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REHABILITATION OF MINE WASTES IN A TEMPERATE ENVIRONMENT

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PREFACE

Some of the rehabilitation procedures outlined in this Bulletin have been significantly modified since the paper was originally presented in 1977.

Continued modification and improvement may be expected in response to findings from on-going research programmes and further clarification of post-mining landuse objectives.

For a more recent summary of rehabilitation procedures associated with the Company's Western Australian operations, the reader is referred to the publications listed below.

*Alcoa of Australia Limited and Dames & Moore 1978:
Wagerup Alumina Project, Environmental Review
and Management Programme (Supplement,
September 1978), 143pp.*

*Tacey, W.H., in prep: A review of landscaping and
revegetation practices used in the rehabilitation
of bauxite mined sites in Western Australia (to
be submitted to Reclamation Review).*

REHABILITATION OF MINE WASTES IN A TEMPERATE ENVIRONMENT

W.H. Tacey¹, D.P. Olsen¹, & G.H.M. Watson²

ABSTRACT

There has been a proliferation of literature concerning the rehabilitation of mine wastes but the majority of it applies to the northern hemisphere at latitudes higher than those of Australia. The temperate zone of Australia is described and three types of mining waste occurring in the region are recognised; namely, remnant pits, processing residue and massive overburden material.

Rehabilitation in any area can be guided by a set of general principles relating to responsibility for works, planning, soil amelioration, species selection, site maintenance and public communication.

Alcoa of Australia Limited mines bauxite, refines alumina and converts this to aluminium using brown coal to supply electricity. Mining, refining and power generation produce remnant pits, process residue and massive overburden material respectively. The nature of each waste type is described and techniques used in rehabilitation discussed in the light of the general principles.

The need for adequate forward planning is stressed and some alternative future uses for former waste areas outlined.

1. GENERAL PRINCIPLES

1.1 INTRODUCTION

Rehabilitation is now a firmly established part of most mining operations. Accompanying this trend is a rapid proliferation of literature on the subject. However, as Coaldrake (1973) points out, most of this information applies to the higher latitudes

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of the Northern Hemisphere. It is the task of this workshop to help alter this situation. To that end this paper summarises the principles of rehabilitation and details Alcoa of Australia's experiences in temperate Australia with three major types of mining residue.

1.2 DEFINITIONS

Temperate environments are those where air temperatures are neither too hot nor too cold, with the average for the coldest month between -3° and 18° (Sale 1965). These are the mediterranean and warm temperate east coast climates of near coastal Australia from Geraldton to Grafton. Note that the definition says nothing about rainfall, hence the harsh summer drought of the mediterranean region is embraced by this area.

Mine wastes are here defined as the remnants of any operations, directly linked to mining, which impose a cost on the environment in their "as abandoned" state. These consist of three main types:

- (i) remnant pits such as open cut bauxite mines,
- (ii) massive overburden material such as the spoil above coal or iron ore deposits, and,
- (iii) processed tailings like the 'red mud' remaining after extraction of alumina from bauxite or the slimes generated by milling operations.

Rehabilitation is the return of an area to long term productive use. "Productive use" ranges from revenue generating operations like grazing to provision of intangible recreational and aesthetic values.

Rehabilitation is not amelioration. Short term measures such as dust suppression do not comprise rehabilitation,

although they may contribute to the final result.

1.3 PRINCIPLES OF REHABILITATION

It is appropriate here to review some of the general principles underlying mine site rehabilitation. Some of these, especially the physico-biological, have been considered in detail many times before, in which case the reader is directed to other appropriate sources.

- Society is increasingly demanding that rehabilitation costs be allocated according to the 'polluter pays' principle
- A rehabilitation area should be pre-planned to fit the landscape and landuse of the surrounding area.
- Adequate control of all aspects of the mine environment should be exercised to maintain the integrity of the site and prevent deleterious spillovers to surrounding areas.
- Provision of an adequate soil medium is necessary prior to revegetation.
- Revegetation species should be subjected to rigorous testing to determine their site tolerance and applicability to achieving long term land use goals.
- Maintenance should follow treatment until the site is self sustaining or is occupied by others.
- Research and application of rehabilitation measures should be effectively communicated to land users and decision makers in a factual manner.

These points will now be considered in detail:

1.3.1 Why Rehabilitate

- Society is increasingly demanding that rehabilitation costs be allocated according to the 'polluter pays' principle.

If there are social and economic benefits to be gained from an operation, it is reasonable that they outweigh its costs. Those deriving the benefit should meet the costs suffered by other members of society. Although rehabilitation is often seen as a luxury cost associated with mining, it can be the greatest single investment towards ensuring continuity of access to ore reserves. It should be an integral part of the mining operation with a level of commitment similar to any other operational phase of the project. As such, budgeting and pre-planning of rehabilitation should be carried out in parallel with long term production planning.

Internationally, rehabilitation plans are required, by law, before approval to mine is granted in many cases (Thirgood & Matthews, 1971; Fenton, 1973; Jones & Beckner, 1974) and legal statutes requiring the deposit of a rehabilitation performance bond have been promulgated (Roberts, 1974).

Although such stringent legal constraints are often absent in Australia, they should not be necessary. Good rehabilitation demonstrates a level of responsibility (Barr & Atkinson, 1970) which can help ensure access to ore.

At such time as a mining operation cannot bear the cost of reasonable rehabilitation, then its continued operation is in doubt.

1.3.2 Land Use Planning

- Prior to mining, areas to be rehabilitated should be pre-planned to fit the landscape and landuse of the surrounding area.

Mining, although intensive, is only a transient land use. Therefore long term land use guidelines are required to ensure the applicability of the planned rehabilitation programme (Thirgood, 1970; Thornberg, 1974). These may be outlined in legal agreements, shire plans, government policy or stated public opinion. On the other hand, they may be effectively non-existent.

When statutory plans do exist, it should be recognised that the decision-makers will be aware of the possibility of mining precluding certain long term uses (Coaldrake, 1973). In that case, demonstrated ability to rehabilitate in a way which will accommodate the desired long term uses could strongly influence the decision.

