NORCO RESOURCES LTD.

VANCOUVER, B. C.

THE PROPOSED NORCO COAL MINE

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Proposed railway
Proposed road
NORCO
PRINCE GEORGE
WILLOW RIVER
PULP HARVESTING FOREST
PURDEN
TREE FARM LICENCE 30
ALEZA LAKE PROVINCIAL FOREST 9999
McGREGOR PLATEAU
Willow River
Giscome
Aleza Lake
Upper Fraser
McGregor
Sinclair Mills
Longworth
Shelley
Salmon Valley
MT BOWRON
SUGARBOWL MTN
SPRING MTN
Red Rock
Stoner
Pineview
Buckhorn
Tabor
Beaverley
Vanway
Miller
Foreman
Ferndale
Somerville
Bonnet Hill
PRINCE GEORGE'S AIRPORT
Micro Wave Relay Station
BOX CANYON
BOAT CANYON
PORTAGE CANYON
BASKET CANYON
BEAR CANYON
GRAND CANYON
SCALE 1 : 250 000

THE PROPOSED NORCO COAL MINE

1. Location and Licenced Area

The central point and probable plant-site of the Norco coal property lies 56 kilometers east of Prince George, in the valley of the Bowron River. Highway 16 runs only 7 km to the north, and will eventually be connected to the plant-site by a road 11 km long. By this connecting road the plant-site will be 65 km from Prince George. The property is presently served by an industrial road from Prince George.

Eventually the property can be connected to the Canadian National Railway at Hansard by the construction of a rail link 37 km long. By this connection the plant-site will be 875 km from a deep-sea shipping point at Prince Rupert, or 1100 km from the deep-sea port at Roberts Bank near Vancouver.

The vicinity of the Norco property is uninhabited. The nearest community is Sinclair Mills, 27 km to the north-east.

The coal property consists of nine coal licences totalling an area of 8.6 square miles (2,227 hectares). Within the coal basin are an additional six coal licences held by another company. Norco is currently negotiating with this company with the intention of bringing the whole basin under its control at which time the area held under licence will be 11.6 square miles (3,781 hectares).

2. History

The Norco property was first identified in 1870 by G. M. Dawson of the Geological Survey of Canada. In the years following, the mine supplied small amounts of coal to nearby communities. After 1960, with improved transportation, the property received more intensive study.

In 1966 Mr. M. Menzies obtained an option to the property from the owners, Northern Coal Company. Six diamond-drill holes were driven, the deepest cutting coal at a depth of 670 m in the centre of the basin. A decline was driven to the uppermost coal seam. The company, represented by Mr. Menzies, dropped its option at this time because of the poor market for coal.

In 1971 Mr. Menzies became president of Northern Coal Company and negotiated an option with Bethlehem Copper Ltd., who drilled five deep holes, then withdrew. Their work is incorporated in the current evaluation of the property. The company was reorganized and refinanced in 1976 in the name of Norco Resources Ltd.

In 1976 the decline was dewatered and an 11-ton sample removed from the upper seam for testing in the laboratory of the Department of Energy, Mines and Resources in Edmonton. The results of these tests are reported under "Coal Quality".

In 1977 a substantial drilling programme was completed under the direction of John R. Kerr, P. Eng., a consulting geologist. 25 holes totalling 6,700 m were drilled and the cores logged and tested.

3. Geological Setting and Preliminary Estimate of Coal Reserves

The Bowron Coal Basin was formed in Late Cretaceous or Early Tertiary times in a quiet inland lake. Three distinct seams of coal have been identified by drilling, suggesting that conditions suitable for coal formation existed over most of the basin in at least three periods. The sequence is generally as follows:

Barren	Variable Barren Cover
Upper Seam	0.1 to 2.4 m thick
Barren	18 m
Middle Seam	0.3 to 3.0 m thick
Barren	24 to 30 m
Lower Seam	1.5 to 9.0 m thick
Barren	18 to 36 m
	Basement

The trend of the beds, as shown in the attached map, is N 30° W and the dip varies from 35° near the western limit to 20° as the formation approaches the center of the trough-like structure.

At least one fault has been identified in the area of intensive drilling. The fault strikes N 50° W, and dips nearly vertically, with a displacement of about 75 m.

In his report of January 5, 1978, John Kerr provided an estimate of coal reserves as follows:

Proven Reserves: Kerr lists a total of 5.94 million tonnes of coal in place as 90% proven, the remaining 10% being probable.

Drill-Indicated or Possible Reserves: Following a review of all work done on the property, Kerr lists a total of 55 million tonnes as drill-indicated.

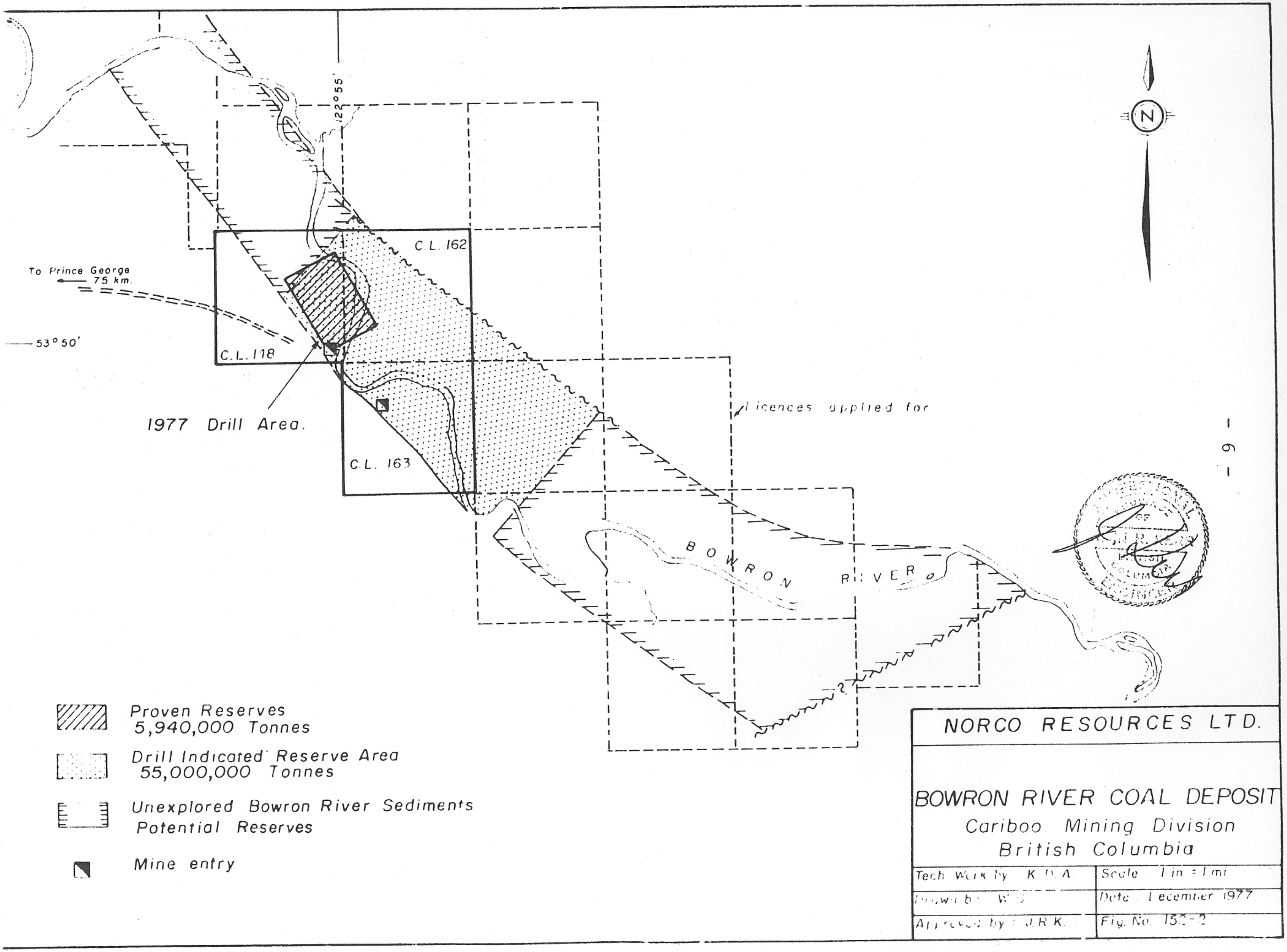
Potential Reserves: Kerr has referred to work by others in listing from 100 million to 250 million tonnes in the potential category. In this calculation the coal measure is considered to extend over the basin delimited by outcrop of the Bowron River sediments and by known faults.

