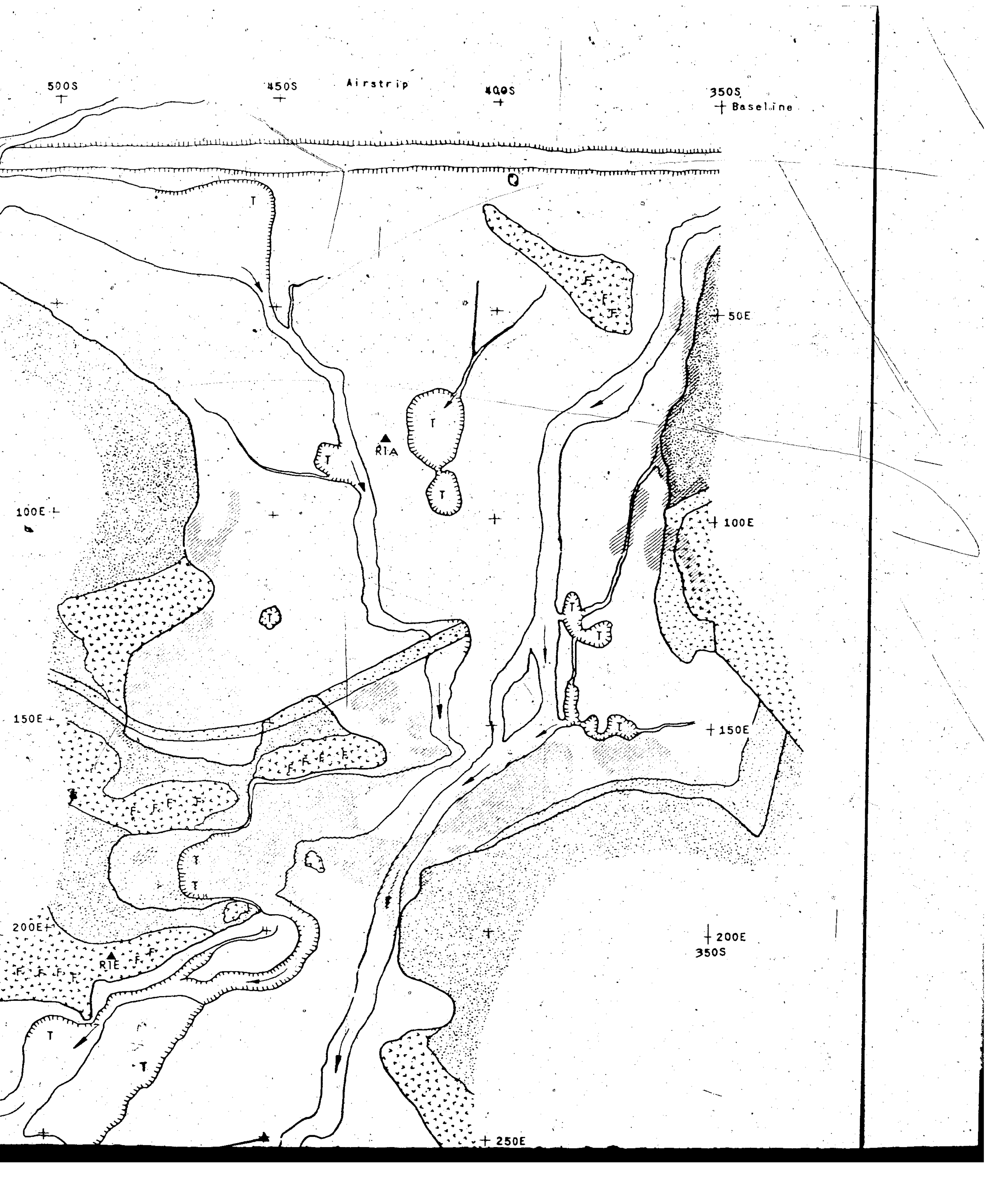
In order to determine the processes of plant succession at work on the Discovery Mine tailings, detailed investigations were undertaken at several locations. This chapter and the two following discuss the details of plant succession and postulate the controlling factors. Chapter 4 presents observations of primary and secondary plant succession within the framework of the four study areas just described. Chapter 5 summarizes revegetation experience at other mines and discusses the factors thought to control the type and rate of plant succession. Chapter 6 then draws on the previous two chapters to outline and briefly discuss the patterns of plant colonization which describe the situation at Discovery.

4.1 THE R1 STUDY AREA

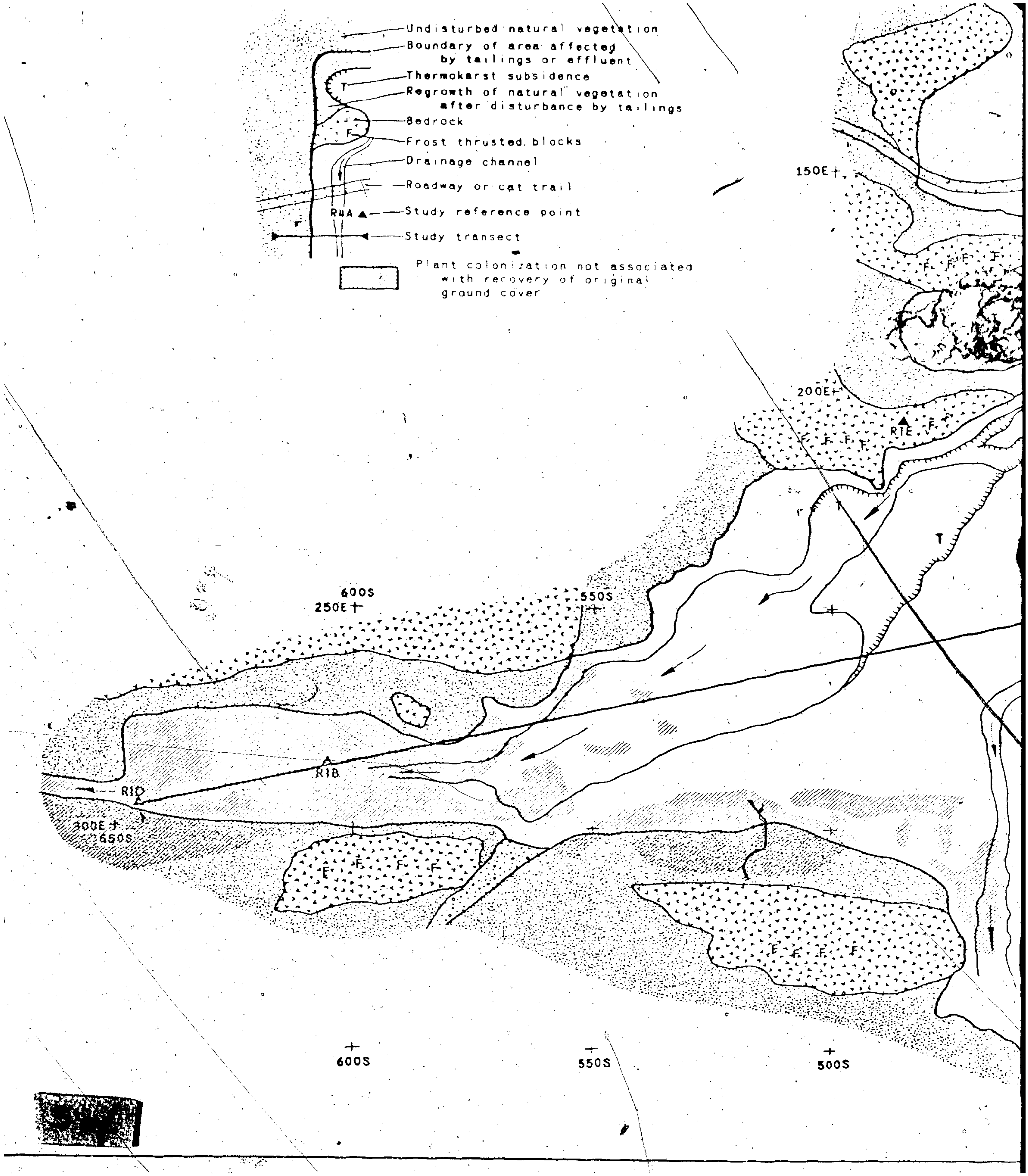
The R1 tailings disposal area is the oldest at the mine site and for this reason is the most interesting with respect to the time element of revegetation[1]. Those areas showing recovery of the former ground cover are outlined in Figure 4-1. Although a large portion of the area remains bare, sizeable sections have been colonized[2]. Most of the primary plant succession is occurring where the tailings deposits

1. "Revegetation" is used to refer to the re-establishment of vegetation. Implied is the fact that the whole area once had a full vegetative cover that has been disrupted to some extent by the deposition of tailings. Revegetation is taken to include both the colonization of a tailings deposit and the recovery of components of the original plant cover.
2. Colonization is taken to mean the establishment of plants not present or not common in the original plant cover.


550S
Baseline
500S
50E
100E
150E
200E
R1E
F
T
600S
250E
550S
LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
R4A
Study reference point
Study transect
Plant colonization not associated with recovery of original ground cover



500S
450S
Airstrip
400S
350S
Baseline
50E
R1A
100E
100E
150E
150E
200E
200E
350S
R1E
250E


Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
Plant colonization not associated with recovery of original ground cover
R4A
T
F
150E
200E
R1E
600S
250E
550S
R1B
R1D
300E
650S
600S
550S
500S

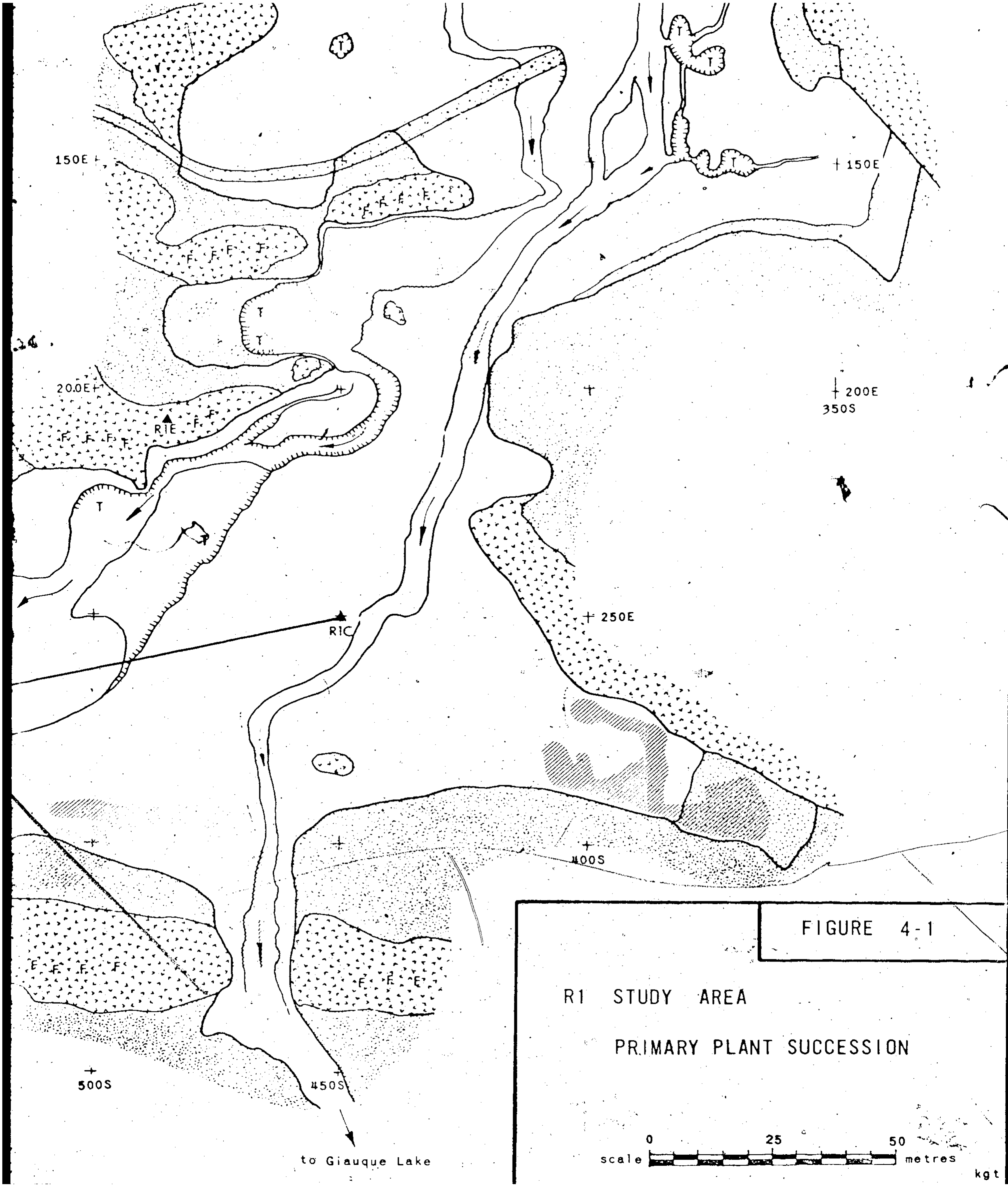


FIGURE 4-1

R1 STUDY AREA

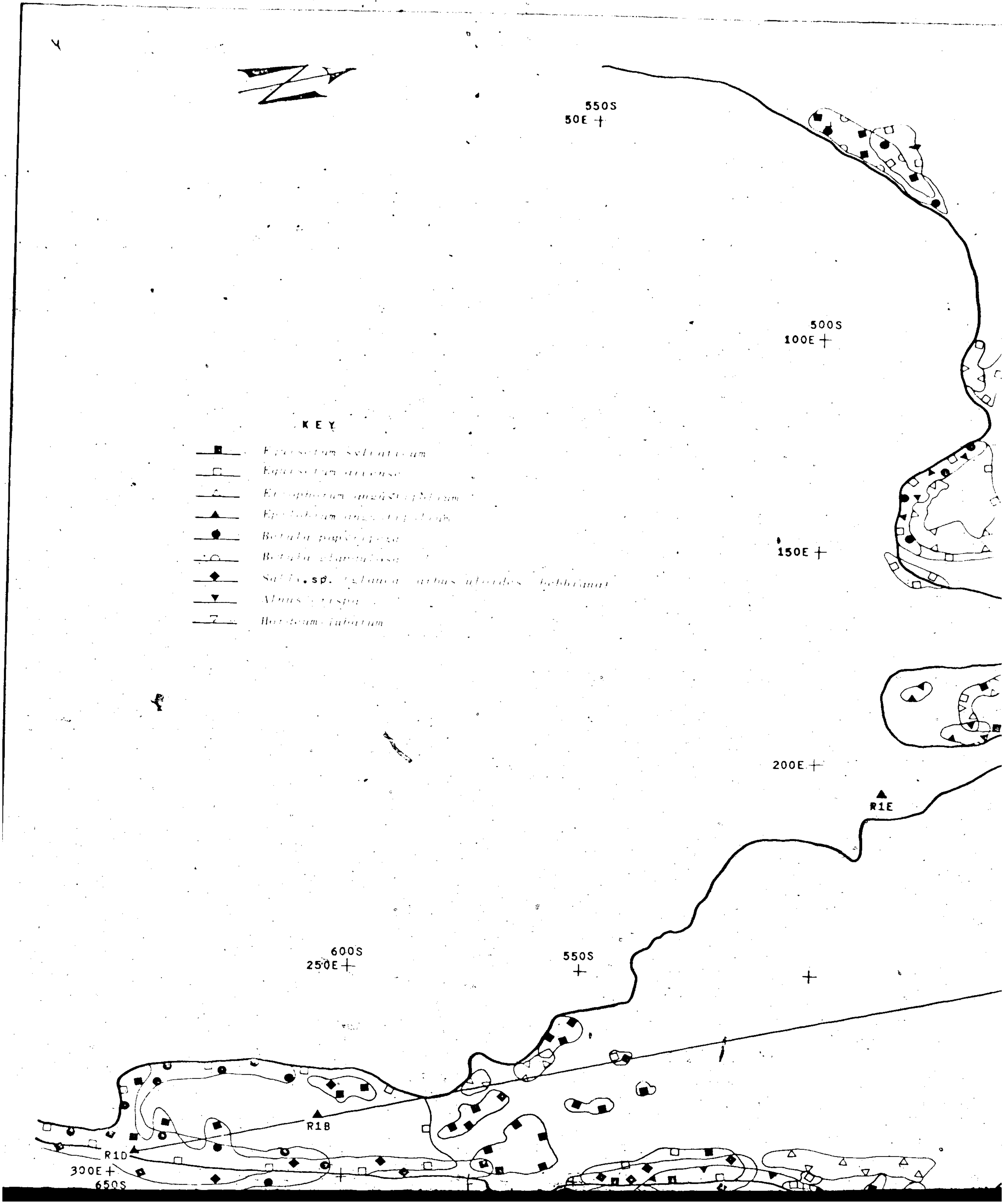
PRIMARY PLANT SUCCESSION

are relatively shallow, or on sections of tailings that are adjacent to undisturbed locations. The distribution of the major colonizing species is shown in Figure 4-2.

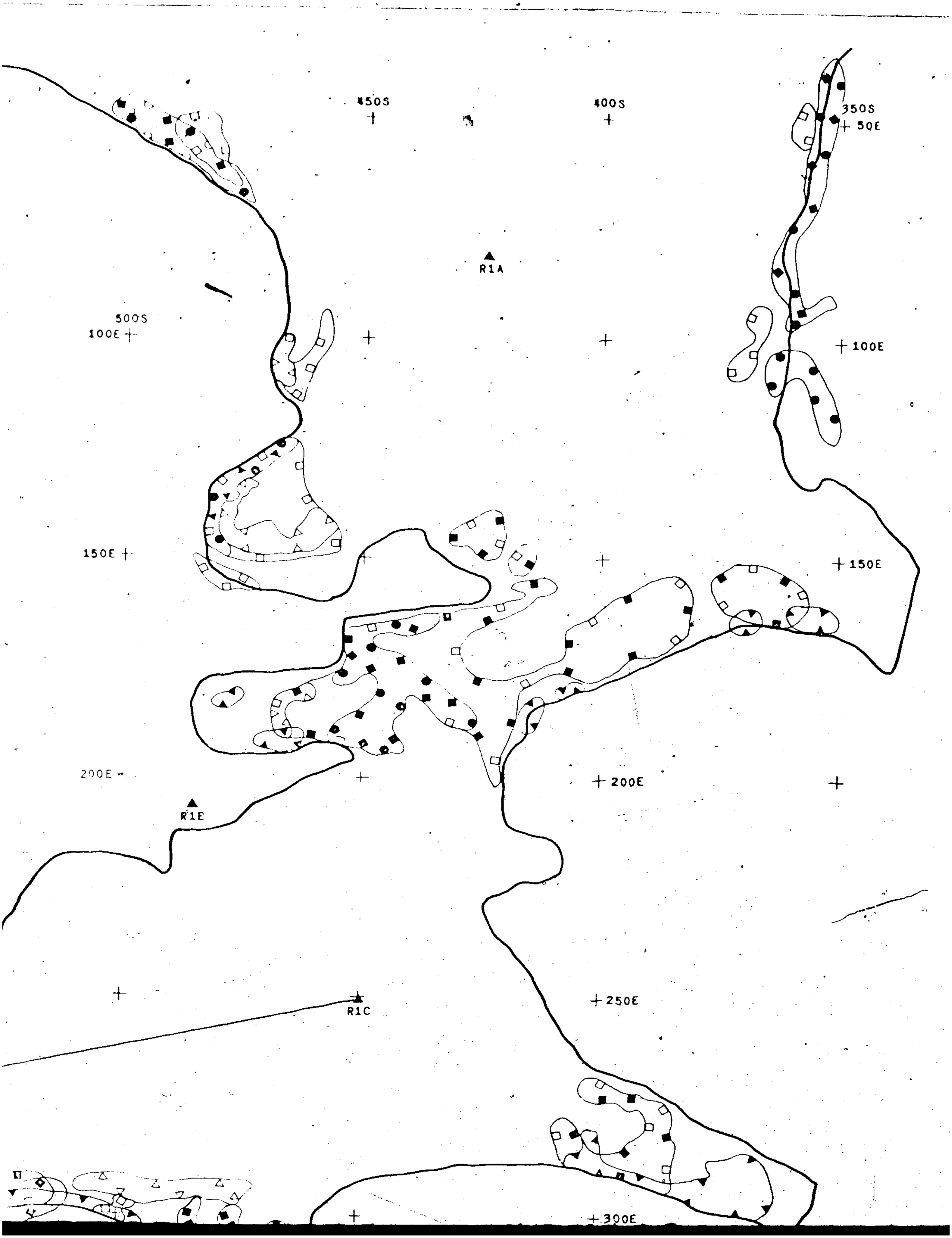
4.1.1 REVEGETATION ALONG A TAILINGS/BEDROCK CONTACT

Plate 4-1 illustrates the barrenness of much of the study area. Plant growth occurs only along the margins of the tailings deposits. Plate 4-2 illustrates one such situation. In this instance plant growth is taking place along a tailings-bedrock interface which forms the western boundary of a depression centered near 470S-142E. On the bedrock to the left of the photo, the highest level of tailings or effluent is marked by the absence of lichens. Along the interface a number of species grow in a hedge-like manner. *Betula papyrifera*, *Alnus crispa*, and *Salix bebbiana* are the dominant species, but *Betula glandulosa*, *Salix arbusculoides*, and *S. glauca* are also present. The herb layer of the depression in the nearby tailings consists of *Equisetum arvense* and *E. sylvaticum*. In the lowest and dampest section *Eriophorum angustifolium* dominates, although *Equisetum arvense* is also present.

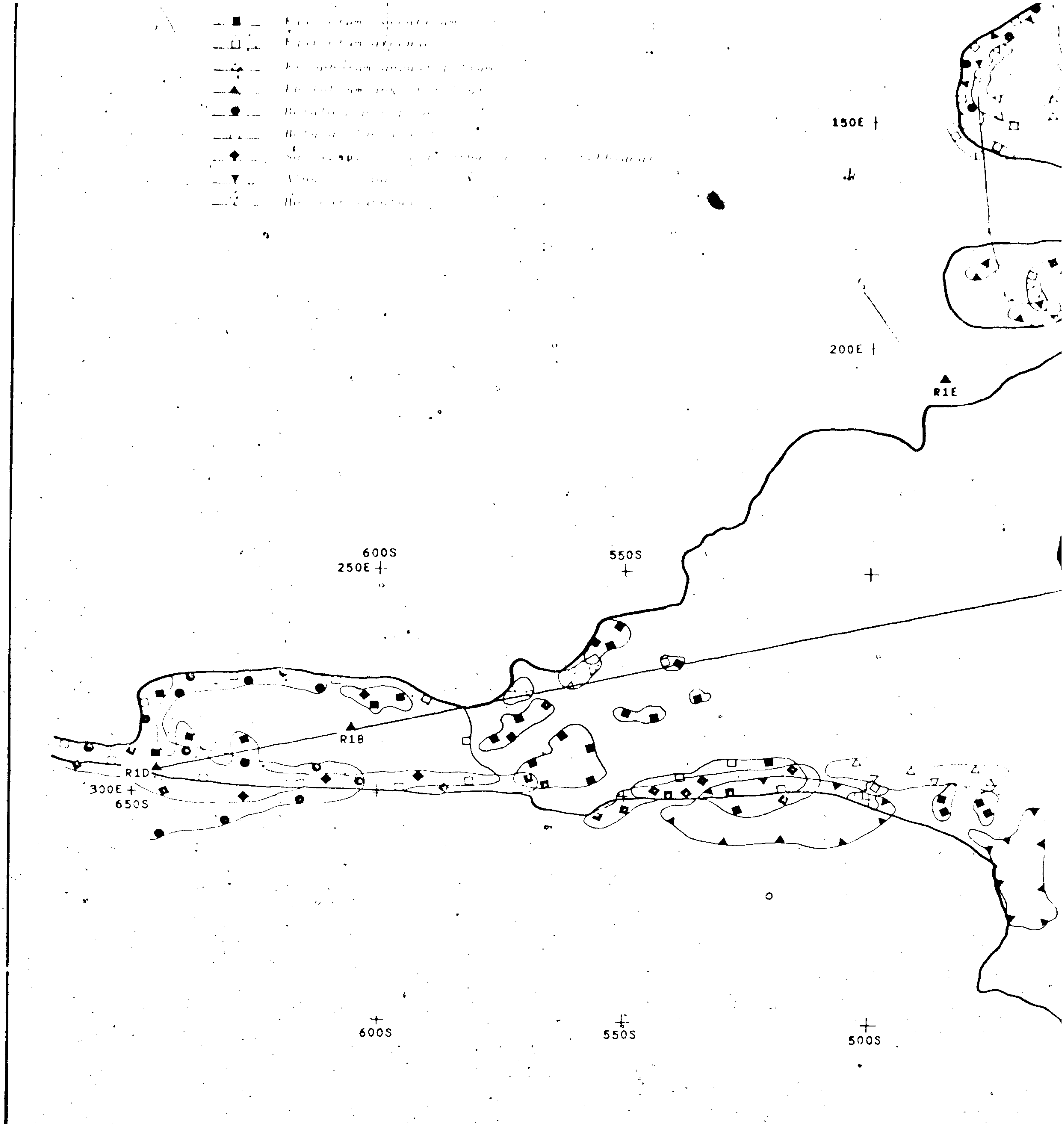
The above phenomena indicate that the availability of nutrients is important in enabling plants to grow on the tailings. It is possible to speculate on the reasons for the conspicuous hedge-like growth along the edge of the tailings. At the edge, the cover of tailings is thinnest, so that the nutrients in the former organics layer (now buried) are available to the roots of seedlings. In addition, in those locations where the tailings are bordered by thinly covered or bare rock the plants are supplied with nutrients washed down by rainwater

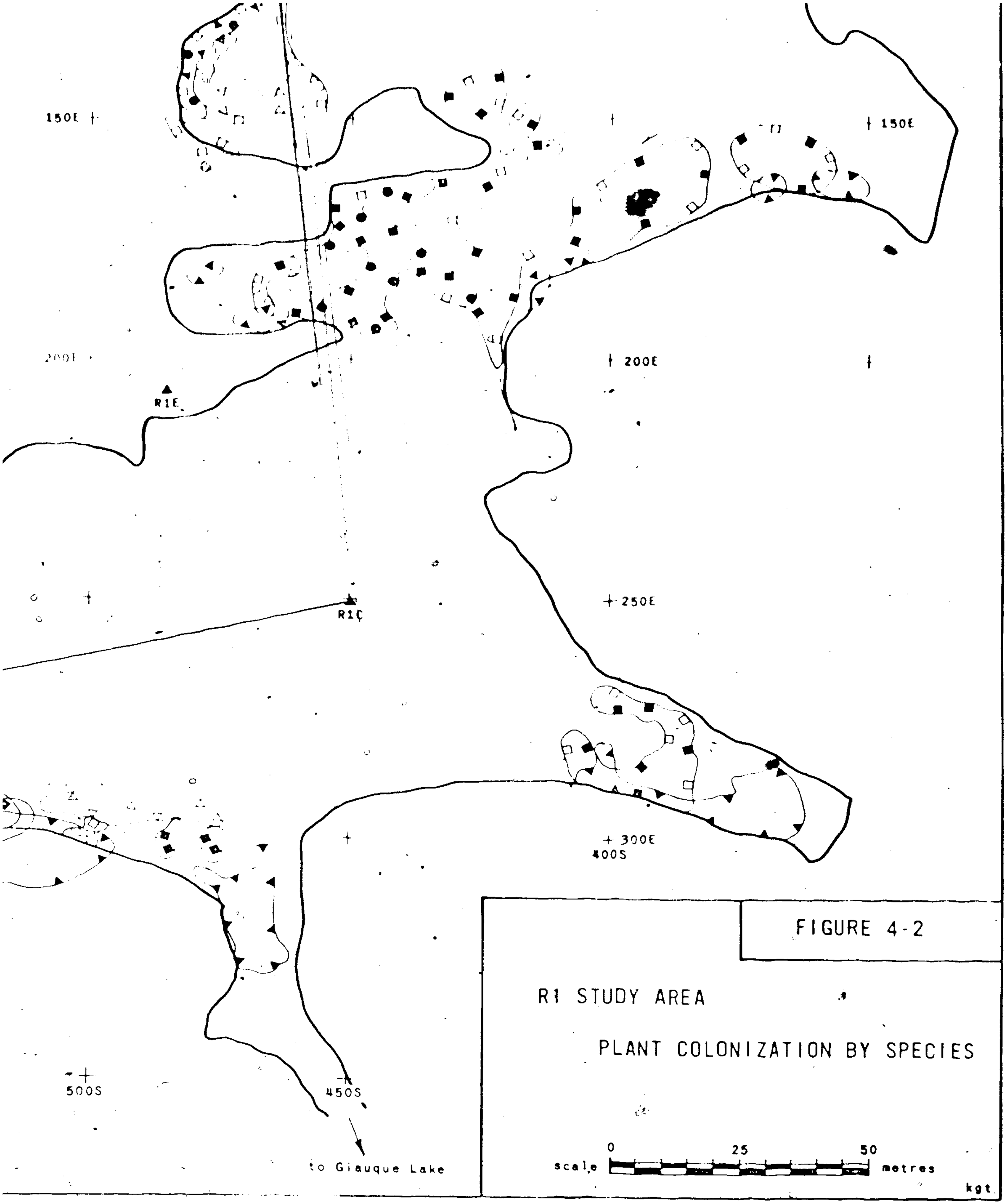

550S
50E
500S
100E
KEY
150E
200E
R1E
600S
250E
550S
R1B
R1D
300E
650S

2 of 1



450S
400S
350S
50E
R1A
500S
100E
100E
150E
150E
200E
200E
R1E
R1C
250E
300E


150E
200E
R1E
600S
250E
550S
R1B
R1D
300E
650S
600S
550S
500S


150E
150E
200E
200E
R1E
R1C
250E
300E
400S
500S
450S
to Giauque Lake
FIGURE 4-2
R1 STUDY AREA
PLANT COLONIZATION BY SPECIES
0
25
50
scale
metres
kgt

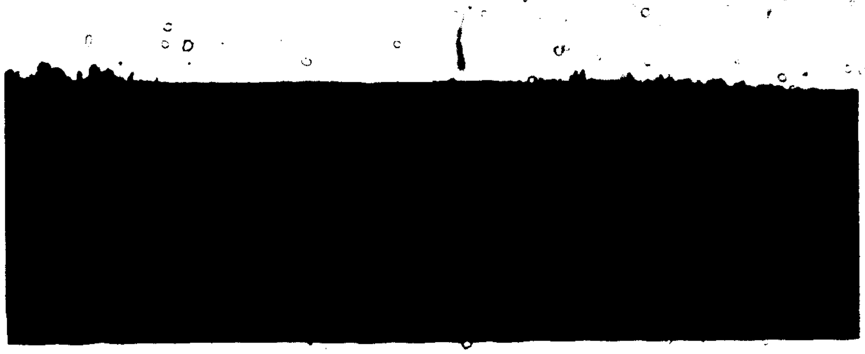


Plate 4-1. Much of the RF study area is completely devoid of vegetation. This view, looking south, shows the portion of the study area adjacent to the airstrip. 27 July 1971 15h30.

Plate 4-2. A hedge-like growth, dominated by *Betula papyrifera* and *Alnus crispa*, occurs along the tailings/bedrock interface at 475S-130E. 15 July 1971 - 14h15.

from the slope above. Of course such runoff need not stop at the bedrock-tailings interface, but may also reach depressions located near the edge of the tailings deposits. The section of the tailings discussed above is bordered on three sides by inward-sloping bedrock. The depression mentioned supports several plant species, whereas more centrally located depressions host little or no vegetation. The availability of runoff-borne nutrients may explain this difference in plant growth.

4.1.2 REVEGETATION OF A PARTIALLY INFILLED BOG

Another location of interest centres at 470S-190E. Here half of a bog approximately 35 by 15 m in area is buried by tailings. The original vegetation at this location was *Picea mariana* with well-developed hummocks on which *Ledum groenlandicum* and lichens were present. Most of the trees, which were less than 10 cm dbh, have been cut above winter snow level, likely by Indians for domestic use at nearby campsites[3].

The surface of the tailings-covered northern half of the bog has settled nearly 1 m below the level of the southern half. In this northern portion plant growth is vigorous. Small patches of *Betula papyrifera*, *Salix arbusculoides*, *S. glauca*, and *S. bebbiana* are surrounded by a herb layer of *Equisetum arvense*, *E. sylvaticum*, *Eriophorum angustifolium*, and *Carex aquatilis* (Plate 4-3). It appears

3. Dogrib Indians, now based in Yellowknife and Detah still maintain a nomadic lifestyle and range through this country hunting caribou in the fall and winter. While the mine was in operation these Indians frequently camped in the vicinity. There is considerable evidence of campsites in the R1 study area. Many of the trees have been cut and several cache platforms remain.

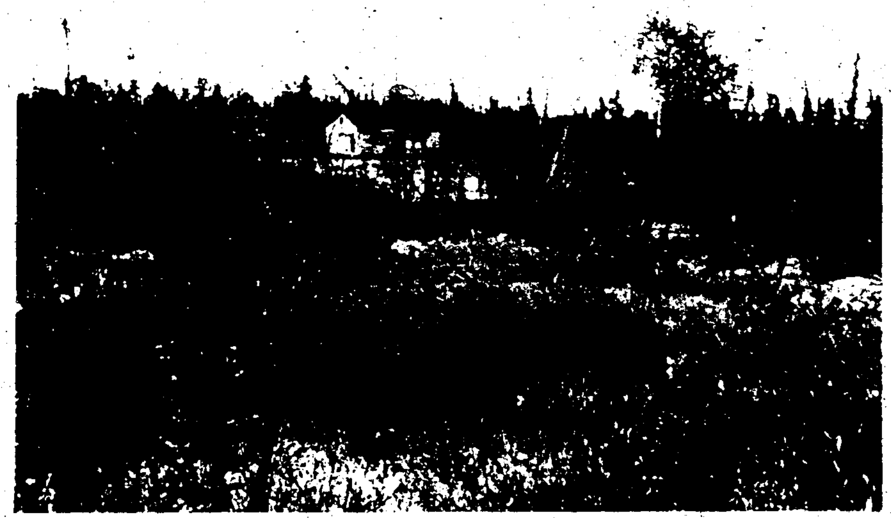


Plate 4-3. Revegetation in the vicinity of 470S-190E takes the form of small patches of *Salix arbusculoides*, *S. bebbiana* and *S. glauca* with a herb layer of *Equisetum arvense*, *E. sylvaticum*, *Eriophorum angustifolium*, and *Carex aquatilis*. 15 July 1971 - 14h00.

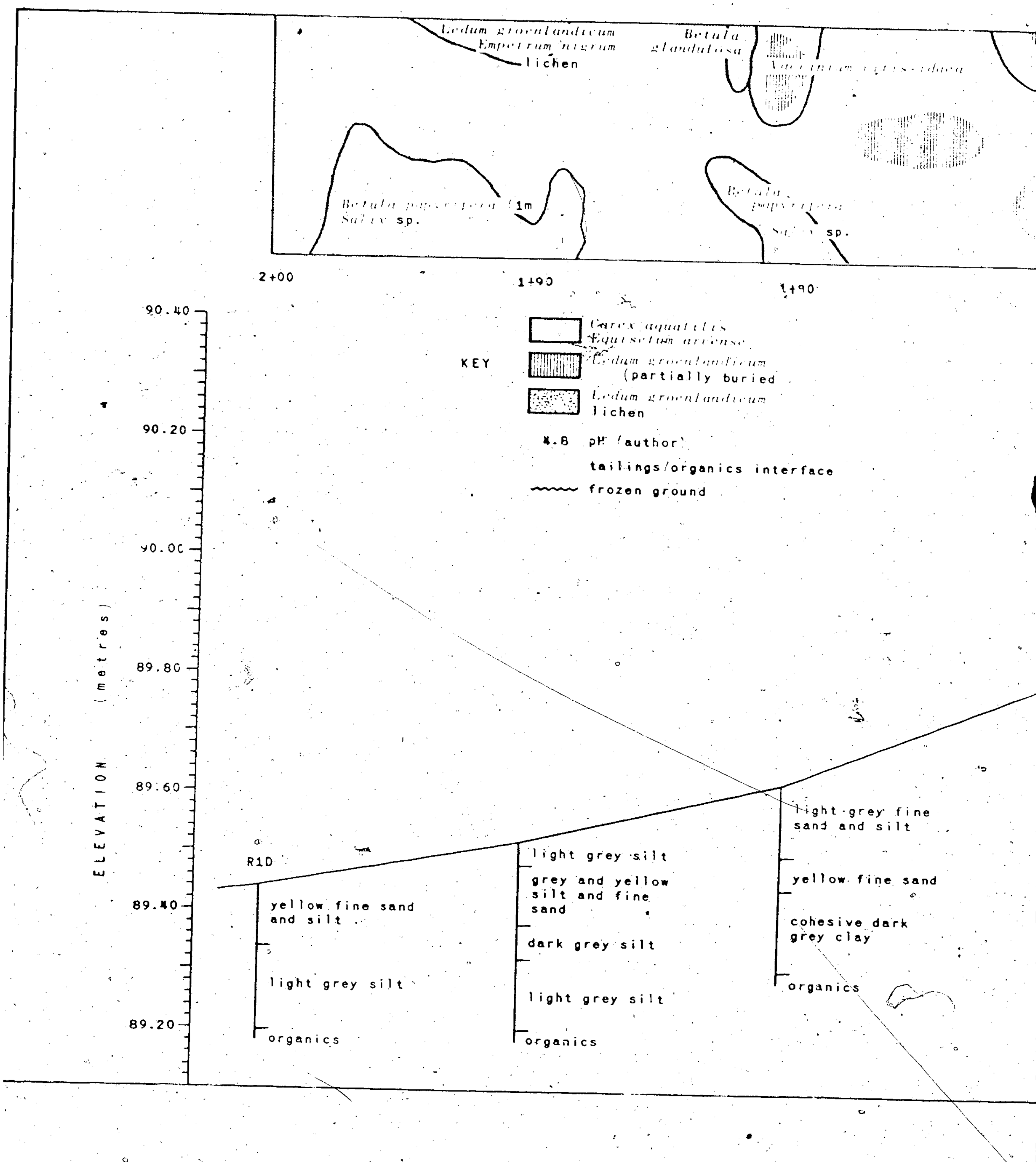
that the shrubs have grown from the occasional specimens found in the original ground cover, whereas the herb layer is more of a primary succession nature.