When such plans do not exist, the miner should not be averse to actively soliciting opinion, both government and public, and supporting the statutory implementation of long term land use plans. The creation of such plans then permits implementation of appropriate rehabilitation measures; thus resulting in maximum efficiency in the use of resources.

1.3.3 Physico-biological Requirements

- Adequate control of all aspects of the mine environment should be exercised to maintain the integrity of the site and prevent deleterious spills to surrounding areas. Necessary controls will vary widely depending on location, but should embrace such things as prevention of turbid runoff (White & Plass, 1974) through suppression of dust (Downing & Vyle, 1971) to minimisation of social disruption (Olschowy, 1973). In each case some requirements will take priority over others, but proper planning will ensure correct identification.
- Provision of an adequate soil medium is necessary prior to revegetation. This requires elimination of toxic effects, the provision of suitable structure and adequate nutrition. All these aspects are adequately discussed by Martinick (1976).
- Species used for revegetation should be subjected to rigorous testing to determine site tolerance and applicability to achieving long term land use goals (Richardson et al, 1971; Martinick, 1976).

As Martinick (1976) points out, trial and error attempts at rehabilitation usually fail. Such failures not only mean that the required information is unavailable, but also damage credibility. Failures can be avoided by an appreciation of the basic principles involved in vegetation establishment, combined with the level of commitment needed to put those principles into effect.

1.3.4 Maintenance

- Maintenance should follow treatment until the site is self sustaining or is occupied by others.

Rehabilitation does not end with the first sowing of vegetation (James, 1966). A nutritionally and vegetatively depauperate site will take many years to become fully vegetated and self sustaining naturally. Rehabilitation often requires an accelerated successional process where an initial cover crop is later replaced by the desired long term vegetation (Plass, 1968; Coaldrake, 1973; Martinick, 1976). Repeated dressings of fertiliser may be required until sufficient store is built up in the soil and recycling commences. Maintenance is needed to achieve a state which is consistent with the long term planning objectives for the area.

1.3.5 Communication

- Research and application of rehabilitation measures should be effectively communicated to land users and decision-makers in a factual manner.

It has been our experience that an 'open door' policy on the involvement of interested parties at the decision making stages of mine and rehabilitation planning generally alleviates criticism due to lack of information. This process also generates a broader spectrum of ideas with beneficial results. It is not sufficient to simply rehabilitate effectively. The Company must be seen to be rehabilitating effectively, or at least making best efforts to do so. As the public are the final decision makers, via the elected government process, they too must be permitted to become informed.

Communication needs to be effective and above all factual. A "brass band" approach can have negative results and it has been found that exposure of problems, provided efforts are being made to solve them, usually draw positive responses.

2. THE ALCOA EXPERIENCE

2.1 PRODUCTION

Alcoa of Australia Limited, commenced production at Kwinana in 1963 at an annual rate of 220,000 tonnes of alumina. Bauxite was supplied from Jarrahdale, 30 km to the south east in the Darling Range. By 1975, capacity had grown to 1.4 million tonnes per annum.

Because of expanding alumina demand, a second refinery was established near Pinjarra, 90 km south of Perth. This refinery commenced production on 2nd May, 1972 and expanded continuously until an annual production capacity of 2 million tonnes was reached in 1976. The Pinjarra refinery is supplied with Darling Range bauxite from Alcoa's Del Park and Huntly mine sites about 6km to the east.

In order to service current alumina production levels, a total of 13.5 million tonnes of bauxite is mined annually. This production requires the clearing and rehabilitation of some 270 hectares of forest.

Alumina is extracted from the bauxite by the Bayer process. At both refineries a hot caustic liquor steam circulates continuously, initially dissolving hydrated alumina from the bauxite. This liquid then undergoes clarification in which waste solids are separated from the liquor. The waste solids form a 'red mud' slurry, still containing

some caustic soda. Production of alumina from Darling Range bauxite yields two tonnes (dry weight) of waste material for each tonne of alumina produced. At current production rates there is an associated dry tonnage of approximately 7 million tonnes of residue per year. This annual volume of residue must be deposited in sealed lakes especially constructed for final disposal of red mud. Alumina is shipped to Point Henry, Geelong, for smelting. Energy requirements are supplied by Alcoa's 150 megawatt power station situated at Anglesea, 35km to the south-west. The station is fuelled by brown coal mined from the company-owned field on-site at Anglesea. Annual coal production is 1.1 million tonnes, involving the clearing of 30 hectares. These operations generate wastes illustrative of the three types previously described, namely remnant pits, processed tailings and overburden material respectively.

The following section gives details of their properties and some techniques which have been used in their rehabilitation.

2.2 BAUXITE PIT REHABILITATION

Following bauxite extraction, the pits remaining have vertical faces averaging five metres in height and a compact kaolinitic clay floor.

2.2.1 Legal Requirements

At Jarrahdale, Alcoa is only legally required to respread previously stockpiled topsoil, then hand the mined areas back to the State Forests Department for replanting. As a result of experience gained at the Jarrahdale site, the Del Park and Huntly operations are covered by a separate agreement. It states that the Company must take adequate measures, at its own expense, for progressive restoration and reforestation and the prevention

of soil erosion and formation of deep water pools. In effect this obliges the Company to return topsoil, create erosion control structures and raise and replant tree stock.

2.2.2 Past Experience

Early mined areas at Jarrahdale were resoiled and directly planted to a range of potential timber producing *Eucalyptus* and *Pinus* species. After fertilisation with blood and bone, growth was fair, although symptoms of nutrient deficiency were apparent. However, as trees increased in size, some windthrow became apparent due to their inability to penetrate the compacted subsoil.

Subsoil ripping techniques were introduced at Company expense and tree nutrition trials started, using inorganic fertilisers with nitrogen and phosphate levels far above those in blood and bone. Ripping to a depth of 1.2 metres was successful in controlling windthrow and trees achieved relatively spectacular growth with two 100 gm applications of mono-ammonium phosphate.

Ripping on contour assisted erosion control considerably but treatment of turbid runoff was still required to protect areas of water catchment. The use of settlement ponds and level concrete overflows proved ineffective, so it was decided to confine all drainage within the pits, relying on infiltration for dissipation of water. It was also decided to render pits safer and more aesthetically pleasing by battering all faces to a slope less than two in one. Experimentation with various contour banks, heights and spacings and the introduction of ripping to 2.1 metres has resulted in adoption of the current rehabilitation technique, described below.