The following summarizes the total geological reserves in the Bowron Coal Basin:

Proven Reserves	6 million tonnes
Drill-Indicated Reserves	55 million tonnes
Potential Reserves	100 to 250 million tonnes
Total Reserve Potential	161 to 311 million tonnes

The attached figure indicates the areas occupied by the three categories of reserves. (See page 6.)

Assuming 50% mineable, the 61 million tonnes of proven and drill-indicated reserves can be expected to yield 30.5 million tonnes of raw coal, or at least 20 million tons of clean coal, enough to supply a million ton operation for twenty years.



122°55'
53°50'
To Prince George
75 km.
C.L. 162
C.L. 118
C.L. 163
1977 Drill Area.
Licences applied for
BOWRON RIVER
Proven Reserves
5,940,000 Tonnes
Drill Indicated Reserve Area
55,000,000 Tonnes
Unexplored Bowron River Sediments
Potential Reserves
Mine entry
NORCO RESOURCES LTD.
BOWRON RIVER COAL DEPOSIT
Cariboo Mining Division
British Columbia
Scale 1 in = 1 mi
Approved by J.R.K.
Fig. No.

4. Coal Quality and Resin Potential

Coal from the Norco property has been described as a good quality thermal coal, ranking as High Volatile B Bituminous. The 11-ton sample of coal sent to Edmonton in 1976 received the most thorough test to date. After washing to an ash content of 9.8%, the coal produced 6,870 calories per gram, or 12,370 BTU per pound, and contained 0.9% Sulphur. The attached sheet entitled "Coal Analysis" records the results of these tests.

Coal samples from drill-core were tested by Commercial Laboratories in 1977. The results were consistent with the EMR tests, and demonstrate a high degree of consistency across the area explored. The attached chart "Relationship of Calorific Value to Ash Content" illustrates the results of these tests.

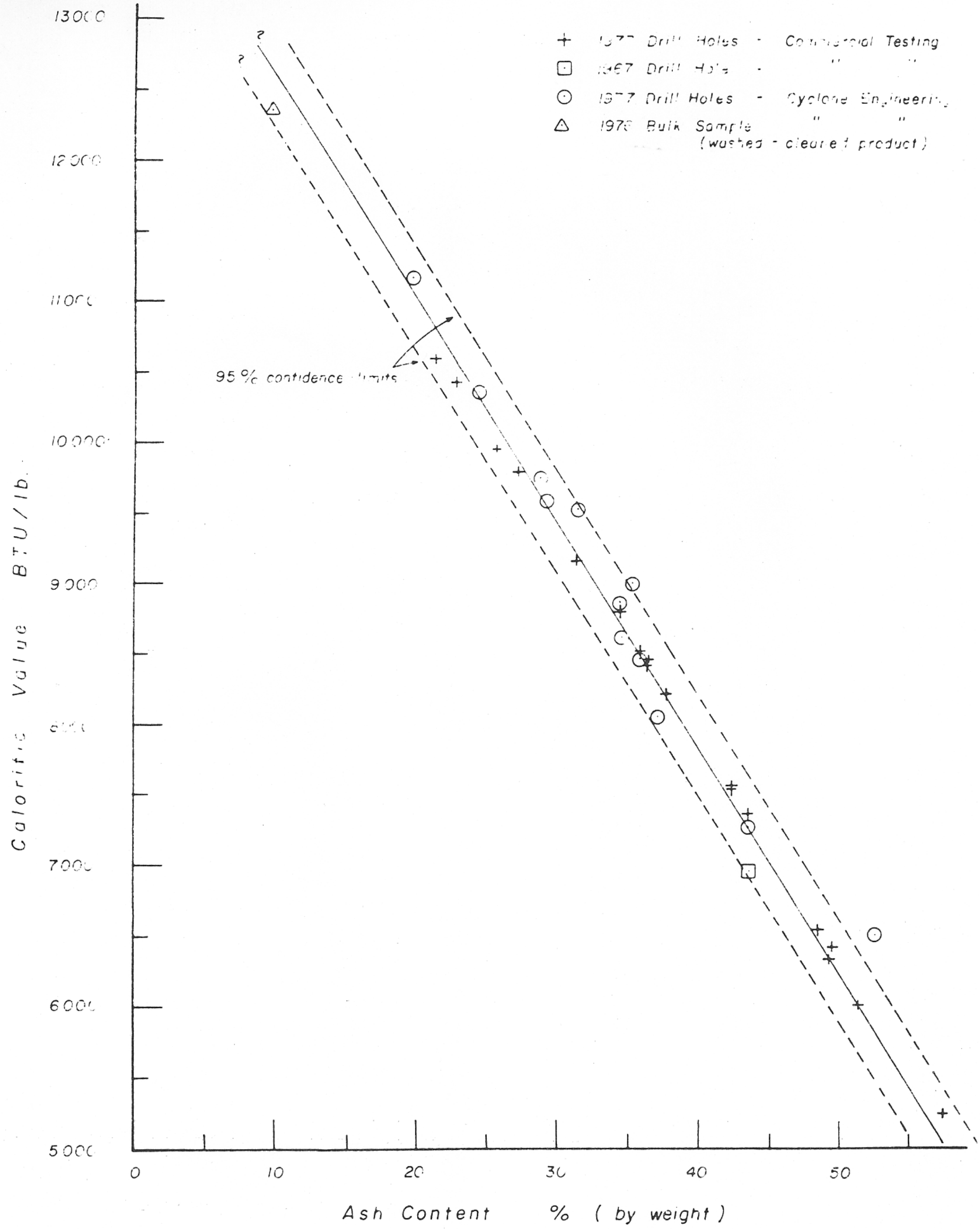
The sulphur contained in this coal is present in sulphide form, as pyrite and marcasite. These heavy minerals may be removed readily in washing coal, but this possibility must be confirmed by further laboratory work.