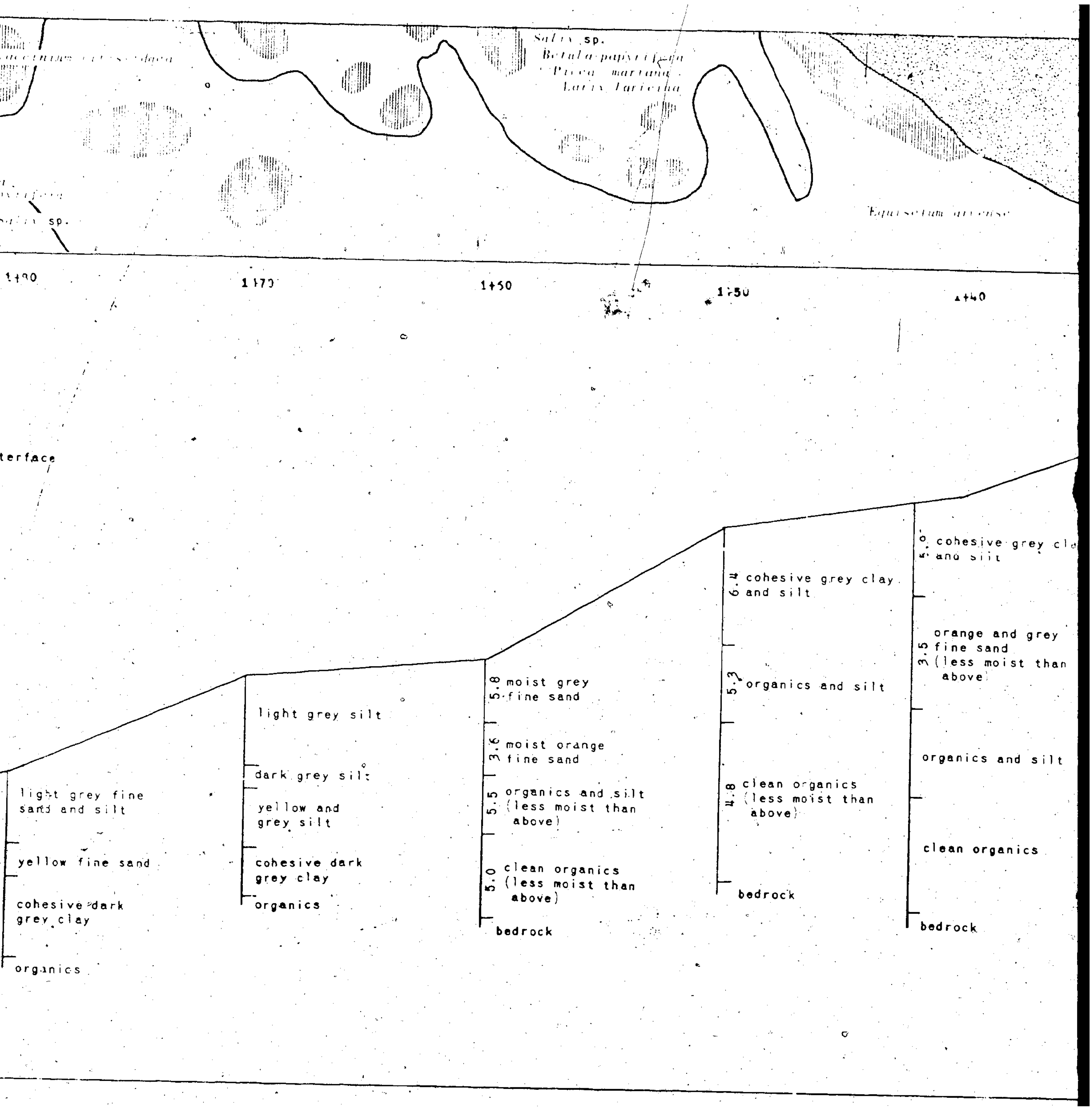
In the southern half of this bog, only the vegetation in the inter-hummock depressions has been killed. The moss and lichen cover on the tops of the hummocks is undamaged. Since there are only small amounts of tailings present, it is likely that only the tailings effluent reached this area. The subsidence of the northern half of this bog is a result of thermokarst action, and subsidence is still occurring along the interface between the two sections.

4.1.3 STUDY TRANSECT R1CD

Much of the eastern half of the R1 study area is covered by unvegetated tailings. In the southern corner, however, there is considerable plant growth near where drainage flows down a slope to the lower level of the R2 study area. Detailed observations were assisted by the establishment of a transect through this portion of the R1 study area (Figure 4-1). The 200 m long transect is shown in plan and profile in Figures 4-3 and 4-4.

Apart from several patches of barely surviving *Equisetum arvense* and *E. sylvaticum* the first 100 m exhibits no vegetation, a situation likely resulting from the depth of the tailings deposit. A soil pit at R1C (0 + 00) showed tailings to a depth of 1.7 m. Other pits along the transect (Figure 4-4) showed that primary succession seldom occurs when the depth of the deposit exceeds 50 cm and in most cases this depth is less than 40 cm. Often plant growth occurs only where the tailings has buried just a part of a hummock of original bog terrain. Small patches of *Equisetum arvense, E. sylvaticum, Carex*,


Ledum groenlandicum
Empetrum nigrum
lichen
Betula glandulosa
Vaccinium vitis-idaea
Betula papyrifera
Salix sp.
1m
Betula papyrifera
Salix sp.
2+00
1+90
1+90
90.40
90.20
90.00
89.80
89.60
89.40
89.20
ELEVATION (metres)
KEY
Carex aquatilis
Equisetum arvense
Ledum groenlandicum
(partially buried)
Ledum groenlandicum
lichen
4.8 pH (author)
tailings/organics interface
frozen ground
R1D
yellow fine sand and silt
light grey silt
organics
light grey silt
grey and yellow silt and fine sand
dark grey silt
light grey silt
organics
light grey fine sand and silt
yellow fine sand
cohesive dark grey clay
organics



Salix sp.
Betula papyrifera
Picea mariana
Larix laricina
Equisetum arvense
sp.
1+70
1+50
1+40
terface
light grey fine sand and silt
yellow fine sand
cohesive dark grey clay
organics
light grey silt
dark grey silt
yellow and grey silt
cohesive dark grey clay
organics
5.8 moist grey fine sand
3.6 moist orange fine sand
5.5 organics and silt (less moist than above)
5.0 clean organics (less moist than above)
bedrock
6.4 cohesive grey clay and silt
5.3 organics and silt
4.8 clean organics (less moist than above)
bedrock
cohesive grey cl
and silt
3.5 orange and grey fine sand (less moist than above)
organics and silt
clean organics
bedrock

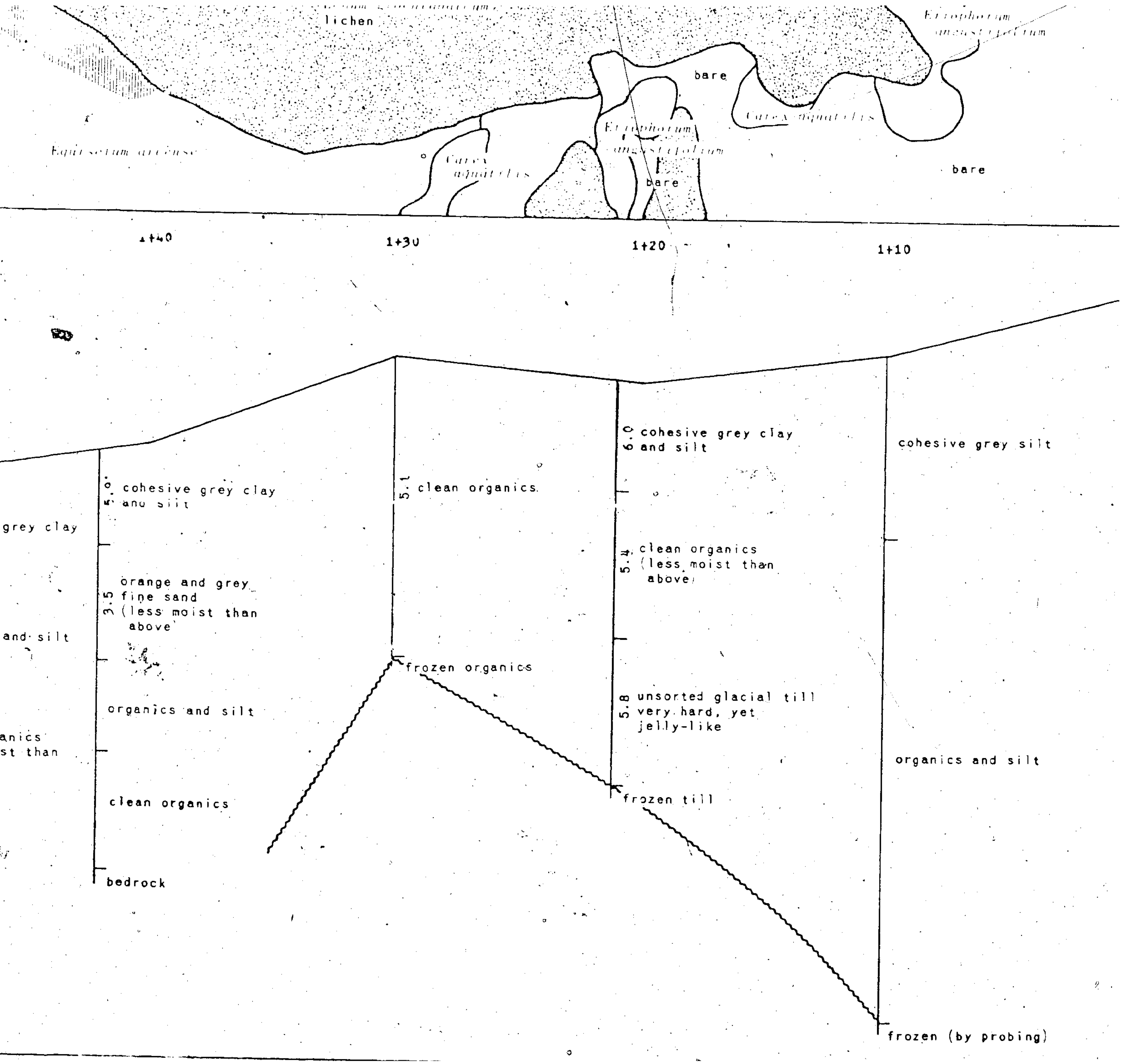
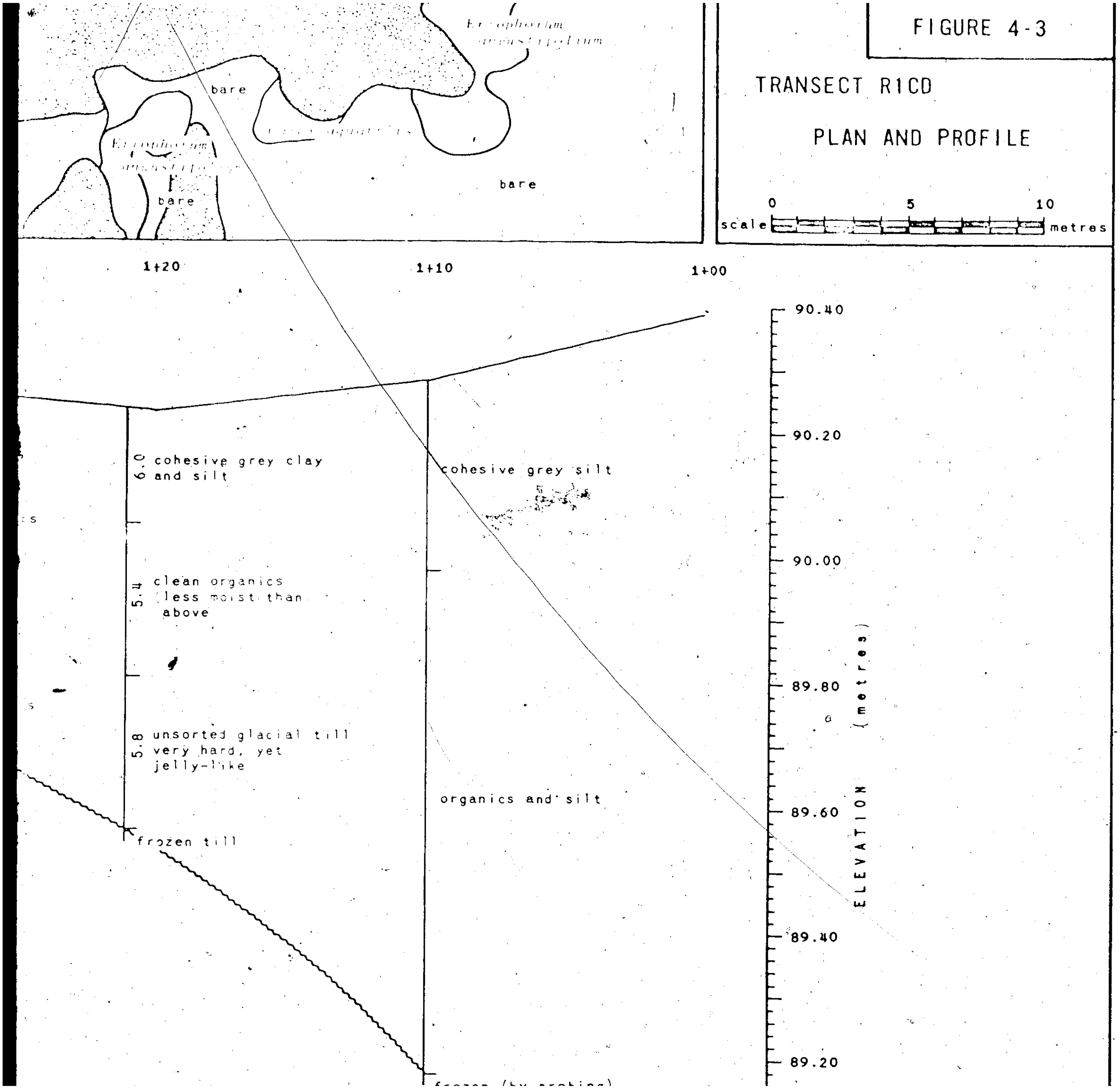

lichen
bare
bare
bare
1+40
1+30
1+20
1+10
6.0 cohesive grey clay and silt
cohesive grey silt
5.0 cohesive grey clay and silt
5.1 clean organics
5.4 clean organics (less moist than above)
3.5 orange and grey fine sand (less moist than above)
frozen organics
organics and silt
5.8 unsorted glacial till very hard, yet jelly-like
organics and silt
clean organics
frozen till
bedrock
frozen (by probing)

FIGURE 4-3

TRANSECT R1CD

PLAN AND PROFILE



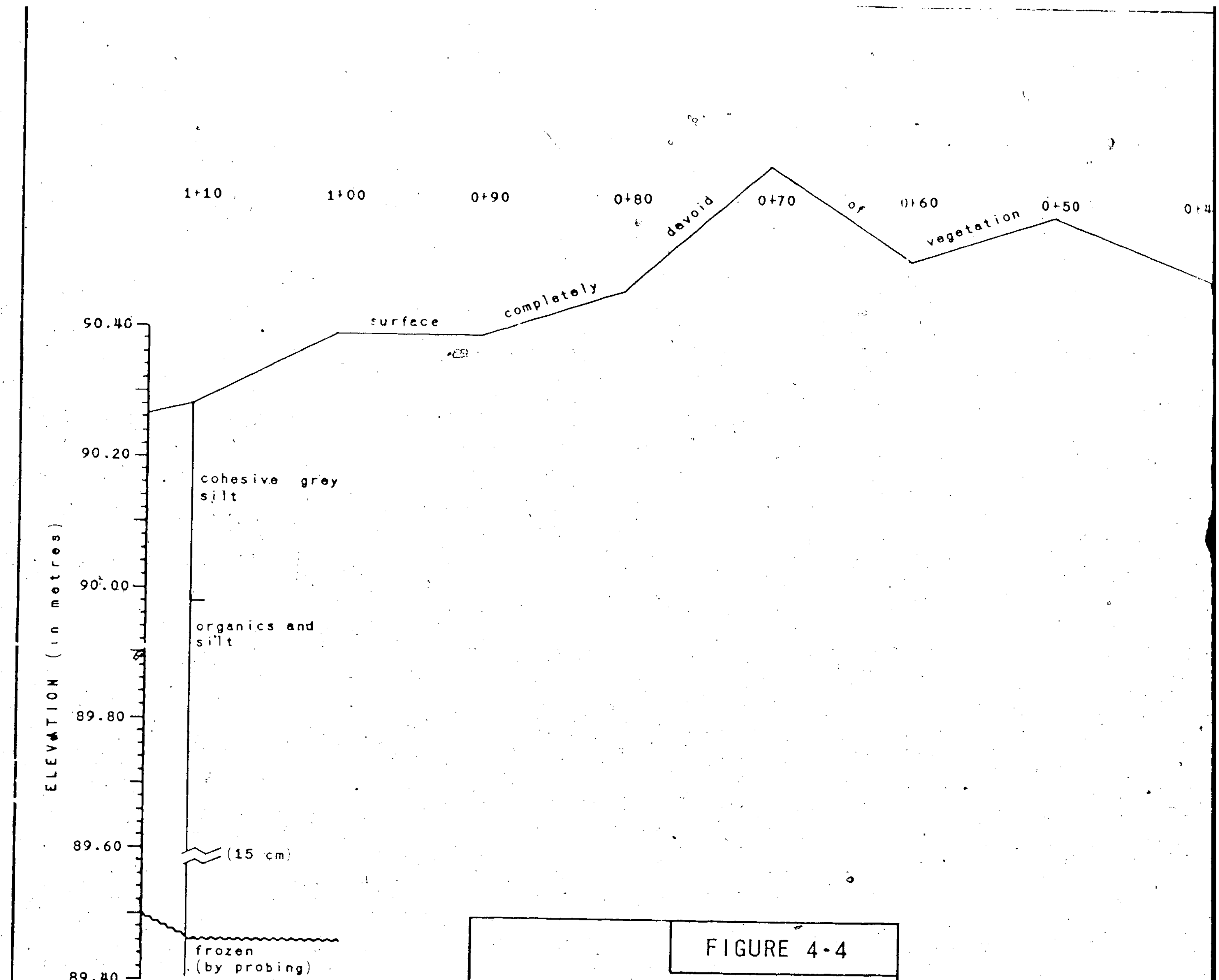


FIGURE 4-4

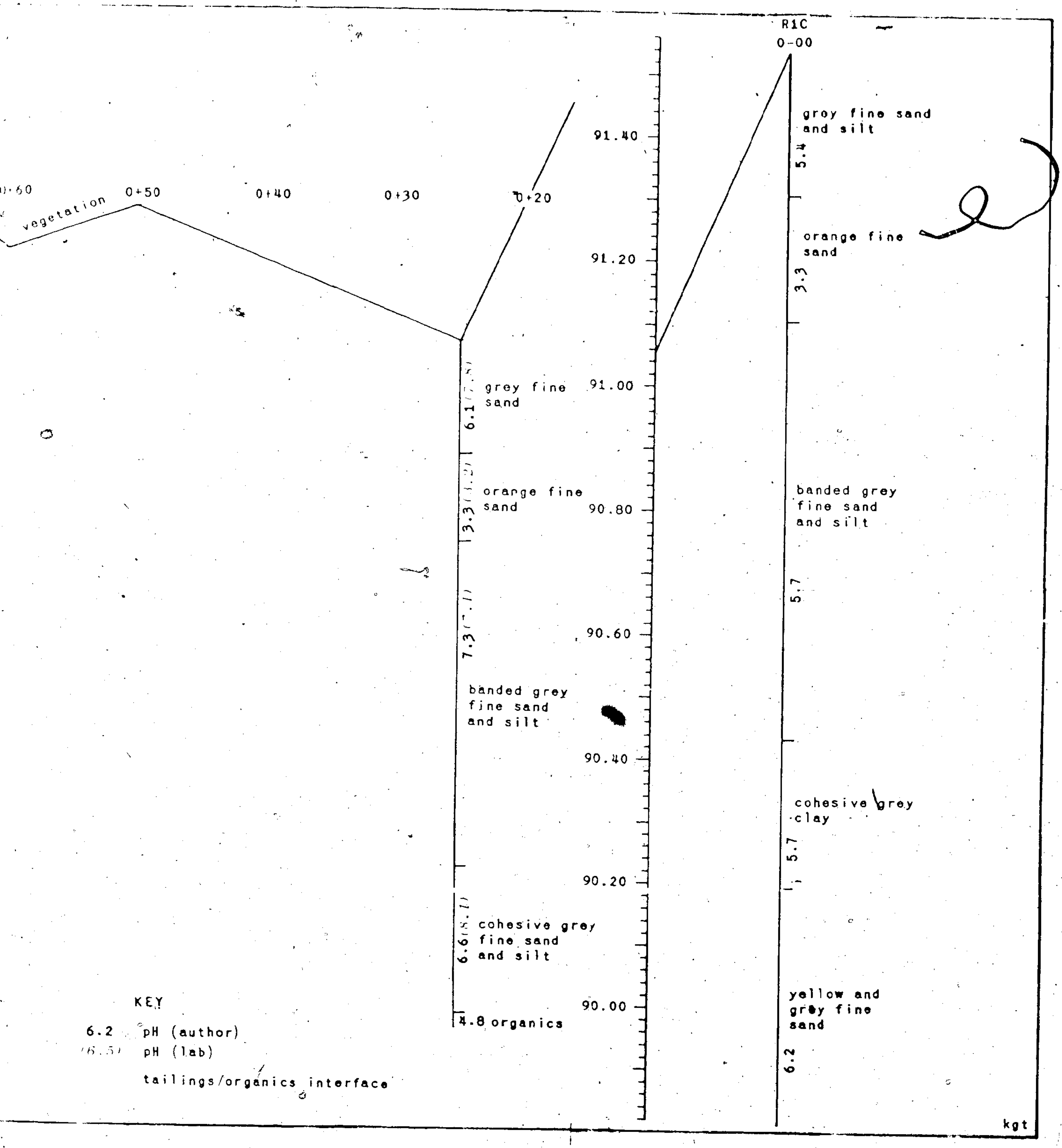
TRANSECT R1CD

PROFILE

scale as shown

KEY

6.2 pH (author)
(6.5) pH (lab)
tailings/organi


R1C
0-00
0+60
0+50
0+40
0+30
0+20
vegetation
91.40
91.20
91.00
90.80
90.60
90.40
90.20
90.00
grey fine sand
6.1
orange fine sand
3.3
7.3
banded grey fine sand and silt
cohesive grey fine sand and silt
6.6
4.8 organics
grey fine sand and silt
5.4
orange fine sand
3.3
banded grey fine sand and silt
5.7
cohesive grey clay
5.7
yellow and grey fine sand
6.2
KEY
6.2 pH (author)
(6.5) pH (lab)
tailings/organics interface
kgt

aquatilis and *Eriophorum angustifolium* are then able to colonize outwards by using the nutrients available from the central hummock of organic material. This characteristic is especially apparent in the vicinity of the transect baseline from about 0 + 90 to 1 + 50. However, in general, the depth of the tailings between 1 + 00 and 2 + 00 on the transect is relatively thin, in the order to 40 cm, so that revegetation is widespread. From approximately 1 + 50 to 2 + 00 *Carex aquatilis* grows in a thick, continuous cover. Mixed in with this, and forming about 10 to 15 percent of the cover, is *Equisetum arvense*. The *Equisetum* extends down the transect to about 1 + 25 and appears to be a primary successional species. Scattered throughout the portion of the transect from 1 + 40 to 2 + 00 are young specimens of *Salix arbusculoides*, *S. Lebbiana*. *S. glauca*, *Betula glandulosa*. *B. papyrifera* and occasionally *Alnus crispa*. Seed sources for these species are located in adjacent non-disturbed areas.

Overall regeneration in this area is excellent, as can be seen from Plate 4-4. Except for the firm sandy base of the tailings which is visible beneath the grass, the appearance is meadow-like. The tree stumps which remain, along with the *Sphagnum* found at the bottom of soil pits indicate that the original cover was that of a *Picea mariana* bog. Along the western side of the transect, between 1 + 00 and 2 + 00 much of the original ground cover remains unaltered, except for the trees, which have been cut for campfire purposes. The main herb components are *Ledum groenlandicum* and *Sphagnum* spp., forming the usual hummocks.

4.1.4 ANALYSIS OF TAILINGS

A detailed soils analysis was carried out on four samples

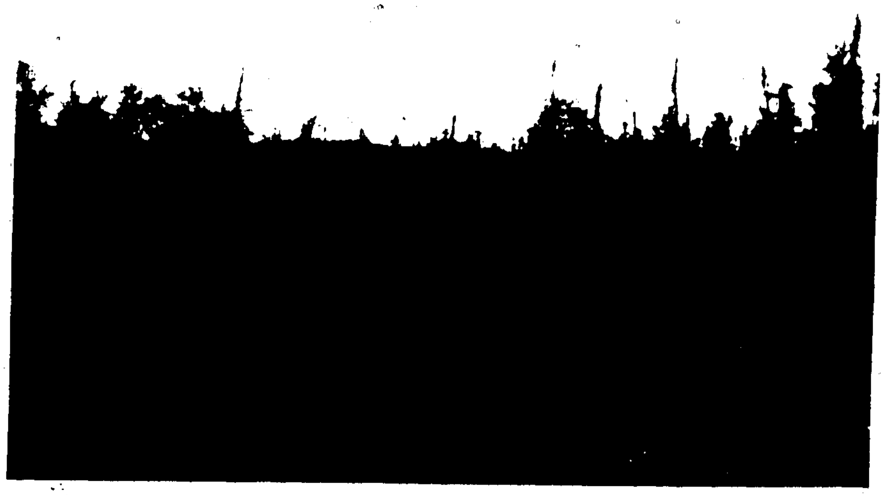


Plate 4-4. This view, looking south to a thermometer shelter location at R1B (1+60 on the transect), reveals a lush ground cover in which *Equisetum arvense* and *Carex aquatilis* are the dominant primary successional species on the tailings. 27 July 1971 - 14h00.

from a soil pit at 0 + 25 on the transect. The results are shown in Table 4.1. Measurements of the pH of other samples from this transect are shown in Table 4.2. The most acid tailings samples (pH 3.[illegible] to pH 5.6) are those with an orange colour. Analysis of sample 55 suggests that this acidity not only triggers high levels of aluminum and manganese but also decreases the availability of potassium. In most other respects the samples are similar. A comparison of the soil profiles at 0 + 00 and 0 + 25 with those at 1 + 21, 1 + 50 and 1 + 60 suggests that acidity is not the sole determining factor in revegetation.

The acidic layer of orange coloured tailings was frequently encountered at a depth of 10 to 20 cm, although it did extend as deep as 43 cm. This layer probably originated in the milling of a high pyrite content section of the mineral vein.

4.2 THE R2 STUDY AREA

This area received the bulk of its deposits about 1958. There appears to have been very little deposition in the area since that time, although some movement of tailings through runoff continues on a minor scale. In the trough-like section closest the airstrip the *Picea mariana* trees have all been killed and all other ground cover has been buried beneath tailings. There is little revegetation of these deposits. Several small patches of *Equisetum arvense* and *E. sylvaticum* have been able to colonize only where the cover of tailings is shallow, less than 20 cm.

4.2.1 REVEGETATION OF PARTIALLY INFILLED BOGS

There are two bog areas in the R2 Study Area which have been partially filled by tailings. The first is located in the vicinity of 860S-225E. In the portion of the bog where tailings have been deposited,

Table 4-1 Analysis of soil samples (Transect RICD)

Sample number	36	55	[illegible]	57
Location	----------------Transect RICD 0+25 ---------------------------			
Depth (cm)	0-18	18-32	32-54	54-111
Description	grey fine sand	orange fine sand	grey fine sand and silt	grey fine sand and silt
Nitrogen (kg/ha)	00	00	00	[illegible]
Phosphorus (kg/ha)	00	07	12	01
Potassium (kg/ha)	551	23	142	151
Sodium	H+	L	L	L+
pH (lab) (author)	7.8 6.1	3.2 3.2	7.1 7.3	5.1 6.6
Sulphate	H	H	H-	L-
Aluminum (ppm)	--	[illegible]20+	--	--
Manganese (ppm)	--	10.6	--	--
Conductivity (mmhos/cm^2)	5.4	6.0	3.3	1.3
Organics	L-	L-	L-	L-

Note: See Appendix B for explanation of analysis techniques and symbols.

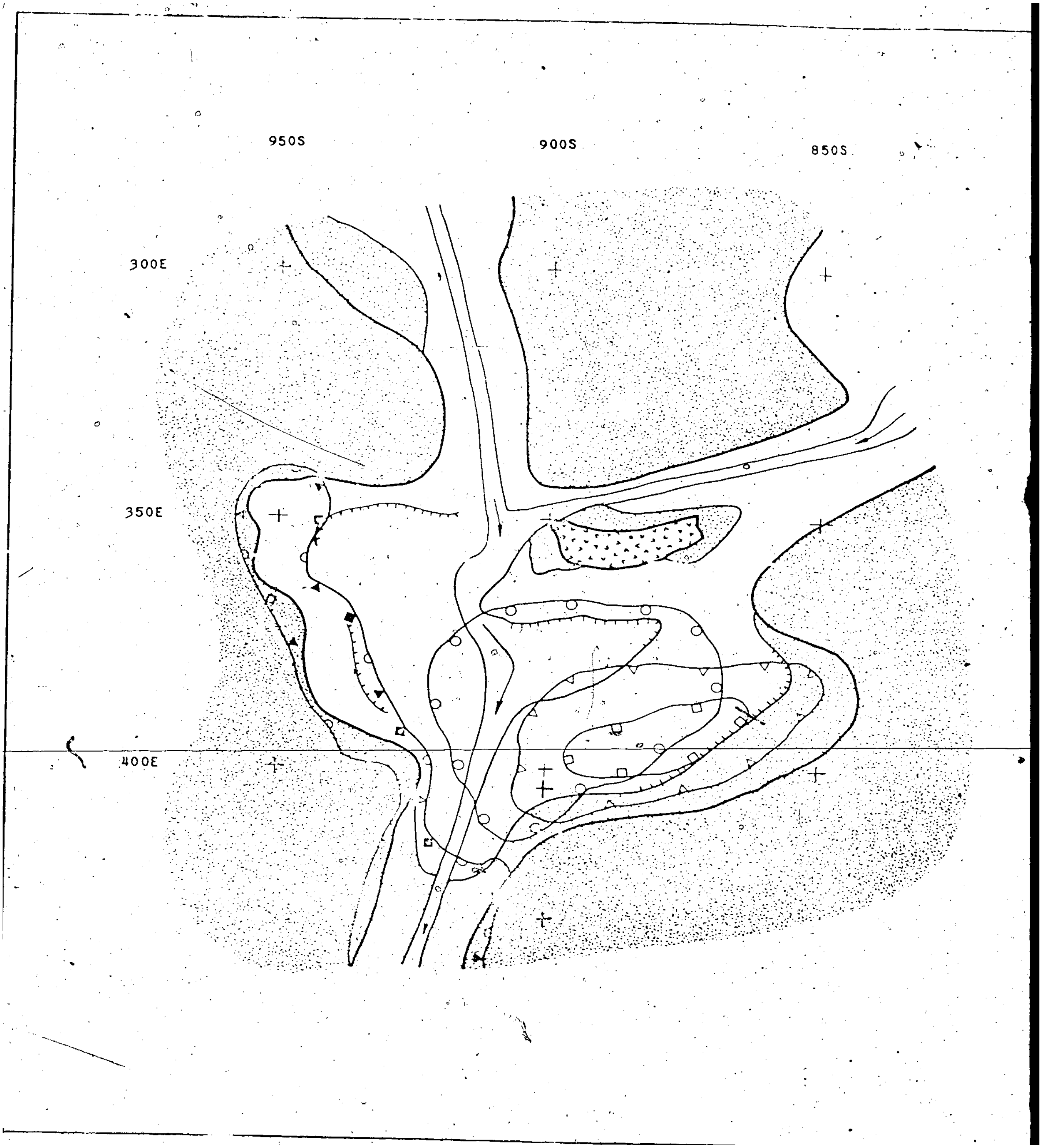
TABLE 4-2 Analysis of soil samples (Transect R1CD)

Sample number	Location on transect	Depth (cm)	pH (author)	Description
105	0+00	0-23	5.7	grey fine sand and silt
111	0+00	23-43	3.3	orange fine sand
110	0+00	43-110	5.7	grey fine sand and silt
112	0+00	110-134	5.8	sticky grey clay
106	0+00	134-170	6.2	yellow-grey fine sand
140	0+25	110+	4.8	brown organics
136	1+21	0-18	6.0	sticky grey silt and clay
141	1+21	18-42	5.4	clean brown organics
59	1+21	42-66	5.8	glacial till
143	1+30	[illegible]50	5.1	brown organics
66	1+42	0-15	5.9	sticky grey silt and clay
62	1+42	15-34	3.4	orange-grey fine sand
58	1+50	0-20	6.4	grey silt and clay
139	1+50	20-33	5.3	moist organics and tailings
147	1+50	33-60	4.8	clean brown organics
63	1+60	0-10	5.8	moist grey fine sand
61	1+60	10-19	3.6	moist orange fine sand
33	1+60	19-29	5.5	organics with tailings
148	1+60	29-43	5.0	clean brown organics

all trees (mostly *Picea mariana*) have survived. Several small clumps of *Alnus crispa* and *Salix glauca* have become established where the tailings have only thinly covered hummocks of the former ground cover.

Figure 3-5 shows that a large area on the northwest side of R2 has been affected by tailings. Although most of the trees are dead, other components of the ground cover are largely unaffected. Two reasons can be put forward to explain this limited damage: first, the area has served as a route for effluent drainage from the airstrip, and the highly alkaline effluent may have sufficiently raised the soil pH to selectively kill some of the plant cover (in this case, *Picea mariana*). A likely second factor is that the eastern (downslope) side of this organic terrain has been sufficiently covered by tailings solids that thermokarst subsidence up to 1 m has occurred. This alteration of the permafrost table has sufficiently lowered the water table to cause the death of hygric species. Loss of the tree layer inevitably results in a greater input of solar radiation to the ground, which causes a warming, and a retreat of the permafrost and water table. ~~Such changes tend to be long term.~~ However, other components of the plant cover here, such as *Ledum groenlandicum* and *Empetrum nigrum*, appear to survive successfully. Warming and drying of the ground results in a decrease in mosses and an increase in lichens and *Equisetum* spp.

Significant revegetation is evident down the hill at 880S-390E, where a corner of a large bog has been infilled by tailings. The distribution of species is presented in Figure 4-5. *Eriophorum angustifolium* is the most vigorous participant in primary succession at this location, although *Equisetum arvense* is also growing well..


950S
900S
850S
300E
350E
400E

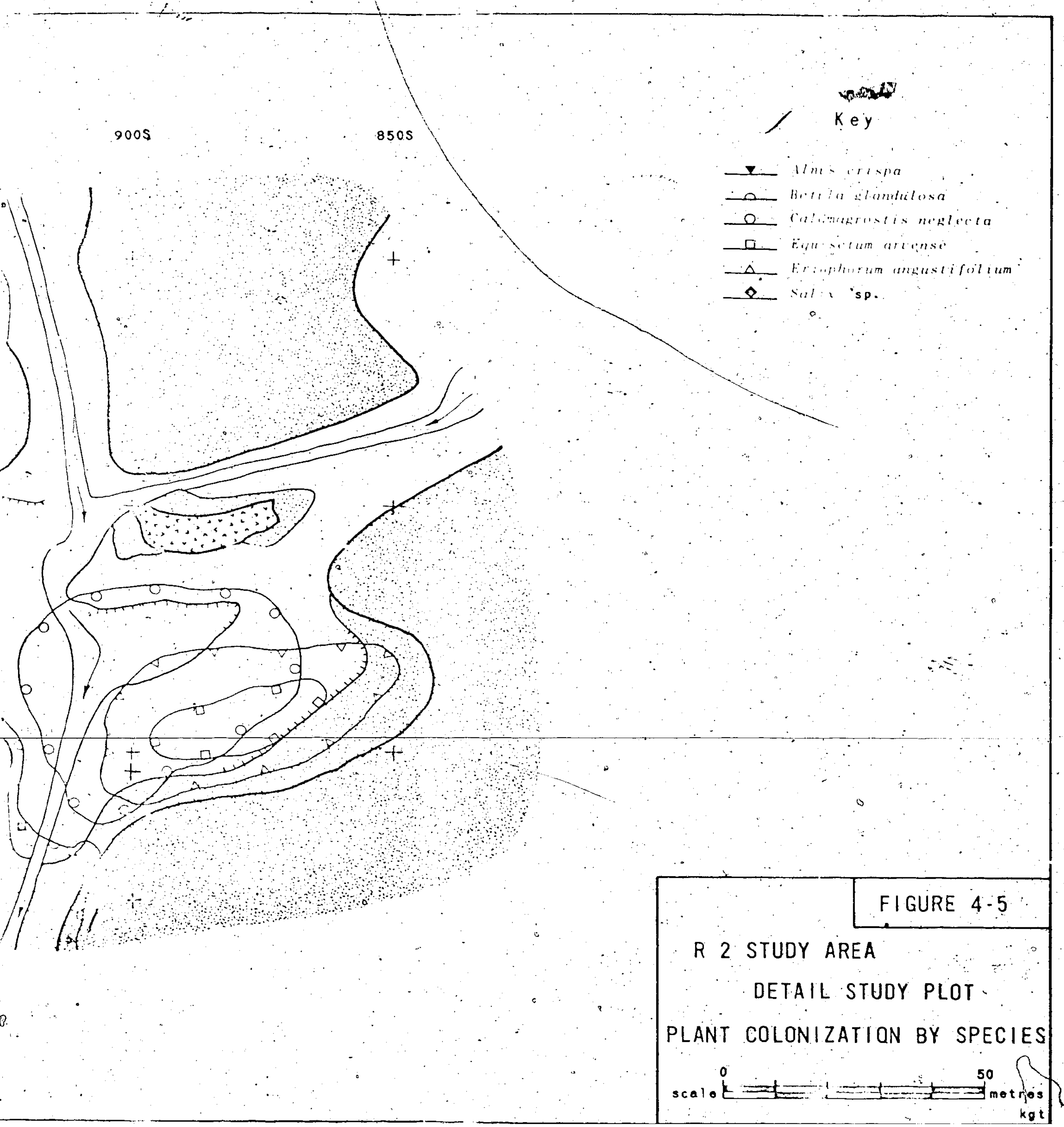


FIGURE 4-5

R 2 STUDY AREA

DETAIL STUDY PLOT

PLANT COLONIZATION BY SPECIES

Calamagrostis neglecta growth is less intense. Along the western tailings-bog contact *Betula glandulosa*, *Alnus crispa*, and several species of *Salix* are common. These shrubs are all components of the adjacent spruce bog.