The experimentation and earthworks described above were originally initiated by the Company, at its expense.

2.2.3 Current Practice

a) Treatment

In 1977 mine site earthworks comprise battering all pit faces, construction of internal contour banks 2 metres high at 15 to 20 metre contour intervals and formation of a 3 metre high contour batter along the lowest edge of the pit/

Internal banks are provided with emergency pipe overflows at 1.2 metres height, which drain into prepared channels if necessary.

Topsoil is then returned to 40cm depth, usually from stockpiles but directly from stripping sites wherever possible. Contour ripping to 2.1 metres depth is achieved with a single tyne on heavy bulldozers specifically purchased for the task. This operation occurs in late summer to promote maximum lateral cracking of the clay between the 2 metre ripping centres.

Following the June rains, seedling stock comprising approximately half eastern Australian and half indigenous eucalypt species are planted, by hand, on contour. Planting is in individual peat pots, at 4 metre spacings, on a single species per block basis. No pines are now used owing to their potential fire management problems. Fertilisation is carried out at planting and again 9 weeks later by placing 100 grammes of mono-ammonium phosphate in a heel hole about 25 cm from the plant. Replanting of any failed trees occurs in subsequent seasons. Specialist treatments including straw and bitumen mulching and hydroseeding are also used as

appropriate on road and conveyor formations and other highly erodible sites.

b) Cost

The above treatment is 'standard' at all mine sites and currently costs* approximately \$10,000 per hectare, of which some \$9,000 is spent on earthworks. Planting and fertilising are carried out by the Forests Department at Jarrahdale while all costs are incurred by the Company at Del Park/Huntly.

2.2.4 Future Options

The standard rehabilitation treatment described above has evolved as a consequence of established forestry practice and is applicable to the high volume production of timber logs. However, timber production is not now seen as the prime landuse; hence a number of the tree species in use have been selected for site suitability rather than timber potential. Nevertheless, they are still being planted in the manner of a plantation crop in 1977.

(a) Landuse planning

At present a number of State Government Departments are involved in the long term land-use planning of the Darling Range and its adjoining coastal plain. The Darling Range is subject to multiple land-use demands, the most important of which is supply and quality protection of domestic water. Other demands include recreation, conservation and timber and honey production (W.A. Forests Department, 1977; M.W.S.S. & D.B, 1977).

* Costs updated, 1979.

Production of water in the Darling Range is favoured by reduction of tree density and hence transpirative capacity. Effective erosion control will still be necessary, however. This strategy may be favoured in the high yielding western zone of the range, but protection of water quality from contamination by soil stored salt is more important to the low yielding eastern zone. In this case, prevention of water table rise is paramount. Development of groundcover treatments capable of preventing the infiltration of excess rainfall or rapid re-establishment of transpiring trees to mimic the natural groundwater hydrology will therefore be required. Contrary to the degree of uniformity necessary for high volume timber production, recreation and aesthetic demands are for diversity of form and function in the vegetation.

b) Rehabilitation Alternatives

It is recognised that different demands will have to be met in different locations. While the landuse planning process is in train therefore, work is progressing on development of techniques suited to each demand. Random planting of overstorey, understorey, shrubs and groundcover has been implemented in a trial simulation of the forest vegetation structure. This structure is suited to areas requiring high transpirative capacity while also having aesthetic and conservation values. Direct return of topsoil has been found to be a valuable method for rapidly returning a diverse ground flora. Where infiltration is undesirable

ripping can be omitted as clover is capable of growing in the topsoil alone, while still providing excellent erosion control. Limited numbers of trees can be added to provide visual relief. Open or clumped planting can be used to create a parkland setting suited to moderately heavy recreational use. As phosphate is rapidly fixed in lateritic soil, it is necessary to add 600 kg/ha of superphosphate to achieve satisfactory first season clover growth. This phenomenon is advantageous however, in that it should be possible for native species to be re-established as the clover sward degenerates due to phosphate depletion. This, and the possibility of using alternatives to clover is being investigated in field trials.

Where infiltration is not desired but agricultural species are unacceptable, straw and bitumen mulch can be undersown with native shrubs, without intensive ripping. Trials indicate that mulch can be effective for two years, by which time a satisfactory shrub cover establishes.

Large sections of forest surrounding bauxitic areas have long been infected with the fungal root pathogen *Phytophthora cinnamomi*. "Dieback" as it is called, results in degradation and death of the forest, ultimately leading to a drastic reduction in transpirative potential. Dieback is therefore of major concern in salt prone areas. As mining progresses it has been proposed by Alcoa that the rehabilitation effort be spread over the envelope of company operations rather than confined to mine pits.

2.3 MUDLAKE REHABILITATION

2.3.1 Properties

The liquor which settles with the residue contains dissolved caustic soda and other sodium compounds. The concentration of lake water averages 12 grams per litre total alkali which includes sodium carbonate plus sodium hydroxide expressed as sodium carbonate equivalent. Lake water readily reacts with carbon dioxide on exposure to the atmosphere converting sodium hydroxide to sodium carbonate.

"Red Mud" consists of a mud fraction, approximately 70% of which is 325 mesh size, and a sand fraction of which approximately 95% is 80 mesh size. There is only a small quantity of material in the intermediate particle size range.

After dumping, the residue separates according to particle size. The sand settles in the immediate vicinity of the dump point and the mud flows to the centre of the lake. This particle size effect leads to areas of soft mud in the filled lake which create problems during rehabilitation.

2.3.2 Rehabilitation

At Kwinana, three mudlakes have undergone the initial stages of rehabilitation with two now capable of supporting permanent pasture and seasonal grazing of sheep.

The problems to be overcome in establishing

permanent pasture on a mudlake can be summarised as follows:

- a) Large volumes and area to be treated
- b) Presence of caustic material throughout the profile
- c) Absence of soil nutritional and structural properties
- d) Soft mud areas incapable of supporting mobile equipment
- e) Wind erosion

Determination of these properties assists selection of amelioration techniques which can convert process residue into a soil medium, prior to revegetation. All unsuitable features must be known.