The Norco coal deposit is unusual in containing a high-grade amber resin. This material is described more fully in Norco's "Memo Describing Amber Resin Found in Norco Coal Deposit".

COAL ANALYSIS

(As Reported by Cyclone Engineering Sales Ltd.)

	Feed Sample	Washed Sample (Prepared by E.M.R.)	
Proximate Analysis			
Ash %	36.1	9.8	
Retained Moisture %	2.2	2.5	
Volatile Material %	31.0	34.9	
Fixed Carbon %	30.7	52.7	
Ultimate Analysis			
Ash %	36.1	9.8	
Carbon %	48.6	67.9	
Hydrogen %	3.8	4.9	
Nitrogen %	0.9	1.2	
Sulphur %	1.0	0.9	
Oxygen (by difference)	9.7	15.4	
Ash Fusibility		Red. Atm.	Ox. Atm.
Initial Deformation Temp. °C	1270	1170	1240
Softening Temp. (spherical)	1360	1240	1280
Softening Temp. (hemispherical)	1390	1280	1320
Fluid Temp.	1480	1430	1480
Calorific Value cal/g	4620	6870	
Free Swelling Index	N/A	1/2	
Hardgrove Grindability Index	58.0	N/A	



BOWRON RIVER COAL DEPOSIT

RELATIONSHIP OF CALORIFIC VALUE TO ASH CONTENT

5. Environmental Considerations

5 (a) The Setting

The Norco property is located in the broad, flat-bottomed valley of the Bowron River, bordered by low benches rising gradually to hills about 500 m above the valley floor. The feature of the environmental setting is the Bowron River, an attractive stream that is important for recreational and fishing values. The project must be planned, built, and operated to maintain its present desirable features.

The climate of the area reflects the northern interior setting. Summer temperatures range form an average monthly minimum of 8° C to an average monthly maximum of 22° C. Winter temperatures fall to minus 18° C as an average monthly minimum. The average annual precipitation is 925 mm, much of it falling as snow in the winter months.

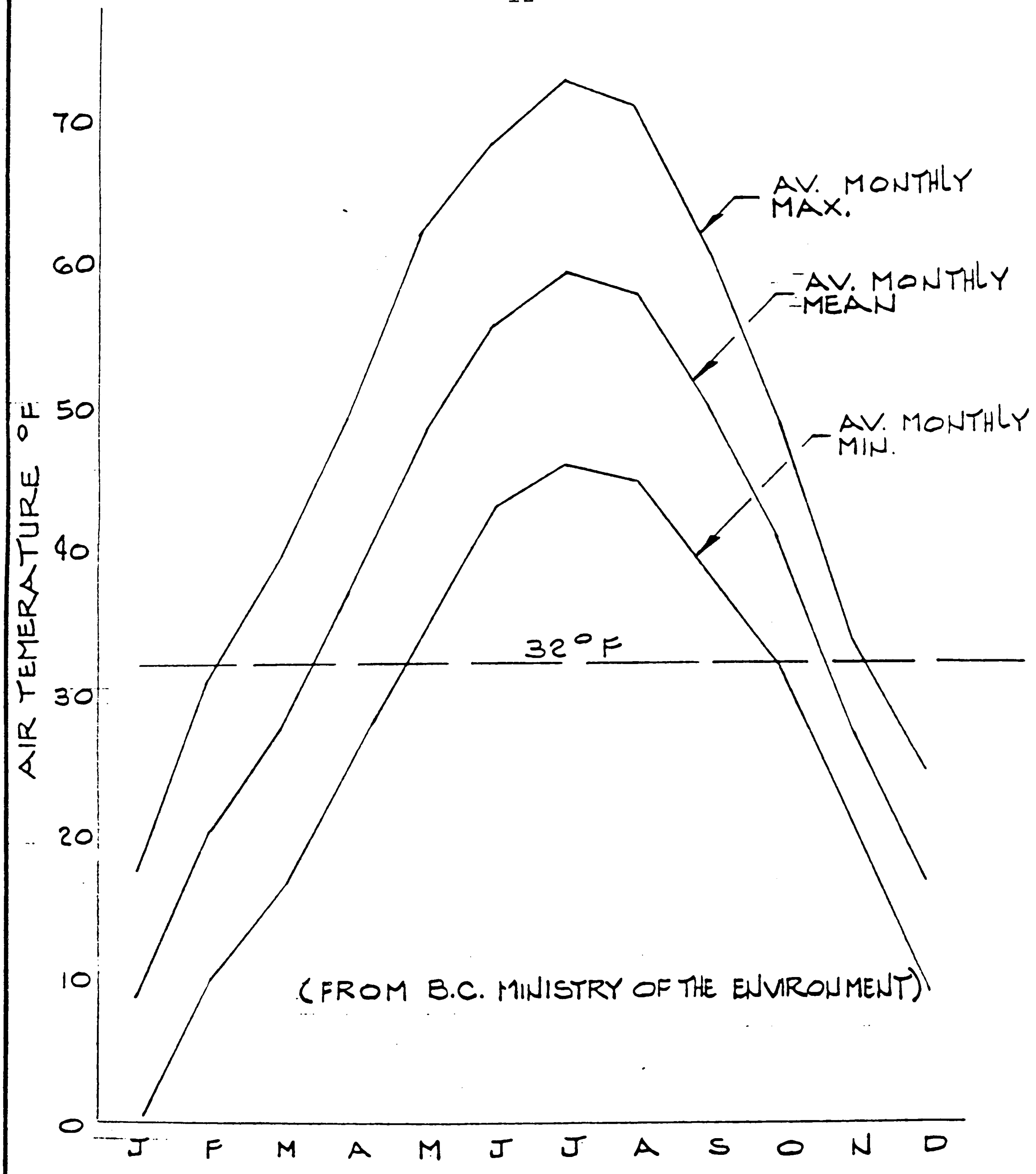
The use of the land is primarily forestry, and the land around the mine has been either logged or burned off.