4.2.2 ANALYSIS OF TAILINGS

Two soil pits were placed in this area. The profiles are presented in Figure 4-6. Although the surface at 900S-403E has subsided at least 50 cm from the original level of the bog (900S-430E), they are shown in the plan as the same elevation. Little can be said about the profile except that with the deposition of tailings the organic layer is compressed, apparently from 16 cm to 3 cm.

The results of the chemical analysis on the soil from the pit at 900S-403E are shown in Table 4-3. Two measurements stand out. The sample from 1-15 cm, although described as a grey fine sand, tested extremely acid with very high aluminum and manganese values, a contrast to previous analyses which suggested that high acidity occurred only with orange-coloured tailings. The presence of a thick and vigorous cover of *Eriophorum angustifolium* at this location is evidence that some species grow well in the highly acid environments of tailings deposits. Also of interest are the results of sample 123, grey clay till. The analysis indicates that natural soils in the region have relatively high values of aluminum and manganese. It then seems plausible that many local plants have developed some sort of tolerance for these metals, and may not suffer from what might otherwise be considered toxic levels.

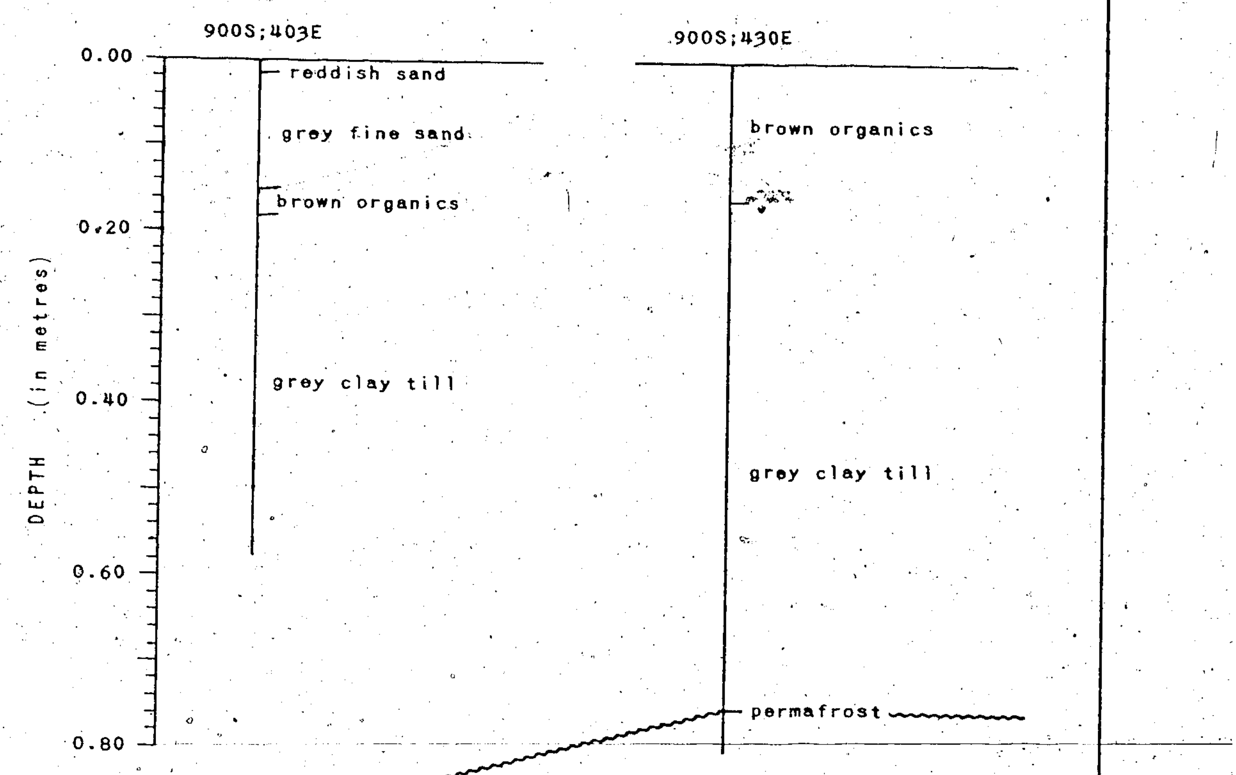


FIGURE 4-6

R-2 STUDY AREA
DETAIL STUDY PLOT
SOIL PIT PROFILES

kgt

Table 4-3 Analysis of soil samples (900S-403E)

Sample number	115	126		123
Location	--------------	--900S-403E ----	--------------	--------------
Depth (cm)	0-1	1-15	15-18	18-54
Description	reddish sand	grey fine sand	brown organics (not analysed)	grey clay till
Nitrogen (kg/ha)	00	00		00
Phosphorus (kg/ha)	01	05		00
Potassium (kg/ha)	342	17		241
Sodium	L	L		L
pH (lab) (author)	3.4 3.6	3.3 3.1		5.5 5.2
Sulphate	H	H		--
Aluminum (ppm)	*	230		0.6
Manganese (ppm)	*	36.8		10.6
Conductivity (mmhos/cm^2)	3.1	6.6		0.3
Organics	L	L		L

Note: See Appendix B for explanation of analysis techniques and symbols.
* insufficient sample for analysis

4.3 THE R3 STUDY AREA

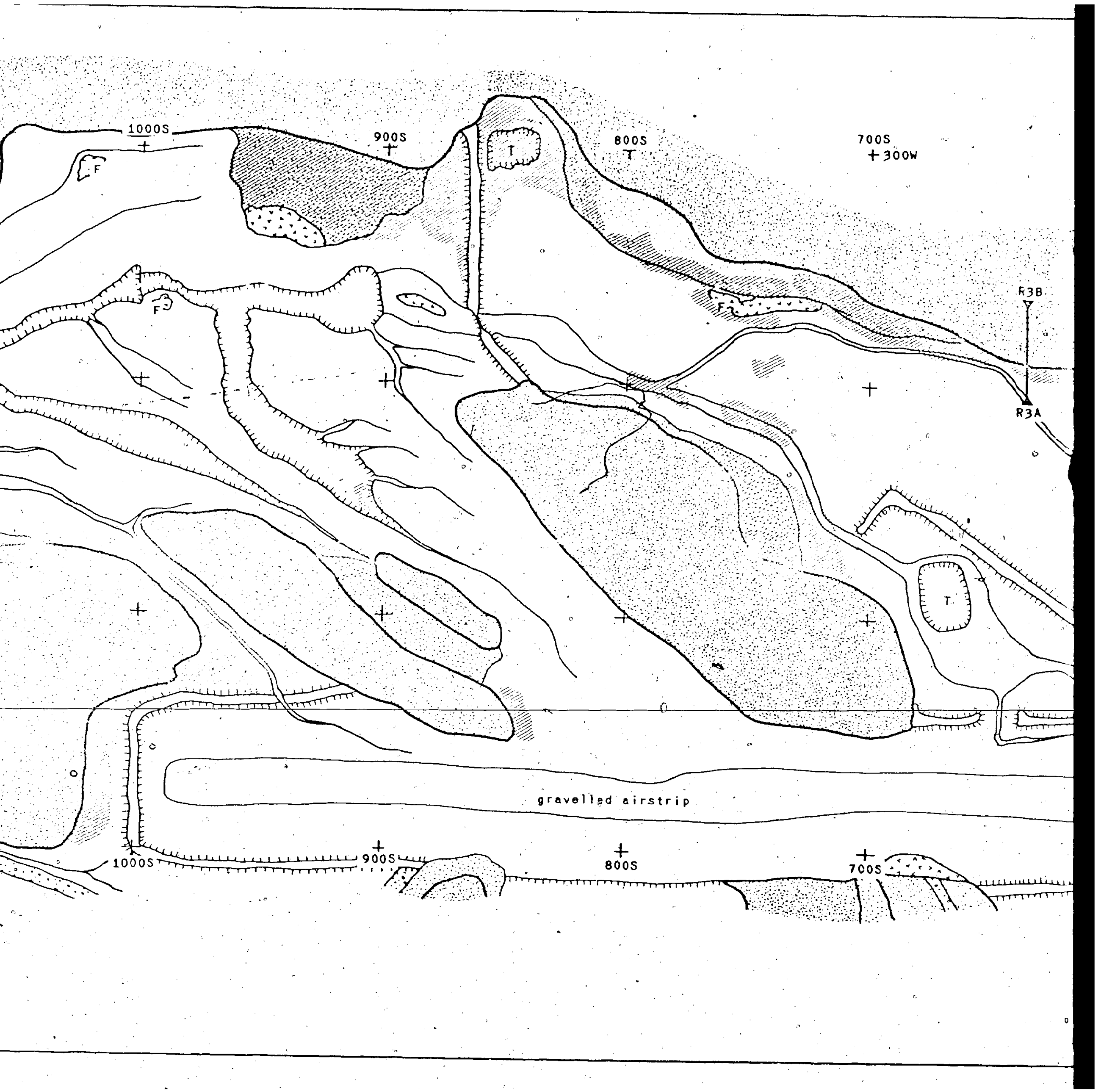
This area includes nearly half of the tailings disposal area at the minesite. It is estimated that tailings flowed into this section as early as 1953 and continued intermittently until 1965. It is likely that much of the surface layers of tailings were laid down between 1961 and 1965, either directly from the tailings effluent pipes or through erosion from upslope disposal locations.

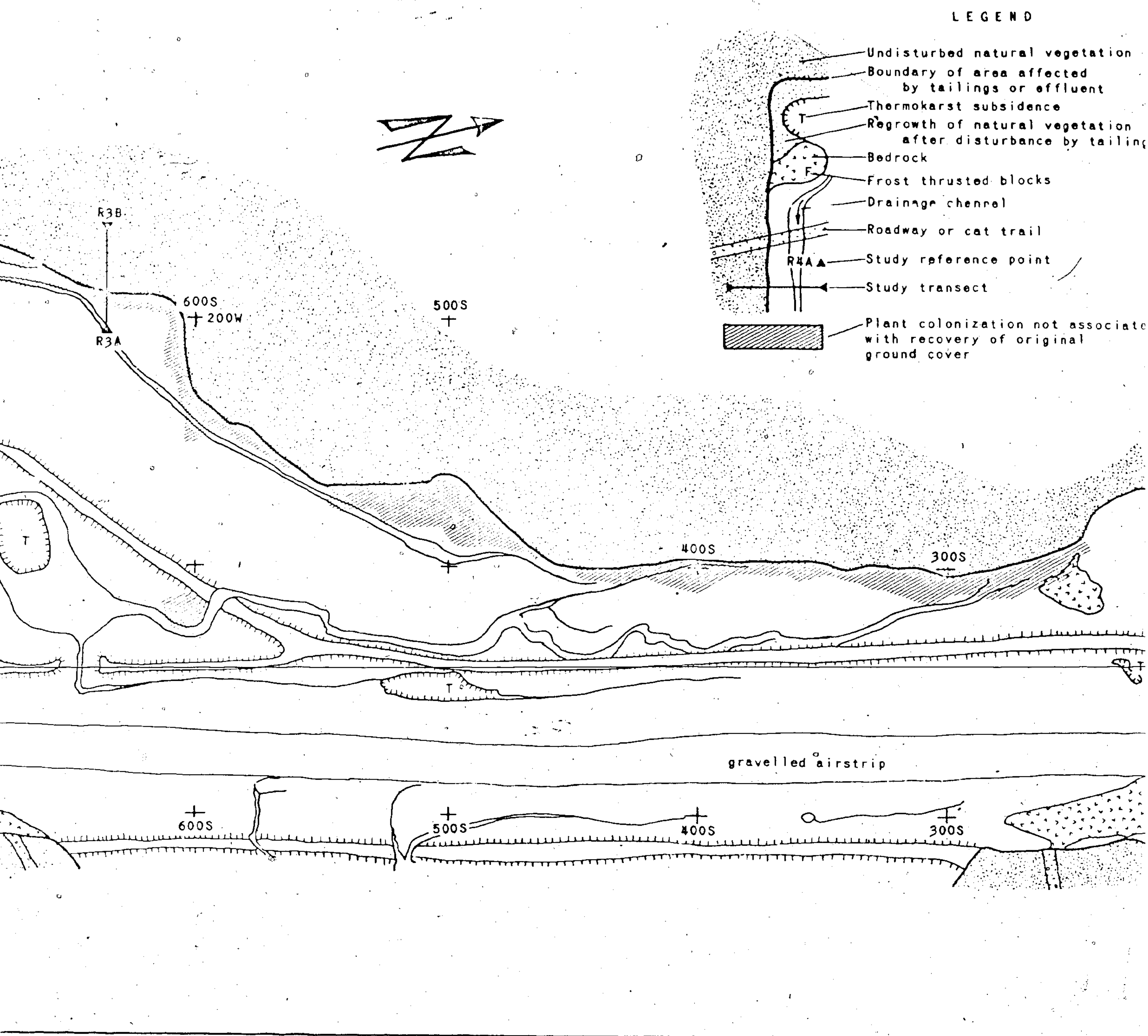
Primary plant succession is outlined in Figure 4-7. In all cases colonization is occurring only where the depth of the tailings is shallow enough that plant roots are able to reach the buried organic material. Figure 4-8 shows the colonization by species. *Equisetum arvense* and *E. sylvaticum* are plants which most commonly colonize tailings where the depth is greater than 15 cm. *Epilobium angustifolium* is the usual colonizer where the tailings depth is less than 20 cm, and is also common where the original plant cover has been killed by effluent but not buried by tailings. *Eriophorum angustifolium* is restricted to moist depressions on the tailings. Species common to the margins of disposal sites where deposition is minor are *Alnus crispa*, *Betula papyrifera*, and several species of *Salix*.

4.3.1 THE MARGIN OF ROUND LAKE

In Round Lake, and at the edge of the fan of tailings which extends well into the lake, *Carex aquatilis* grows vigorously at the shoreline, whereas *Equisetum fluviatile* is found in shallow water. Both s[illegible]ur naturally around the margins of the lake and are able to [illegible] tailings deposits. *Myriophyllum exalbescens* is als[illegible]ant of the shallow water over the tailings.

1400S
300W
1200S
1100S
F
T
200W
ROUND LAKE
100
+ baseline
1400S
1200S
1100S
R3D


1000S
900S
800S
700S
+300W
F
F
F
T
T
R3B
R3A
gravelled airstrip
1000S
900S
800S
700S


LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailing
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
Plant colonization not associate with recovery of original ground cover
R4A
R3B
R3A
600S
200W
500S
400S
300S
gravelled airstrip
600S
500S
400S
300S
T
F

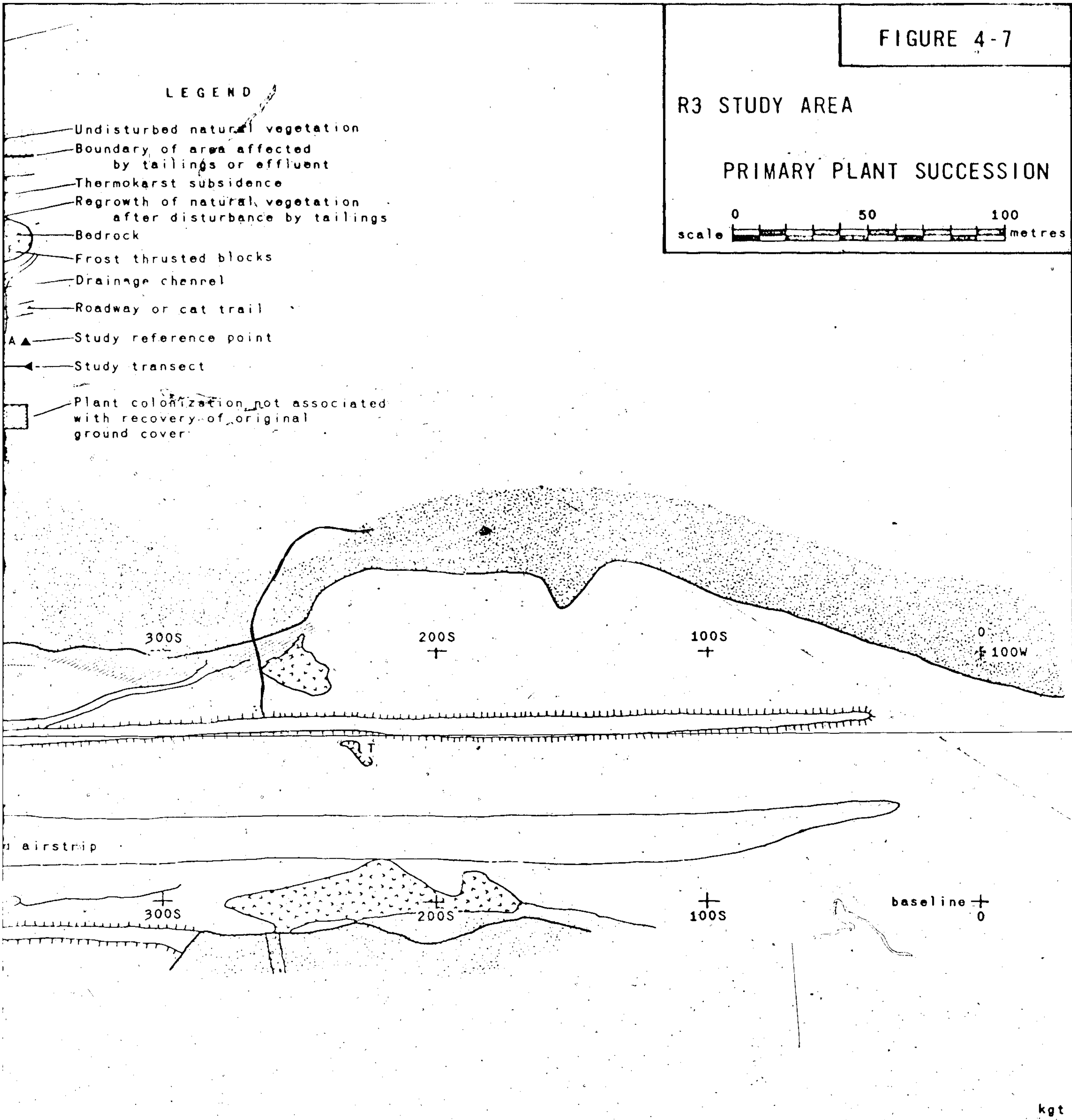
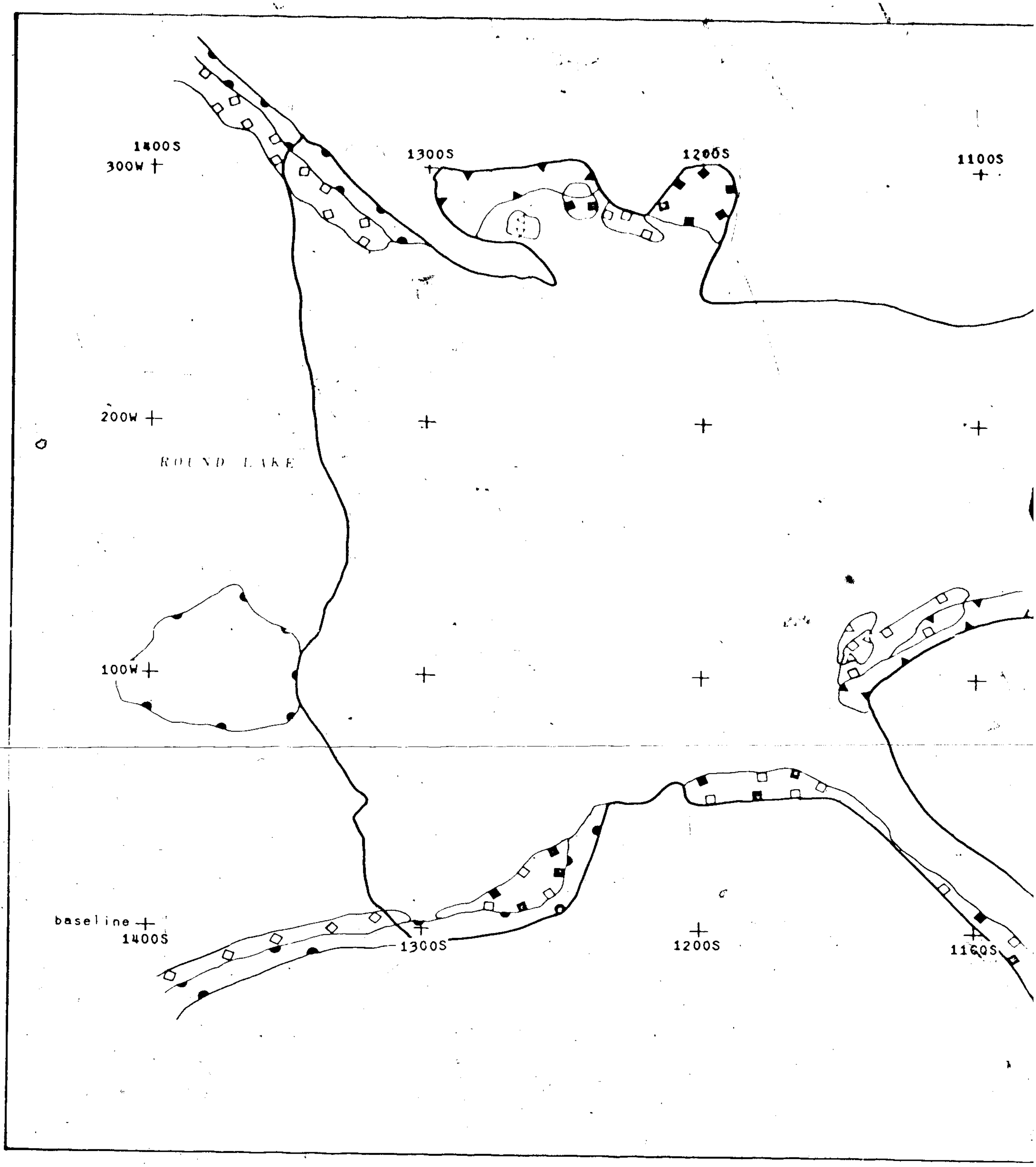
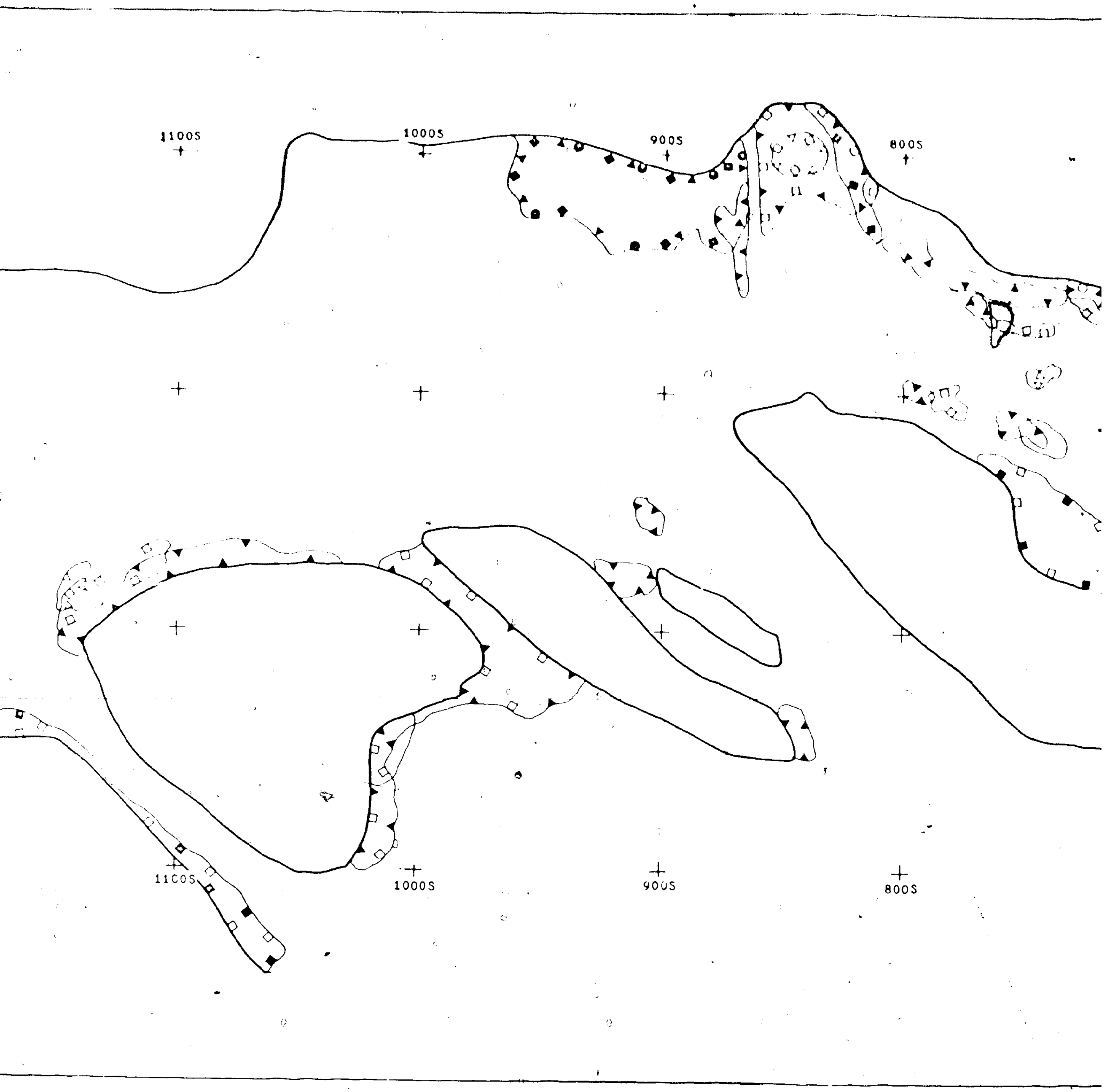
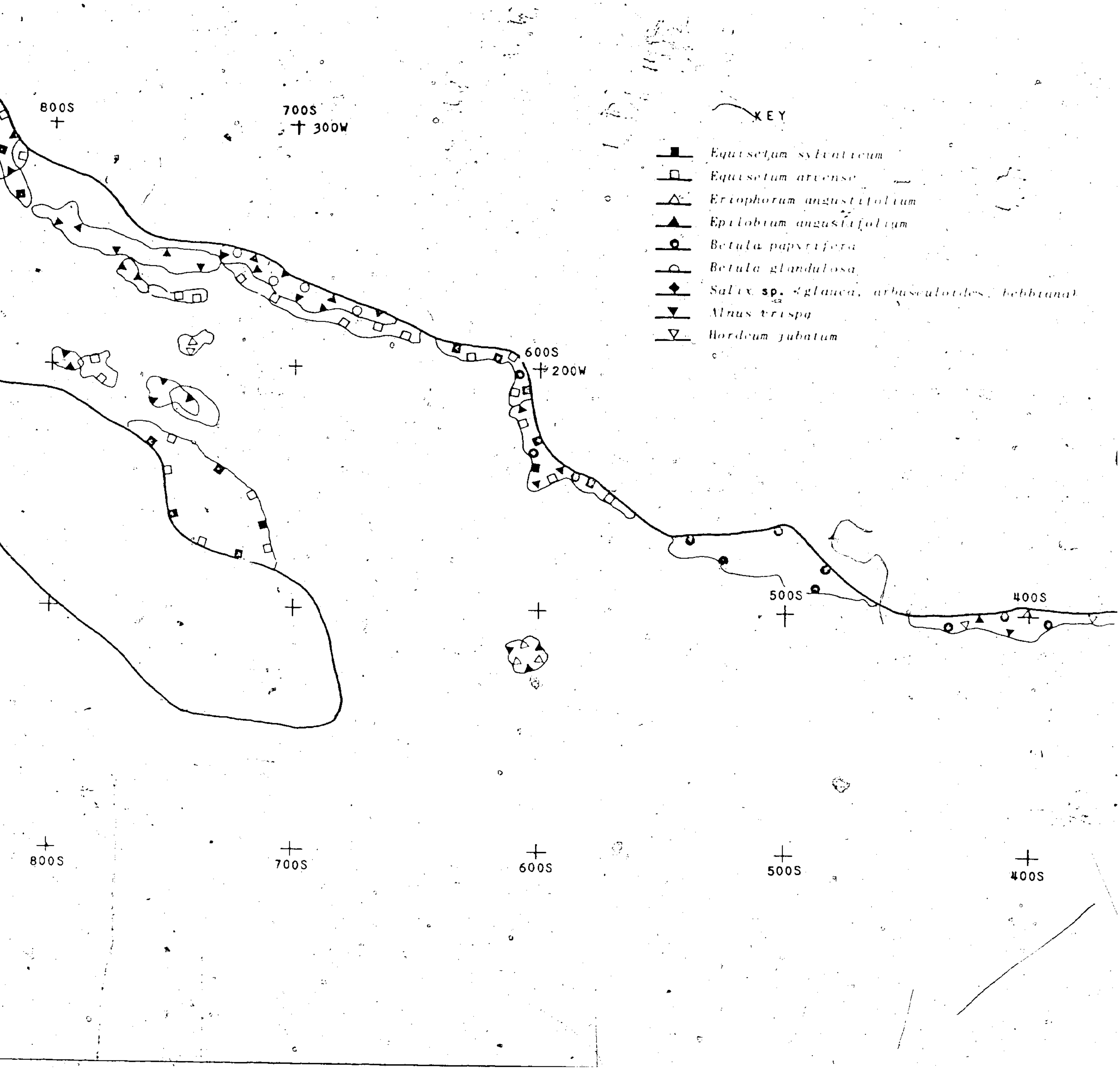


FIGURE 4-7
R3 STUDY AREA
PRIMARY PLANT SUCCESSION
0
50
100
scale
metres
LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
Plant colonization not associated with recovery of original ground cover
300S
200S
100S
0
100W
airstrip
300S
200S
100S
baseline
0
kgt


1400S
300W
1300S
1200S
1100S
200W
ROUND LAKE
100W
baseline
1400S
1300S
1200S
1100S


1100S
1000S
900S
800S
1100S
1000S
900S
800S


800S
700S
300W
KEY
Equisetum sylvaticum
Equisetum arvense
Eriophorum angustifolium
Epilobium angustifolium
Betula papyrifera
Betula glandulosa
Salix sp. (glauca, arbusculoides, bebbiana)
Alnus crispa
Hordeum jubatum
600S
200W
500S
400S
800S
700S
600S
500S
400S

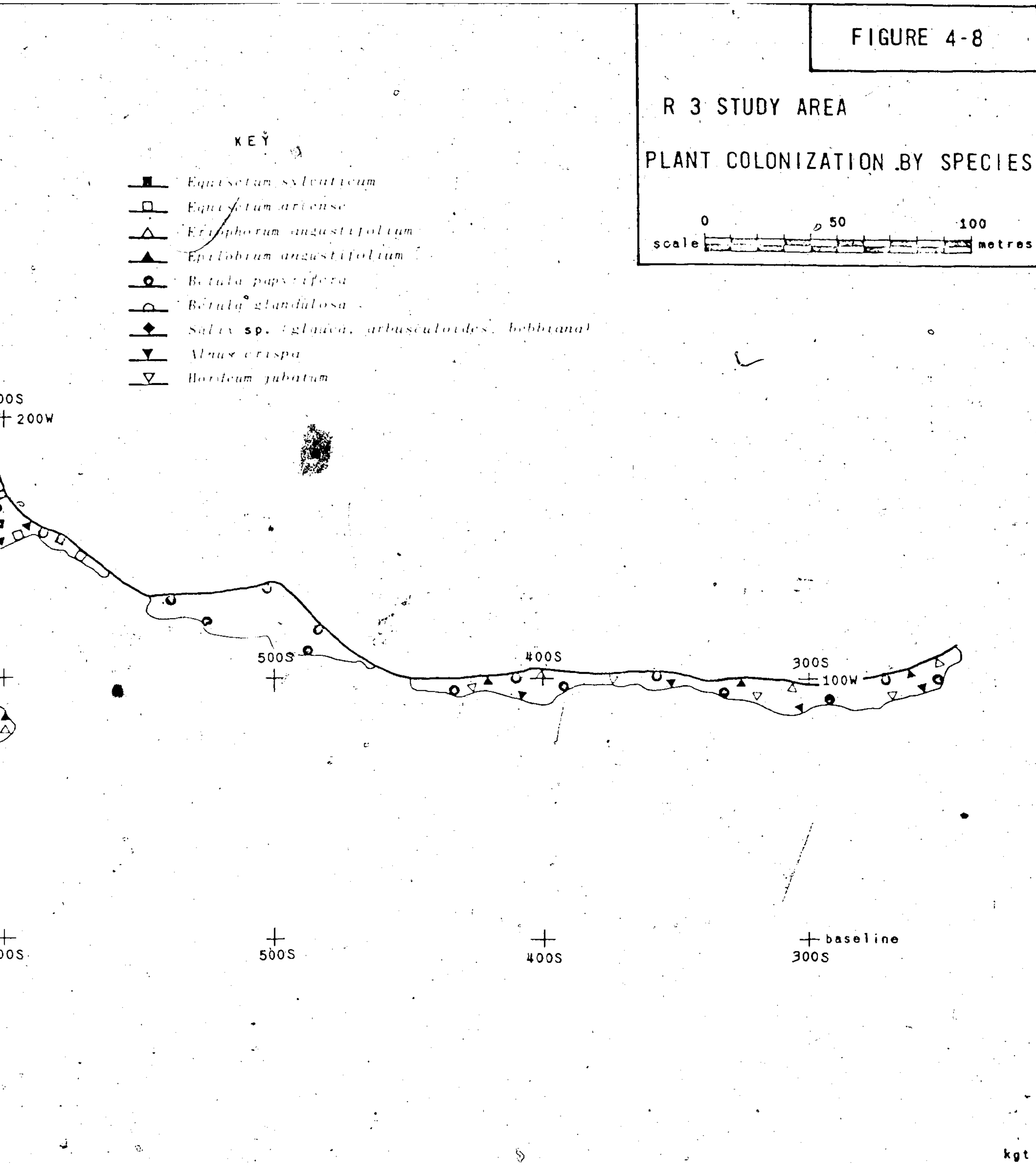


FIGURE 4-8

R 3 STUDY AREA

PLANT COLONIZATION BY SPECIES

4.3.2 STUDY TRANSECT R3AB

Two transects, shown in Figure 4-7, were chosen for more detailed study. Transect R3AB is located along the 635S grid line at the western edge of the tailings disposal area. The undisturbed site consists of a gently sloping *Picea mariana* - *Ledum groenlandicum* woodland in which the slope is toward the tailings. It is one of the few locations where the tailings do not border a spruce bog or rock outcrop.

Figure 4-9 shows the R3AB transect in plan and profile. *Equisetum arvense* and *E. sylvaticum* are both present on shallow tailings at the edge of the disposal area. The profile suggests that *Equisetum* in this location is able to grow on tailings where the depth reaches 0.5 m or more. However, it is likely that *Equisetum* has colonized this site by obtaining nutrients laterally from the edge of the tailings through the use of rhizomes.