Once the red mud problems have been defined it is possible to determine the course which revegetation should follow:

a) Volume

Simple volume calculations can be useful in determining the costs of alternative treatments and cost effectiveness of the completed job. Red mud is only a waste product because it cannot be sold today. Part of the rehabilitation effort is therefore directed towards finding alternative uses for red mud other than fill for mud lakes. Alternative uses have been found as road base material and in acoustic tile production. Unfortunately, the annual volume of red mud produced outstrips requirements in these areas.

Use of the mud as a soil ameliorant on the very sandy Swan Coastal Plain of W.A. is at present being investigated. If soil amelioration is a possibility, large volumes of treated red mud could be directed from use as relatively unproductive lake fill to the improvement of water holding capacity in sandy soils.

b) Caustic Soda Content

The mixing of hot caustic and crushed bauxite during the refining process ensures that the residual clays are thoroughly saturated with sodium. Consequently, the soil available for rehabilitation is unsuitable for plant growth. Its main features are:

- i) Very high total dissolvable salts which can reach 10,000 ppm in the top 5 cm.
- ii) A very high free sodium ion concentration in the soil solution. This concentration is well above toxic levels of most plants.
- iii) Soil pH ranging from 10.5 to 11.5 with associated nutrient availability problems.
- iv) High sodium saturation of the clays giving the mud fraction a structureless character.

On drying, the mud is very hard setting and this leads to problems of seed emergence and water infiltration. These problems are further exaggerated by the seasonal rise and fall of the water table. In Western Australia's mediterranean climate, the winter surplus of rainfall often leads to above surface water tables. This causes repeated redistribution of caustic material throughout the profile. During summer the water table falls but capillary rise and subsequent evaporation at the surface still occur. This markedly increases

caustic concentration on the surface. Large areas of white sodium carbonate crusts form on the soil surface. The problem of the rising and falling water table is being overcome by the use of an eductor system which withdraws liquor from the bottom of the lake. The liquor retrieved is pumped into an operating mudlake and eventually reused in the refinery. Thus the eductor system controls water table level and at the same time recovers extra caustic soda for reuse in the process. The following table is evidence of the effectiveness of the system.

TABLE 1

	Date commissioned	Rate of Pumping Kl/hr	Total Pumped to 15.12.75 (Kl)	Tonnes NaOH recovered
A lake	January '75	11	183,679	2661
B lake	July '75	18	79,591	1129
C lake	September '75	70	100,784	1630
	TOTAL		364,054	5420

Mean liquor levels dropped from one metre below the surface to more than five metres, within one year. A long term problem with the de-liquoring system in its present form is the requirement for an operating mudlake nearby. This will not always be the case and future plans for transferring the caustic material or de-activating it will have to be made. The eductor systems must operate continually to maintain the lowered water table. This pumping will be necessary until caustic concentrations are sufficiently diluted by rainfall to allow the seal of the lake to be punctured and the lake water table to achieve

equilibrium with the surrounding groundwater table.

Other alternatives include:

- (i) Surface drainage systems
- (ii) Continued long term pumping
- (iii) Cropping with salt tolerant species
- (iv) Other alternative uses for the red mud stored in the lakes.

The continuation of pumping is limited by the volume of liquor that a refinery can accept. At present the volume is acceptable, however, with ever increasing areas of mudlakes being deliquored, the time may come when the refinery cannot accept all the liquor being retrieved. This emphasises the importance of accurately determining the volume of material involved prior to treatment. The high sodium saturation of the clays can be treated by the addition of gypsum.

It is of interest that gypsum is considered a waste by-product of superphosphate production in the Kwinana area whereas Alcoa utilises it as an ameliorant. To date only laboratory work and small field trials have been performed but results are very promising. Up to tenfold increases in permeability have been achieved in the laboratory. In a pot trial, improved germination of cereal rye has been obtained with increased application rate of gypsum (See Table II).

Gypsum t/ha	% Germination	pH
0	2	10.5
25	0	10.5
50	1	10.2
100	6	9.6
200	53	8.4
400	66	8.1

Table II : Effect of adding gypsum to red mud on cereal rye germination and pH.

Improved permeability should help alleviate the problems of excessive total soluble salt content and the high free sodium ion concentration by directly increasing water infiltration and leaching. The addition of gypsum also decreases pH of the profile directly (see Table II).

(c) Soil Nutrition and Structure

Apart from direct reduction of the toxic effects of high alkalinity, the decrease in pH is expected to have a beneficial affect on nutrient supply within the profile. Increase in structural stability due to addition of gypsum will also provide a better physical environment for plant growth.

Red mud does not contain organic matter and so does not have the buffering and nutrient storage properties of a normal soil. Chemical toxicity

prevents initiation of biological activity by soil fungi and bacteria. Therefore, organic matter must be imported. This is usually in the form of fowl manure or sewerage sludge. These too are normally waste materials for which an alternative use has been found.

There is an extremely low level of all essential plant nutrients in red mud. At present these have to be introduced as artificial fertilisers. Ideally there might be other waste products produced somewhere in Perth which might supply all or some of the essential nutrients.

d) Treatment of Soft Mud Areas

As a consequence of differential settling of the different size fractions, all lakes appear as areas of coarse sand interspersed with areas of fine mud, indicating the pattern of dumping points.

The sands present much less of a problem in revegetation than do the mud areas. The coarse sand, although structureless, does have voids which allow rapid infiltration. This permits toxic materials to be flushed down the profile. To further improve infiltration, ripping to 60cm depth at 60cm centres was carried out on the filled lakes at Kwinana in 1977 to break up the hard setting surface, caused by the presence of sodium in the red mud.

At present the soft mud areas are covered with coarse sand to permit equipment to travel over them. This is a massive earthmoving operation and is hence very expensive. It is not always possible to cover all mud areas even on the old, relatively small, filled lakes at Kwinana. The size of the present operating lakes is between 180 and 250 hectares, making it

essential to periodically rotate the dumping point to assist the even distribution of residue and minimise the formation of mud lenses.