5 (b) The Development

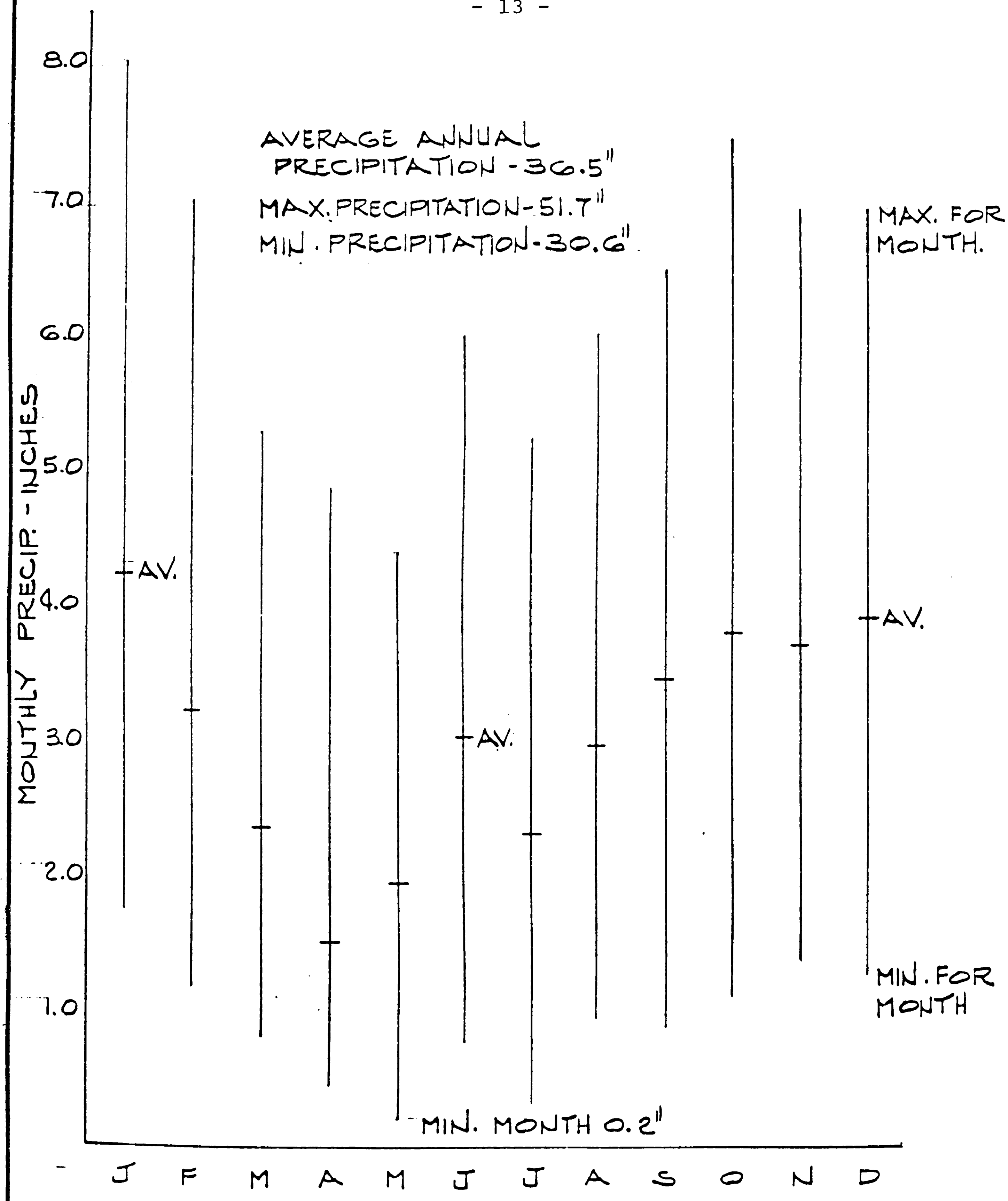
The surface evidence of the proposed development will be two mine portals leading to the underground workings, a group of modern plant buildings for cleaning the coal and refining the associated resin, smaller service buildings, and storage and waste piles and lagoons. The area occupied by the surface facilities will be about 60 hectares. A pump-house built on the bank of the Bowron River will be the only impact on the river itself. Access to the property for personnel and product haulage will be constructed to the highway and railway, generally along established transportation corridors. The mine staff will live in nearby communities or along the highway.

5 (c) Mitigation and Reclamation

Waste piles and lagoons will be designed and built to minimize the possibility of polluting the Bowron River, as required by provincial agencies. After the operation is complete, all such facilities will be restored to a condition that is consistent with the surrounding area. Buildings will be removed, paved areas broken up, and in general the area will be restored to further use.



AIR TEMPERATURE
ALEZA LAKE STATION № 109009
FOR YEARS 1952 - 74



MONTHLY PRECIPITATION RECORDS
ALEZA LAKE
FOR YEARS 1952-74

6. Proposed Development Plan

6 (a) Schedule

In brief, the schedule of development is as follows:

STAGE I - PREPRODUCTION

(A) 1979 - 1980: Exploration

Diamond Drilling

Preliminary Underground

Metallurgical Study

(B) 1980 - 1982: Development

Dual Entries, Haulage Tunnel, Seam Drifting

Trial Mining, Short Wall, Room and Pillar, Hydraulic

STAGE II - CONSTRUCTION

1981 - 1983: Mine

Surface Plant, Coal Cleaning and Shipping

Environmental and Reclamation Requirements

STAGE III - OPERATION - 1984

(Full-scale operation in 1985)

6 (b) Summary of Activities Associated with Feasibility Study, 1979-80

In preparing for the proposed on-site activity, a new and larger camp must be assembled, with adequate facilities for drilling crews, underground workers, and technical staff. At the same time, existing photography and ground control will be used to prepare detailed topographic maps of the area.

The existing pattern of drilling will be extended, but on wider spacing, to prove up coal reserves in the central coal licences (Coal Licences 147, 162 and 163). The drilling contract will be for 3,000 m of NQ wireline. A parallel contract will provide for electrologging of all holes, including those of the 1977 drilling programme that remain open. The geological staff will use the information from this programme to develop accurate estimates of coal reserves.

The existing decline will be extended to explore all three coal seams. During this operation the coal will be sampled extensively, and the coal measures will be studied to determine the best techniques to employ in mining, and the cost of development and mining will be calculated by coal-mining specialists.

With bulk samples of coal available, the coal processing facility will be designed by a competent firm of coal specialists. The design will provide the cost of the plant and the cost of operation required to produce the quality of coal to export. Included in the design will be the separation of amber resin from the coal, although further processing of of the resin would be conducted separately.

The feasibility study will also discuss transportation of coal to shipping ports, training and accommodation of mine staff, the environmental aspects of the development, and similar considerations. The study will be conducted with the collaboration of regulatory agencies, and with the cooperation of local authorities and people.

The final activity in this study will be the analysis of all data to establish the feasibility of the project.

In brief, Norco intends to proceed with all speed toward the development of a modern underground coal mine that will deliver one million tonnes of high-quality clean coal per year.

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MEMO DESCRIBING AMBER RESIN FOUND IN NORCO COAL DEPOSIT

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DIRECTOR, ENGINEERING SERVICES

AUGUST, 1979

MEMO DESCRIBING AMBER RESIN FOUND IN NORCO COAL DEPOSIT

1. Resin as Found in Coal

1 (a) A distinctive feature of the Norco deposit is the presence of two types of resin. They have been studied in the Battelle Memorial Institute in 1966 and 1967.