Of more interest is the step-like profile at the edge of the tailings. Although the Figure exaggerates the vertical scale, there is a distinct drop in the elevation of the ground surface at the limit of the effluent-killed vegetation, and another where the ground surface had been buried by tailings. Although this drop is similar to those found at the edge of tailings in bog areas, here the surface of the tailings slopes away from the contact, rather than towards it as is the case in other locations. In contrast then, this contact appeared to be stable. There was no evidence of permafrost, at least at shallow depth, to the west of 2+10. Since it is unlikely that nearly 30 cm of subsidence can be accounted for by the compaction of the organic layer, it is likely

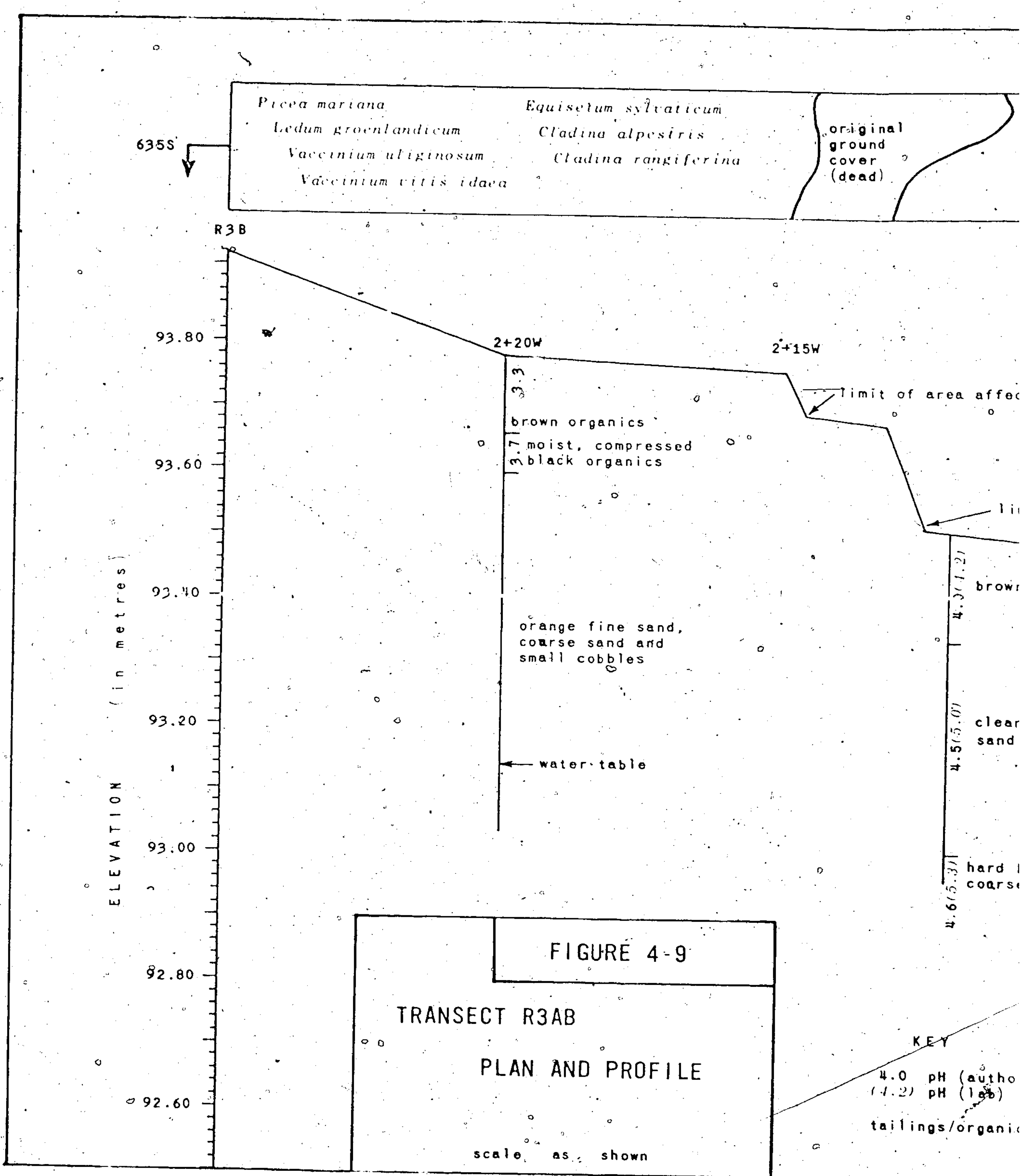
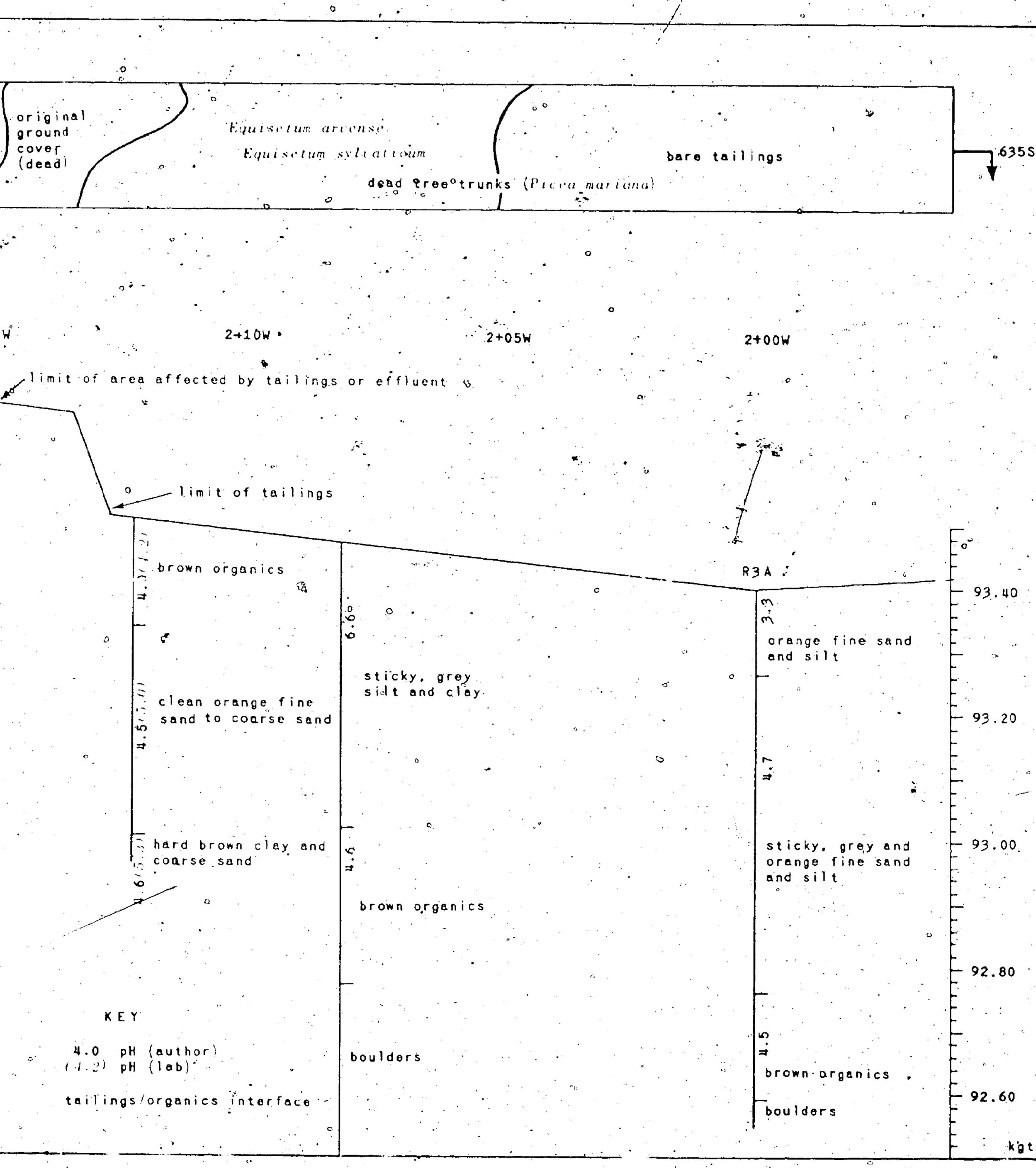


FIGURE 4-9

TRANSECT R3AB

PLAN AND PROFILE

scale as shown


original ground cover (dead)
Equisetum arvense
Equisetum sylvaticum
dead tree trunks (Picea mariana)
bare tailings
635S
2+10W
2+05W
2+00W
limit of area affected by tailings or effluent
limit of tailings
R3A
brown organics
clean orange fine sand to coarse sand
hard brown clay and coarse sand
sticky, grey silt and clay
brown organics
boulders
orange fine sand and silt
sticky, grey and orange fine sand and silt
brown organics
boulders
3.3
4.7
4.5
6.6
4.6
93.40
93.20
93.00
92.80
92.60
kgt
KEY
4.0 pH (author)
(4.2) pH (lab)
tailings/organics interface

that 2 + 10 marks the western limit of a spruce bog which is now overlain by tailings.

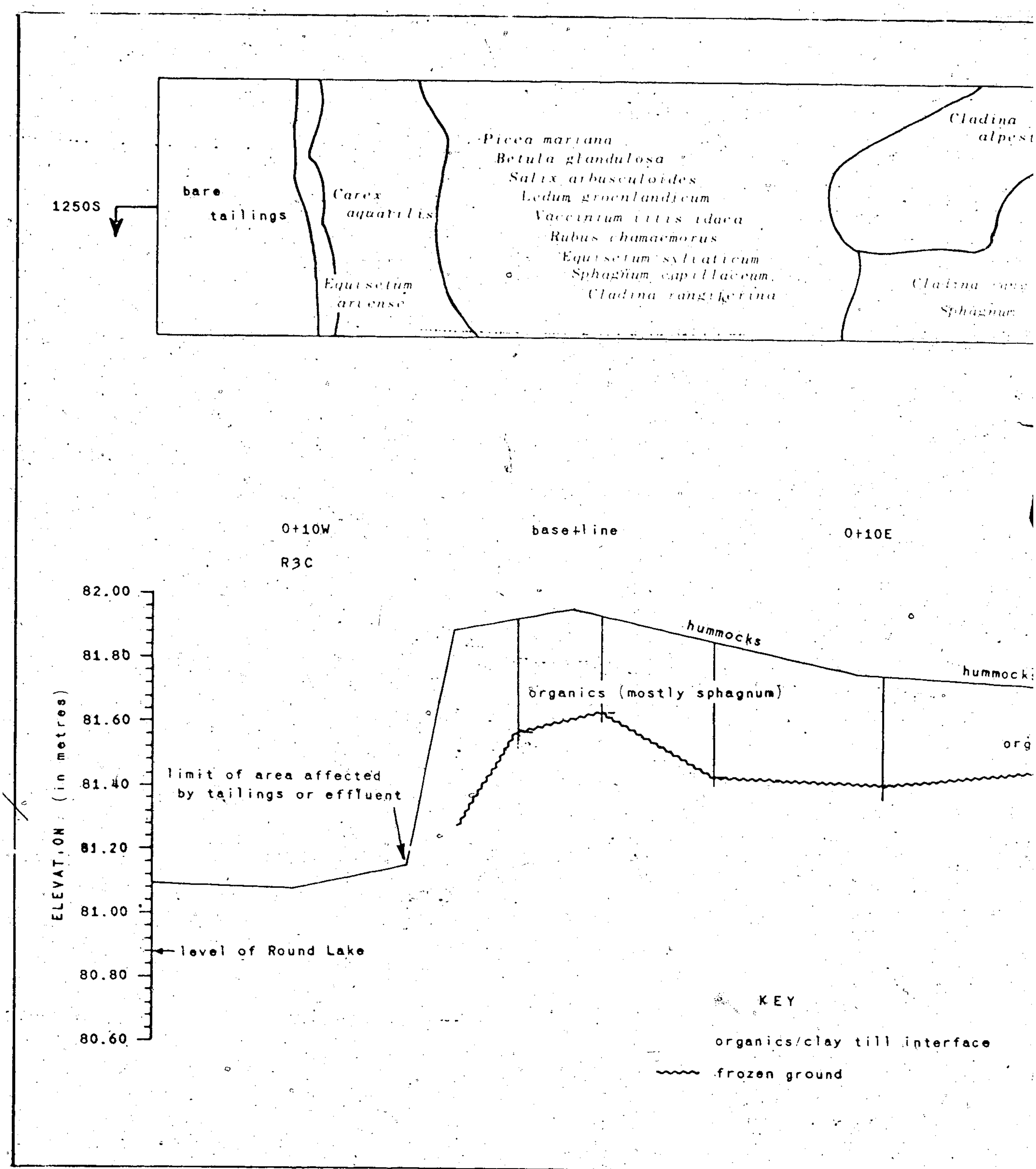
Several other observations can be made from the profile. The contrast in the acidity between orange (pH. 3.3) and grey (pH. 4.7) tailings is similar to that in the R1 study area. It is also of interest to note that the pH of undisturbed surface organic material is 3.3, whereas the pH of that same organic layer, once buried by tailings rises to about 4.5.

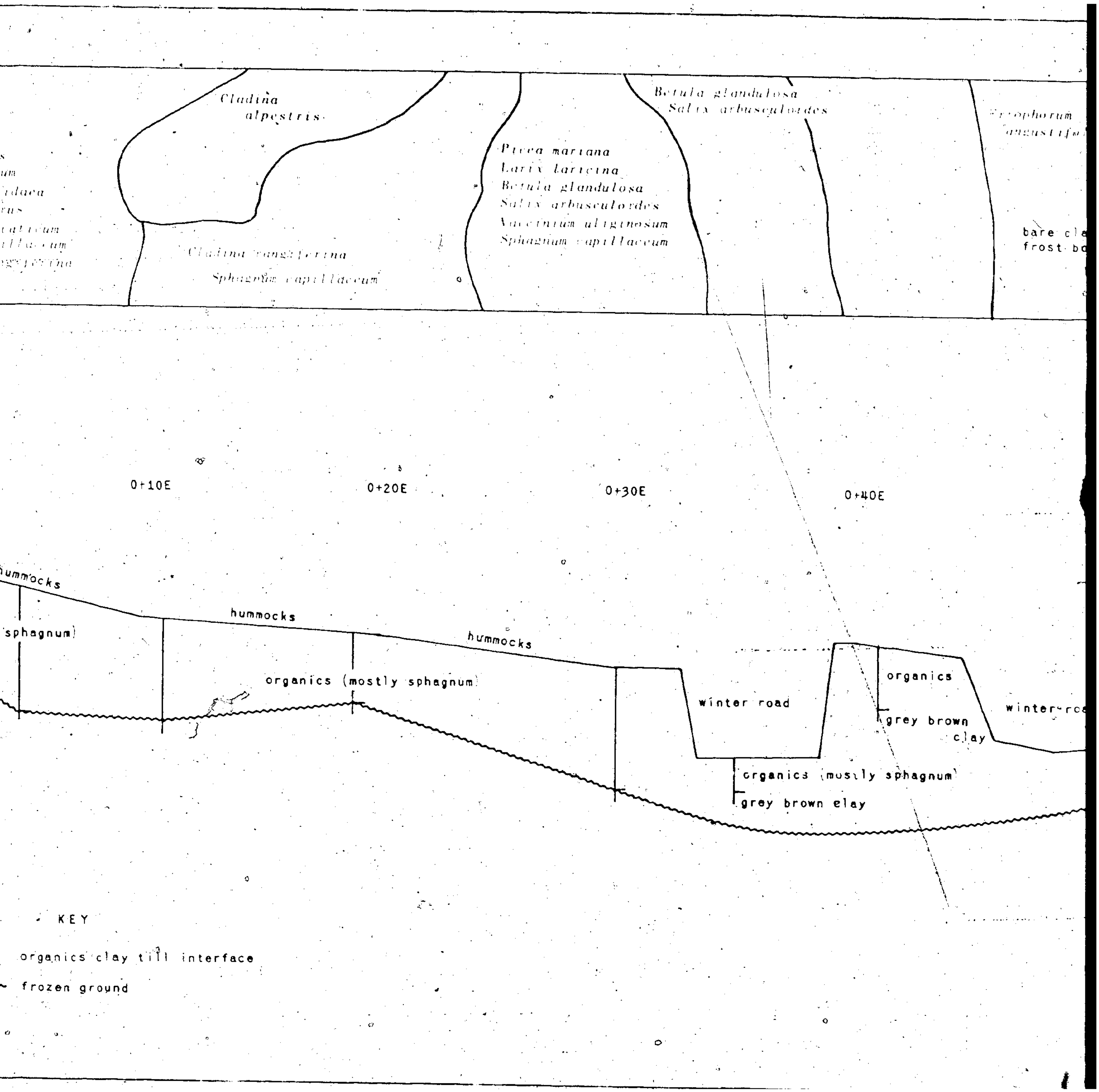
The only detailed soil analysis from this transect was of samples of natural soils at 635S-212W. The results of the analysis are discussed in section 4.5.

4.3.3 STUDY TRANSECT R3CD

The second transect in this study area (R3CD in Figure 4-7) is located just northeast of Round Lake. The transect was placed to intersect the edge of the tailings as well as two winter roads. The vicinity of the transect can be generally described as a hummocky *Picea mariana-Sphagnum* bog. The transect is presented in Figure 4-10. The profile shows that the depth of the active layer in the *Sphagnum* ranges from 20 to 40 cm. On this transect, the step at the edge of the tailings (0 + 10W) is quite high, nearly 1m. The steep angle of the *Sphagnum* bank suggests that the retreat of permafrost is continuing, although not at a rapid pace.

Subsidence following thermal disruption is also evident in the winter roadbeds. Although a detailed examination of the permafrost table was not undertaken it is likely that much of the subsidence in the roadways is a result of subsoil thawing. However, it appears that


1250S
bare tailings
Carex aquatilis
Equisetum arvense
Picea mariana
Betula glandulosa
Salix arbusculoides
Ledum groenlandicum
Vaccinium vitis idaea
Rubus chamaemorus
Equisetum sylvaticum
Sphagnum capillaceum
Cladina rangiferina
Cladina alpest
Cladina
Sphagnum
0+10W
R3C
baseline
0+10E
82.00
81.80
81.60
81.40
81.20
81.00
80.80
80.60
ELEVATION (in metres)
hummocks
organics (mostly sphagnum)
org
limit of area affected by tailings or effluent
level of Round Lake
KEY
organics/clay till interface
frozen ground


Cladina alpestris
Picea mariana
Larix laricina
Betula glandulosa
Salix arbusculoides
Vaccinium uliginosum
Sphagnum capillaceum
Betula glandulosa
Salix arbusculoides
Cladina rangiferina
Sphagnum capillaceum
0+10E
0+20E
0+30E
0+40E
hummocks
hummocks
hummocks
organics (mostly sphagnum)
winter road
organics
grey brown clay
organics (mostly sphagnum)
grey brown clay
KEY
organics clay till interface
frozen ground

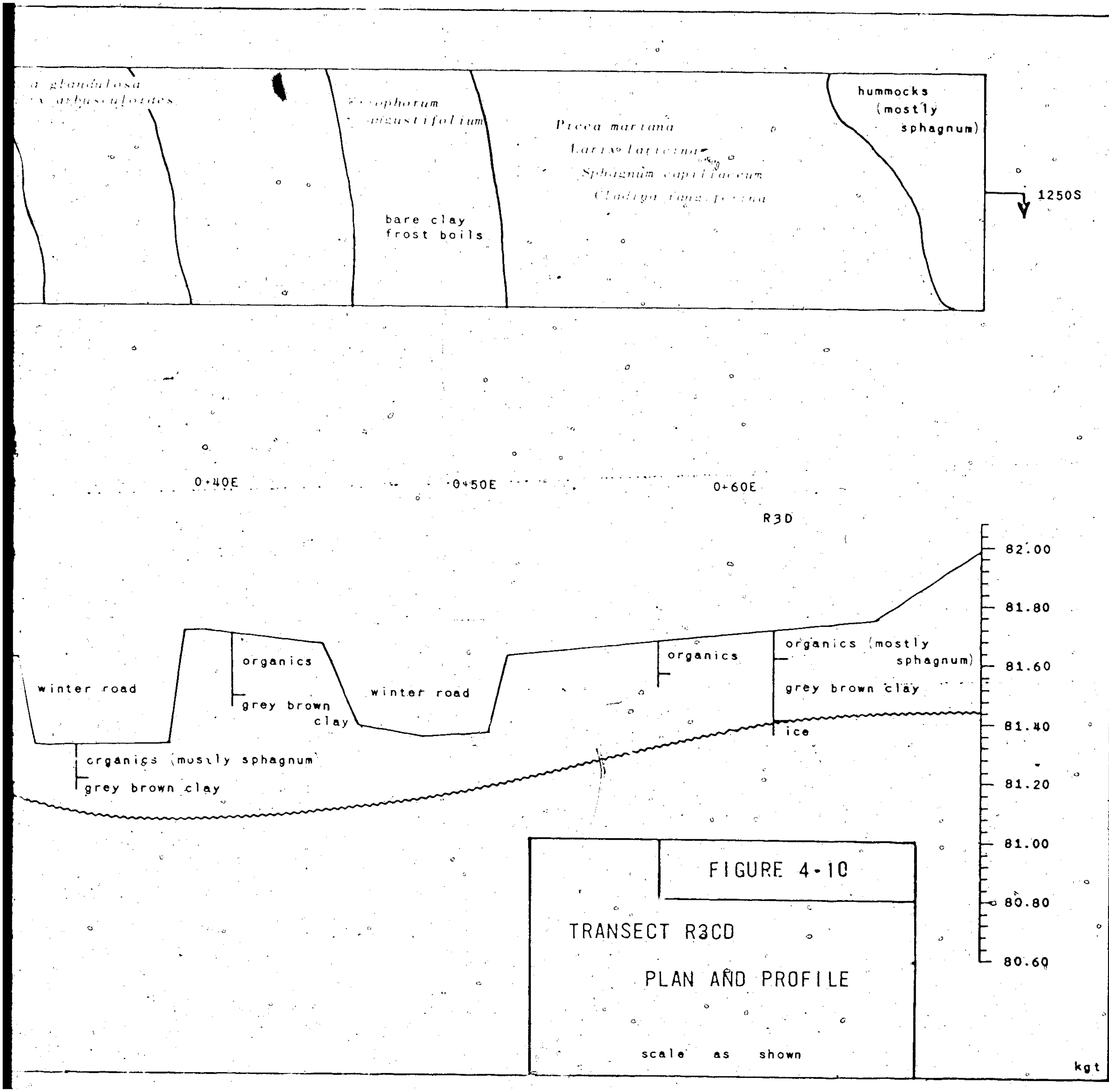


FIGURE 4-10

TRANSECT R3CD

PLAN AND PROFILE

scale as shown

these two routes were fairly heavily used, so that some of the surface organics may have been carried away on the wheels or tracks of vehicles using the roads in spring or fall. It is also likely that heavy traffic resulted in compaction of the non-frozen clay subsurface during autumn, before freezeback was complete. Indeed, the depression of the clay profile at the road, and the rise of the profile between the two roadways, suggest that the clay was squeezed laterally. In this context it is worth noting that some of the clay till beneath other bogs exhibited plasticity, particularly when gentle pressure or vibration was applied.

One can also speculate on why the original winter road was abandoned for a route only 10 m to the east. The two routes can be clearly seen on Plate 3-6. It is quite possible that the organic layer was thicker at the first location than at the second. The melting of the permafrost in the thick organics would result in the roadbed sinking into the bog, enough to cause a relocation to a more stable route. Thus it may be that 0 + 40E marks the eastern limit of a bog section of lake shoreline which will gradually be infilled by tailings through thermokarst processes.

Figure 4-10 shows that *Carex aquatilis* and *Equisetum arvense* are the most important colonizers of the tailings. Both are able to reach onto the tailings by using creeping rootstalks which can provide colonizing plants with nutrients from the organic material at the edge of the tailings. The bed of the abandoned winter road has a few small patches of mosses, but *Betula glandulosa* and *Salix arbusculoides* are colonizing vigorously. The surface of the more recently used winter road consists of patches of bare clay (remnants of the frost boils commonly found in such bog locations), and shallow water-filled depressions. *Eriophorum angustifolium* is well established in many of these depressions.

4.4 THE R4 STUDY AREA

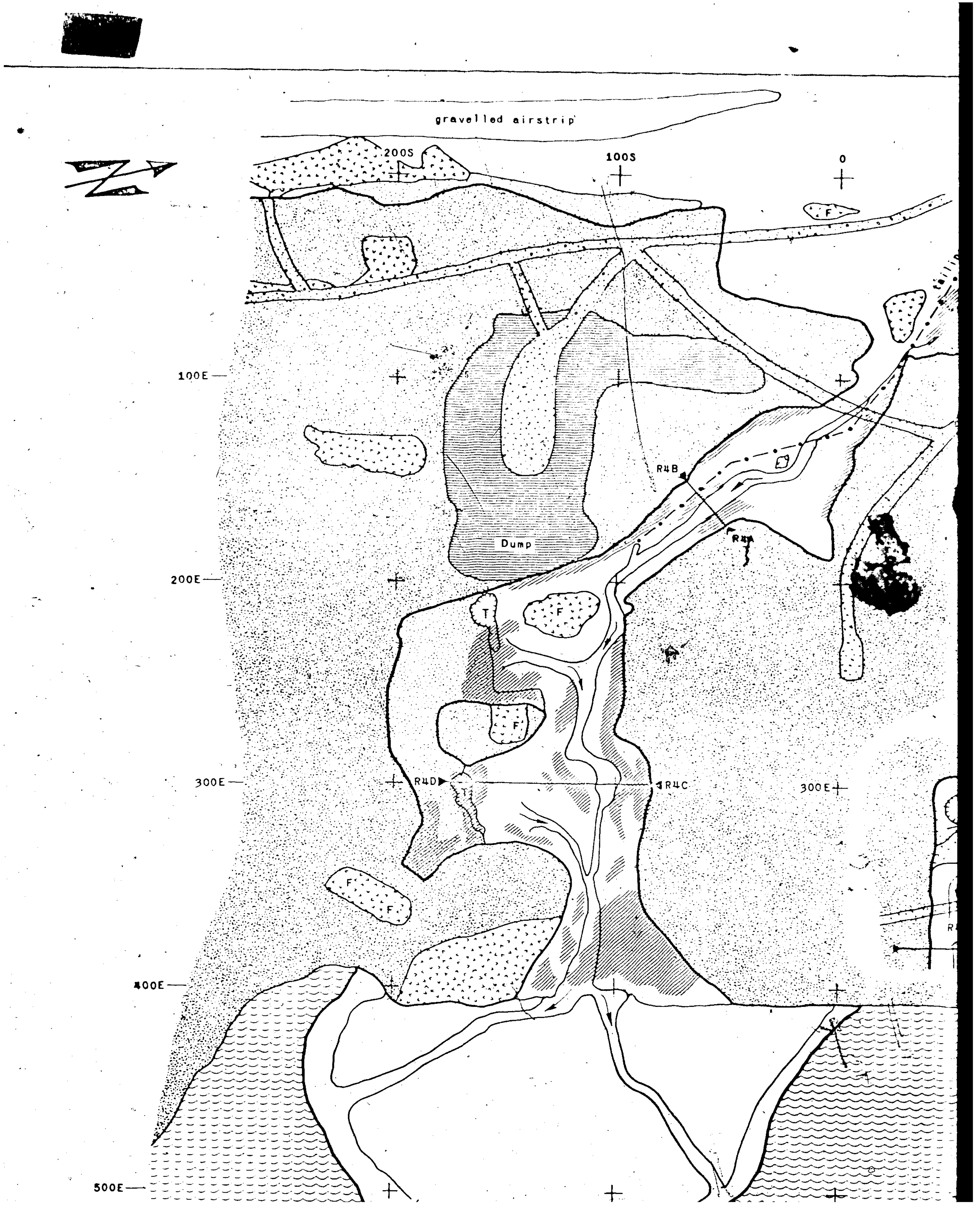
Most of the tailings disposal in this area occurred during the last years of operation, between 1965 and 1968. Since the site is a depression leading from the mineshaft to Giauque Lake (Plate 4-5) it is highly probable that small amounts of tailings were present in the gully from early in the operation of the mine.

Primary plant succession in the study area is shown in Figure 4-11, and colonization by species is presented in Figure 4-12. In general *Equisetum arvense* and *E. sylvaticum* are the most common colonizers, and patches are found scattered throughout the area. *Epilobium angustifolium* is also common, especially along margins of the affected area, where effluent killed the original vegetation, but where tailings deposition was minimal. *Eriophorum angustifolium* is present in depressions where water has ponded. *Betula papyrifera* and *Alnus crispa* occur along the edges of the tailings, most often where the tailings meet a bedrock slope.

4.4.1 STUDY TRANSECT R4AB

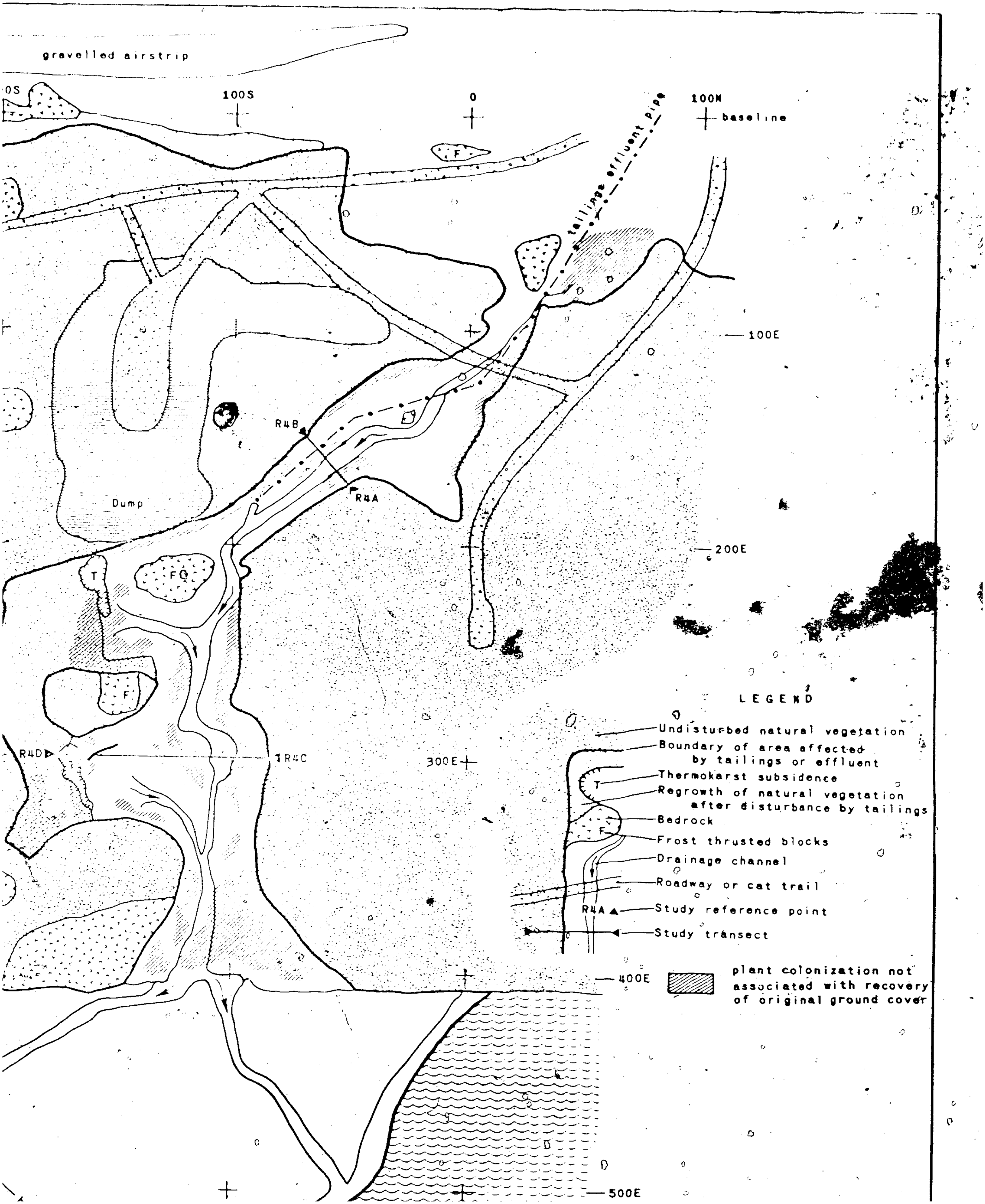
Two transects were located in this study area. Transect R4AB is presented in Figure 4-13. Plate 4-6 views R4B from about 0 + 10m on the transect, and Plate 4-7 shows R4A from 0 + 20m. In both photos the center-line of the transect is indicated by the steel tape. The photos illustrate the vigorous colonization of *Equisetum arvense* on portions of the transect.

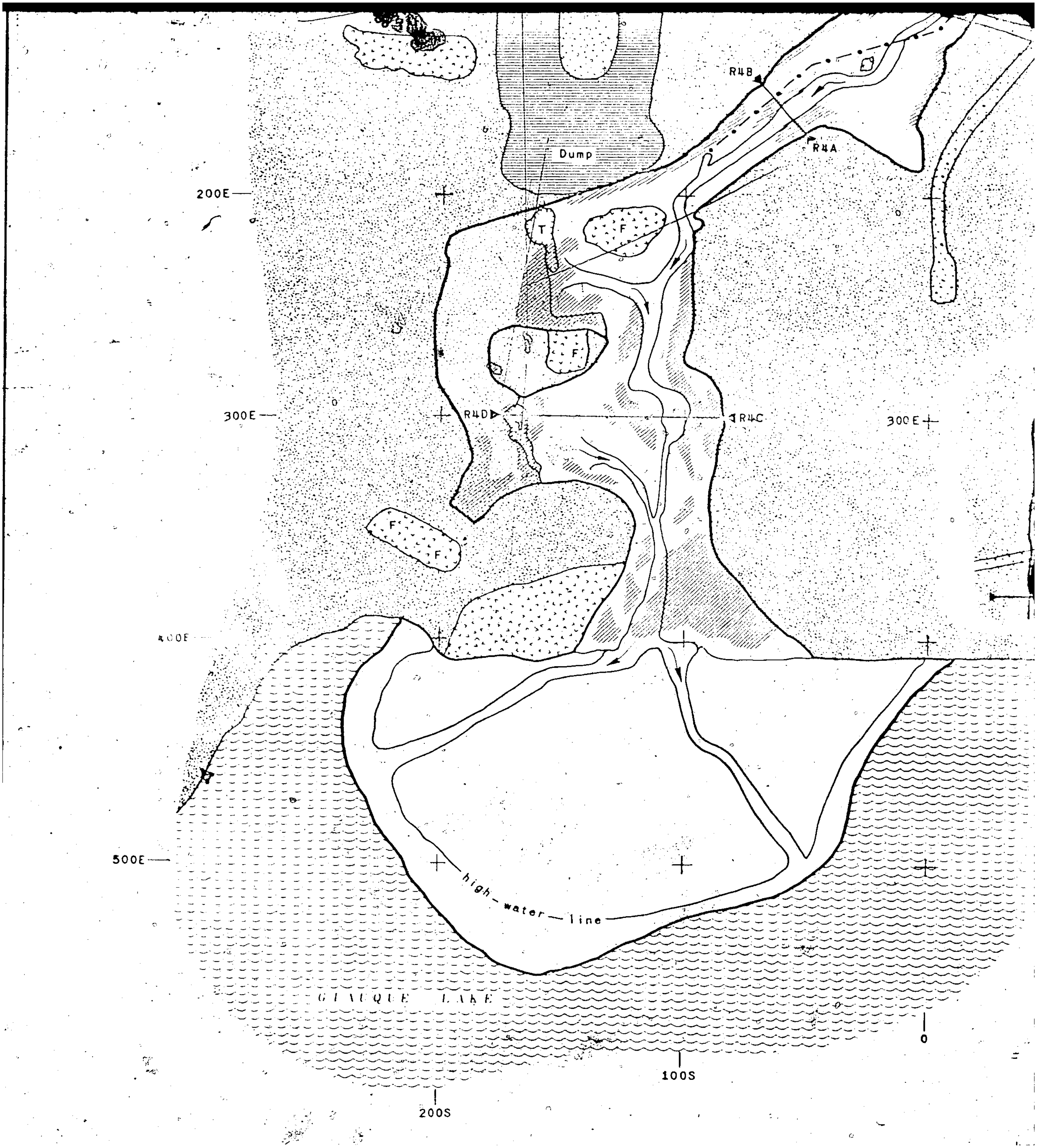
Plate 4-5. The R4 study area consists primarily of a tailings-filled depression in the bedrock, leading from the vicinity of the mineshaft eastward to Giauque Lake. Tailings have infilled the northern portion of a *Picea mariana-Sphagnum* bog located midway to the lake. July 1971 - 12h30.



gravelled airstrip
200S
100S
0
100E
200E
300E
400E
500E
300E
F
F
F
F
F
T
T
Dump
R4B
R4D
R4C
tailin

2 of 1


gravelled airstrip
100S
0
100N
baseline
tailings effluent pipe
100E
200E
300E
400E
500E
R4B
R4A
R4C
R4D
Dump
LEGEND
Undisturbed natural vegetation
Boundary of area affected by tailings or effluent
Thermokarst subsidence
Regrowth of natural vegetation after disturbance by tailings
Bedrock
Frost thrusted blocks
Drainage channel
Roadway or cat trail
Study reference point
Study transect
plant colonization not associated with recovery of original ground cover



R4B
R4A
Dump
200E
T
F
F
R4D
R4C
300E
300E
F
F
400E
500E
high-water-line
GLAUQUE LAKE
0
100S
200S