(e) Wind Erosion

Wind erosion occurs on the mudlakes prior to the establishment of a vegetative cover. The windblown material comprises both the red mud itself and sodium carbonate. Both materials affect plant growth and for that reason benefits will be obtained by wind erosion control. To date wind erosion has been temporarily prevented by spraying with dust suppressants. It is controlled in the long term by proper rehabilitation and vegetation. The problem of wind erosion on operating lakes still exists as does the removal of sodium carbonate from soft mud areas which have not been covered by sand. Techniques are available for erosion control on these areas, all relying on a reduction of wind velocity at the soil surface. Some of the techniques which could be used are:

- i) Straw mulch and bitumen emulsion
- ii) Bitumen emulsion alone or other surface sealant
- iii) Crimped straw mulch
- iv) Rocks randomly spread on the soil surface
- v) Hydromulcher technique
- vi) Deep ripping and surface roughening

2.4 REHABILITATION OF COAL MINING OVERBURDEN

Anglesea is a small seaside town of about 1,000 permanent residents. The town serves as a retirement, tourist and holiday centre, and being only two hours' drive from Melbourne

is a popular resort. The Company's mining lease boundary runs to within 50 metres of the closest residential development in Anglesea, and mining is planned to within 250 metres of this development.

2.4.1 Planning

Rehabilitation is guided by a well defined plan rather than proceeding on an ad hoc basis as material becomes available. The aim is to shape a rolling landscape with a large lake left at the site of the final workings of the cut. A creek that was diverted prior to mining will be returned to a natural course through the back filled area.

The backfill is placed to predetermined contours and vegetation is planned to produce a pattern of open heathland, broken by irregular masses of trees and shrubs. An external overburden dump has been shaped to form a large plateau with trees and shrubs planted to blend the dump into the surrounding landscape.

2.4.2 Overburden Characteristics

Overburden removal has proceeded in two stages:

- (i) removal to an external dump,
- (ii) backfilling

Over two million cubic metres of overburden were removed to an external dump before sufficient coal was uncovered and backfilling could proceed in the mined-out section of the cut.

In situ thickness of the overburden varies, but averages 40 metres over the lease. Sandy material

dominates the profile, with clay restricted to the upper levels. The lower 15-20 metres is water logged and excessive amounts of sulphides (mainly pyrite) are present.

In common with similar coal mine overburden, once this reduced material is brought to the surface oxidation of the sulphides produces acid sulphates and results in soil with a pH ranging from 3 to 4. The consequent aluminium toxicity and fixation of plant nutrients makes revegetation impossible without heavy lime applications.

Physical characteristics of the overburden include a tendency to surface seal during summer. Clay seams also tend to be dispersible, leading to erosion problems.

Initially overburden was deposited in the external dump and part of the backfill, in such a way that the sandy pyritic material was placed near the top of the dump. In some areas this was mixed with clay as the material was spread.

The result was a highly acidic surface (pH 3-4) tending to surface seal in summer.

2.4.3. Acid Overburden Revegetation

Revegetation of the acidic overburden requires heavy lime applications. Extensive pH surveys and lime requirements tests indicate levels required. Rates vary from 30 t/ha on clay material to 2 t/ha on very sandy overburden. The lime application also helps with surface seal problems.

Fowl manure is spread and cultivated into the overburden at a rate of 50 m³/ha to boost the organic matter level which is only 1-2% originally.

The external overburden dump has been sown down with perennial pasture species to the following prescription

Seed	4 kg/ha Sirossa Phalaris (<i>Phalaris tuberosa</i>)
	3 kg/ha Currie Cocksfoot (<i>Dactylis glomerata</i>)
	2 kg/ha Fescue (<i>Festuca arundinacea</i>)
	1 kg/ha Strawberry Clover (<i>Trifolium fragiferum</i>)
	2 kg/ha White Clover (<i>Trifolium repens</i>)
	2 kg/ha Seaton Park sub clover (<i>Trifolium subterraneum</i>)
	2 kg/ha Bacchus March sub clover (<i>Trifolium subterraneum</i>)

Fertiliser at sowing

250 kg/ha Pivot Super Lime 1 and 1 (0:4.7:0)
Mo 0.025%

The following spring

250 kg/ha Pivot Super Potash 3 and 1, (0:6.9:4.5)
Cu 0.5%, Zn 0.5%, Mo 0.015%

75 kg/ha Ammonium nitrate

These techniques were first used in the 1976 season. Establishment and persistence have been satisfactory. The above species have high fertility requirements. They have been used firstly to provide fast groundcover, and secondly to allow for the possibility, with fertility reduction, of later replacement with native groundcover species as establishment techniques are developed.

As noted above, sandy acid material was initially placed on top of the backfill. The backfill has been treated in 1977 in the same way as the external overburden dump except that it has been stabilised with a light cover crop of rye corn (*Secale cereale*) undersown with a native seed mixture. Trials incorporating various seeding rates and cultural techniques have been initiated, but it is too early to assess results.

2.4.4 Topsoiled Overburden Revegetation

The difficulties and cost of revegetation have led to the evolution of the following mining sequence:

- Clearing, windrowing and burning of vegetation
- Removal of topsoil to a depth of 40cm in two stages
 - top 15cm
 - remaining 25cm
- The return of the topsoil to the top of the backfill in the same two stages.
- The remaining overburden is then removed and backfilled. Where operationally possible the lower 15-20 metres is placed at the bottom of the cut.

This sequence is only possible where sufficient coal has been uncovered to enable backfilling to proceed at three levels:

- a lower level for the pyritic material
- an upper level for the less toxic material,
- a surface level to be brought to pre-determined contours ready for topsoiling.

Due to the importance of topsoil as a seed source (Carroll and Ashton 1965) its preservation is essential. However, its value diminishes with stockpiling time and so storage if necessary, is kept to a minimum (Clarke 1975).

Before replacing topsoil, the overburden is sampled and analysed for pH. Lime is added where necessary and ripped in.

Topsoil was first replaced in the 1976 season. At that time, the area was stabilised by sowing rye corn in strips 2 metres wide alternating with bands of the same width left unseeded. The rye corn was sown at 30 kg/ha with 100 kg/ha of Pivot Super (0:9.2:0), Cu 0.5% Mo 0.015%. Mulch cut from heathland to be mined in future years was then spread evenly on the unseeded strips. *Acacia* spp., at 1 kg/ha, and *Leptospermum juniperinum* 25 gm/ha was also broadcast.