1 (b) The more common resin is finely disseminated, and is referred to in the Norco reports as "Refined Resin". It is a mixture of ester and carboxylic acid, and is readily soluble in conventional solvents. In application, this resin would compete with a synthetic in the paint and varnish industry, at a price of about $1.40 (U.S.) per pound (Rubber World, June, 1979). Although this material can be separated from the coal by solution, it is considered to be inferior to the associated Amber Resin, and the present operational plan calls for leaving this Refined Resin in the coal product, except for the minor amount that may be separated with Amber Resin.

1 (c) The Norco Amber Resin occurs as blebs in the coal and in shaly partings, as much as 15 mm in diameter, but generally flattened and elongated. Although this material has been studied in very small volumes, the Battelle reports give its composition as principally ester, with very little ash, and a softening point of about 450° C. The material as mined is substantially insoluble in the conventional solvents. The unique characteristics

of this material promise applications in the fields of plastics and protective coatings, and the present operational plan provides for the recovery of a substantial volume of Norco Amber from the coal product. The material would be cleaned at the mine-site for shipment to market.

Norco Amber Resin is a clear, light-amber-colored material that can be identified readily in the coal. The material is very friable, and tends to fracture into small particles as the coal is crushed. The percentage to be found in the coal has been determined by tracing the outline of blebs exposed on the exterior surface of drill-core, and from the outlined area calculating the volume and weight of resin. Kerr (1978) has reported an average percentage of 1.2% through the coal measures, and a greater percentage of 2.5% in the commercial coal seams. The percentage reported appears reasonable to other geologists that have examined the core.

The proposed rate of coal production is one million tonnes per year, and the projected production of Norco Amber Resin is 20,000,000 pounds per year.

At this time the Norco Amber can be assumed to be a consistent product, because it contains very little impurity and has been normalized by geologic action. Because the production of Amber Resin will be associated with the operation of a viable coal mine, this should be considered a reliable, long-term source of a high-quality resin product.

2. Potential Applications of Norco Amber Resin

2 (a) Plastics

As a material that is principally ester and has been subjected to extreme pressure and temperature through 55 to 58 million years, the Norco Amber Resin may find a specialized application in the plastics industry. Recent work reported in Materials Engineering (5 - 77) has been directed toward structural and protective materials stable under temperatures of 500° F to 700° F (260° C to 370° C), with the possibility of short-term exposures of 800° F (430° C). The Norco Amber Resin has demonstrated stability at a temperature over 430° C.

2 (b) Technical Coatings

2(b)i - Probably Norco Amber will prove to be more expensive than materials commonly used in decorative or common varnishes. The natural and synthetic resins have been developed to cover this field effectively and economically. It should be noted, however, that Battelle reports that Refined Resin, an inferior product in their opinion, could be used to produce a varnish equal or superior to coatings made with Congo resin, although considerably darker in colour.

2(b)ii - Norco Amber Resin can probably be used in a coating resistant to chemical action. The initial tests by Battelle indicate that the material as mined is, "for all practical purposes, completely insoluble in chloroform, benzene, or pyridine." Much work must be completed before this application can be presented to the industry, but the potential in terms of dollar volume is very great.

2(b)iii - As a high-temperature coating, Norco Amber Resin offers great potential. As reported by Battelle, "a differential thermal analysis in nitrogen, indicates that Amber Resin does not melt until approximately 450° C, at which temperature it is volatilized (probably with decomposition)." A protective coating incorporating Norco Amber Resin as the principal ingredient would find many uses, as indicated by the description of new high-temperature-resistant plastics in Materials Engineering (5 - 77) (See attached).

2(b)iv - A third potential application for Norco Amber Resin will depend on dielectric properties. Although not documented by the Battelle tests, these properties can reasonably be inferred from comparison with Baltic Amber, a material that is markedly resistant to the flow of electricity. Probably the best applications will be found where thermal stability is required with insulating qualities.

3. Comparison of Norco Amber with Other Natural Resins

3 (a) Most of the natural resins are complex assemblies of complex chemical products, and their properties vary widely, making classification difficult. The following ranking is therefore approximate and for descriptive purposes only.

Resin	Age	Origin	Melting Range	Acid Value *
Norco Resin	55-58 m yrs.	B. C.	450°C	
Baltic Amber	60-70 m yrs.	Baltic	280°C - 290°C	
Congo Copal	Fossil	Congo	100°C - 150°C	120-140
Kauri Copal	Fossil	New Zealand	100°C - 115°C	50-115
Dammar	Recent	Malaysia	70°C - 115°C	20-35

* The acid value is the expression for free acidity, and is determined by titration. The number expresses the milligrams of Potassium Hydroxide required to neutralize one gram of the test material.

3 (b) Norco Amber Resin, the material that we find in the Norco coal deposit, is the fossilized residue of coniferous trees that grew in Tertiary times in the Bowron Basin. Since deposition, this material has been subjected to great pressure and temperature over a period of 55 to 58 million years. We can assume that in this time the oleoresins found in recent resins have been driven off or modified, leaving a hard material that is stable at high temperatures.

Norco Amber Resin is principally ester, a clear, light-amber-coloured material that breaks with sharp edges and conchoidal fractures. A single microanalysis has been reported by Cyclone Engineering Sales Ltd., as follows:

Carbon	81.3%
Hydrogen	10.0%
Ash	0.4%

The composition of Baltic Amber is reported to be $C_{10}H_{16}O$, which would correspond very closely with these figures.

Norco Amber Resin is, for all practical purposes, completely insoluble in chloroform, benzene, or pyridine. It does not soften at temperatures as high as 400°C (750°F). A differential thermal analysis in nitrogen indicates that Amber Resin does not melt until about 450°C (840°F), at which temperature it is volatilized (probably with decomposition).

The resin is lighter than coal (approximately 1.1 specific gravity, compared with 1.35 to 1.40) and can be separated on this basis alone, after the coal is crushed. The resin, being friable, breaks up to a smaller size during the crushing. The separation can probably be assisted by froth flotation, using multiple cells in series if necessary.

3 (c) Baltic Amber has been known through history for its decorative and therapeutic values. It is the residue of an extinct conifer, Pinus Succinifera, of 60 to 70 million years age (Tertiary/Eocene).

The resin contains some bituminous substance, which remains in the residue after heating, and becomes an important part of amber varnish, a very hard material that was highly prized in early history. The resin is generally described by the formula $C_{10}H_{16}O$.

Baltic Amber, when finely divided, dissolves in cold Sulphuric Acid, also in hot Nitric Acid, and partially in alcohol, ether, chloroform, and turpentine. It melts at 280°C to 290°C with the release of white fumes. The hardness is 2.5, the specific gravity 1.05 to 1.10, and the refractive index 1.53 to 1.55.

Baltic Amber is now used primarily for the manufacture of jewelry. The volume available is small, the material is expensive, and the varnish made with Baltic Amber is quite dark in colour.