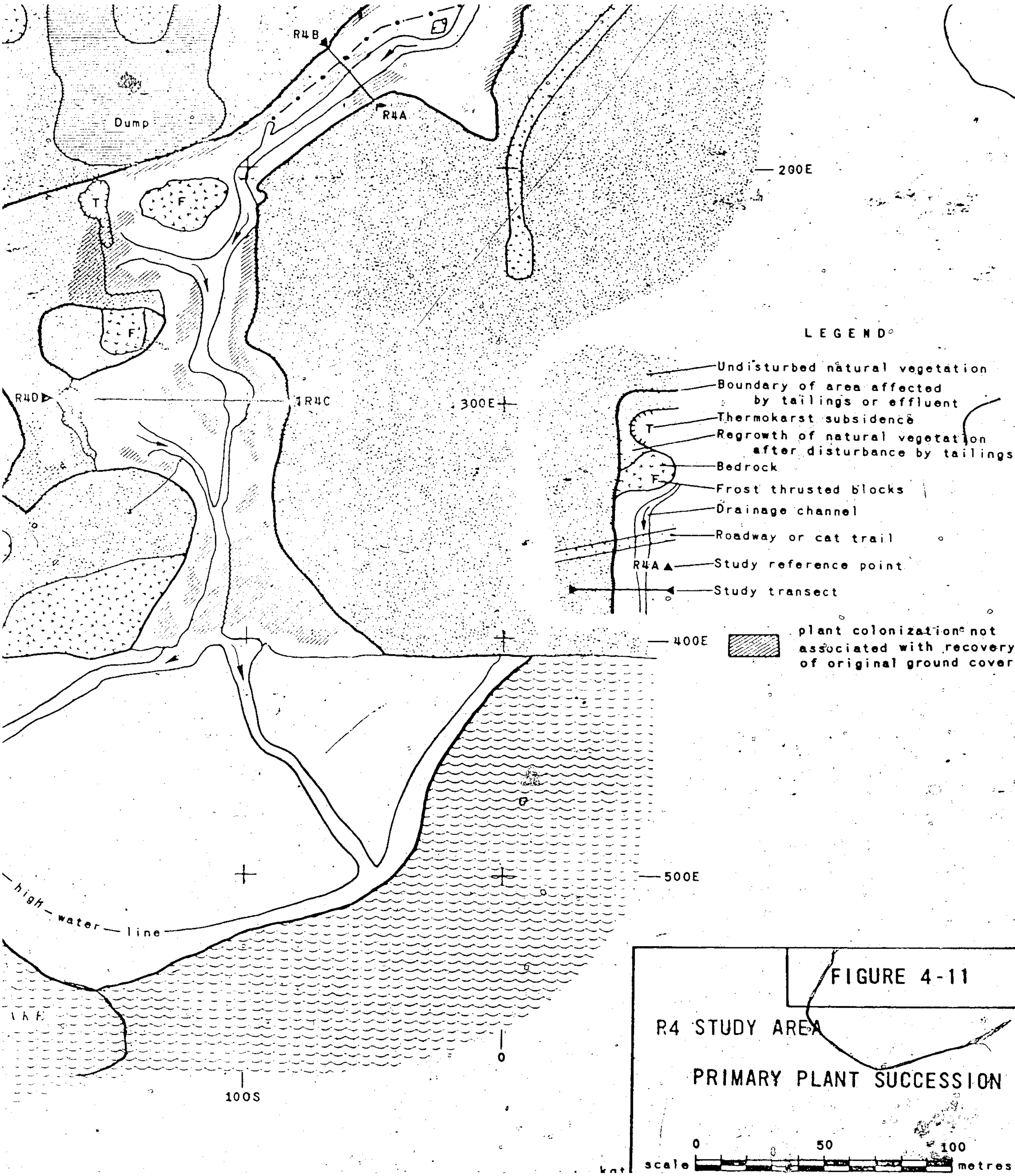


FIGURE 4-11

R4 STUDY AREA

PRIMARY PLANT SUCCESSION

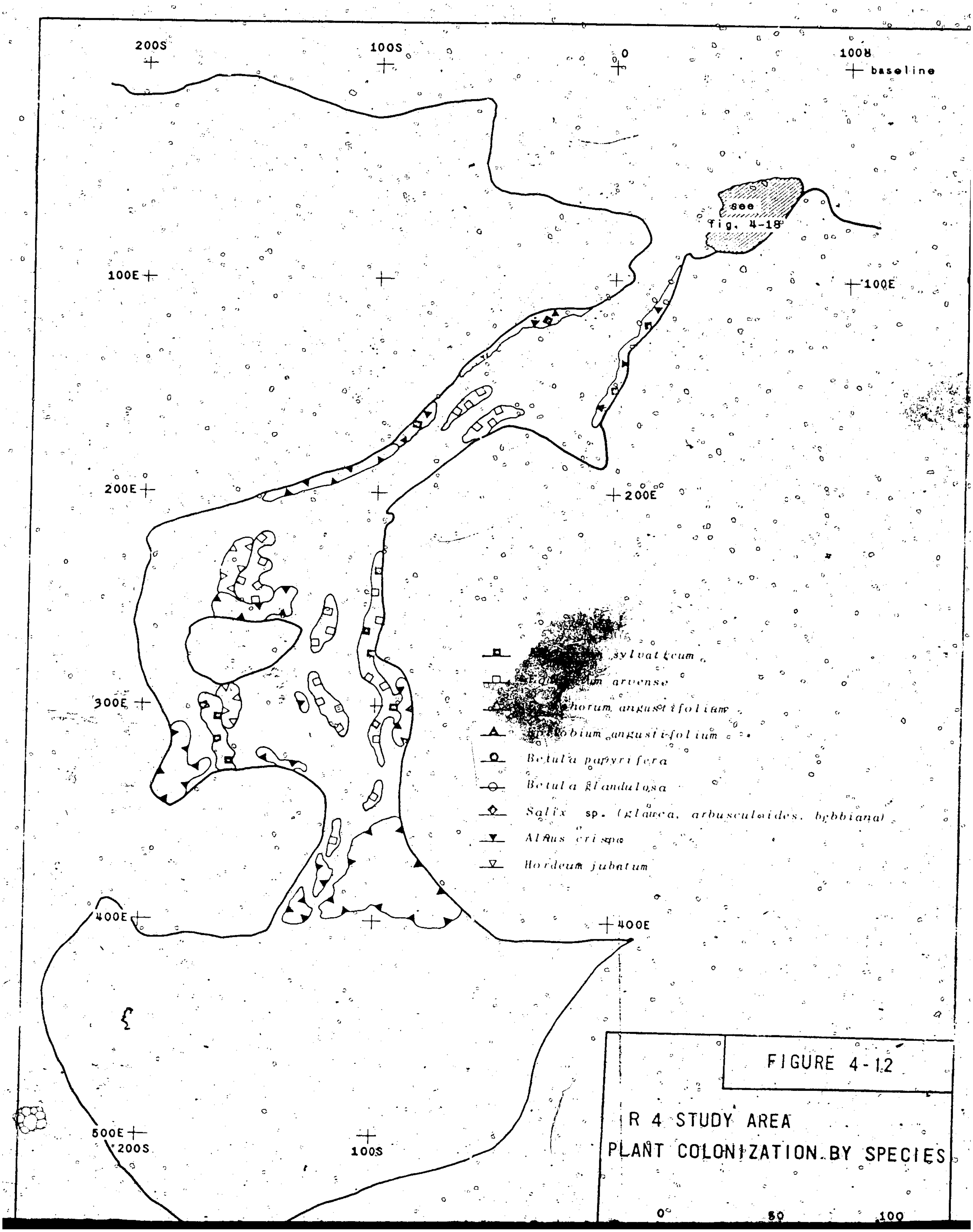


FIGURE 4-12

R 4 STUDY AREA
PLANT COLONIZATION BY SPECIES

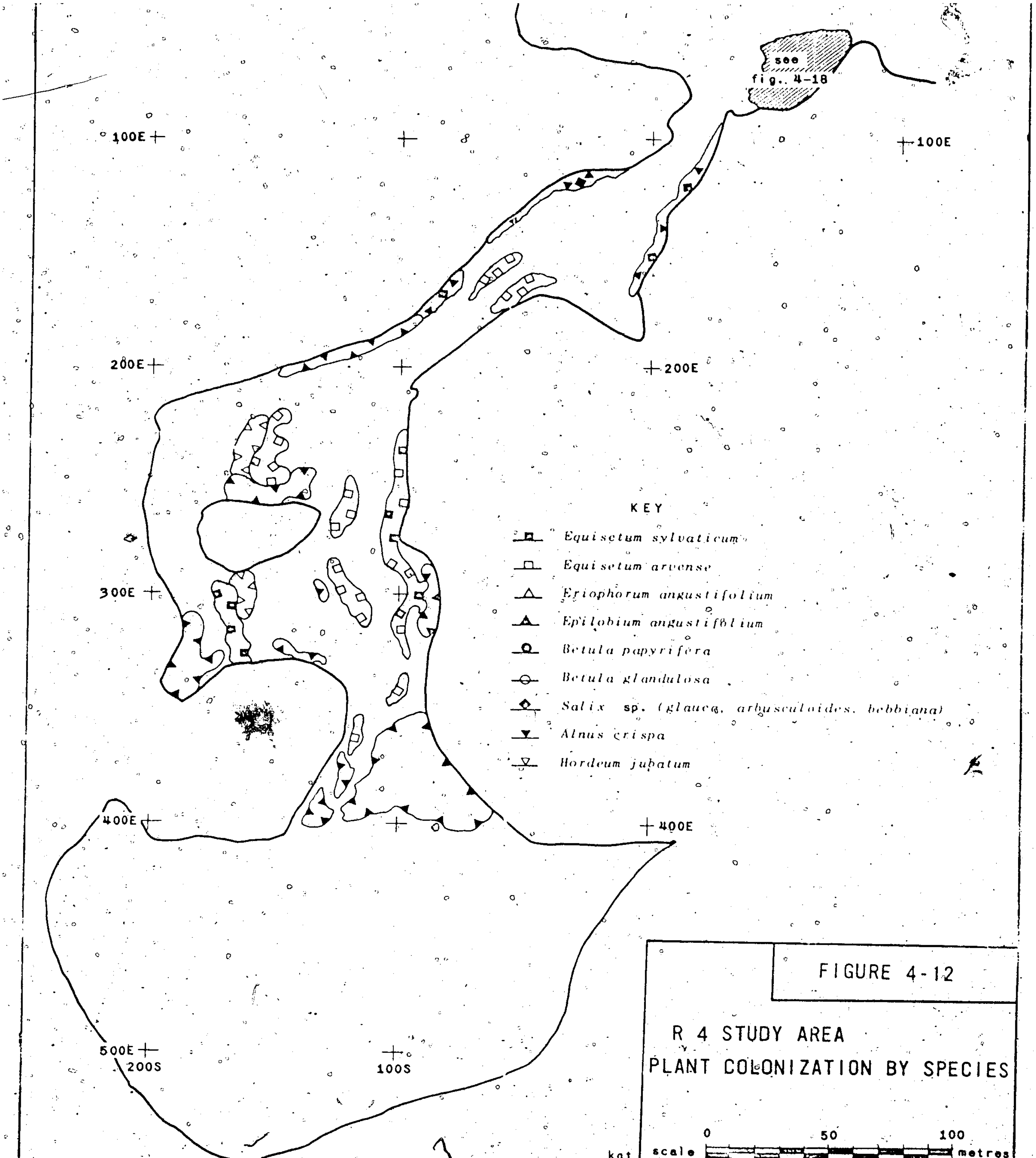
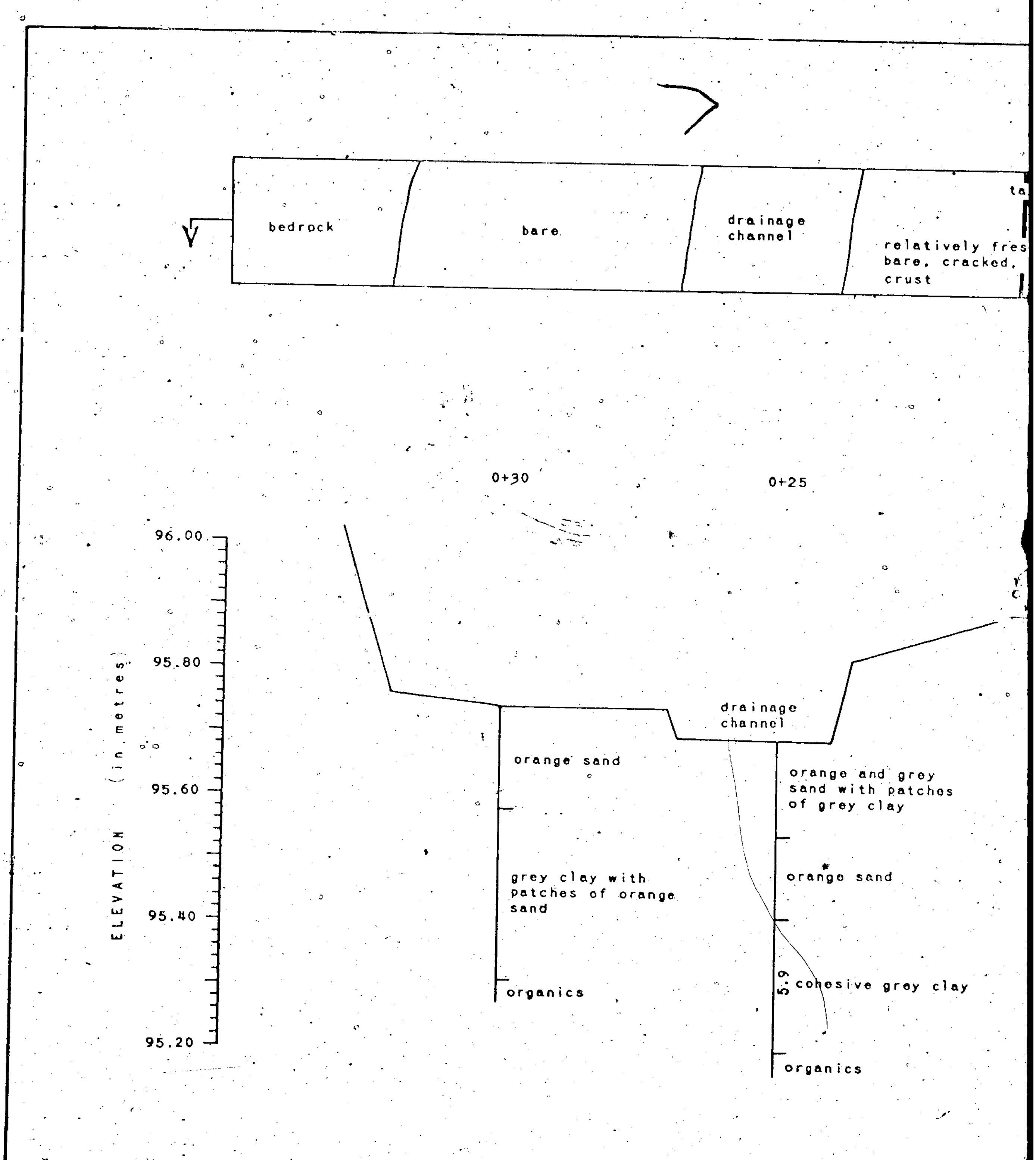


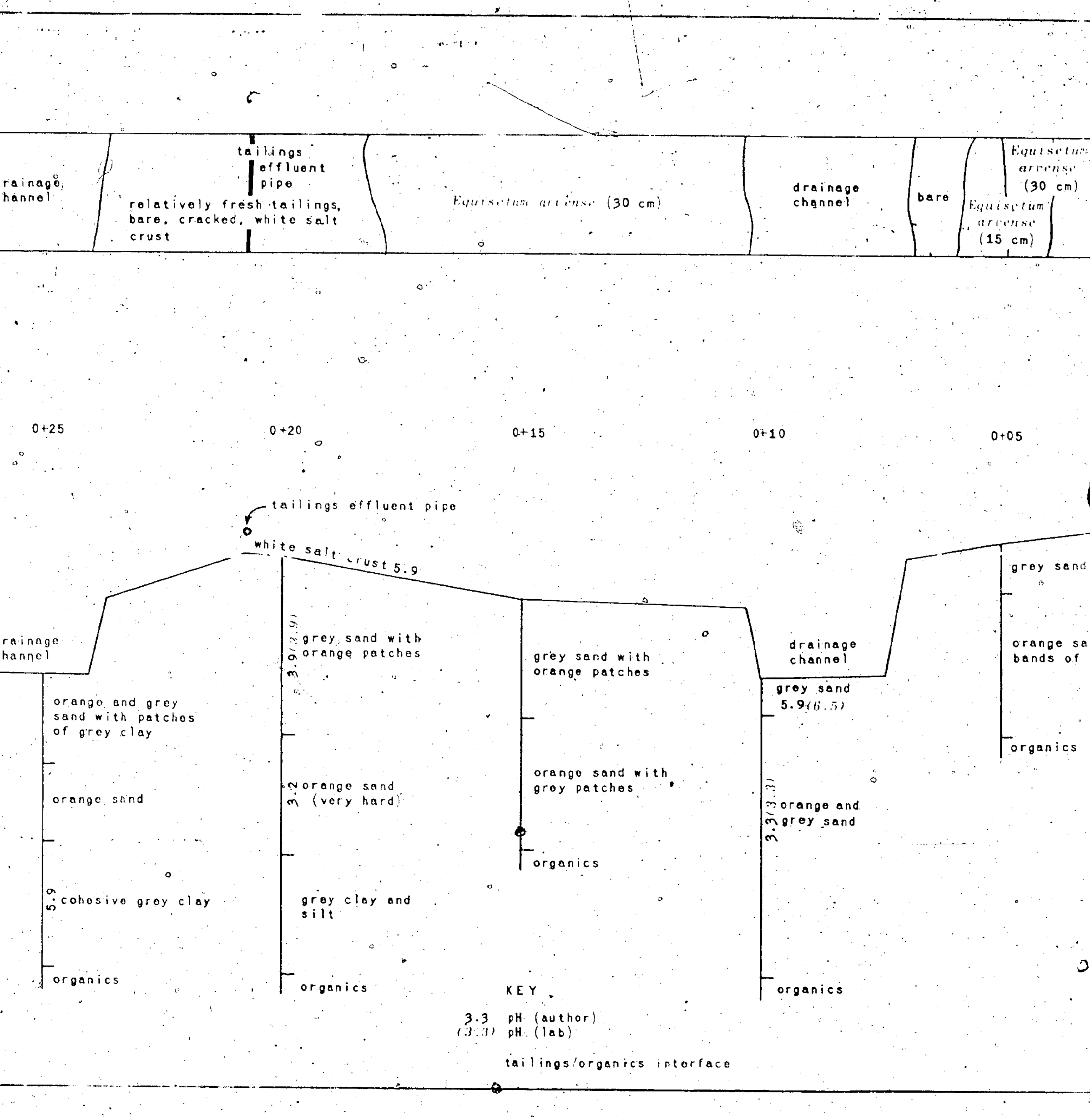
FIGURE 4-12

R 4 STUDY AREA
PLANT COLONIZATION BY SPECIES



bedrock
bare
drainage channel
ta
relatively fres
bare, cracked,
crust
0+30
0+25
96.00
95.80
95.60
95.40
95.20
ELEVATION (in metres)
drainage channel
orange sand
grey clay with patches of orange sand
organics
orange and grey sand with patches of grey clay
orange sand
5.9
cohesive grey clay
organics

2 of 1



rainage
hannel
tailings
effluent
pipe
relatively fresh tailings,
bare, cracked, white salt
crust
Equisetum arvense (30 cm)
drainage
channel
bare
Equisetum arvense (30 cm)
Equisetum arvense (15 cm)
0+25
0+20
0+15
0+10
0+05
tailings effluent pipe
white salt crust 5.9
rainage
hannel
orange and grey
sand with patches
of grey clay
orange sand
5.9
cohesive grey clay
organics
3.9(3.9)
grey sand with
orange patches
3.2
orange sand
(very hard)
grey clay and
silt
organics
grey sand with
orange patches
orange sand with
grey patches
organics
drainage
channel
grey sand
5.9(6.5)
3.3(3.3)
orange and
grey sand
organics
grey sand
orange sa
bands of
organics
KEY
3.3 pH (author)
(3.3) pH (lab)
tailings/organics interface

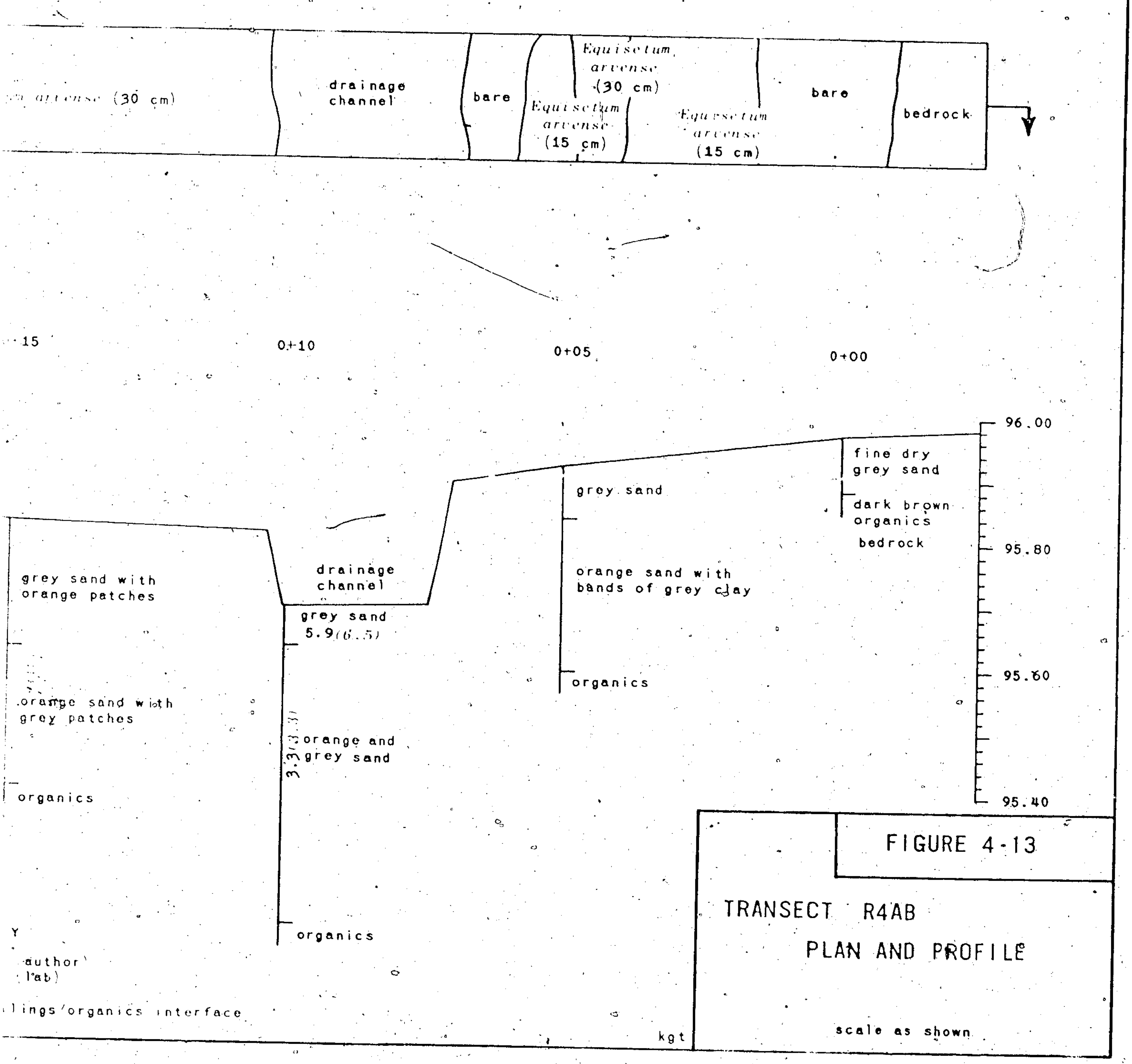


FIGURE 4-13

TRANSECT R4AB
PLAN AND PROFILE

scale as shown

Plate 4-6. The southern end of transect R4AB as viewed from 0+10 m on the transect. Note the tailings disposal pipeline, a wire-bound wooden stave pipe in use until mine closure. Vigorous colonization of *Equisetum arvense* is evident in the foreground. 10 July 1971 - 11h00.

Plate 4-7. The northern portion of transect R4AB, viewed from 0 + 20 m. *Equisetum arvense* has colonized portions of the transect. 10 July 1971 - 11h00.

This transect also reveals that the acidity of the tailings is related to the proportion of iron (represented by the orange-coloured sand). *Equisetum* has colonized the grey sand, especially where buried organics material is in reach of the plants (between 0+02 and 0+05). Table 4-4 analyses three soil samples taken along this transect. Once again the orange tailings prove to be highly acidic with high levels of aluminum and manganese. Similarly, the levels of potassium are suppressed in these acidic samples. All of these conditions are thought to be detrimental to plant growth and may explain the patchy colonization patterns evident in the R4 area.

4.4.2 STUDY TRANSECT R4CD

The middle portion of the R4 study area exhibits several examples of vigorous plant succession. Plate 4-8 illustrates a dense cover of *Equisetum arvense* and *E. sylvaticum* along the northern edge of the tailings. Transect R4CD extends across this portion of the study area.

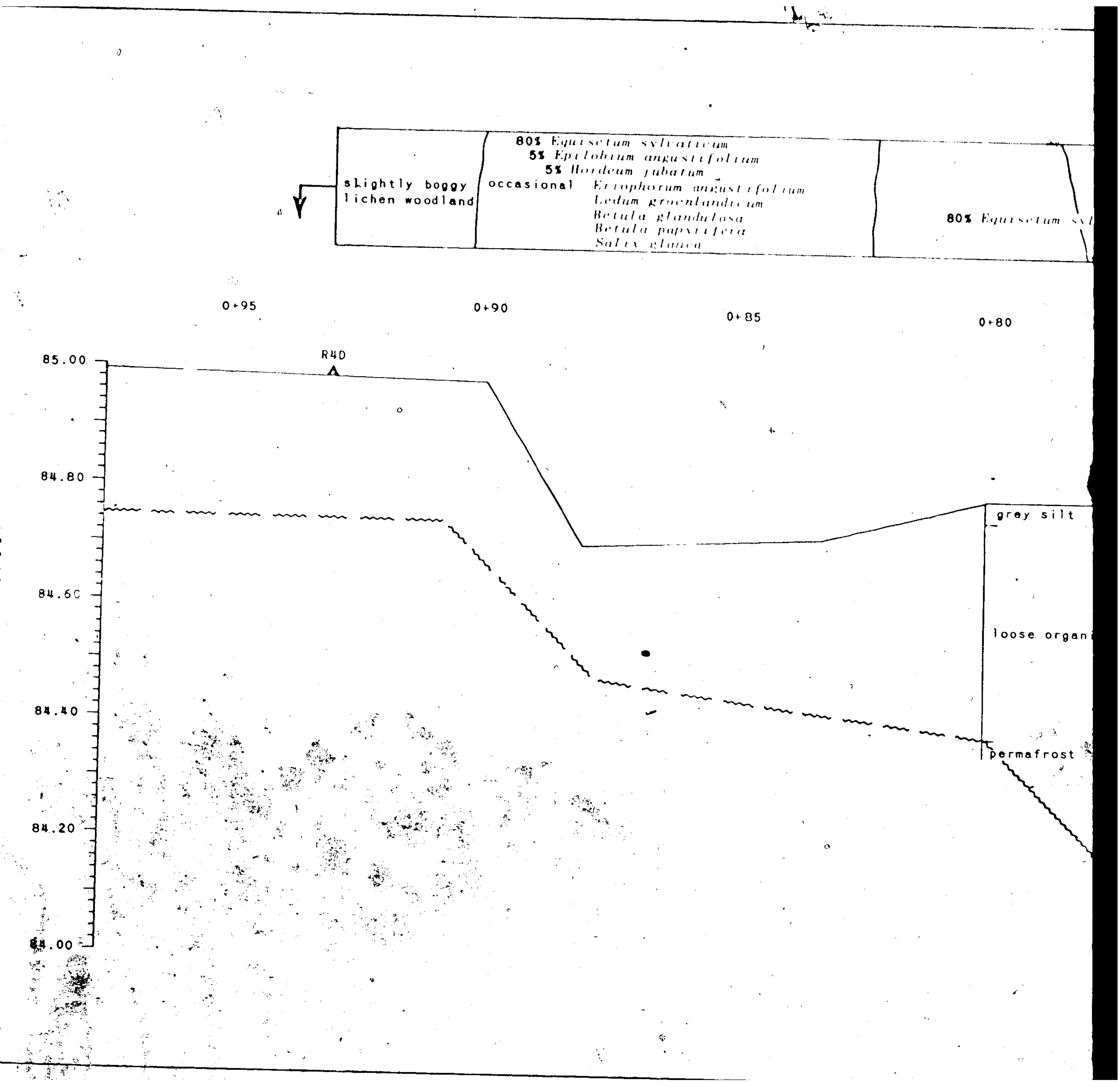
Transect R4CD is illustrated in two parts (Figures 4-14 and 4-15). Again a lower relative acidity occurs in the grey or iron-poor tailings. The overall successional pattern indicated a tendency for *Equisetum* and *Epilobium* to grow best where the depth of the tailings is less than 20 cm. Although colonization has been very successful at some locations (Plate 4-8), large bare sections also exist along the transect. The absence of vegetation between 0+17 and 0+30 (Plate 4-9) is probably caused by the thickness of the tailings, in the order of 40 cm. Observations also suggest that surface instability caused by wash erosion is also a factor. The presence of iron-rich (high-acidity)

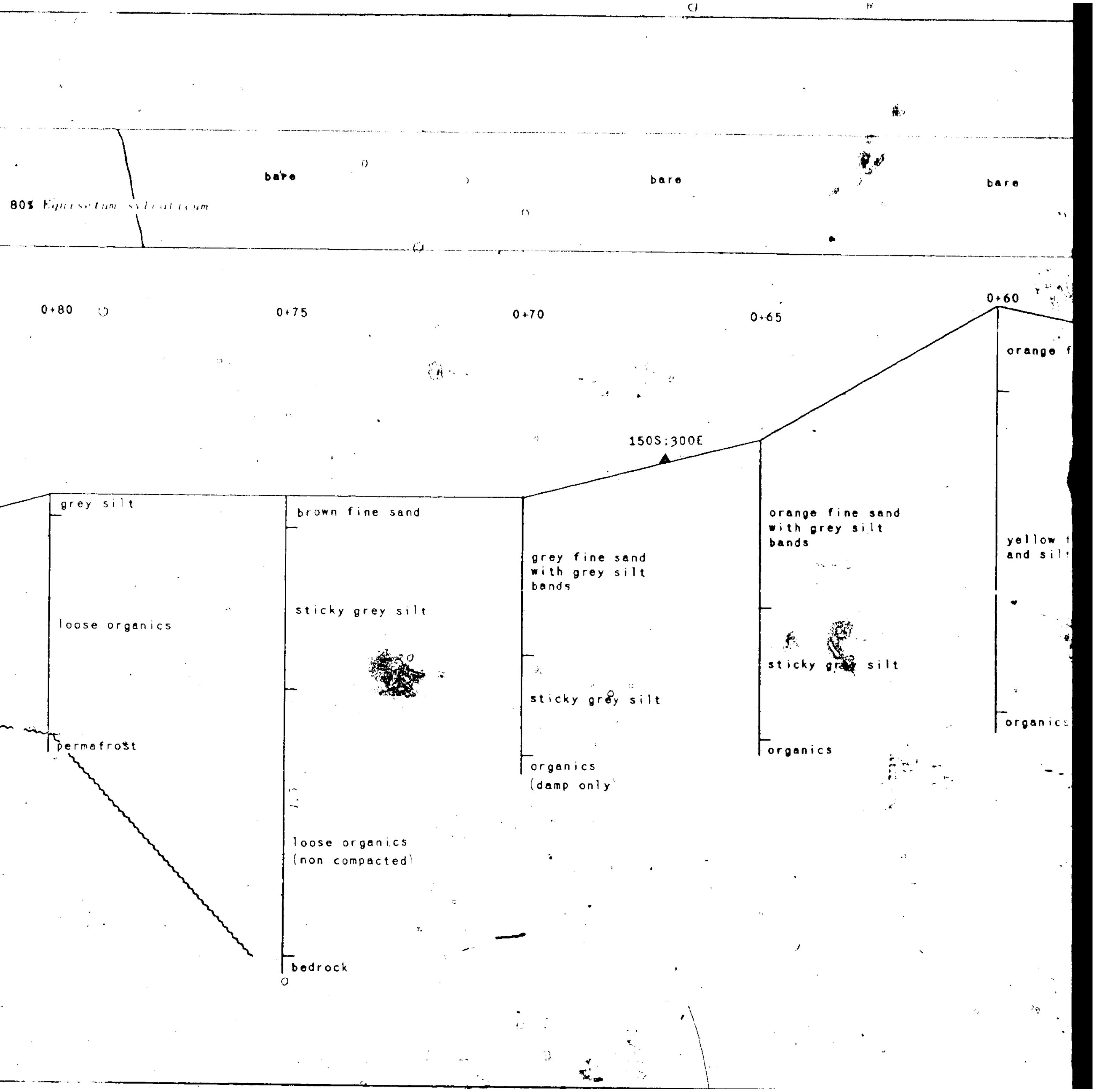
Table 4-4 Analysis of soil samples (Transect R4AB)

Sample number	38	39	40	
Location	0 + 10	0 + 10	0 + 20	
Depth (cm)	0-6	6-50	0-30	
Description	grey fine sand	orange and grey fine sand	orange and grey fine sand	
Nitrogen (kg/ha)	00	00	00	
Phosphorus (kg/ha)	02	03	02	
Potassium (kg/ha)	263	82	73	
Sodium	L-	L-	H-	
pH (lab) (author)	6.5 5.9	3.3 3.3	3.9 3.9	
Sulphate	M-	M	H	
Aluminum (ppm)	---	20+	14.4	
Manganese (ppm)	---	3.8	20+	
Conductivity (mmhos/cm^2)	2.1	2.5	5.0	
Organics	L-	L-	L-	

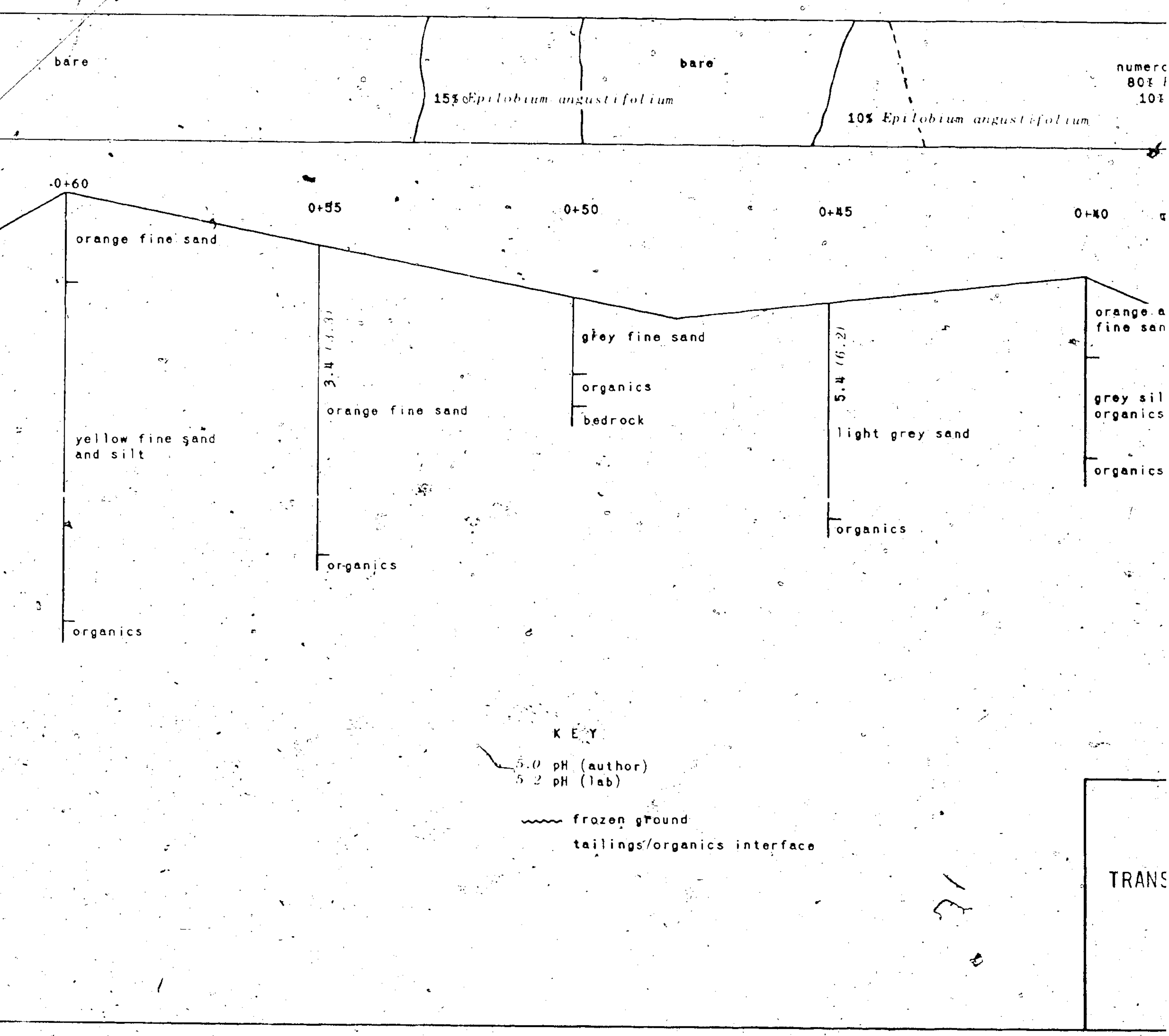
Note: See Appendix B for explanation of analysis techniques and symbols.