After emergence of the rye corn, the area was top-dressed with Super (0:9.3:0) Mo 0.015% at 250 kg/ha and Ammonium nitrate at 100 kg/ha. Regeneration of native species has been satisfactory in the mulched strips, although the value of the native mulch as a seed source is doubtful. Further experimentation with cutting time is expected to improve this situation.

Seeding rates for rye corn were too high and indications are that, with the opposing constraints of erosion control and moisture-nutrient competition, 10 kg/ha may be a more optimum rate for control erosion, while at the same time keeping competition for the emerging native species to a minimum.

2.4.5. Tree Planting

A diverse range of tree species has been planted in the past using various slow release fertilisers. The presence of *Phytophthora cinnamomi* restricts the choice of local species and as a result some fast growing resistant species such as *Eucalyptus globulus* have been introduced.

From 1977 the range of species is to be reduced in an attempt to plant communities of trees and shrubs rather than a random mix of a wide range of species.

Trials are underway to assess fertiliser requirements but current practice is to use 100 grams of Pivot 12 (12:20:0) three weeks after planting in autumn and another 100 grams in the following spring.

An important aspect of planting is to establish an environment suitable for the relocation of the creek through the backfill. As the creek bed is shaped, a series of water impounding hollows are being left. These hollows will store water for most of the year, thereby aiding the establishment of native vegetation more suited to swampy environments.

2.5 CONCLUSION

Rehabilitation techniques have been formulated for examples of each of the three mine waste types described.

Successful rehabilitation of each has resulted in erosion control, prevention of deleterious spillovers to the surrounding environment, improved aesthetic standards and creation of surfaces which have positive future landuse potential. This success is dependent on the general rehabilitation principles applicable to all mine wastes. In addition, the

need for continuing research and development of techniques is recognised and there is a need to maintain flexibility in future planning.