3 (d) Congo Copal is a broad descriptive term applied to fossil resin found in the area formerly known as the Belgian Congo. The material is located in the ground at depths as great as three feet by prodding with a steel-tipped shaft, or by recovery from stream-beds after washing from the banks. It is the hardest of the natural resins in commercial supply, and is known as the universal (natural) resin of the varnish maker.

The physical and chemical properties of Congo resin vary widely. The colour ranges from water-white to brown, and the acid values from 42 to 150. This, coupled with the requirement of cleaning the surface of lumps of resin found in the field, limits the large-scale use of this material in modern plants. Traditionally the running of Congo Copal is done in small batches by skilled craftsmen. The varnish produced in this way is, however, considered by many to be superior to varnish made with synthetic resins, and as recently as 1969 the market was stable at about 10,000 tons per annum.

3 (e) Kauri Copal is the fossil residue of an extinct conifer found in the ground in New Zealand. This resin has the lowest acid value of the fossil copals (50 to 115) and is readily soluble in alcohols, ketones, and some lacquer solvents. After the process of running, or heating, the resin could be used with the conventional vehicles to produce varnish, which was slow-drying but presented a very high gloss.

Kauri Copal is one of the natural resins no longer available in bulk quantities, and is not listed in market reports (American Paint Journal, 1979).

3 (f) Dammar is a recent exudation of a family of trees in the Malay Peninsula. It is readily soluble in turpentine and in coal-tar hydrocarbons, and consequently is widely used in the manufacture of so-called spirit varnishes. In this application the melting point (70^{o} - 115^{0} C) is not significant. The acid value is 20 to 35.

4. Market Potential

The plastics and varnish markets are both expanding rapidly as new materials and uses are identified. Norco Amber Resin can probably fill an important role in the market that exists at this time, but probably will take a more important part in materials and coatings that are not yet developed. The description of the present market is, then, no more than a starting point for the evaluation of this important material's market potential.

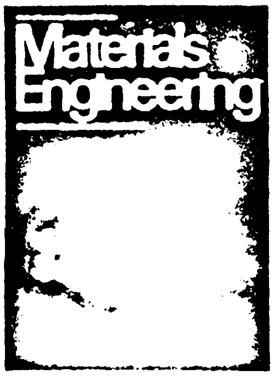
The records show the total shipment of copals from Africa in 1969 was at least 11,000 tons. Later records of imports to the United States (1970-72) indicate that the total shipments of natural resins would be at least 30,000 tons. The material was used primarily in the paint and varnish industry which has converted largely to synthetic resins because of assured supply, uniform specifications, and characteristics developed to meet specific needs. Norco Amber Resin, which claims the same advantages, can probably take a part of this market that requires its particular properties.

In its study of refined resin, a material that they consider inferior to the Amber Resin, the Battelle Memorial Institute compared varnishes made with refined resin and those made with high-grade Congo Copal, and found the refined resin to be superior, although considerably darker. The price for the synthetic equivalent of Congo Copal is now (June, 1979) reported in Rubber World to be from $1.38 (U.S.) to $1.41 (U.S.). A price of $1.60 (Can.) for refined resin is, then, conservative. The Norco Amber Resin, on the basis of the Battelle evaluation, should be more valuable.

Norco has learned of a British coal mine that is extracting and selling a resin as a by-product. We know only that the material is selling for about $8 per kilogram, or about $4 per pound, and from this information assume the material is a high-grade resin similar to Norco Amber Resin. We have written to London, asking for more information about this material and its marketing.

Probably the most significant information relating to potential markets is contained in Materials Engineering (Special Report, 5 - 77), describing a search for new heat-resistant plastics. A polyimide, developed for a specification of 500° to 550° F (260° to 290° C), has been reported at Langley by NASA. The material is relatively inexpensive, with raw materials costs anticipated to be $3.00 to $3.50 per pound. The material with the highest rating, up to 700° F (370° C) is a polyimide developed by Hughes Aircraft and available from Gulf Oil Chemicals. The material was available in 1977 at $75.00 per pound, and in full-scale production was expected to sell at $25.00 per pound. Norco Amber Resin, as mined, is reported to remain stable at 400° to 450° C, temperatures well above the specification temperature of this new, space-age plastic.

New heat resistant plastics cover 275-700 F range



A number of plastics introduced in the past three years feature improved heat resistance relative to former class grades while other recent grades of traditionally heat resistant families of plastics provide improvements in other important performance properties or processing characteristics.

by **John A. Vaccari**, Editor

Recent developments in plastics for improved heat resistance range from a new polyimide capable of sustaining temperatures of 700 F (644 K) to heat-stabilized polypropylenes for long-term use at 300 F (422 K). Some types, for example, the more heat resistant polypropylenes, are quite modestly priced, as low as $0.34/lb ($0.75/kg). Others, such as the new fluoroplastics, polysulfones and polyimides are far more expensive.

Polyimide takes 700 F+

The most heat resistant plastic introduced in the past three years is HR-600, an addition-curable thermosetting polyimide. Its outstanding properties stem largely from its ability to cross-link with little or no off-gassing. Developed by Hughes Aircraft in research sponsored by the U.S. Air Force, it is available from Gulf Oil Chemicals. Developmental quantities of HR-600 are currently priced at $75/lb ($165/kg) in 100-lb (220-kg) lots, but Gulf expects the price to drop to $25/lb ($55/kg) for commercial quantities in 1978.

Graphite fiber-reinforced HR-600 laminates show weight losses of less than 1% after 500 hr in air at 500 F (533 K) and only 4% after 50 hr at 700 F (644 K). The new polyimide even may be able to withstand short time exposures to temperatures as high as 800 F (700 K).

At ambient temperatures, graphite-reinforced laminates have flexural strengths of over 200,000 psi (1380 MPa), flexural moduli above 16,000 psi (110 MPa) and short beam shear strengths of 17,000 psi (117 MPa). Solid lubricative composites, which also can be made with the polyimide, have extremely high wear resistance.

A promising, low cost, addition-type polyimide is in development at NASA (Langley). Called LARC-160, it is a solvent-free liquid system with excellent tack and drape in prepreg form enabling the production of complex shapes. Being a liquid system, it also enables "true autoclavability," or low pressure (200 psi, 1.4 MPa) forming, at 600 F (589 K). LARC-160 can withstand long-term exposure at temperatures of 500-550 F (533-561 K) and short-term exposure (200 hr) at temperatures as high as 600 F (589 K). It is potentially a relatively inexpensive material with raw materials costs anticipated to be just $3-3.50/lb ($6.60-7.70/kg).

Other recently introduced polyimide grades or forms are Fiberite's PI-700 series compounds and Du Pont's Kapton XH-649 film. PI-700 grades are also of the addition type noted for thermal stability and strength retention at high temperatures. XH-649 film, which is intended for advanced microcircuits, features excellent dimensional stability at high temperatures. Shrinkage, for example, is less than 0.005 in./in. (0.005 mm/mm) after 1 hr at 392 F (473 K).

More versatile epoxies

Most of the recent improvements in epoxies, traditionally one of the more heat resistant families of plastics, stem from the use of hardeners, modifiers and fillers. The result is a variety of new grades which either extend high temperature limits or combine high temperature resistance with improvements in thermal shock resistance or processability.