Plate 4-8. A zone of vigorous *Equisetum sylvaticum* and *E. arvense* growth is located along the northern edge of the tailings at approximately 100S-300E. 9 July 1971 - 15h30.


slightly boggy lichen woodland
80% Equisetum sylvaticum
5% Epilobium angustifolium
5% Hordeum jubatum
occasional Eriophorum angustifolium
Ledum groenlandicum
Betula glandulosa
Betula papyrifera
Salix glauca
80% Equisetum
0+95
0+90
0+85
0+80
R4D
85.00
84.80
84.60
84.40
84.20
84.00
grey silt
loose organi
permafrost



80% Equisetum sylvaticum
bare
bare
bare
0+80
0+75
0+70
0+65
0+60
150S;300E
grey silt
loose organics
permafrost
brown fine sand
sticky grey silt
loose organics
(non compacted)
bedrock
grey fine sand
with grey silt
bands
sticky grey silt
organics
(damp only)
orange fine sand
with grey silt
bands
sticky grey silt
organics
orange f
yellow
and sil
organics


bare
15% Epilobium angustifolium
bare
10% Epilobium angustifolium
numerc
80%
10%
0+60
0+55
0+50
0+45
0+40
orange fine sand
yellow fine sand and silt
organics
3.4
orange fine sand
organics
grey fine sand
organics
bedrock
5.4 (6.2)
light grey sand
organics
orange a fine san
grey sil organics
organics
KEY
5.0 pH (author)
5.2 pH (lab)
frozen ground
tailings/organics interface
TRANS

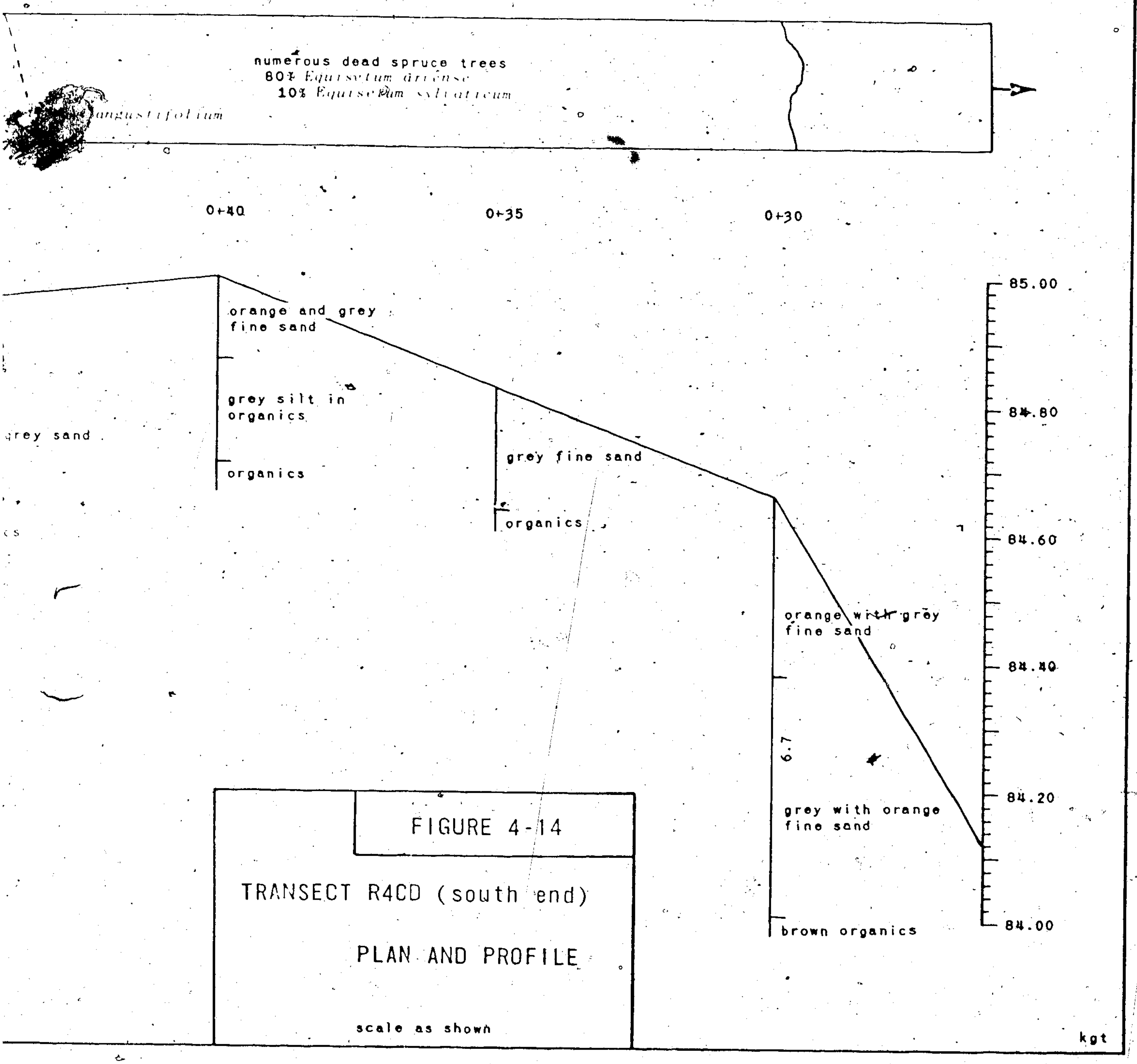
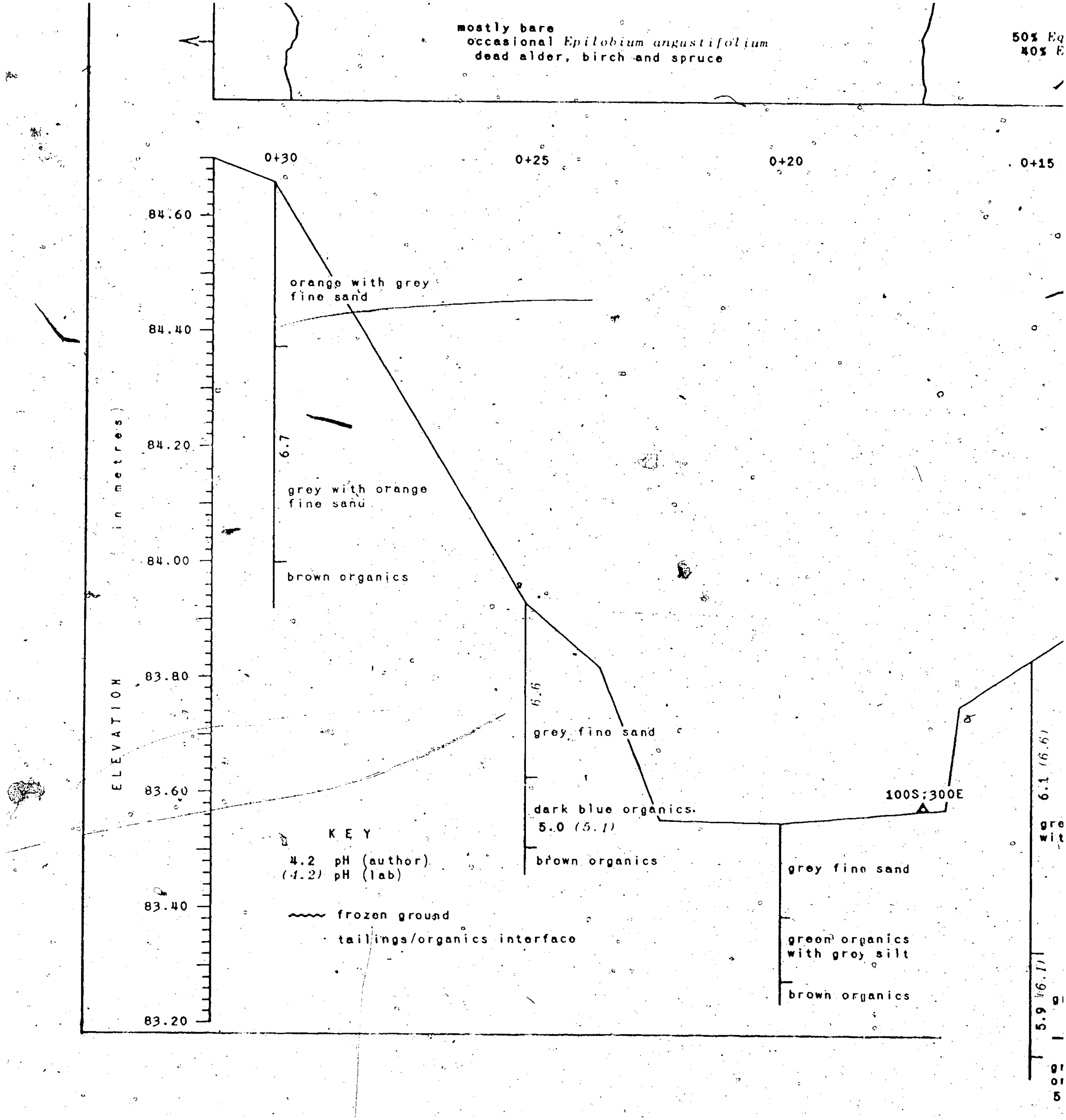


FIGURE 4-14

TRANSECT R4CD (south end)

PLAN AND PROFILE

scale as shown


mostly bare
occasional *Epilobium angustifolium*
dead alder, birch and spruce
50% Eq
40% E
0+30
0+25
0+20
0+15
84.60
84.40
84.20
84.00
83.80
83.60
83.40
83.20
ELEVATION (in metres)
orange with grey fine sand
6.7
grey with orange fine sand
brown organics
6.6
grey fine sand
dark blue organics
5.0 (5.1)
brown organics
grey fine sand
green organics with grey silt
brown organics
100S;300E
6.1 (6.6)
5.9 (6.1)
KEY
4.2 pH (author)
(4.2) pH (lab)
frozen ground
tailings/organics interface

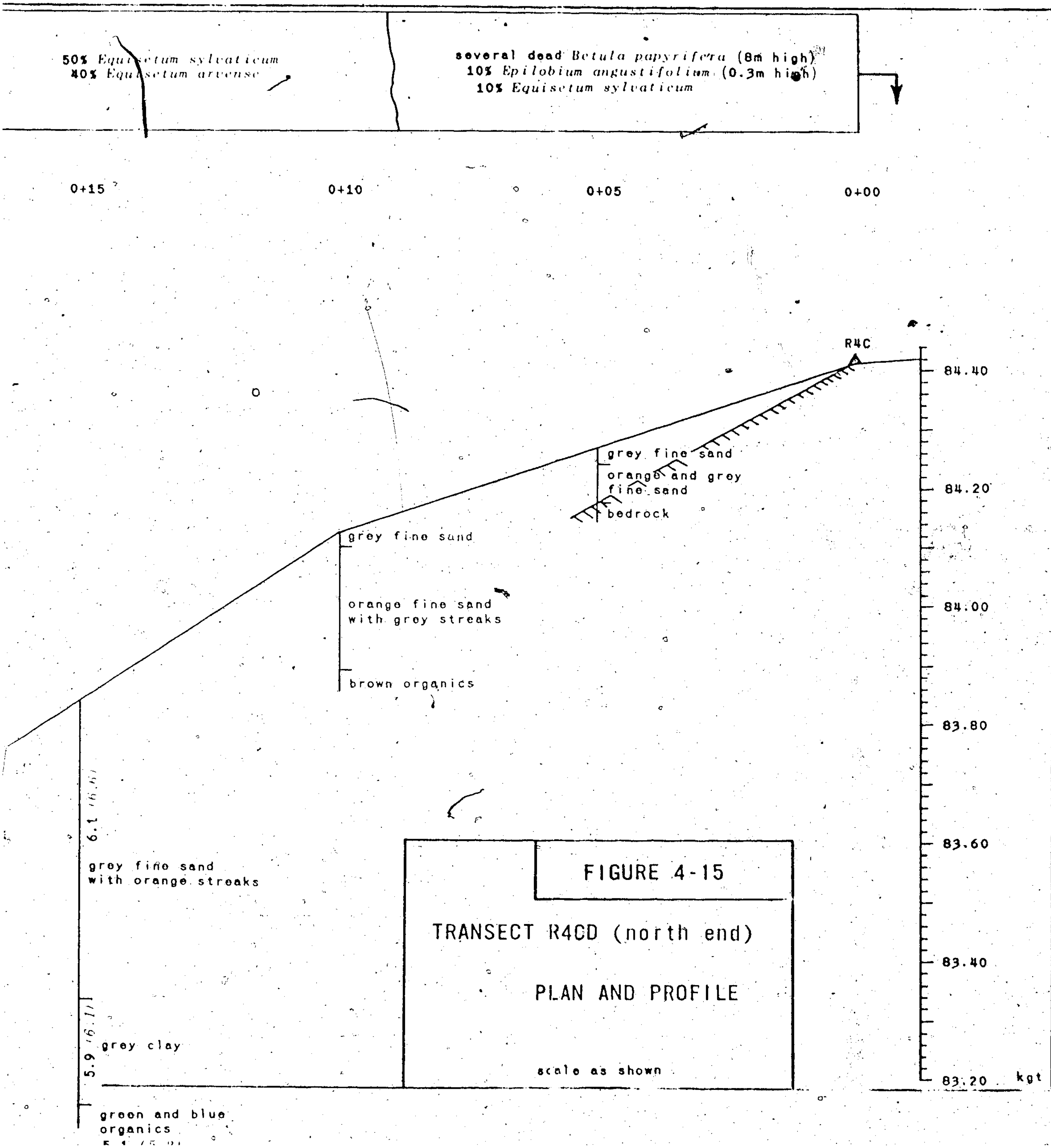


FIGURE 4-15

TRANSECT R4CD (north end)

PLAN AND PROFILE

scale as shown

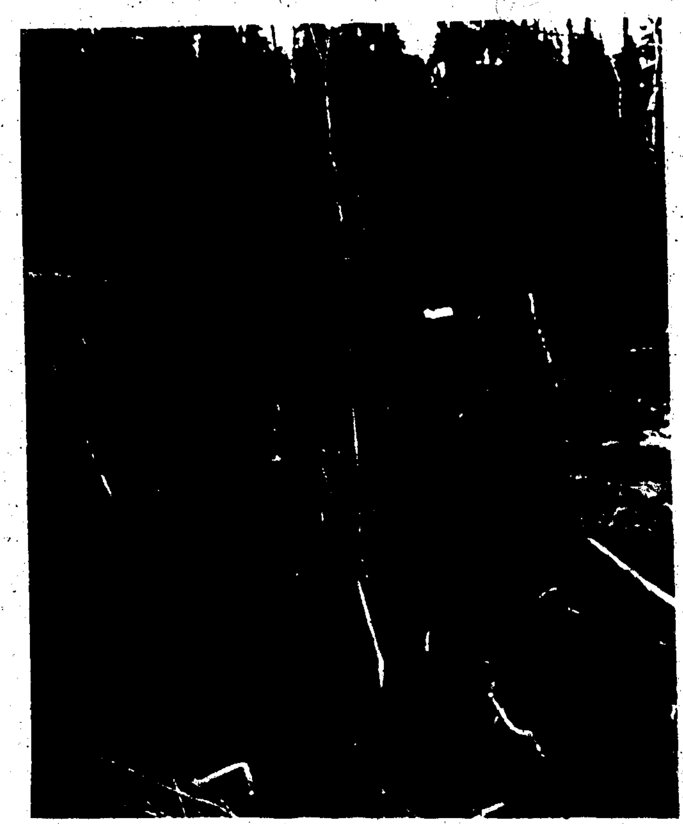


Plate 4-9. The R4CD transect north from 0 +53 shows many dead shrubs of the former plant cover in the foreground and virtually no regeneration to 0 +17, near the white pad of paper. Beyond this point *Equisetum arvense* and *E. sylvaticum* grow vigorously. 13 July 1971 - 10h00.

tailings in the surface layers may also inhibit colonization.

The portion of the transect between 0 + 53 and 0 + 73 (Plate 4-10) is devoid of vegetation, likely for the same reasons. The depth of tailings is considerable, reaching 70 cm, and acid iron-rich tailings are present in the surface layers. Although the slope of this section is considerably less than that of the previous section, observations suggest some surface instability due to thermokarst activity.

Analysis of soil samples are shown in Tables 4-5 and 4-6. It is notable that the green-blue organics under the tailings tested moderately acid with relatively high values of aluminum and manganese. The cause of the blue colour is not known, but a blue ring was also noted on some of the old tree trunks, at heights of up to 50 cm above the present level of the tailings. As before, only organic material had significant nitrogen values.

4.4.3 THERMOKARST

The southern end of the R4CD transect provides evidence of continued thermokarst settling. Plate 4-11 shows the depression found at the south end of the R4CD transect. At times of peak runoff it appears that the depression overflows (to the right in Plate 4-11) into the main channel of the study area. However, to the south and east of the depression is a low divide over which minor amounts of tailings or effluent evidently passed when the area was used as a prime disposal area. At that time there would have been no depression so it may be assumed that considerable subsidence has occurred since 1968. The fact that the profile of the depression is asymmetrical, with the lowest point at the tailings-bog interface, suggests active thermokarst

Plate 4-10. This view south from 0+53 m on the R4CD transect shows tailings completely devoid of vegetation. 13 July 1971 - 12h00

Table 4-5 Analysis of soil samples (Transect R4CD)

Sample number	137	56	60	
Location	0 + 25	0 + 45	0 + 55	
Depth (cm)	30-42	0-34	0-49	
Description	dark blue organics	grey fine sand	orange fine sand	
Nitrogen (kg/ha)	90+	01	00	
Phosphorus (kg/ha)	03	02	02	
Potassium (kg/ha)	532	347	17	
Sodium	H+	M+	L	
pH (lab) (author)	5.1 5.0	6.2 5.4	3.3 3.4	
Sulphate	L	H	H	
Aluminum (ppm)	1.2	---	20+	
Manganese (ppm)	36.8	---	14.4	
Conductivity (mmhos/cm^2)	2.5	6.0	5.2	
Organics	L	L-	L-	

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-6 Analysis of soil samples (Transect R4CD)

Sample number	57	130	142	54
Location	0+15	0+15	0+15	0+25
Depth (cm)	0-37	37-58	60	0-30
Description	grey fine sand	grey clay	green/blue organics	grey fine sand
Nitrogen (kg/ha)	00	00	21	01
Phosphorus (kg/ha)	00	00	20	03
Potassium (kg/ha)	140	157	140	230
Sodium	L-	L	L+	M
pH (lab) (author)	6.6 6.1	6.1 5.9	5.2 5.1	6.6 ---
Sulphate	H	H	---	H
Aluminum (ppm)	---	---	1.7	---
Manganese (ppm)	---	---	14.8	---
Conductivity (mmhos/cm^2)	4.7	3.3	0.4	4.7
Organics	L-	L	H+	L-

Note: See Appendix B for explanation of analysis techniques and symbols.

Plate 4-11. Considerable thermokarst subsidence has occurred along the tailings/bog interface in the vicinity of 150S-300E. This depression is gradually expanding into the bog area on the left. Small piles of earth in the background indicate soil pits on the R3CD transect. 13 July 1971 - 12h00.

settling. As the tailings-bog interface gradually migrates farther south into the bog, the tailings then move (through slumping and runoff) to gradually fill the depression. This surface instability has at least a minor inhibiting effect on colonizing plants.

A similar depression is found to the west in the vicinity of 160S-220E (shown on Figure 3-7). Both depressions are wet and contain *Eriophorum angustifolium*.

The vegetation growing from 0 + 78 to the end of the transect is shown in Plate 4-12. *Equisetum sylvaticum* is the most successful colonizer, although a number of other plants are evident in this tailings-bog transition zone. The portion of the transect south of 0+78 has a very shallow cover of tailings.

Plate 4-13 shows a low divide southeast of the depression, where a bog once existed. Now all the trees are dead and there are many deadfalls. A thin tailings cover now supports a vigorous growth of *Epilobium angustifolium*.

4.4.4 DELTA INTO GIAUQUE LAKE

The remaining portion of the RM study area, the delta of tailings into Giauque Lake (Plates 4-15 and 4-15), supports no plant cover. Figure 4-16 shows the physical features of this delta and the location of soil samples. This area was systematically sampled for several reasons; it represents a large deposit of known age, and has been unaffected for the most part by runoff from adjacent undisturbed areas.

Tables 4-7 to 4-10 list results of tests carried out on the soil samples. No distinct patterns emerge, except that all samples exhibit extremely low values of nitrogen and phosphorous.

Plate 4-12. The southern end of the R4CD transect, viewed from 0 - 80 m. *Equisetum sylvaticum* and *Eriophorum angustifolium* are the dominant colonizing species at this location. 13 July 1971 - 12h00.

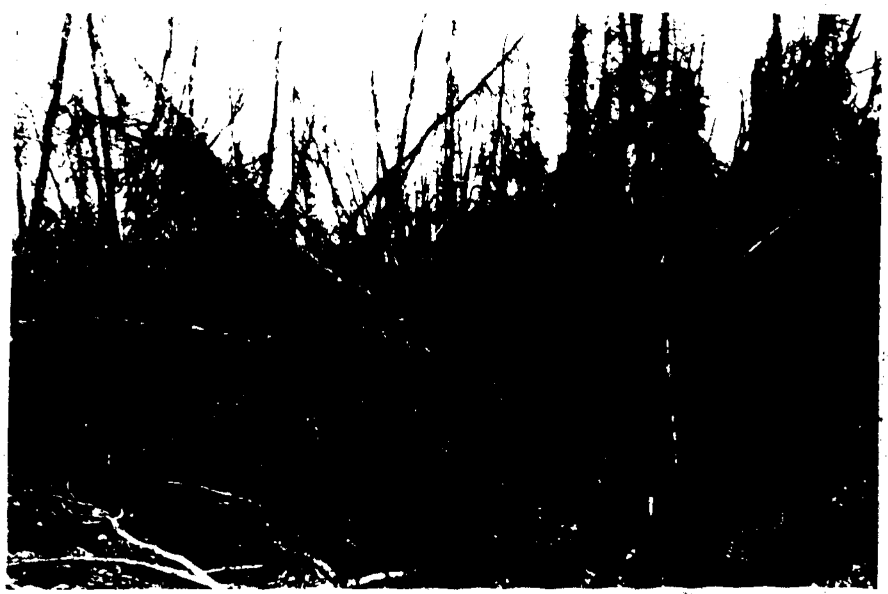
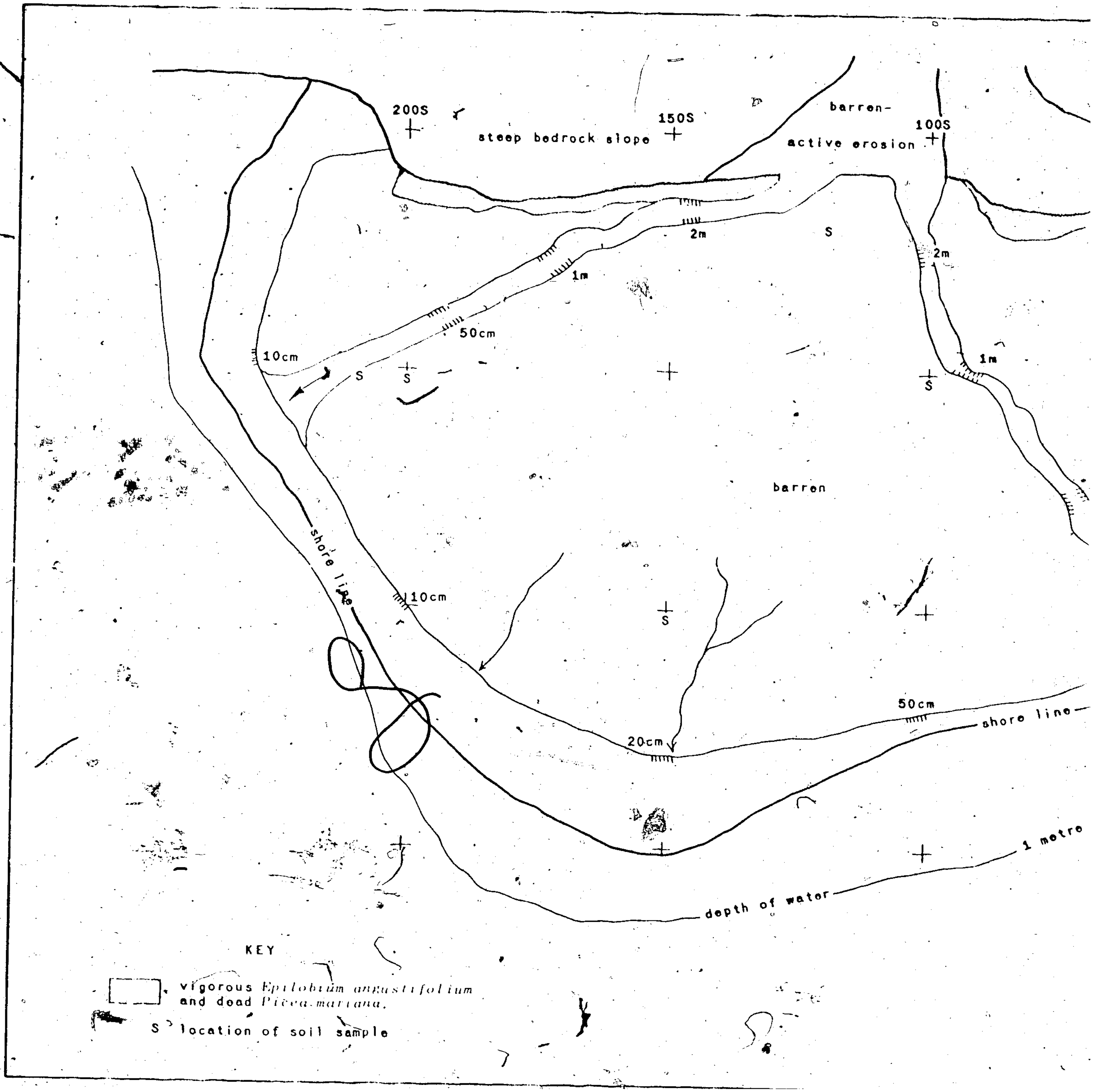


Plate 4-13. *Epilobium angustifolium* grows vigorously amid dead *Picea mariana* on a low divide at 200S-350E. 13 July 1971 - 12h00.

Plate 4-14. Oblique aerial view of the delta in Giauque Lake showing eroded slope down to lake level and the two main channels crossing the delta. 21 July 1971 - 12h30.

Plate 4-15: Tailings deposited into the R4 area are creating a large delta in Giauque Lake. 13 July 1971 - 12h30.



KEY

vigorous *Epilobium angustifolium* and dead *Picea mariana*.

S location of soil sample

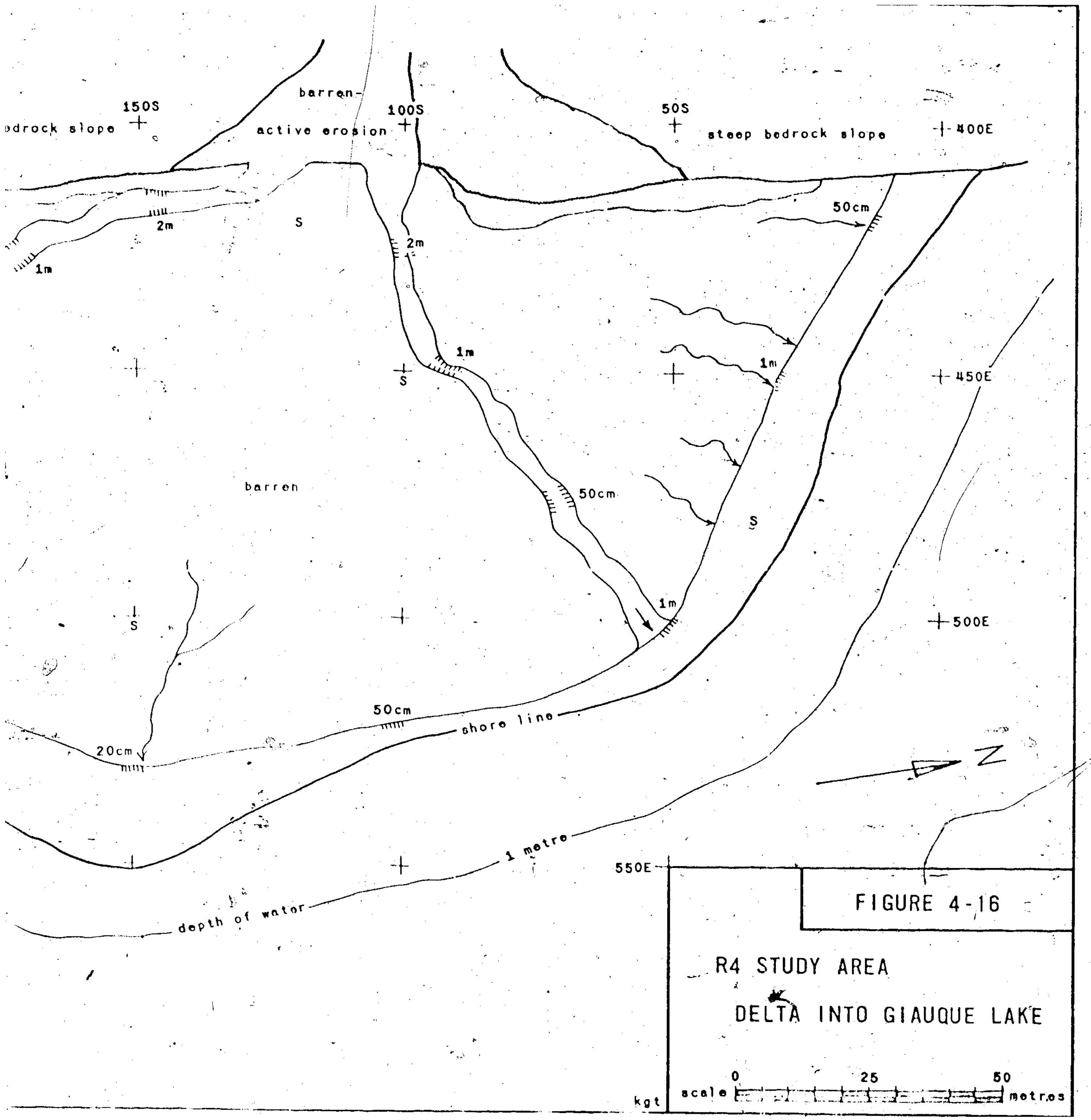


FIGURE 4-16

R4 STUDY AREA

DELTA INTO GIAUQUE LAKE

Table 4-7 Analysis of soil samples (R4 Delta)

Sample number	86	49	81	88
Location	----------	---- 35S - 480E	----------	----------
Depth (cm)	0-2	2-24	24-36	36-55
Description	grey fine sand	grey fine sand	grey fine sand	grey fine sand
Nitrogen (kg/ha)	01	00	01	01
Phosphorus (kg/ha)	00	00	01	01
Potassium (kg/ha)	1176	297	342	302
Sodium	H+	H+	H+	L+
pH (lab) (author)	5.4 4.4	3.7 4.5	6.4 6.0	7.6 5.6
Sulphate	H	H	H	H-
Aluminum (ppm)	28.0	6.2	---	---
Manganese (ppm)	31.6	31.6	---	---
Conductivity (mmhos/cm^2)	10.3	6.0	4.5	3.3
Organics	L-	L-	L-	L-

Note: See Appendix 3 for explanation of analysis techniques and symbols.

Table 4-8 Analysis of soil samples (R4 Delta)

Sample number	134	99	98	89
Location	35S-480E	100S-450E	120S-420E	150S-500E
Depth (cm)	53-90	0-10	0-10	0-10
Description	grey fine sand	grey fine sand	grey fine sand	grey fine sand
Nitrogen (kg/ha)	00	00	02	00
Phosphorus (kg/ha)	00	00	00	00
Potassium (kg/ha)	241	336	151	448
Sodium	M-	H+	L+	H+
pH (lab) (author)	7.8 6.1	5.3 5.5	7.0 5.9	6.7 6.1
Sulphate	[illegible]	M+	L+	M+
Aluminum (ppm)	---	0.2	---	---
Manganese (ppm)	---	00	---	---
Conductivity (mmhos/cm^2)	2.3	[illegible]	3.1	4.3
Organics	L-	L	L	L

Note: See Appendix 3 for explanation of analysis techniques and symbols.

Table 4-9 Analysis of soil samples (R4 Delta)

Sample number	100	95	96	94
Location	120S - 420E			
Depth (cm)	10-50	50-100	100-130	130-140
Description	grey fine sand	grey fine sand	grey fine sand	grey fine sand
Nitrogen (kg/ha)	01	00	00	.01
Phosphorus (kg/ha)	00	01	03	00
Potassium (kg/ha)	151	118	84	241
Sodium	H+	M-	M+	M
pH (lab) (author)	6.2 5.6	6.2 5.2	4.0 4.3	7.4 5.8
Sulphate	M-	---	H-	M
Aluminum (ppm)	---	---	8.0	---
Manganese (ppm)	---	---	00	---
Conductivity (mmhos/cm^2)	4.1	0.1	5.6	3.5
Organics	L	L	L	L

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-10 Analysis of soil samples (R4 Delta)

Sample number	104	102		
Location	200S-450E	213S-450E		
Depth (cm)	0-10	0-10		
Description	grey fine sand	grey fine sand		
Nitrogen (kg/ha)	00	00		
Phosphorus (kg/ha)	00	00		
Potassium (kg/ha)	39	06		
Sodium	H+	L-		
pH (lab) (author)	3.4 3.4	3.2 3.2		
Sulphate	H	H-		
Aluminum (ppm)	94	268		
Manganese (ppm)	---	---		
Conductivity (mmhos/cm^2)	7.4	6.2		
Organics	L	L		

Note: See Appendix B for explanation of analysis techniques and symbols.

Two vertical series of samples were taken for analysis. The samples at 120S-420E (Table 4-9) were taken from the bank of one of the erosion channels in the surface of the delta. This series is relatively uniform. It should be noted that because of the height of the delta at this point (5 m above lake level), these samples were all quite dry. The other series of vertical samples (Table 4-7) was located at 35S-480E, where a 1 m bank has been eroded by wave action on the north side of the delta. This profile shows considerable variation in pH, from 4.4 (3.4) to 6.1 (7.8). This suggests that tailings which are kept continually wet (at the bottom of the sample series, near lake level) are only marginally affected by oxidation resulting in acid conditions. On the other hand, those tailings which are only intermittantly moist tend to be quite acid because of more effective oxidation. It is probable that the tailings at the location of the previous sample series were too dry for extensive oxidation.

The only regeneration evident in the vicinity of the delta is on the gully leading to it. The slope (Plate 4-16) is badly eroded and consists of a tangle of deadfalls. However, the northern portion of this slope, where erosion is minimal, has a vigorous cover of *Epilobium angustifolium*.

4.4.5 STUDY PLOT

A small study plot was also established in the R4 study area close to the airstrip. The site consists of a shallow tailings-filled depression adjacent to a bedrock slope which was originally covered by organic terrain. It has probably received tailings since opening of the mill in 1950. This plot was singled out for study primarily because

Plate 4-16. The gully leading to the delta is best described as a tangle of dead trees and tailings material. 23 August 1971 - 10h00.

a variety of plants have colonized a small area. The pattern is shown in Figure 4-17, which also shows the pH of surface soil samples. The results of other soil tests are presented in Tables 4-11 to 4-15.

There appears to be no correlation between colonization and surface acidity. Nitrogen and phosphorus values are low, but those for potassium are high, in contrast to most other samples of tailings. The cause of the unusually high values of nitrogen and potassium in samples 30 and 28 is unknown.

There are two sections of *Equisetum arvense* outlined in Figure 4-17. The northern section is made up of relatively vigorous plants, while those in the southern section are stunted. Samples 8 and 132 represent the soils of the healthy plants, and samples 65, 22 and 33 the soils of the stunted plants. Although such a comparison may have limited validity, there are several factors which, in a relative sense, appear to be beneficial to the colonization of *Equisetum arvense*. These factors are: lower sodium (L vs M)*; lower pH (4.8 vs 7.8) ; lower sulphate (L vs H-) ; and lower conductivity (1.0 vs 3.9) .