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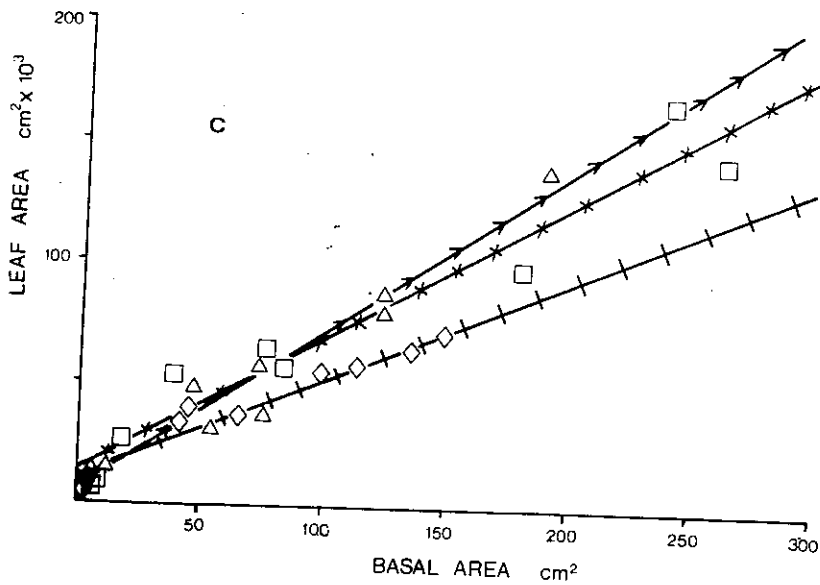
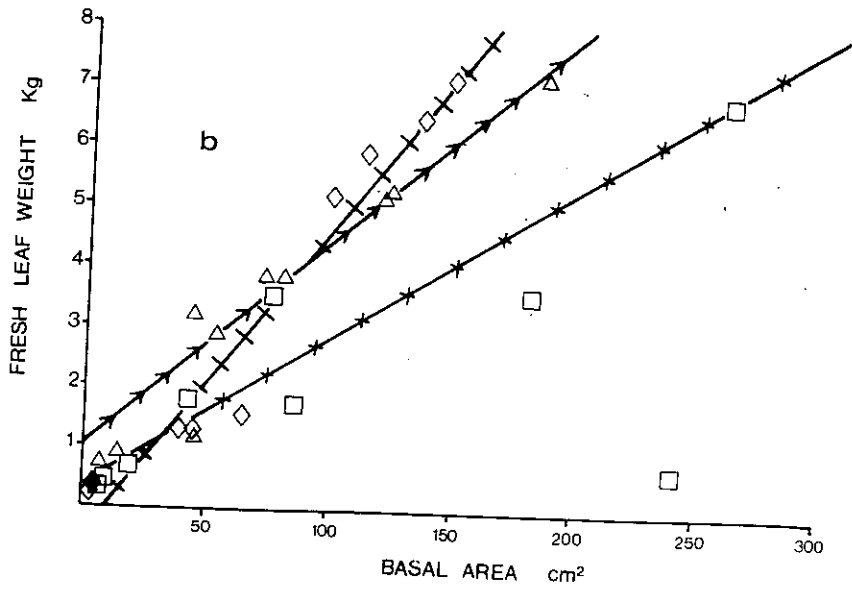
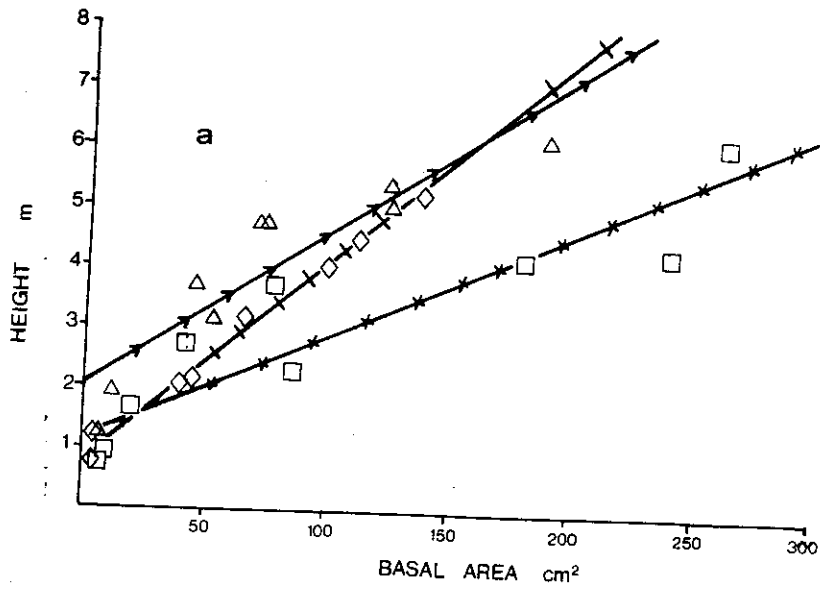
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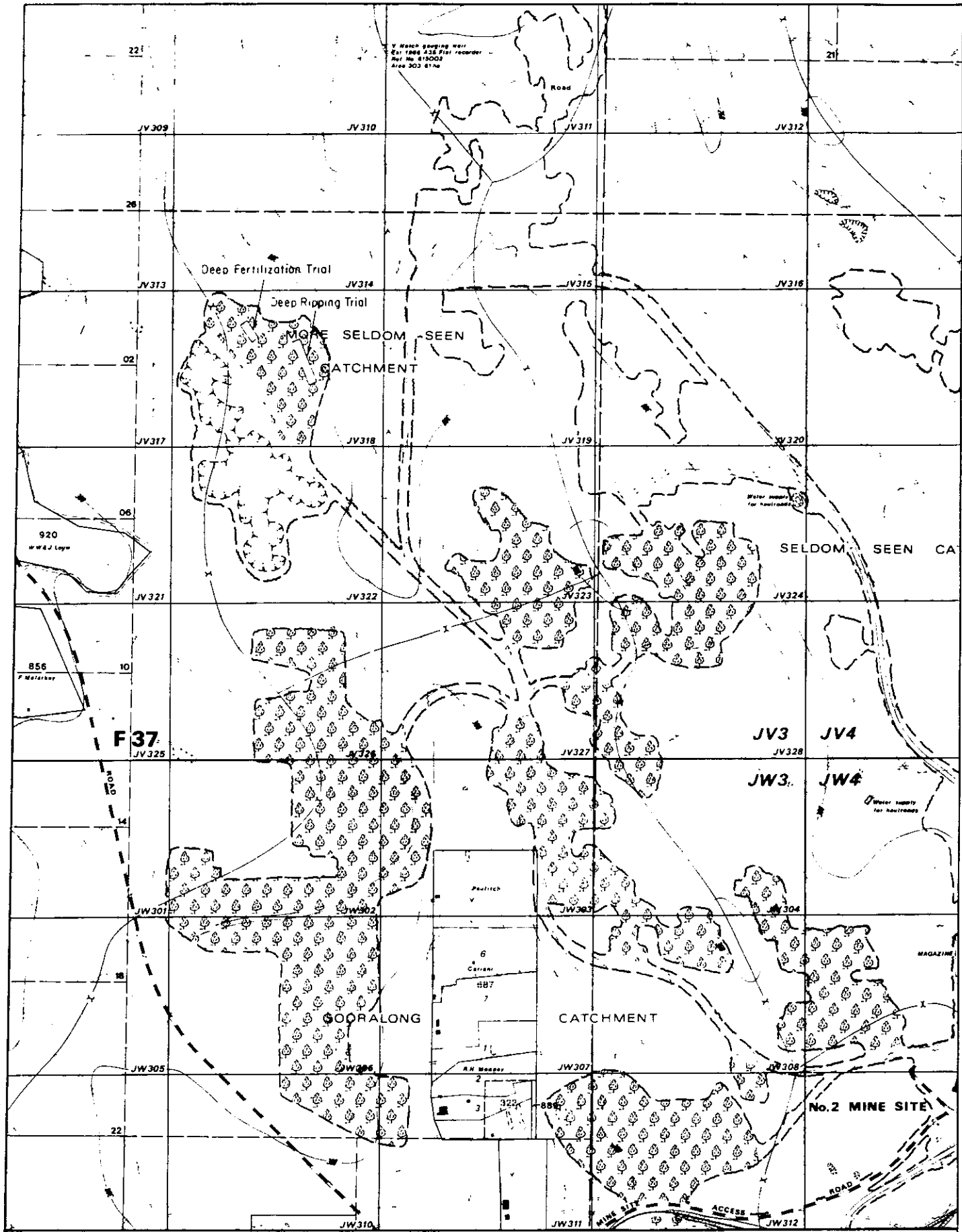
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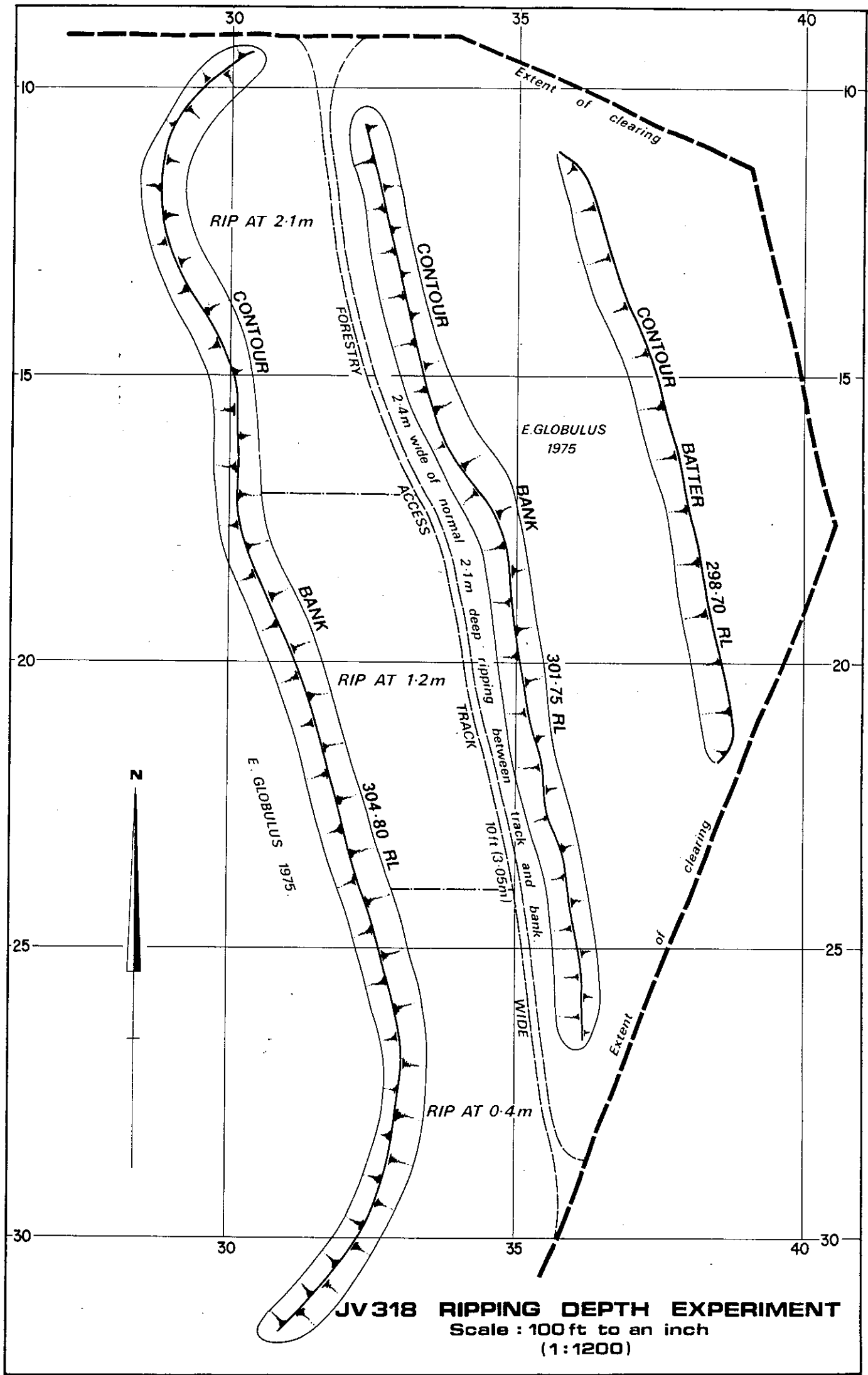