New novolac epoxies, for example, are said to be capable of withstanding temperatures in excess of 700 F (644 K). Partially responsible for such high operating temperatures is the use of dianhydride hardeners which are capable of increasing operating temperatures by about 90 F (50 K) over traditional anhydrides. The new novolacs also have excellent chemical resistance and low shrinkage and warpage characteristics.

Faster mold cycles and cure time are other recent developments in high temperature novolac epoxies. Dow Chemical's XD-7855 resin reduces mold cycle time to about one minute at 300 F (422 K). The resin's high glass transition temperature helps prevent lead shear in semiconductor applications, a problem when encapsulants expand too quickly and impose excessive stress on microleads.

Modified novolacs, such as Celanese's SU-8, combine heat distortion temperatures as high as 525 F (547 K) with rapid press cure. Used alone or with other resins, they are finding use for both electrical components and graphite-reinforced laminates.

Heat resistance, high strength and moisture resistance are combined in Ciba-Geigy's MY-720, a liquid diamine epoxy. Also used for graphite-reinforced aerospace structures, it features ambient flexural strengths of 67,000-75,000 psi (462-517 MPa) and can retain much of this strength at temperatures up to 400 F (478 K).

A more recent family of epoxies available from Ciba-Geigy are the hydantoin resins which provide outstanding adhesion, good dielectric characteristics and resistance to discoloration at high temperatures. The resins also have excellent light transmittance after thermal aging, and important property for their use as encapsulants of light emitting diodes. The resins can endure several thousand hours at temperatures in excess of 300 F (422 K) with minimal discoloration. They also can maintain considerable strength and rigidity at temperatures of 400 F (478 K).

"New novolac epoxies . . . are said to be capable of withstanding temperatures in excess of 700 F."

Work by Union Carbide indicates that the use of polyol modifiers in cycloaliphatic epoxies provides a better balance between heat distortion temperature and thermal shock resistance. Heat distortion temperatures for the modified epoxies are in the range of 295-309 F (419-427 K). As shown in Table 1, mechanical and electrical properties tend to decrease, as thermal shock resistance increases, with increasing modifier content. About 22% modifier additions seem to provide an optimum property balance.

Research by Cordova Chemical recently led to the development of a catalyst which eases the processing of epoxy-imide resins, giving these resins a possible processing advantage over polyimides. The resins provide heat distortion temperatures of about 430 F (493 K) and retain about 60% of their room temperature strength at 500-550 F (533-561 K). Potential uses include cloth impregnation of glass-reinforced laminates.

A new, highly filled epoxy casting resin, Emerson & Cuming's Stycast 2762 FT, combines high thermal conductivity with excellent dielectric characteristics. Low shrinkage and low exotherm during cure make it suitable for encapsulating or casting large sections. Suitable for service temperatures of −300 to 500 F (89-533 K), it can be used for various electronic and temperature control applications.

Triazine rivals epoxies

Triazine A, a thermosetting polymer introduced last year by Mobay Chemical, offers several advantages over conventional epoxies in printed circuit board applications, specifically higher service temperature, lower coefficient of thermal expansion, better dimensional stability and greater clad-laminate peel strength at temperatures of molten solder.

The new material has a glass transition temperature of 482 F (523 K). Flexural strength ranges from 89,000 psi (614 MPa) at ambient temperatures to 25,000 psi (172 MPa) at 482 F (523 K). In addition, it couples excellent room temperature dielectric properties with low dependence on temperature and frequency. Permittivity decreases slightly with increasing frequency, that is, from 4.4 at 50 c/s (Hz) to 4.1 at Gc/s (GHz). Room temperature dissipation factor is 0.003-0.007 in the same range.

Polyesters for 500-600 F

An injection moldable aromatic copolyester provides excellent dielectric and mechanical properties at temperatures above 500 F (533 K) and low moisture absorption. Developed by Carborundum and called Ekkcel 1-2000, it is suitable for long-term use at temperatures up to 550 F (561 K). Its moisture absorption after 24 hr in boiling water is less than 0.025%.

Introduced about three years ago, the material can be processed on standard injection molding equipment. Applications include high performance electrical and electronic components, bearings for fractional horsepower motors, radiation resistant valve parts and other products requiring high temperature strength.

Another recent polyester base material developed by Carborundum is a polyester (Ekonel) polytetrafluoroethylene (PTFE) fluoroplastic blend which provides long-term resistance to temperatures as high as 600 F (589 K). The composite also has low thermal expansion, dissipation and moisture absorbtion, and high dielectric strength and thermal conductivity. Uses include packing and compression ring sets, O-rings, spring-loaded and lip seals, self-lubricated bearings and pump seals and vanes.

New 'phenolics' for near 500 F

Another recent family of heat resistant thermosets is Ciby-Geigy's Xylok resins. Based on the condensation products of phenols and aralkyl ethers, their properties are said to be similar to phenolics with heat resistance to 480 F (522 K).

The resins are also noted for good mechanical strength, thermal stability and dielectric characteristics. Applications include electrical insulation parts, brake pads, motor components, bearings and handles for cooking utensils.

New fluoroplastic takes 550 F

The most recent fluoroplastic to become commercially available is Allied Chemical's CM-1, a hexafluoroisobutylene and vinylidene fluoride (HFIB-VF_2) thermoplastic having a maximum continuous service temperature of 550 F (561 K) and high creep resistance. It also possesses excellent chemical resistance, dielectric characteristics and release properties.

The new fluoroplastic is melt-processable and thus suitable for injection, compression and extrusion molding. Potential uses currently being explored include a variety of release coatings, chemical processing equipment components, fuel cell separators, bearings and other mechanical parts. It also can be used as a binder for various fiber-reinforced composites.

"The most recent fluoroplastic . . . HFIB-VF_2 . . . (has) a maximum continuous service temperature of 550F and high creep resistance."

Special fibers enhance fluoroplastics

Recent performance improvements in fluoroplastics also stem from the use of special reinforcing fibers rather than from the introduction of new base resins.

Use of long glass fibers and a special coupling agent, for example, enhances the mechanical properties of a new line of fluorinated ethylene propylene (FEP) fluoroplastics, Thermocomp LF, produced by LNP. In addition, the new grades provide improved flexural properties, dimensional stability and wear resistance while retaining the inherent electrical, thermal and chemical resistance of the base material. As a class, FEP plastics have a continuous service temperature of about 400 F (478 K).

At room temperature, the new compounds have 6000 psi (41 MPa) tensile strength, 10,500 psi (72 MPa) flexural strength and 800,000 psi (5520 MPa) flexural modulus which, as indicated in Table 2, are far superior to those of milled glass-filled FEP.