4.5 NATURAL SOILS

Several soil pits were located to investigate the profile and characteristics of natural soils at Discovery. Three pits were located in the vicinity of 600S-200E. The forest type at this location

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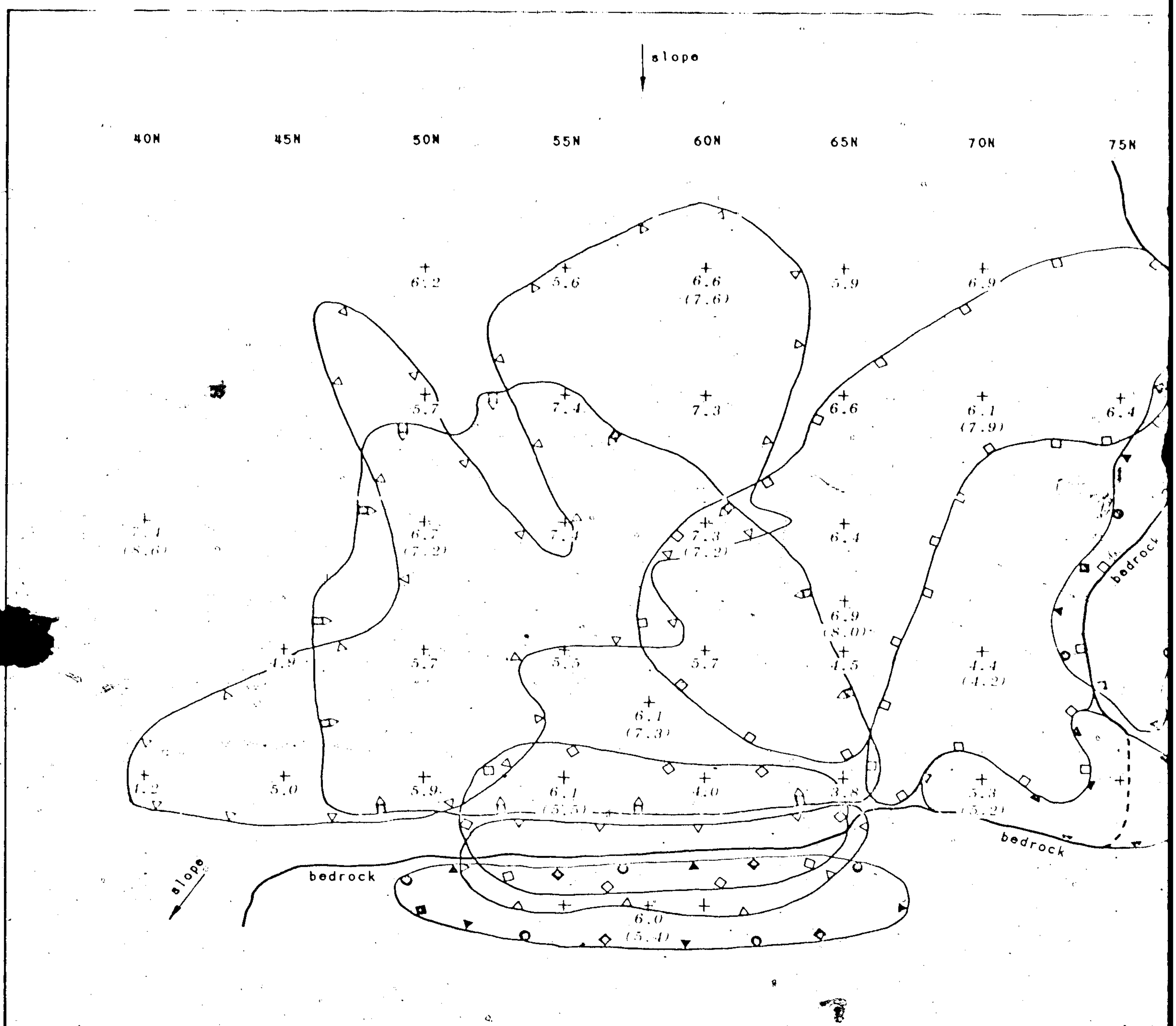
* These are average values for samples. Specific values for high (H), medium (M) and low (L) can be found in Appendix B.



slope
40N
45N
50N
55N
60N
65N
70N
75N
bedrock
bedrock
bedrock
slope

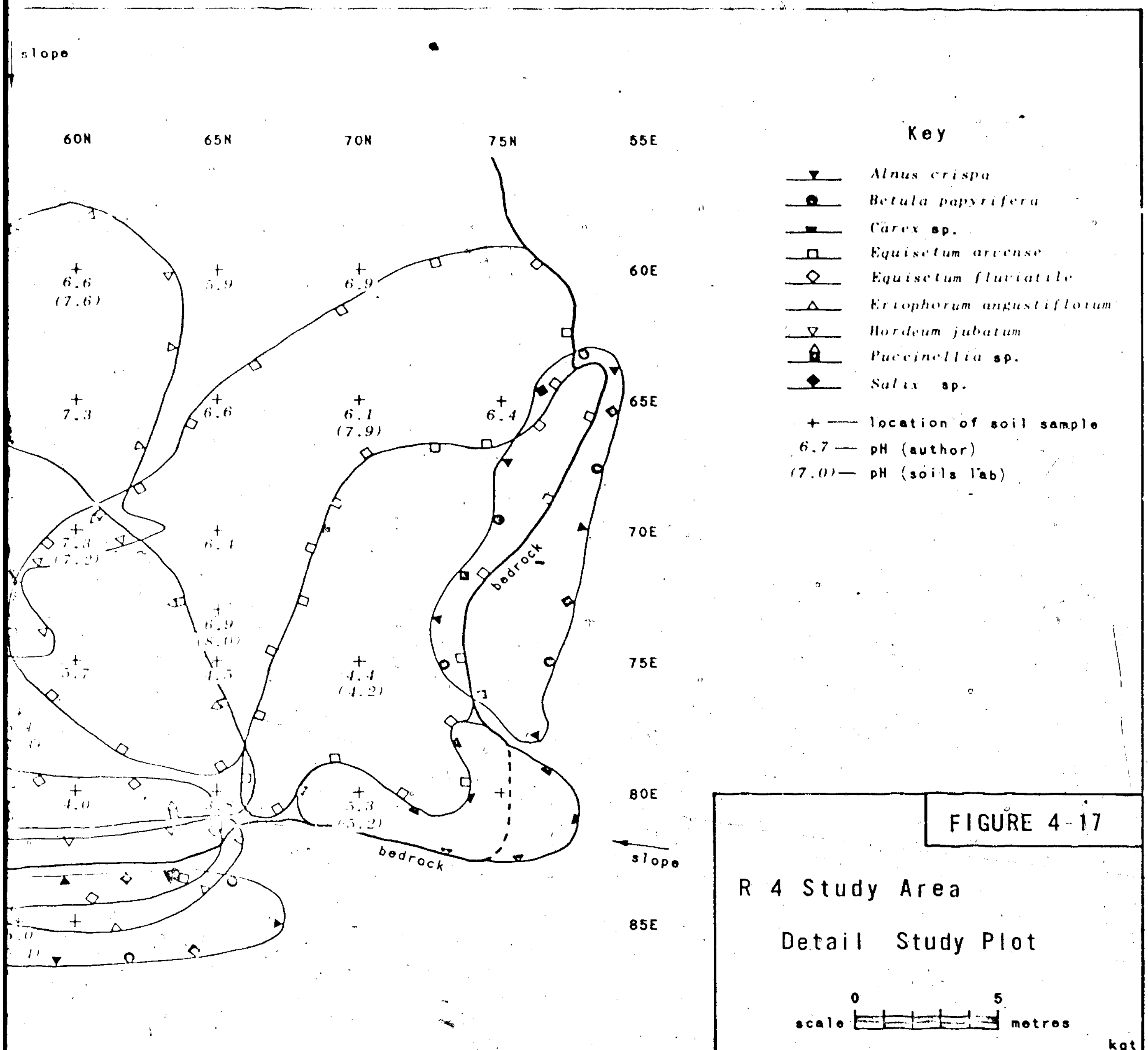


FIGURE 4-17

R 4 Study Area

Detail Study Plot

Table 4-11 Analysis of soil samples (R4 Study Plot)

Sample number	30	28	29	27
Location	40N-70E			50N-70E
Depth (cm)	Salt crust	0-3	3-10	[illegible]
Description	grey fine sand	grey fine sand	grey fine sand	grey fine sand
Nitrogen (kg/ha)	196	16	00	60
Phosphorus (kg/ha)	03	01	01	00
Potassium (kg/ha)	2817 +	2800 +	274	241
Sodium	H +	H +	H-	L
pH (lab) (author)	8.4 7.6	8.6 7.4	7.0 6.9	7.2 6.7
Sulphate	H	H	H	H
Aluminum (ppm)	---	---	---	---
Manganese (ppm)	---	---	---	---
Conductivity (mmhos/cm^2)	16	6.5	6.0	5.2
Organics	L	L	L	L-

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-12 Analysis of soil samples (R4 Study Plot)

Sample number	78	19	10	20
Location	55N-80E	---58N-77E---		
Depth (cm)	0-10	white crust	0-3	3-16
Description	grey fine sand	---	grey fine sand	grey fine sand
Nitrogen (kg/ha)	01	00	00	02
Phosphorus (kg/ha)	01	01	00	01
Potassium (kg/ha)	622	784	1736	246
Sodium	M+	H+	H+	L
pH (lab) (author)	5.5 6.1	7.3 6.8	7.3 6.1	7.5 7.0
Sulphate	H-	H	H	L-
Aluminum (ppm)	---	---	---	---
Manganese (ppm)	---	---	---	---
Conductivity (mmhos/cm^2)	3.1	5.2	10.3	1.4
Organics	L	L	L	L

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-13 Analysis of soil samples (R4 Study Plot)

Sample number	4	21	85	26
Location	58N-77E	58N-77E	58N-85E	60N-60E
Depth (cm)	16-36	36-60	0-10	0-10
Description	grey fine sand	grey fine sand	grey fine sand	grey fine sand
Nitrogen (kg/ha)	03	00	00	00
Phosphorus (kg/ha)	00	01	01	00
Potassium (kg/ha)	403	493	364	112
Sodium	L	L	L-	L-
pH (lab) (author)	8.0 7.6	5.9 6.2	5.4 6.0	7.6 6.6
Sulphate	L-	---	H-	L-
Aluminum (ppm)	---	---	0.4	---
Manganese (ppm)	---	---	10.4	---
Conductivity (mmhos/cm^2)	1.4	0.9	1.3	2.3
Organics	L	L	L-	L-

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-14 Analysis of soil samples (R4 Study Plot)

Sample number	33	22	23	12
Location		-65N-73E-		
Depth (cm)	0-10	0-5	5-24	25+
Description	grey fine sand	grey fine sand	grey fine sand	sticky grey clay
Nitrogen (kg/ha)	00	00	00	00
Phosphorus (kg/ha)	00	04	00	00
Potassium (kg/ha)	375	274	252	510
Sodium	L+	M-	L	L
pH (lab) (author)	7.2 7.3	8.0 6.9	7.9 7.2	8.2 ---
Sulphate	H	M	L	L-
Aluminum (ppm)	---	---	---	---
Manganese (ppm)	---	---	---	---
Conductivity (mmhos/cm^2)	3.9	3.7	1.9	1.7
Organics	L	L	L	L

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-15 Analysis of soil samples (R4 Study Plot).

Sample number	65	8	132	
Location	70N-65E	70N-75E	70N-80E	
Depth (cm)	0-10	0-5	0-10	
Description	grey fine sand	grey fine sand	grey fine sand	
Nitrogen (kg/ha)	00	00	00	
Phosphorus (kg/ha)	00	03	03	
Potassium (kg/ha)	454	230	386	
Sodium	M	L-	L	
pH (lab) (author)	7.9 6.1	4.2 4.4	5.2 5.3	
Sulphate	H	---	L-	
Aluminum (ppm)	---	14.8	1.2	
Manganese (ppm)	---	6.4	5.0	
Conductivity (mmhos/cm^2)	4.1	0.6	1.5	
Organics	L-	L	L	

Note: See Appendix B for explanation of analysis techniques and symbols.

is *Picea mariana*.- *Ledum groenlandicum* woodland. The profiles of these pits are presented in Figure 4-18. Detailed soil analyses for one of the profiles is shown in Table 4-16.

In most tests the samples scored similar to many of the tailings samples, especially those with an orange coloring. A soil sample taken from the surface of an esker on the east side of Giauque Lake (*Picea glauca*-lichen woodland) was also tested, with similar results. Other samples of natural soils were taken at 635S-212W on Transect R3AB. The results of analysis are shown in Table 4-17.

Of significance in all samples of natural soils is the low pH, ranging from 3.6 to 4.7 (4.2 to 5.5). These low natural values suggest that acidity of the tailings material is not the major limiting factor limiting plant growth. Levels of aluminum and manganese are higher than one might expect, if one was to assume that toxic levels of these elements as found in the tailings is unnatural. It is notable that values of nitrogen are relatively high in samples 145 and 119, yet not in samples 124 and 118.

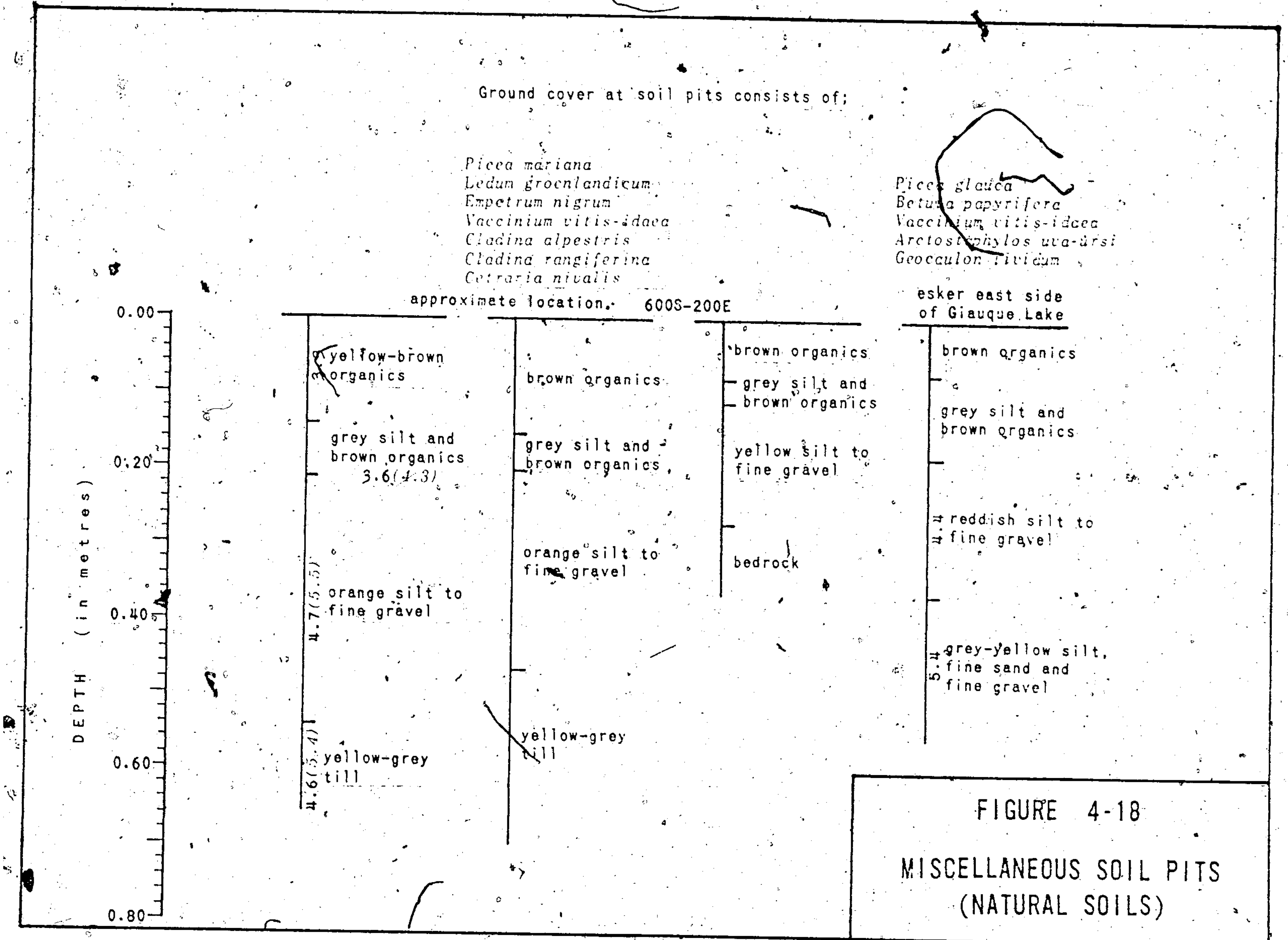


FIGURE 4-18

MISCELLANEOUS SOIL PITS (NATURAL SOILS)

Table 4-16 Analysis of soil samples (Natural Soils)

Sample number	124	118	121	35
Location	approximately 600S-200E			Esker
Depth (cm)	44-21	21-34	54-65	0-10
Description	grey silt and brown organics	orange silt to fine gravel	yellow-grey till	grey sand
Nitrogen (kg/ha)	01	01	01	00
Phosphorus (kg/ha)	05	07	01	27
Potassium (kg/ha)	101	95	97	73
Sodium	L-	L	L-	L-
pH (lab) (author)	4.3 3.6	5.5 4.7	5.4 4.6	4.7 3.9
Sulphate	00	00	00	---
Aluminum (ppm)	20+	5.5	---	6.0
Manganese (ppm)	0.6	0.2	---	36.8
Conductivity (mmhos/cm^2)	0.2	0.1	0.2	0.1
Organics	L-	L-	L-	L-

Note: See Appendix B for explanation of analysis techniques and symbols.

Table 4-17 Analysis of soil samples (Transect R3AB)

Sample number	145	119	115	
Location	-----------------Transect R3AB 635S-212W			
Depth (cm)	0-17	17-50	50+	
Description	brown organics	fine to coarse orange sand	hard brown clay	
Nitrogen (kg/ha)	86	15	00	
Phosphorus (kg/ha)	07	07	00	
Potassium (kg/ha)	129	50	185	
Sodium	L-	L-	L-	
pH (lab)	4.2	5.0	5.3	
(author)	4.0	4.5	4.6	
Sulphate	---	---	---	
Aluminum (ppm)	19.6	5.0	2.2	
Manganese (ppm)	5.0	2.0	12.6	
Conductivity (mmhos/cm^2)	0.4	0.1	0.1	
Organics	M	L-	L	

Note: See Appendix B for explanation of analysis techniques and symbols.

CHAPTER 5

FACTORS CONTROLLING PLANT SUCCESSION - A GENERAL DISCUSSION

There is no simple answer to the question of which factors are important to the control of revegetation on the tailings at Discovery. There are many aspects worthy of consideration, each of which appears to be a complicating factor in the colonizing process.

5.1 THE PROBLEM OF TAILINGS ACIDITY

In studies of mine waste revegetation the world over, soil acidity has proved to be the most difficult problem to deal with. Although the observations at Discovery suggest that acidity is not the sole controlling fa[illegible] is important to understand some of the mechanics of the weathering of tailings and the resultant generation of acids.

The factors leading to acidity in mine tailings and the consequences of such acidity are complex and not fully known. Considering that the tailings slurry is very basic when it leaves the mill (pH approximately 10), it is surprising that acidity should be a problem. However, shortly after leaving the mill, and upon exposure to the air, certain components of the tailings, primarily iron sulphides such as pyrite ($Fe\ S_2$) and pyrrhotite ($Fe_{n-1}\ S_n$), quickly oxidize, producing acid which soon lowers the pH of the tailings.

Brant and Moulton (1960) and Hawley and Shikaze (1971) outline a series of chemical reactions to describe the process of acid production in a tailings area:

Step # 1 - Sulphide to Sulphate

When naturally occurring sulphides (usually in combination with iron) are exposed to oxygen and water, two reactions may occur. If the supply of water is limited, sulphur dioxide and (water soluble) ferrous sulphate will be produced.

(1) $FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2$

If, however, water is plentiful, then equal amounts of sulphuric acid and (water soluble) ferrous sulphate are produced. This is thought to be the major reaction found in most mining environments.

(2) $2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4$

Step # 2 - Oxidation of Iron (Ferrous to Ferric)

In the presence of sulphuric acid and oxygen, ferrous sulphate oxidizes to form (water soluble) ferric sulphate and water.

(3) $4FeSO_4 + 2H_2SO_4 + O_2 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$

Step # 3 - Precipitation of Iron

The ferric iron associated with the sulphate ion combines with the hydroxyl (OH^-) ion of water (HOH) to form ferric hyroxide. In an acid environment, ferric hydroxide is largely insoluble and precipitates.

(4) $Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$

An alternate reaction may occur whereby the ferric iron may enter into an oxidation-reduction reaction with any sulphides available to form sulphates. In such a case the acid forming process is accelerated.

(5) $Fe_2(SO_4)_3 + FeS_2 + H_2O \rightarrow 3FeSO_4 + 2S^o$

(6) $S^o + 3O + H_2O \rightarrow H_2SO_4$

Considering that the fine particles of tailings present an enormous surface area for oxidation by plentiful amounts of water, supplied by the mill or through precipitation, it is not surprising that large amounts of sulphuric acid can be produced. It also becomes apparent that, depending on the proportion of sulphides in the tailings, acid production may continue for many years.

Acid conditions in the tailings often trigger other reactions to complicate the problem, especially in conjunction with alumino - silicates such as the host rock at Discovery.

Table 5-1 lists the major minerals present in the ore at Discovery. Group "A" lists those of the host rock while Group "B" lists the major minerals of the mineralized zones and veins in which the gold was found. Pyrrhotite was clearly the major constituent of this second group. However, the proportions of each group to be found in any one section of tailings varied with daily changes in the vein being mined.

In general the acid produced through oxidation of the minerals in Group "B" (as outlined above) would react with the minerals of Group "A", most of which decompose readily. The principle products are kaolinite ($H_4Al_2\ Si_2O_9$), a clay mineral, and hydrous metal oxides, principally of iron and aluminum. Under very acid conditions where there is an abundance of hydrogen ions

$$(7) \quad H_2SO_4 \longrightarrow H^{++} + SO_4^-$$

the metallic ions become dissociated from the clay lattice. Thus acid soils, generally those of pH less than 5, have a large number of metallic ions present. In aluminosilicates, where aluminum is the predominant metal, an equilibrium is established between hydrogen (H^+) and aluminum (AL^{+++}) ions. As well, other ions such as magnesium (Mg^{++}), manganese (Mn) or iron (Fe^{++}) may also be present. It is thought that at low pH values most of the aluminum is present as the hexahydrated Al^{+++}ion (Seatz and Peterson 1964).

However, at pH values greater than 5, hydrolysis can occur as shown in reactions (8), (9) and (10), resulting in the release of hydrogen ions.

$$(8) \quad Al^{+++} + H_2O \longrightarrow Al\ (OH)^{++} + H^+$$

TABLE 5.1 - WEATHERING OF TAILINGS COMPONENTS

	MINERAL NAME	FORMULA	COMMENTS ON WEATHERING
Group "A"	QUARTZ	$Si\ O_2$	Quartz is very resistant to change. It is very hard and highly insoluble.
Major elements of the host rock	SODIUM AND CALCIUM FELDSPARS	$Na\ Al\ Si_3\ O_8$ $Na\ Ca\ Al_2\ Si_6\ O_{16}$ $Ca\ Al_2\ Si_2\ O_8$	The feldspars decompose fairly readily in the presence of H_2O and CO. The Ca goes to the carbonate or more soluble bicarbonate and the Na to carbonate. Some SiO_2 is split off and may remain as insoluble $Si\ O_2$ or form silicic acids and soluble or colloidal hydrated silicates. Most of the Al and much of the Si go into the formation of hydrated alumino-silicates (koalinite). The Ca feldspars decompose much more readily than do the Na feldspars.
	BIOTITE	$\begin{pmatrix}H\\K\end{pmatrix}_2 \begin{pmatrix}Mg\\Fe\end{pmatrix}_2 \begin{pmatrix}Al\\Fe\end{pmatrix}_2 Si_3O_{12}$	When much iron is present in biotite, it decomposes readily; otherwise the micas break up physically quite easily but decompose chemically quite slowly.
	HORNBLENDE (AMPHIBOLE)	$\begin{pmatrix}Ca\\Mg\\Fe\end{pmatrix}_2 Si_4O_{12}$ $Na_2\ Al_2\ Si_4\ O_{12}$ $\begin{pmatrix}Mg\\Fe\end{pmatrix}_2 \begin{pmatrix}Al\\Fe\end{pmatrix}_2 Si_2\ O_{12}$	Hornblende decomposes fairly readily because of its easy cleavage and high content of ferrous iron. On decomposition (oxidation; ferrous → ferric), it produces a rust-coloured clay which is a constituent of many red soils.
Group "B"	PYRRHOTITE	$Fe_{n-1}\ S_n$	Oxidation of sulphides forms H_2SO_4
Associated with gold mineralization	PYRITE	$Fe\ S_2$	
	CHALCOPYRITE	$Cu\ Fe\ S_2$	
	SPHALERITE	$Zn\ S$	

Table was compiled with reference to Byrne (1950), Gilluly, et al. (1968), and Tremblay (1952).

(9) $Al(OH)^{++} + H_2O \rightarrow Al(OH_2)^{+} + H^{+}$

(10) $Al(OH_2) + H_2O \rightarrow Al(OH)_3 + H^{+}$

A similar stepwise hydrolysis may occur with other metallic ions. Under acid conditions the metals from the hydrous oxides may be brought into solution and thence undergo stepwise hydrolysis with the release of hydrogen ions. Seatz and Peterson (1964, p. 299) suggest that in such circumstances there are then two measures of acidity, active and potential;

> "Active acidity includes those H^{+} ions that are present in the solution phase and that can be measured by normal procedures. Potential acidity may be considered to be the exchange acidity, and it can make up the bulk of the total acidity of the system. This potential acidity becomes active as active acidity is neutralized and cation -exchange processes occur which bring the potential acidity into solution. An equilibrium exists between the active and potential acidity.

It has long been thought that the free hydrogen ion in acid soils has been detrimental to plant growth (Black, 1968). However, in recent years it has become evident that certain metallic ions, released under extremely acid conditions, may have greater toxic effect. Aluminum appears to be the major problem in this instance, but manganese is also thought to be important (Black 1968 and Nyborg 1972).

There are a number of effects thought to be attributable to aluminum toxicity, the inhibition of root development being the most visually obvious (Black 1968). Investigations have indicated that aluminum inhibits cell division. In addition, high levels of the aluminum ion appear to cause a decrease in the permability of the protoplasm of the root cells. Consequently, the uptake of many essential plant nutrients is severely inhibited and the plant dies.

The standard method of dealing with soil acidity over the centuries has been some form of liming, which aims at raising the pH of the rooting zone of the soil.

Very often ground limestone or dolomite is used. The reaction is written (Seatz and Peterson 1964),

$$(11) \quad CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$

$$(12) \quad Ca(HCO_3)_2 \longrightarrow Ca^{++} + 2HCO_3^-$$

$$(13) \quad H^+ + HCO_3^- \longrightarrow H_2CO_3 \rightleftharpoons H_2O + CO$$

In situations such as that postulated for Discovery large amounts of lime would be needed to neutralize both active and potential acidity. As the potential acidity was neutralized as outlined in equations (8), (9) and (10), the available aluminum would also be reduced to levels not toxic to plants.

Although the problems of aluminum or manganese toxicity are seldom referred to in research on tailings acidity elsewhere the standard practice of liming would nevertheless solve any potential problems. The extent of liming necessary for any one site varies and must be determined by field measurements. Common practice entails an initial application of slaked lime to rapidly raise pH. This is followed by an application of crushed limestone, which reacts more slowly, to provide a long term buffering effect. This technique has been successful in reducing tailings acidity enough to permit plant growth in locations all over the world (Chenik 1961, 1965; Czapowskyj 1973, James 1964, Young 1969).

Another technique has been developed in South Africa, to deal with the acidity of areas where the addition of the large amounts of limestone needed was considered to be impractical (James and Mrost 1965). The aim is to apply large amounts of water to the area, promoting heavy leaching, so that the zone of highest acidity is depressed below the zone of plant rooting. Since in South African revegetation experience drought has been a factor limiting plant growth, this application of water solved two problems.

Steps can be taken then to ameliorate acidity of the surface of tailings enough to permit revegetation. Nevertheless, the techniques which can be used do require considerable care and even considerable expense to implement successfully.

Surface acidity is not, however, the only problem associated with acid-mine tailings. Since the production of acid takes place throughout the tailings, and since infiltrating surface waters containing oxygen in fact speed up the acid-forming processes, it is not surprising that water draining from tailings areas may be extremely acid. Acid-mine drainage is a problem in many parts of the world. Extensive coal mining in Ohio has resulted in many situations where acid drainage has severely reduced water quality in natural watercourses to the point of killing aquatic life. Although the problem has been recognized in the States for many years, effective solutions have not been found. Controlled flooding of mines and tailings areas is seen as the best method of reducing acid formation (Brant and Moulton 1960).

Similar problems of acid-mine drainage have been encountered at some Ontario mines (Hawley and Shikaze 1971), and there too the problem has proven difficult to deal with. It is known that once the acidification process has reached a certain stage, continued bacterial action can make the situation practically irreversible. Thus, once established, acid-mine drainage may remain a problem for decades.

In the Ontario context a number of measures have been put forward to at least control, if not stop, acidification of natural watercourses in the vicinity of mines. Of prime importance are steps to reduce the flow of oxygen-rich air or water through the tailings. Thus, natural drainage channels can be diverted around tailings areas. Surface areas can be revegetated to reduce both runoff and infiltration. The ponding of seepage flows and the neutralization of these waters before they are directed into natural watercourses is another, though perhaps more expensive, solution. However, when this latter solution is utilized to raise the pH to approximately 8.5, it has the added advantage of effectively reducing harmful heavy metals which may also be in solution.

Although the effects of acid-mine drainage on the environment can be controlled they cannot be eliminated and they may remain as a potentially serious long-term problem. However, the seriousness of the situation varies between sites and depends on factors such as climate, geology, and dilution potential of adjacent natural waters.

5.2 THE TOXICITY OF CYANIDE

Since cyanide and its compounds are lethal for both plants and animals, its presence in mine tailings may be an important factor restricting plant colonization. In alkaline solutions such as that present in mill circuits, the reactivity of cyanides is limited. However, once the tailings solution leaves the mill the pH quickly drops, and cyanide reactivity rapidly increases.

Cyanide is extremely dangerous to both plants and animals. Most simply, it causes asphyxiation at the cellular level. In this respect it is similar to carbon monoxide except that it acts much more swiftly. Many botanists use cyanide in the lab to kill plants almost instantaneously. Hydrogen cyanide (HCN) is the acting agent. Upon contact with free cyanide hydrolysis takes place within a plant or animal, and HCN is formed. This HCN then inhibits the working of the porphyrin enzyme cytochrome oxidase. Cytochrome is a complex pigmented compound containing iron which is closely related chemically to chlorophyll and the haematin of hemoglobin. The oxidase enzymes are essential carriersfor transfer of hydrogen and oxygen between sap or blood and cells. HCN very quickly immobilizes these enzymes and the cellular tissues soon die (Meyer and Anderson 1952).

Low concentrations of HCN can result in only minor symptoms of poisoning but the lethal concentration is very low. It is estimated that the minimum lethal dose for domestic animals is 4.4 mg. of HCN per kg. of animal per hour (Kingsbury 1964). It has also been reported that brook trout died in 47 minutes when placed in a dilution of cyanide mill effluent equivalent of 2.0 ppm of NaCN (Smith 1938). Schaut (1939) found that a concentration of 0.8 ppm NaCN produced 100% mortality in fish in 24 hours. Although some plants do not contain cytochrome oxidase and thus have a limited tolerance to cyanide, most find it extremely lethal.

It is impossible now to determine the amount of cyanide once present in the tailings at Discovery, the length of time it remained, or the damage to plant and animal life which may have resulted. In acidic environments cyanide compounds form HCN which, being extremely volatile, escapes to the atmosphere. In all likelihood, as soon as the tailings left the mill, the pH dropped to an acidic condition. Presumably the cyanide present in the effluent would quickly be converted to HCN and escape to the atmosphere. Although it was highly unlikely that any cyanide compounds would remain in the tailings, a number of samples were tested for cyanide.[1] Since no traces of cyanide were found it is safe to assume that cyanide is not one of the factors continuing to inhibit revegetation of the tailings. Any damage attributable to cyanide probably would have

1. A total of 45 soil samples were tested (by the author) for evidence of NaCN. The tests followed the procedures outlined in Canadian Industries Limited (1945). Of these samples, 32 had been stored 9 months for testing. However, 13 samples were collected in the study area during July 1972, and were tested within two weeks. Three of the samples analysed at the Alberta Soil and Feed Testing Lab were tested for HCN. In all cases there was no evidence of HCN or NaCN.

occurred in conjunction with the deposition of fresh tailings.

Recent studies of tailings ponds at two gold mines in Yellowknife yield results which suggest the situation that was once operative at Discovery (Bérubé *et al.* 1973). The milling process at the Con (Cominco Ltd) mill is similar to that used at Discovery and a comparison of the major reagents added to the mill circuit is shown in Table 5.2. Analysis of the effluent discharge at Con showed 4.2 ppm cyanide. Bérubé estimates that the size of the tailings pond allows a retention time of approximately 17 days (summer operation). The amount of cyanide present in the effluent following ponding, and at a distance of about 1.6 km from the mill outfall was reduced to 0.002 ppm. It is not known how the large number of reagents added to the Giant (Giant Yellowknife Gold Mines) mill circuit (not listed) affect a comparison with Con effluent. However, mill discharge at Giant analysed 31 ppm cyanide. Following an estimated ponding of up to 16 days the concentration of cyanide was reduced to 12 ppm at the outfall of the pond, and dropped to 0.1 ppm following dilution by a creek. Bérubé concluded that the ponding appears to be an effective method of removing cyanide from mine effluent, through either degassing or oxidation.

As previously stated, the concentration of cyanide lethal to animals and fish is very low. A literature search revealed no reference to the amounts of cyanide toxic to plants. However, it is safe to assume that the concentration of cyanide present in fresh mill effluent would be enough to effectively kill vegetation which came into contact with it. Bérubé's (1973) measurements show that the concentration of cyanides present in the tailings does decrease rapidly once the effluent is released from the mill. Thus it is probable that the effects of cyanide though perhaps marked in the immediate tailings disposal area, would be minor outside of that area.

TABLE 5-2 MAJOR MILL REAGENTS

MINE	DISCOVERY[1]	CON[2]
Average Daily Tonnage	200	220
Lime (lb/day)	1400	540
Zinc Dust (lb/day)	8	40
NaCN (lb/day)	500	540

Sources: 1 - Milling of Canadian Ores, 1957.
2 - Bérubé *et. al.*, 1973.

Considering the toxicity of cyanide, the advisability of routing tailings into Giauque Lake relatively close to the mine's water supply intake (located in the small bay immediately north of the mine) is questionable. Thus it is of interest that before mine tailings were dumped into the lake metallurgists assured management that

> "contained free cyanide was almost nil, and metallic cyanates were both nearly insoluble and oxidized by the time they reached the lake, so as to be harmless to animal life.

The author was also assured (Kilgour 1972) that

> "In any case fishing remained as good as ever, and no dead fish were ever seen near the tailings (or) elsewhere in the lake.

5.3 DEFICIENCY OF ELEMENTS ESSENTIAL FOR PLANT NUTRITION

There are a number of nutrients which are either essential for, or beneficial to, the growth of plants. Most soils contain these nutrients in some proportion, enabling at least certain plants to grow on them. However, mine tailings consist primarily of finely ground rock and thus contain virtually no nutrients. It is not surprising, then, that it is extremely difficult for most plants to become established on mine tailings. In revegetation studies throughout the world plant nutrition has been found to be a major and critical factor. For this reason fertilizers are nearly always added when seeding of tailings dumps is carried out.

It is generally agreed that the major elements needed for plant growth are nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and iron. All of these elements have certain essential roles in plant life, and deficiencies of these elements result in stunted or deformed growth, or even death. The roles that each element plays are outlined in most texts on plant physiology (such as Meyer and Anderson 1952) but are discussed summarily below.

In temperate climates the amounts of essential elements needed for agricultural crops have been well studied. It has been found that nitrogen (N), phosphorous (P) and potassium (K) are most commonly deficient. One would like to assume that the problems are similar for arctic and sub-arctic locales, but the lack of data on the question dictates caution. Nevertheless, some northern researchers (Ronning 1968, Viereck 1966) suggest that deficiencies of these three nutrients do restrict plant growth in northern regions.

5.3.1 THE ROLE OF NITROGEN

Nitrogen is considered to be one of the most critical elements required to sustain plant life. All of the physiological reactions characteristic of living cells centre around the physical and chemical properties of protein molecules and related compounds, in which nitrogen is an important compound. Although there is abundant free nitrogen in the air, plants are unable to utilize gaseous nitrogen, so that they must absorb it from the soil. In northern latitudes the major sources of nitrogen in the soil are in the form of nitrates and ammonium compounds.

The factors governing the formation of nitreous compounds in the soil are very important. Under natural conditions large amounts of nitrogen can be removed from the soil through the leaching action of rainwater or through the removal of plant cover (ie., fire or harvesting). Since nitrogen is not a constituent of bedrock the maintenance of a supply of nitrogen is due to the activities of nitrogen-fixing bacteria. Two groups of bacteria are able to fix atmospheric nitrogen.

A) Symbiotic nitrogen-fixing bacteria (*Rhizobium*) which live in the roots of certain leguminous plants synthesize organic nitrogen from the carbohydrates of the host plant and the gaseous nitrogen of also applied to seeded areas in most of these reclamation projects (Strip mine tailings, which consist primarily of overburden materials, are less barren of nutrients than mill tailings and thus require less fertilization for plant regeneration).

It is interesting that certain non-leguminous plants are also known to be able to fix nitrogen. Stewart (1966) lists *Alnus*, *Myrica* and *Shepherdia* among the genera with this ability. Lawrence *et al.* (1967) found that *Dryas drummondii* was also able to fix nitrogen. Some researchers in Alaska (Lawrence *et al.* 1967, Van Cleve *et al.* 1971, Viereck 1966) have demonstrated that the initial colonization of *Dryas* and *Alnus* on new land greatly facilitates the colonization and growth of other plants. When these same plants do not grow in association with the nitrogen-fixing species they exhibit symptoms of nitrogen deficiency.

At Discovery no special investigation of nitrogen was undertaken, so that in retrospect it is difficult to discuss nitrogen-related problems in detail. However, since virtually all soil samples tested for nitrogen had less than 2.2 kg/ha and many had none, it may be assumed that the tailings are nitrogen deficient.[2] A figure of 89.5 kg/ha is given as optimal for the growth of most agricultural crops (Carson, 1972). As a result of the lack of carbohydrates in a purely mineral soil, and because weathering has resulted in a pH of less than 6, ammonification and the saprophytic group of nitrogen-fixing bacteria are not functional. Thus bacteria living in nodules are the only source of nitrogen for colonizing species. Of course, nitrogen is always available in organic matter buried or incorporated by tailings.

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2. The values mentioned in this discussion refer to analysis results presented in Tables 4-1 to 4-17.

Although *Shepherdia canadensis* and *Myrica gale* are found in the vicinity of Discovery they were not found growing on the tailings. *Alnus crispa* does grow on the tailings, but it is assumed that in most cases the roots were able to reach organic matter either adjacent to or buried beneath the tailings. The roots of *Alnus* were not investigated for nodules. However, nodules were found on specimens of *Equisetum* in the central portion of the R4 Study Area. It is not known whether these nodules contained nitrogen-fixing bacteria, and no reference to nodulation on *Equisetum* has been found in the literature. However, it is possible that these nodules do fix nitrogen for the use of *Equisetum* and that fact may explain the vigorous growth of that species evident in the R4 Study Area.

5.3.3 PHOSPHORUS

Another essential element is phosphorus (P), which is present in nucleic acids and is used in various metabolic processes. A symptom of deficiency is a purple colouration of leaves. It is known that in acid soils aluminum may precipitate phosphorus and so decrease its availability to plants.

For optimum growth conditions 56 to 67 kg/ha of phosphorous should be available in soils (Carson 1972). Analysis of tailings revealed values ranging from 1 to 7 kg/ha indicating a severe deficiency of the element. As mentioned, this deficiency may be compounded by the presence of the aluminum ion in acidic soils, a situation found in the tailings at Discovery.

5.3.4 POTASSIUM

Potassium (K) is also an essential element for plants. It is used in the synthesis of proteins from amino acids. Evidence suggests that potassium deficiency hinders cell division and photosynthesis.

Potassium deficiency can be ameliorated somewhat by the presence of sodium ions.

About 336 kg/ha is recommended for best agricultural growth (Carson 1972). Values of potassium in the tailings samples ranged widely, from 6 to 2817 kg/ha, but averaged close to the recommended value.

Nevertheless, it is perhaps significant that several plants (*Epilobium angustifolium* and *Calamagrostis neglecta* were observed growing at the site of a small campfire at approximately 12000S-2000W on the tailings. The potash present in the ashes would be a source of potassium for these plants as well as an agent to reduce potential acidity at that location.

5.3.5 OTHER ESSENTIAL TRACE ELEMENTS

Each of the following elements is essential in small quantities for plants, and deficiencies can restrict growth.

Calcium (Ca) influences the permeability of the cell wall, and also plays an important role in the balancing of soil acidity. Magnesium (Mg) is a constituent of chlorophyll and thus is essential for the metabolism of plants. A symptom of magnesium defiency is the yellowing of older leaves. Normally soils contain sufficient quantities of this element. Sulphur (S) is an important constituent of amino acids. It is usually present in soils in sufficient quantities, and because of the nature of the ore will probably be available in sufficient quantities in the tailings. Iron (Fe) is supposed to be important in chlorophyll synthesis. Its deficiency results in a yellowing (chlorosis) of leaves but it is probably available in sufficient quantities in the tailings.