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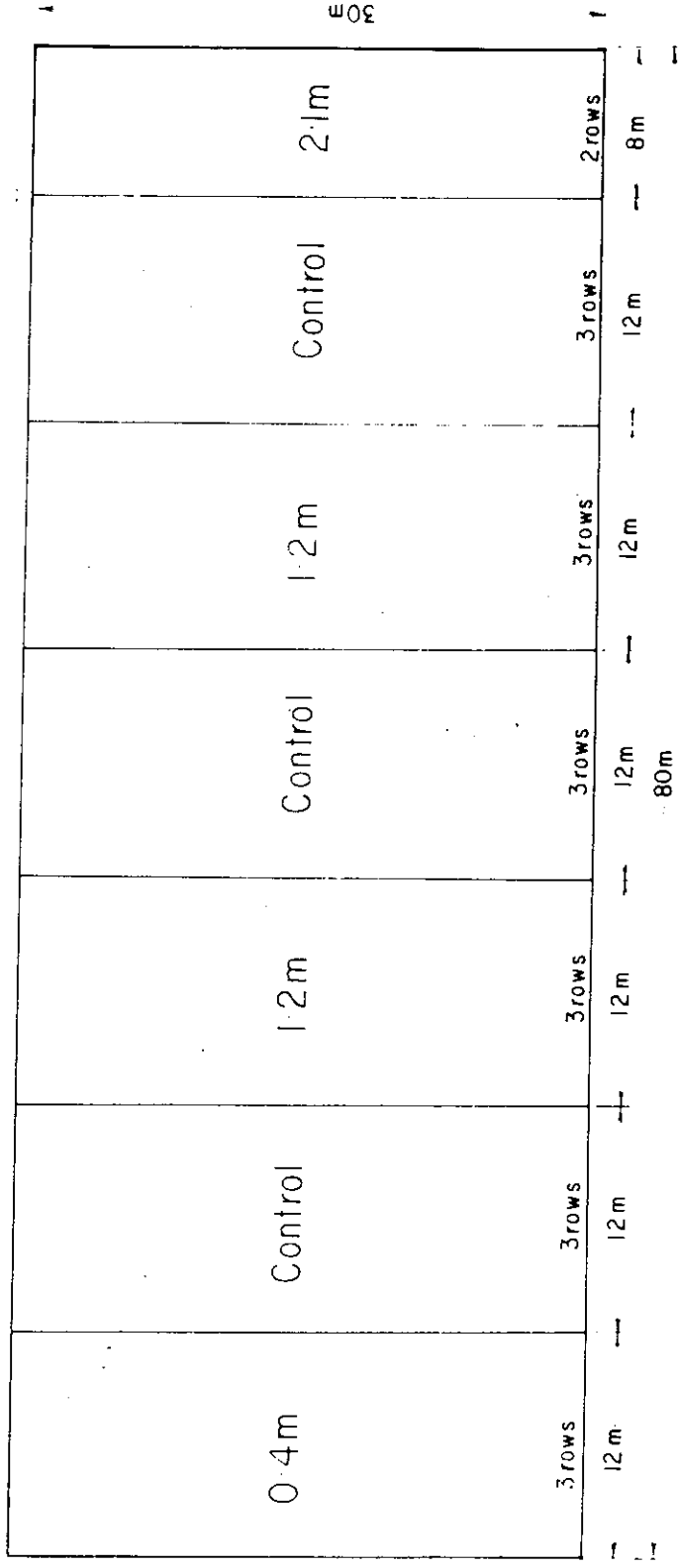
LOCATION OF DEEP RIPPING AND DEEP FERTILIZATION TRIAL PLOTS

Scale: 1:20000



JV318 RIPPING DEPTH EXPERIMENT
 Scale: 100 ft to an inch
 (1:1200)

North (approx)



JV 318 DEEP FERTILIZATION TRIAL NW CORNER OF PIT