1 Properties of cycloaliphatic resins[a]

Property	Resin, 11.5% modifier[b]	Resin, 16.3% modifier[b]	Resin, 23.2% modifier[b]
Ten str, 1000 psi (MPa)	10.8 (74.5)	9.81 (67.6)	6.1 (42.1)
Ten mod, 10^5 psi (MPa)	14.6 (10,067)	11.3 (7791)	10.9 (7516)
Power factor, %[c]	9.9	78	>100
Vol res, ohm-cm (ohm-m)[d]	2×10^{16} (2×19^{14})	2×10^{16} (2×10^{14})	1×10^{15} (1×10^{13})
Heat distort temp, F (K)	297 (420)	295 (419)	309 (427)
Ther shock res[e]	6.9	7.5	12.3

[a]All resins contain the same amount of anhydride hardener, mesh silica and curing agents. [b]Solid polycaprolactone diol modifier (PCL-300). [c]At 60 cyc/sec (60 Hz) and 302 F (423 K). [d]At 73 F (296 K). [e]Average cycles to failure (Union Carbide test).

2 Properties of glass-reinforced FEP

Property	Reinforcement	
	Long glass[a]	Milled glass
Ten str, psi (MPa)	6000 (41)	2400 (17)
Flex str, psi (MPa)	10,500 (72)	4000 (28)
Flex mod, 10^3 psi (10^3 MPa)	800 (5.5)	250 (1.7)
Wear factor (K)	15	28

[a]Thermocomp LF

3 Properties of styrenic terpolymer

Property	Base	40% glass	FR[a] with 30% glass
Specific gravity	1.1	1.42	1.52
Mold shrinkage in./in. (mm/mm)	0.008 (0.008)	0.001 (0.001)	0.0015 (0.0015)
Water absorp, 24 hr, %	0.2	0.1	0.1
Ten str, 1000 psi (MPa)	6.9 (48)	18 (124)	15.5 (107)
Flex mod, 1000 psi (MPa)	300 (2069)	1200 (8274)	990 (6826)
Imp str[b], ft-lb/in. (J/m)	1.7 (91)	2.8 (149)	2.1 (112)
Heat defl temp[c], F (K)	275 (408)	305 (425)	300 (422)
Coef of ther exp, 10^{-5} in./in./F (10^{-5} m/m/K)	2.5 (4.5)	1.2 (2.2)	1.3 (2.3)
Flammability, UL 94	HB	HB	V-0

[a]Flame retardant. [b]Izod (notched), 0.25-in. (6.4-mm) bar. [c]At 264 psi (1.3 MPa).

4 Heat-stabilized polypropylene[a]

Specific gravity	0.905
Melt flow, g/10 min	4
Mold shrinkage, in./in. (m/m)	0.01-0.03 (0.01-0.03)
Water absorption, %, 24 hr	<0.01
Tensile strength, psi (MPa)	5000 (34.5)
Ultimate elongation, %	>100
Impact str[b], ft-lb/in. (J/m)	0.8 (42.7)
Flexural modulus, 10^5 psi (MPa)	2.0 (1379)
Tensile modulus, 10^5 psi (MPa)	2.5 (1724)
Hardness, Durometer D	78
Heat deflection temp, F (K)	
At 66 psi (0.46 MPa)	221 (378)
At 264 psi (1.8 MPa)	140 (333)
Melting point[c], F (K)	330 (439)
Vicat softening point, F (K)	302 (423)

[a]Diamond Shamrock PP8622. [b]Izod (notched). [c]Crystalline.

The better wear resistance of the new grades is indicated by their substantially lower wear factor (K). This combination of properties makes the materials especially suitable for high temperature bearings operating in corrosive media and for various electrical and electronic applications.

LNP also recently introduced a line of carbon fiber-reinforced fluoroplastics designated Thermocomp UC. Compared to glass-reinforced fluoroplastics, these compounds have lower coefficients of thermal expansion, which reduces shrinkage during molding, and good thermal conductivity. These property improvements are combined with the inherent thermal stability, chemical inertness and lubricity of the base material.

Another recent fluoroplastic is Du Pont's Tefzel 210. The ethylene tetrafluoroethylene (ETFE) fluoroplastic permits faster injection molding of intricate parts and faster extrusion of small-gage wire insulation. ETFE fluoroplastics are generally suitable for continuous use at temperatures as high as 300 F (422 K).

Tough polysulfone for 375 F+
A new polysulfone combines high heat resistance with exceptional toughness and resistance to environmental stress cracking. Designated Radel and produced by Union Carbide, the injection moldable and extrudable plastic is available in both opaque and transparent grades.

Radel has a heat deflection temperature of 400 F (477 K) and excellent oxidative and thermal stability for continuous use in air up to temperatures of at least 375 F (464 K). With a notched Izod impact strength of 15 ft-lb/in. (800 J/m), it is about three times tougher than polyarylsulfone and seven times tougher than polyethersulfone and conventional polysulfone. The new polysulfone is intended for applications in the aerospace, chemical processing and microelectronics industries.

About three years ago, LNP introduced new glass-reinforced and/or lubricated polyethersulfone compounds suitable for continuous use at temperatures up to about 360 F (455 K). Called Thermocomp JF, they also provide excellent dielectric characteristics, good mechanical properties and low shrinkage.

Special styrene a superior styrene
A line of new styrenic terpolymer compounds provides considerably greater heat resistance than conventional polystyrene. Developed by Dow Chemical and available from LNP in various color, glass-reinforced and flame retardant grades (see Table 3), the terpolymer has 264-psi (1.3-MPa) heat deflection temperatures ranging from 275 F (408 K) for the base material to 305 F (425 K) for the 40% glass-reinforced grade. In contrast, conventional polystyrene has a heat deflection temperature of about 220 F (378 K) for both general purpose and 30% glass-reinforced grades.

Introduced last year, the terpolymer is a candidate for pump housings and impellers, camera cases, business machine parts, electrical connectors and TV components. A 30% glass-reinforced grade with 15% TFE (tetrafluoroethylene) lubrication has potential for self-lubricated bearings and other parts requiring high wear resistance.

Heat stabilized polypropylenes
Improved stabilization systems have extended the maximum service temperature of polypropylene to as high as 300 F (422 K) in recent years. Hercules' talc-filled homopolymer (6XF4) and copolymer (7XF4) grades are good examples. The copolymer, which provides high impact strength but has a lower heat deflection temperature, withstands five months oven aging at 300 F (422 K). The homopolymer, with twice as much talc, can take about four months at these conditions.

Another new polypropylene with improved heat stabilization is Diamond Shamrock's appliance grade, PP8622 (see Table 4), which has an Underwriters Labs' relative thermal index of 239-248 F (388-393 K) in 0.03-0.06-in. (0.8-1.6-mm) thicknesses, respectively. Still another is Hercules' 6X-25 (240 F, 389 K) which has high resistance to elevated temperature aging in both dry and wet environments. Each of these grades is intended primarily for dishwasher liners.

A heat-stabilized, glass-reinforced grade recently introduced by LNP and designated MF-1006 HS has a thermal index rating of 221 F (378 K). At 140 F (333 K), it has a tensile strength of 4400 psi (30 MPa) and a tensile modulus of 460,000 psi (3170 MPa). □