5.4 MICROENVIRONMENT

The term microenvironment collectively describes a range of characteristics present in the soil/atmosphere interface zone. Although these characteristics can be discussed separately, most are interdependent and controlled by the major factor, radiation from the sun.

5.4.1 SOLAR RADIATION

Solar radiation, with the components of heat and light, is the strongest control over microenvironment. Light, as well as heat, is of course essential for all plant life, but excessive solar radiation can have a number of negative effects on plant life. Dehydration or overheating of the soil and plant are the most obvious, which when combined with a lack of soil moisture, is more commonly termed drought. Such conditions are especially hazardous to young seedlings not well established.

In addition, high levels of solar radiation on unprotected soils draw water to the surface, where it evaporates, leaving a hard baked surface or a crust of mineral salts (Plate 5-1). There was bountiful evidence of both conditions on the tailings at Discovery. Neither condition is condutive to the germination and rooting of seeds.

5.4.2 SHELTER

The above factors are partially a function of shelter, or the availability of protection from the full intensity of the sun's rays. But shelter is also important in providing protection from the wind. In a region where summers are dry, with a low relative humidity, moving air can also be a factor contributing to plant dehydration. Lack of shelter from the wind, when coupled with unconsolidated surface materials, can result in the movement of soil particles and abrasion of the stems of young plants. And shelter, in the form of other plants can also be beneficial in the interception of rainfall so that seedlings are protected from the full force of raindrops, as well as the potential disturbance

Plate 5-1. In many sections of the tailings disposal area the surface consists of a hard, sun-baked crust. Many of the cracks in this surface were covered by a white crust of mineral salts. Geologist's hammer gives scale. 27 July 1971 - 15h00 (4255-225E).

of the soil surface. The presence of vegetation can also retard runoff, permitting greater infiltration of rainfall and a greater measure of soil moisture recharge, important during dry summers when much precipitation occurs in the form of thunderstorms.

Any one of these factors may have only a minor effect in retarding plant colonization on tailings at Discovery, but in combination, these factors can have a major role in restricting plant growth and the colonization of tailings.

5.5 SURFACE INSTABILITY

Surface instability, as touched on previously, often presents insurmountable difficulties to the establishment of seedlings. Also, the deposition of eroded material may create as big a problem as the process of water and wind erosion that causes its removal. In the case of erosion by water, low areas, which tend to be most favourable for plant colonization because of shelter and soil moisture, can be infilled, burying the plants which are growing there. Only species that are able to place new adventitious roots from their rhyzomes into the overlying material, such as *Equisetum fluviatile*, are able to thrive in such situations.

Material transported by the wind can also bury plants. At Discovery this is most evident along the edge of the tailings disposal area where sand had been deposited in nearby vegetation. The tailings area is actually slowly expanding through this process (Plate 5-2). In such situations, for example along the edge of the tailings at 200S-baseline, *Actostaphlos uva-ursi* is one of the few shrubs able to survive on top of the aggrading surface.

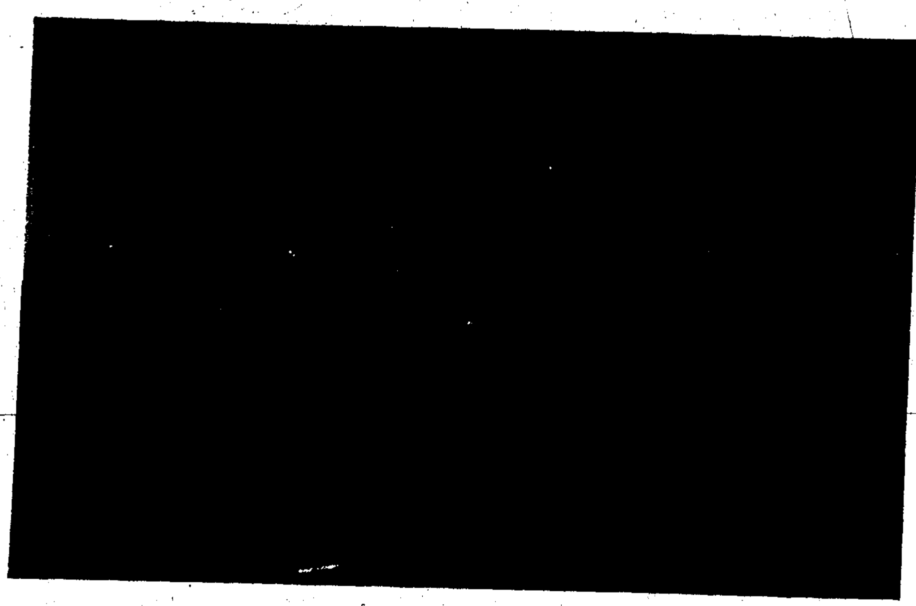

Plate 5-2. Strong winds during dry summer days pick up the fine tailings material and create huge clouds of dust. In this photo, taken from the south end of the airstrip, the mine shaft and buildings are nearly obscured by dust. The dust was a constant problem for those living at the minesite. Such conditions also resulted in considerable transport of fine material onto locations adjacent to the tailings disposal area. 3 August 1971-1200.

CHAPTER 6

SUMMARY OF PLANT COLONIZATION PATTERNS

Most of the tailings dump at Discovery remains barren and without a vegetative cover. The overall impression is that of a sterile sand flat. Thus, in a gross sense, natural revegetation at Discovery is very limited, and it will be many years before the tailings will support a cover of vegetation. However, under certain favourable conditions, colonization and natural recovery are possible. The conditions favourable to plant growth are classified below, ranging from most to least favourable.

6.1 RECOVERY OF ORIGINAL VEGETATION

The patterns grouped under this class include plants that have experienced disturbance where effluent or tailings solids have been only temporarily present. Within this class several degrees of damage may be distinguished.

6.1.1 DAMAGE BY EFFLUENT ONLY

Certain locations in the tailings disposal area exhibit a selective killing of certain plant species. Thus *Picea mariana*, *Larix laricina*, and mosses and lichens might be dead, while *Ledum groenlandicum*, *Betula glandulosa*, *B. papyrifera* and *Salix* spp. survive. In such instances the damage is caused principally by the effluent, and no solids are deposited. The effects are indirect, resulting from variations (temporary to permanent) in the height of the water table or in the chemical composition of the groundwater. Thus, plants affected by too much or too little water may die, or plants sensitive to an effluent-caused change in soil chemistry (Section 5.1) may die.

Where the changes are temporary, tolerant plants survive and are able to recover.

Even more direct are environmental changes which may be triggered by the temporary presence of effluent. Thus, when effluent causes the death of certain components of the plant cover, the thermal balance may be altered, causing a lowering of the permafrost table. This, in turn, may reduce the height of the water table and reduce the amount of soil moisture available for plant growth, indirectly causing the death of other species.

6.1.2 DAMAGE BY LIGHT DEPOSITS OF SOLIDS

Certain areas which received a light deposit of tailings solids (5-10 cm thick) also exhibit regeneration of components of the former plant cover. Such a thin cover can be viewed as impermanent since, with time, wind, rain and snowmelt runoff erode the tailings from the hummocks into the intervening hollows. This concentration of tailings in depressions may result in differential thermokarst subsidence, accentuating the micro-relief. In this situation plants, such as mosses, that occupy the moist depressions are buried, while plants that grow on top of the hummocks, such as *Ledum groenlandicum*, survive. Also, low-growing plants such as lichens may be killed by burial, whereas taller plants, such as *Betula glandulosa*, survive. Colonization of the disturbed sites occurs primarily through lateral extension of plant rhizomes from the still-vegetated areas. The hollows may also provide suitable seed beds for the establishment of wind-borne seeds from plants such as *Eriophorum angustifolium*.

In general, the natural recovery of this class is good. In most instances the surviving vegetation effectively reclaims the disturbed land.

6.2 REVEGETATION OF MODERATELY THICK TAILINGS DEPOSITS

In this class, most of the plant cover is killed and buried by a deposit that ranges in depth from 10 to a maximum of 50 cm. Occasionally a large and vigorous specimen of *Betula* or *Salix* is able to resist death, and may live to develop a seed crop. The original organic layer is normally not buried very deeply. Thus, even moderately deep-rooted plants are able to reach this supply of nutrients and once they do, grow well. Plants which reproduce through creeping rootstalks then may colonize outward from a location in which the roots are able to reach the buried organics.

Revegetation is not, however, without difficulty. Exposure on the tailings makes it difficult for seedlings to become established. In addition, thermokarst subsidence and fluvial and wind erosion may result in surface instability, which adversely affects seedling growth. Nevertheless, some species grow successfully. Notable are *Equisetum arvense*, *E. sylvaticum*, *Epilobium angustifolium*, and *Hordeum jubatum*. *Eriophorum angustifolium*, *Carex aquatilis*, *Calamagrostis neglecta*, *Betula glandulosa*, *Salix* spp., and *Alnus crispa* are others which regenerate under favourable conditions.

6.3 REVEGETATION OF DEEP TAILINGS DEPOSITS

A large portion of the tailings at Discovery is made up of deposits exceeding 50 cm in depth. The original plant cover (except for an occasional tree) and the former topography have been thoroughly buried. Only under exceptional circumstances is plant colonization possible in these areas. Such instances may occur when organic material becomes incorporated into the surface of the tailings to provide nutrients, shelter and moisture to colonizing seedlings. Animal feces or an old campfire, for example, are able to foster new seedlings. Such footings, however, are extremely tenuous. An especially dry year may destroy the success of previous years. In general the prospects for significant natural recovery over the bulk of the tailings are thus marginal. The combination of lack of nutrients, inherent soil acidity, seasonal drought, and surface crusting and instability all combine to minimize the unassisted establishment of a plant cover in the short and medium term.

Observations in 1971 indicated that despite the negative effects of soil acidity, the lack of shelter and nutrients were the greatest handicaps to the establishment of plants on open tailings surfaces. The lack of vegetation in depressions in the centre of the tailings suggested that soil moisture was not the critical factor. Consequently, in late August an experiment was initiated. Approximately 0.5 m^3 of surface organic material was excavated from 1 + 30 on the RLCD transect and placed on the surface of an open section of the tailings at 0 + 55 to determine if this mass of organics (containing mosses, lichens, and specimens of *Ledum groenlandicum, Empetrum nigrum,* and *Vaccinium vitis-idaea)* would foster plant colonization. Plate 6-1 shows this location three years later (September 1974). As can be clearly seen, no plant colonization occured within the mass of organics. The material was considerably reduced in size (likely from wind erosion) and was very dry and dusty. The exercise suggests that the mere presence of organic materials on the surface of the tailings is insufficient to initiate plant growth.

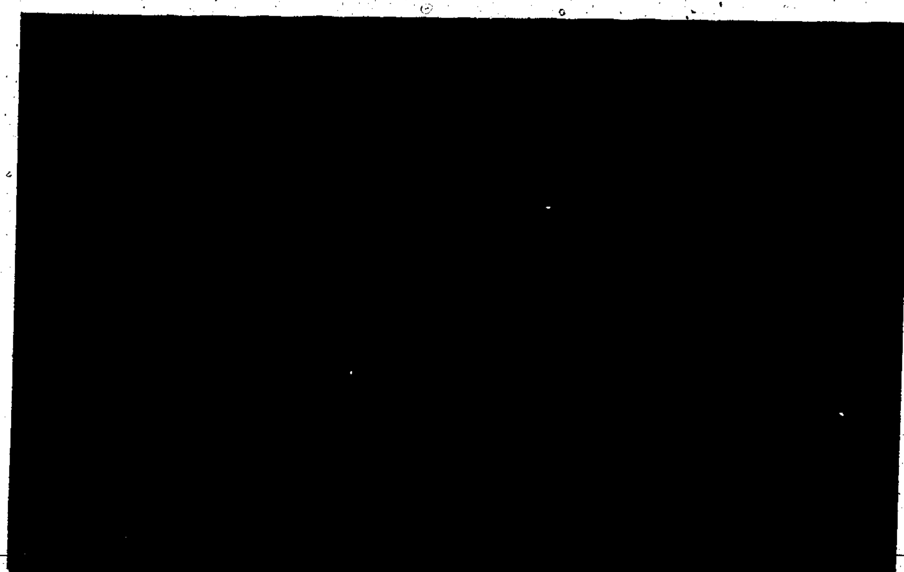

Plate 6-1. There is no sign of plant life in this block of organic material placed on an open section of the tailings in 1971 in the hope that it might provide the shelter and nutrients needed by colonizing plant species. 15 September 1974 - 12h00.

CHAPTER 7

CONCLUSIONS

The investigations at Discovery indicate, not surprisingly, that natural revegetation at a northern minesite is a slow process. Discovery does have a harsh climate, in both summer and winter, and it is to be expected that few plants have the capability to quickly colonize *terra nova* of any kind in such a marginal environment. Therefore, it can be concluded that the reclamation of northern mine workings requires at least some human assistance as it does in the south.

7.1 LONG TERM VERSUS SHORT TERM RECLAMATION

The degree of assistance required depends, of course, on the time frame allowed for an acceptable level of reclamation. Since a significant portion of development in the North occurs in remote locations, isolated from the mainstream of human activity, planning for a relatively inexpensive, unassisted long-term recovery may seem desirable. Although such a plan seems logical, it is often impractical. Uncontrolled disposal areas for industrial wastes such as mine tailings require many years to reach even the erosional equilibrium necessary for plant colonization. And once development occurs at a particular location, seldom does it return to its former isolation, since even abandoned workings inevitably attract people. If Canadians are to be safeguarded against the blight of industrial wastes in the midst of the wilderness, reclamation plans must be formulated for at least the medium term, and preferably the short term. For the purposes of this discussion a time period of 10 years will be taken as representative of the short term, and 20 to 30 years as representative of the medium term.

This study enables one to conclude that natural reclamation at Discovery will not occur in the short term, and suggests that revegetation will be effective over the medium term only in certain favourable locations. Whichever term is chosen, a reclamation plan, including the desired end result, and the estimated year-by year progress toward that result, is a necessity. Gone are the days when we could afford to deposit our industrial wastes simply on the basis of short term convenience, with no thought to the future.

7.2 THE NEED FOR LONG TERM RECLAMATION PLANNING

The need for long term planning in the reclamation of industrial works in the North is now widely recognized. Government response has taken the form of the Territorial Lands Act (1970). By 1976 all land use operations in the north have come under the review and inspection procedures of these land use regulations. However, close control of land use is not always easy in a land besieged by seemingly urgent and often massive developmental projects. The present mechanism provides for the screening and inspection of land use activities, but more emphasis must be placed on monitoring impact and on planning reclamation. Any significant development in the North should be required to present a statement outlining not only the impact of the project while it operates, but also the form of the final reclamation program, and the steps which will be taken during the life of the project [illegible]litate final reclamation. There must be an awareness that the [illegible] development and waste disposal determines the optio[illegible] the reclamation phase.

7.2.1 CAREFUL CHOICE OF TAILINGS DISPOSAL AREAS

With mine tailings perhaps the most basic decision to be made concerns the manner of deposition. The final topography must be erosion-resistant, if not erosion-proof. When one is dealing with an easily erodable material such as mill slurry, it should be deposited to take advantage of natural topography. To a certain extent this has been done at Discovery. Some of the tailings material is contained within natural depressions where ongoing erosion is minor. However, much of the tailings was deposited within easily erodable embankments, or with no embankments at all. Under these conditions, erosional processes will continue for decades. In time, for example, the middle portion of the airstrip, and the tailings to the west, will be washed into Giauque Lake and Round Lake. At Discovery the achievement of even a basic requirement, a stable surface on the tailings, will require the long term. Obviously there can be little hope for significant extensive revegetation in less time. Even at the Giant Mine in Yellowknife, where dykes for the tailings ponds are constructed of mine muck (a mixture of broken rock and fine material), something as predictable as a heavy or sudden spring runoff can break dykes and cause massive erosion. The necessity of planning permanent dyking that will remain viable long after the departure of the workers becomes apparent.

7.2.2 THE NEED FOR LOCAL REVEGETATION EXPERIMENTATION

There are a number of measures which can be taken to stimulate the revegetation of tailings. Although much of the revegetation technology from the south has application in the north, the specific site conditions which have to be met in each region are unique. At the present time there are few large mining developments in the Canadian north and, as a result, practical revegetation experience is limited. Therefore, there is a necessity to experiment with revegetation while a mine is in operation. Test plots should be set up and operated over a number of years. The toxic components of each mine's unique tailings must be identified. Test plantings are needed to determine the optimum or even minimum levels of nutrients, whether they are chemical fertilizers or local organics; the need for irrigation, if any; and the necessity of shelter. Only with such a background of experience can an effective revegetation program be instituted.

7.3 MEASURES TO ASSIST IN RECLAMATION

The necessity of planning disposal to ensure a stable surface for plant rooting has been stressed. The use of natural basins such as bogs might also be effective in decreasing problems of drought. In fact, the planned infilling of selected lakes could be a suitable way to manage disposal and reclamation by providing the topographic control and stability so basic to reclamation. However, the infilling of any natural depression to a significant depth necessitates measures to provide nutrients to the surface layer of the tailings. The approach used in the south would require extensive soil tests and the controlled spreading of crushed limestone or lime to decrease acidity. Chemical fertilizers could then be spread over the tailings, along with a mix of seeds of plants known to have the ability to establish quickly, or those with the ability to colonize under the cover of a catch species.

In a situation such as Discovery such measures would undoubtedly prove expensive. Other methods that would significantly assist natural reclamation capabilities rate consideration. For example, steps could be taken to restrict the depth of tailings deposits to less than 50 cm, thus enabling the colonizing species to root into the buried organic cover. In view of the size of most modern mines, this option is not too realistic, yet it is indicative of the approach needed. Another alternative is to make organic debris available at regular intervals by bulldozing the vegetation into windrows before the tailings are deposited. The placement of organic materials such as straw, brush or peat on the surface of the tailings would also be effective in providing surface stability, nutrients, shelter, and moisture. Locally treated sewage might prove very effective for fertilization and the creation of surface stability. Any measure which would serve to ameliorate an environment marginal for plant establishment and growth may be crucial to ensure final revegetation sucess.

Several species of plants found on the tailings at Discovery stood out for their ability to colonize an inhospitable environment unassisted. *Equisetum* spp., *Eriophorum angustifolium* and *Carex aquatilis* showed an ability to adapt to moist locations. *Epilobium angustifolium* and *Hordeum jubatum* showed success in dry and even exposed locations. These species and shrubs such as *Salix* spp., *Betula* spp., and *Alnus crispa* should always be given consideration for the role which they may be able to play in the natural reclamation of a disturbed area.

The thorough reclamation of industrial sites is difficult and expensive no matter where it occurs. As with most other facets of northern operations, reclamation too will be more delicate, time-consuming, and expensive than in the south. However, the critical components of northern reclamation programs are foresight, an understanding of the local environment, and the willingness to work within its restraints. Such a responsible approach can result in the satisfactory reclamation of northern mine sites within an acceptable time span and without excessive cost.

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APPENDIX A

PLANT SPECIMENS COLLECTED AT DISCOVERY

During the field season representative plant specimens were collected, pressed and dried. The specimens were tentatively identified by the author in the fall of 1971, prior to confirmation of the identification. I am indebted to Ms. M. Dumais (Assistant Curator, Herbarium, Department of Botany, The University of Alberta) and Mr. W.J. Cody (Curator, Vascular Plant Herbarium, Biosystematics Research Institute, Research Branch, Canada Department of Agriculture, Ottawa) for their assistance in confirming the identification of the vascular plants. Professor D.H. Vitt (Department of Botany, The University of Alberta) identified the bryophytes, and Mr. M. Ostafichuck (then at the Department of Botany, The University of Alberta) identified the lichens. The nomenclature of the lichens follows Hale and Culbertson (1970).

Voucher specimens of some of the plants were retained by the persons listed above. The remaining specimens have been deposited with the Department of Geography at The University of Alberta.

The following list of the plants collected at Discovery includes common names where possible. The initials MD (Ms. M. Dumais), WJC (Mr. W.J. Cody), DHV (Professor D.H. Vitt) and MO (Mr. M. Ostafichuck) indicate the authority who confirmed the identification. The letters UAH (Herbarium, Department of Botany, The University of Alberta) or NH (National Herbarium, Ottawa) indicate the location of notable voucher specimens.

APPENDIX A - LIST OF PLANT SPECIMENS COLLECTED AT DISCOVERY

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
POLYPODIACEAE				
Dryopteris fragrans	Fragrant Shield Fern	MD	UAH(104)	104,102,103, 105,247
EQUISETACEAE				
Equisetum arvense	Common or Field Horsetail	MD	-	143,163,164, 188,192,193, 266,268
Equisetum fluviatile	---	MD	-	110,111,146, 194,200,276, 313
Equisetum sylvaticum	Woodland Horsetail	MD	-	183,184,155, 156,112,113, 126,239,257, 261,267
LYCOPODIACEAE				
Lycopodium complanatum	Ground Cedar	MD	-	253
PINACEAE				
Juniperus communis	Ground Juniper	MD	-	137
Larix laricina	Tamarack	MD	-	116,312
Picea glauca	White Spruce	author	-	D25,D26

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
Picea mariana	Black Spruce	author	-	D50
Pinus banksiana	Jack Pine	author	-	D27,D28
SPARGANACEAE				
Sparganium multipedunculatum	Bur-reed	MD	-	274,271
GRAMINEAE				
Agrostis scabra Willd.	Hair Grass, Tickle Grass	WJC	-	244
Agrostis (?) *scabra* Willd.	---	WJC	NH	141
Beckmannia syzigachne	Slough Grass	MD	-	157,158,162
Calamagrostis neglecta (ehrh.) Gaertn., Mey., and Schreb.	Reed Grass	WJC	-	195,197,284, 285,258
Calamagrostis purpurascens R. Br.	Purple Reed Grass	WJC	-	240
Deschampsia (?)	---	MD	UAH	142
Festuca saximontana Rydb.	Fescue	WJC	-	296
Hordeum jubatum	Foxtail Barley	MD	-	147,152
Poa glauca	Bluegrass	WJC	-	245,246

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
CYPERACEAE				
Carex aenea	---	WJC	-	294,295
Carex aquatilis	---	MD	-	280,281,189,190, 191,173,181,182, 272
Carex rostrata Stokes	---	WJC	-	327,328
Eleocharis palustris (L.) R. and S.	Spike Rush	WJC	-	151
Eriophorum angustifolium	Cotton Grass	MD	-	282,283,185,186, 187,149,154,172
ARACEAE				
Calla palustris	Wild Calla	MD	-	321,322
SALICACEAE				
Populus tremuloides	Aspen	author	-	123,309,325
Salix arbusculoides Anderss.	---	WJC	-	174,109
Salix bebbiana Sarg.	Beaked Willow	WJC	NH(179)	177,178,179,180, 304,120
Salix glauca L.	---	WJC	-	250,255,238,118, 119,230,279,251, 303,241,231,233, 311,259,305

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
Salix myrtillifolia Anderss.	---	MD	-	204
Salix planifolia Pursh	---	WJC	NH(306)	237,176,319,234, 252,306
Salix pyrifolia Anderss.	Balsam Willow	WJC	-	242
MYRICACEAE				
Myrica gale	Sweet Gale	MD	-	263,226,326
BETULACEAE				
Alnus crispa	Green Alder	MD	-	318,117
Betula glandulosa Michx.	Dwarf Birch	WJC	-	310,167
Betula occidentalis (?) Hook.	Water Birch	WJC	-	166
Betula papyrifera	White Birch	WJC	-	165,243,316
Betula pumila L. var. *glandulifera* Regal	Swamp Birch	MD	-	169
SANTALACEAE				
Geocaulon lividum	Bastard Toad Flax	MD	-	108,144,198
CARYOPHYLLACEAE				
Stellaria longipes	Long-stalked Chickweed	MD	-	160

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
NYMPHAEACEAE				
Nuphar variegatum	Yellow Pond-lily	MD	UAH	320
RANUNCULACEAE				
Anemone parviflora	---	MD	-	199
Ranunculus gmelinii	Yellow Water Crowfoot	MD	-	265
FUMARIACEAE				
Corydalis sempervirens	Pink Corydalis	MD	-	201,202,297
Rorippa islandica	Yellow Cress	MD	-	132,159,161,323
SAXIFRAGACEAE				
Ribes glandulosum	Skunk Currant	MD	-	260,254
Saxifraga tricuspidata	Saxifrage	MD	-	106,138,248
ROSACEAE				
Potentilla norvegica	Rough Cinquefoil	MD	-	292
Potentilla palustris	Marsh Cinquefoil	MD	-	270,275,324
Rosa acicularis	Prickly Rose	MD	-	140,286
Rubus chamaemorus	Cloudberry	MD	-	128
Rubus strigosus	Wild Red Raspberry	MD	-	291,290

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
LEGUMINOSAE				
Astragalus frigidus	Milk Vetch	MD	-	228,229
EMPETRACEAE				
Empetrum nigrum	Crowberry	MD	UAH	129,130,136
ELAEAGNACEAE				
Shepherdia canadensis	Canadian Buffalo Berry	MD	-	203,211,287
ONAGRACEAE				
Epilobium angustifolium	Fireweed	MD	-	114,115
HALORAGACEAE				
Hippuris vulgaris	Mare's Tail	MD	-	273
Myriophyllum exalbescens	Water Milfoil	MD	UAH(315)	269,314,315
PYROLACEAE				
Pyrola virens	Greenish-flowered Wintergreen	MD	-	205
ERICACEAE				
Ledum groenlandicum	Common Labrador Tea	MD	-	235

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
VACCINIACEAE				
Arctostaphylos rubra	Alpine Bearberry	MD	-	212
Arctostaphylos uva-ursi	Common Bearberry	MD	-	214,133
Oxycoccus microcarpus	Small Bog Cranberry	MD	-	125
Vaccinium uliginosum	Bog Bilberry	MD	-	135, 210,236,264
Vaccinium vitis-idaea	Bog Cranberry	MD	-	196,131,127,134
CAPRIFOLIACEAE				
Viburnum edule	Low-bush Cranberry	MD	-	225,139,262
COMPOSITAE				
Arnica alpina (L.) Olin ssp. *attenuata* (Greene) Maguire	---	WJC	NH	145
Erigeron lonchophyllus	Wild Daisy, Fleabane	MD	-	293

BRYOPHYTES

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
HEPATICAE				
Ptilidium ciliare	---	DHV	UAH (219,D21) (289c)	219,D21,289c, 249
SPHAGNALES				
Sphagnum capillaceum	---	DHV	UAH	288
Sphagnum capillaceum var. *tenellum*	---	DHV	UAH	D4b
Sphagnum girgensohnii	---	DHV	UAH	206
Sphagnum magellanicum	---	DHV	UAH	D4a
Sphagnum squarrosum Crome	---	DHV	UAH(209)	209,208
EUBRYA				
Aulacomnium palustre	---	DHV	UAH	213b
Aulacomnium turgidum	---	DHV	UAH(289d) (213a)	289d,D5a,213a, D20
Dicranum undulatum	---	DHV	-	D5b
Hylocomnium splendens	---	DHV	UAH	289b
Polytrichum commune	Hair-cap Moss	DHV	UAH	124, D4c

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
Polytrichum juniperinum var. *gracilis*	---	DHV	UAH(215)	215,216,217,D12
Ptilium crista-castrensis	---	DHV	UAH	289

LICHENS

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
Actinogyra muehlenbergii	---	MO	UAH(D15)	D15
Cetraria hepatizon	---	MO	UAH(D13b)	D13b
Cetraria nivalis	---	MO	UAH(223,D10a) (D9a)	223,D10a,D9a, D17
Cladina alpestris (L.) Harm.	---	MO	UAH(224)	224
Cladina arbuscula	---	MO	UAH(D1b)	D1b,D2a
Cladina mitis (Sandst.) Hale and W. Culb.	---	MO	UAH(D16a,D1a) (D23b,D9b)	D16a,D1a,D23b, D9b,D2b,D24b
Cladina rangiferina (L.) Harm	---	MO	UAH(222,D16b) (D18ab)	222,D16b,D18ab
Cladonia amaurocraea	---	MO	UAH(221a,D11b)	221a,D11b,D14a
Cladonia cornuta	---	MO	UAH(D19b,D22) (D3b,D11a)	D19b,D22,D14b, D3b,D11a
Cladonia deformis	---	MO	UAH(D3a)	D3a
Cladonia gracilis	---	MO	UAH(218b)	218b
Cladonia phyllophora	---	MO	UAH(218c)	218c
Cladonia uncialis	---	MO	UAH(D10b)	D10b
Cladonia verticillata	---	MO	UAH(221b)	221b
Nephroma arcticum	---	MO	UAH(D23a)	D23a,D24a,D8

Scientific Name	Common Name	Determination by	Voucher specimen	Author's number
Parmelia separata	---	MO	UAH(D13a)	D13a
Peltigera aphthosa	---	MO	UAH(207,D19a)	207,D19a,220
Peltigera malacea	---	MO	UAH(221c)	221c
Stereocaulon pacchale	---	MO	UAH(D29)	D29,D30
Stereocaulon tomentosum	---	MO	UAH(218a)	218a

APPENDIX B

ANALYSIS OF TAILINGS SOIL SAMPLES

Samples of the tailings at Discovery were collected both from the surface and from soil pits. Each sample was numbered and placed in a plastic bag. At the end of the field season the samples were transported to Edmonton where they were oven dried at 40° C, and transferred into small plastic containers with snap-on lids. They were stored at room temperature during the winter of 1971-72.

B.1 SOIL pH AS MEASURED BY AUTHOR

In April 1972 the pH of the soil samples was tested according to the procedures described in Peech (1965). The samples were tested in a solution of calcium chloride. The results should be reported as soil pH measured in 0.01 M $CaCl_2$.

B.2 TEST FOR CYANIDE BY AUTHOR

Although it seemed unlikely that any cyanide would be found in tailings samples which had been deposited some years ago, tests were nonetheless undertaken. The procedures followed are outlined in Anonymous (1945). The determination was for total cyanide in cyanide solutions, or an indication in terms of NaCn (or KCn), of the cyanogen existing in the form of simple cyanides, hydrocyanic acid and the double cyanides of zinc. The procedure was to measure 25 cc of clear cyanide solution and add 10 cc of caustic sod-potassium iodide solution and titrate with standard silver nitrate solution to a permanent yellow opalescence. The test was performed on a total of 45 samples, but none showed any evidence of cyanide. Of these samples, 10 were collected by a friend during the summer of 1972, and sent to Edmonton in plastic bags for tested a week after their collection.

B.3 TESTING BY THE ALBERTA DEPARTMENT OF AGRICULTURE

The Soil and Feed Testing Laboratory of the Alberta Department of Agriculture provides a public service whereby they will subject soil samples to a wide variety of tests for a nominal fee. These tests are designed primarily for farmers who want to know how to improve soil fertility, but it was felt that these tests would provide useful information about the tailings at Discovery. The methods used for the tests are noted below;

1) Nitrate - Phenoldisulphonic Acid Method.

2) Phosphorus - Available phosphrous is determined using a combined nitric vanadate molybdate colorimetric determination.

3) Potassium and Sodium - An available determination by flame photometry (I.L. flame photometer). soil-solution ratio 1:5

L− as 0-7 ppm	M− as 22-28 ppm	H− as 42-48 ppm
L as 8-14 ppm	M as 29-35 ppm	H as 49-55 ppm
L+ as 15-21 ppm	M+ as 36-41 ppm	H+ as > 55 ppm

4) SO_4 The modified Johnson Nishita procedure for the determination of water soluble SO_4. H+ is greater than 200 ppm.

6) Organic matter -
L as 0-1 percent
M as 1-3 percent
H as greater than 4 percent

APPENDIX C

During the field season, regular observations of temperature, humidity and precipitation were made at several locations. A listing of the readings taken in the R2 study area may be found below.

Temperature and humidity readings were taken at two locations. Station R2A is located at 985S-148E, in the middle of the R2 tailings disposal area. Station R2B is located to the south, in an area of undisturbed spruce bog, at 1045S-138E. The instruments used were Taylor maximum-minimum recording thermometers. The thermometers were mounted in a wooden box (approximate dimensions 30 X 20 X 30 cm) mounted on a wooden stake at a height of 150 cm. The boxes had several 3 cm diameter air holes, both top and bottom, but were otherwise covered in aluminum foil. The humidity readings were taken with a portable, battery-operated aspirated psychrometer. Readings were taken at ground level and at the height of the thermometer shelter. The readings are as shown in the tables. The heading 'Inst.' represents the instantaneous temperature reading.

A plastic, wedge-style rain guage was mounted on a wooden stake about half-way between R2A and R2B. The readings are as shown in the table.

Daily readings of temperature and relative humidity

Date	Time	R2A (958S-[illegible]E)					R2B (1045S-138E)				
		Temperature °C			Humidity		Temperature °C			Humidity	
		Inst.	Lo	Hi	Ground	150 cm	Inst.	Lo	Hi	Ground	150 cm
June 29	1330	18	-	-	-	-	22	-	-	-	-
30	1330	22	10	23	-	-	25	9	26	-	-
July 1	1330	17	13	18	-	-	18	13	19	-	-
2	1030	20	10	22	-	-	20	8	23	-	-
3	1630	20	13	20	-	-	21	12	22	-	-
4	1900	20	11	21	-	-	21	10	23	-	-
5	1900	14	12	20	-	-	15	12	22	-	-
6	1700	13	6	15	-	-	14	4	15	-	-
7	1900	11	5	15	-	-	11	4	17	-	-
8	1900	14	7	16	-	-	16	6	17	-	-
9	1900	18	4	20	-	-	19	3	22	-	-
10	1900	21	7	22	-	-	22	6	24	-	-
11	1900	22	7	25	-	-	23	5	27	-	-
12	1900	12	12	23	-	-	12	12	21	-	-
13	1900	15	10	19	-	-	16	9	20	-	-
14	1900	13	10	18	-	-	13	9	18	-	-
15	1900	17	11	19	43%	38%	18	10	21	34%	36%
16	1900	20	12	20	49%	46%	21	12	21	50%	47%
17	1900	14	13	16	65%	69%	14	13	17	69%	69%
18	1300	23	7	23	39%	36%	21	8	21	40%	37%
19	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-
21	1900	16	3	25	-	-	15	4	23	-	-
22	1700	16	4	20	-	-	16	5	18	-	-
23	1100	17	9	22	41%	41%	16	10	20	47%	43%
24	1300	18	5	23	36%	36%	18	6	22	44%	39%
25	1200	22	5	26	37%	34%	20	6	23	38%	35%
26	1000	17	9	22	42%	41%	16	9	20	48%	47%

Daily readings of temperature and relative humidity

Date	Time	R2A (958S-148E) Temperature °C			R2A Humidity		R2B (1045S-138E) Temperature °C			R2B Humidity	
		Inst.	Lo	Hi	Ground	150 cm.	Inst.	Lo	Hi	Ground	150 cm
July 27	1200	22	4	24	26%	28%	20	5	23	33%	31%
28	1030	23	6	27	30%	30%	21	7	25	33%	33%
29	0945	25	11	29	40%	42%	24	11	28	49%	46%
30	1000	12	10	20	63%	59%	11	10	19	63%	58%
31	1030	20	9	-	36%	36%	19	10	-	42%	42%
August 1	1000	23	9	31	33%	32%	23	10	29	35%	35%
2	0900	22	15	32	61%	57%	23	17	31	54%	51%
3	0930	20	16	27	74%	66%	20	17	26	59%	59%
4	1000	9	8	13	76%	76%	9	8	13	77%	76%
5	0915	11	3	14	68%	68%	12	5	13	72%	67%
6	0930	12	7	18	90%	85%	12	8	18	90%	85%
7	0915	14	4	22	66%	66%	16	5	21	66%	66%
8	0945	18	5	22	43%	42%	18	6	22	48%	44%
9	1045	15	4	18	48%	44%	14	4	17	46%	50%
10	0945	12	9	18	93%	88%	12	9	18	88%	88%
11	0945	12	9	12	82%	82%	12	9	13	69%	69%
12	1000	4	2	9	78%	78%	5	2	8	78%	70%
13	0900	9	-1	17	69%	65%	8	0	17	69%	65%
14	1000	9	4	14	48%	48%	8	4	13	59%	52%
15	0915	10	5	19	51%	46%	10	6	18	56%	50%
16	1415	19	8	19	40%	36%	18	8	18	36%	41%
17	0945	9	9	10	88%	88%	9	9	10	88%	88%
18	0930	10	5	15	-	-	10	6	15	-	-
19	1015	15	2	20	-	-	14	2	19	-	-
20	1000	12	8	21	-	-	12	9	21	-	-
21	0900	14	12	18	-	-	13	12	18	-	-
22	1030	18	7	18	-	-	18	9	18	-	-

Daily readings of temperature and relative humidity												
Date	Time	R2A (958S-148E)					R2B (1045S-138E)					
		Temperature °C			Humidity		Temperature °C			Humidity		
		Inst.	Lo	Hi	Ground	150 cm	Inst.	Lo	Hi	Ground	150 cm	
August 23	0930	14	7	17	-	-	14	8	17	-	-	
24	0900	10	4	17	-	-	11	5	17	-	-	
25	~~1000~~	14	6	17	-	-	14	7	17	-	-	
26	0900	12	8	-	-	-	12	8	-	-	-	

Rain Guage Observations		
Date	Time of Recording	Amount (cm)
July 1	1330	0.13
2	1930	0.25
6	1700	0.05
7	1900	0.05
8	1900	0.13
12	1900	0.38
14	1900	0.30
17	1200	0.38
24	1200	0.03
30	1000	0.03
August 2	0900	0.33
3	0930	0.35
6	0930	0.48
10	0945	0.20
11	0945	1.02
12	1000	0.10
13	0900	0.13
17	0945	1.68
18	0930	0.05
21	0900	0.05
23	0915	0.23

The rain guage was located at the edge of the R2 study area, approximately half-way between R2A and R2B.