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IRON ORE EXPLORATION AND EXPLOITATION ON A LARGE SCALE

by

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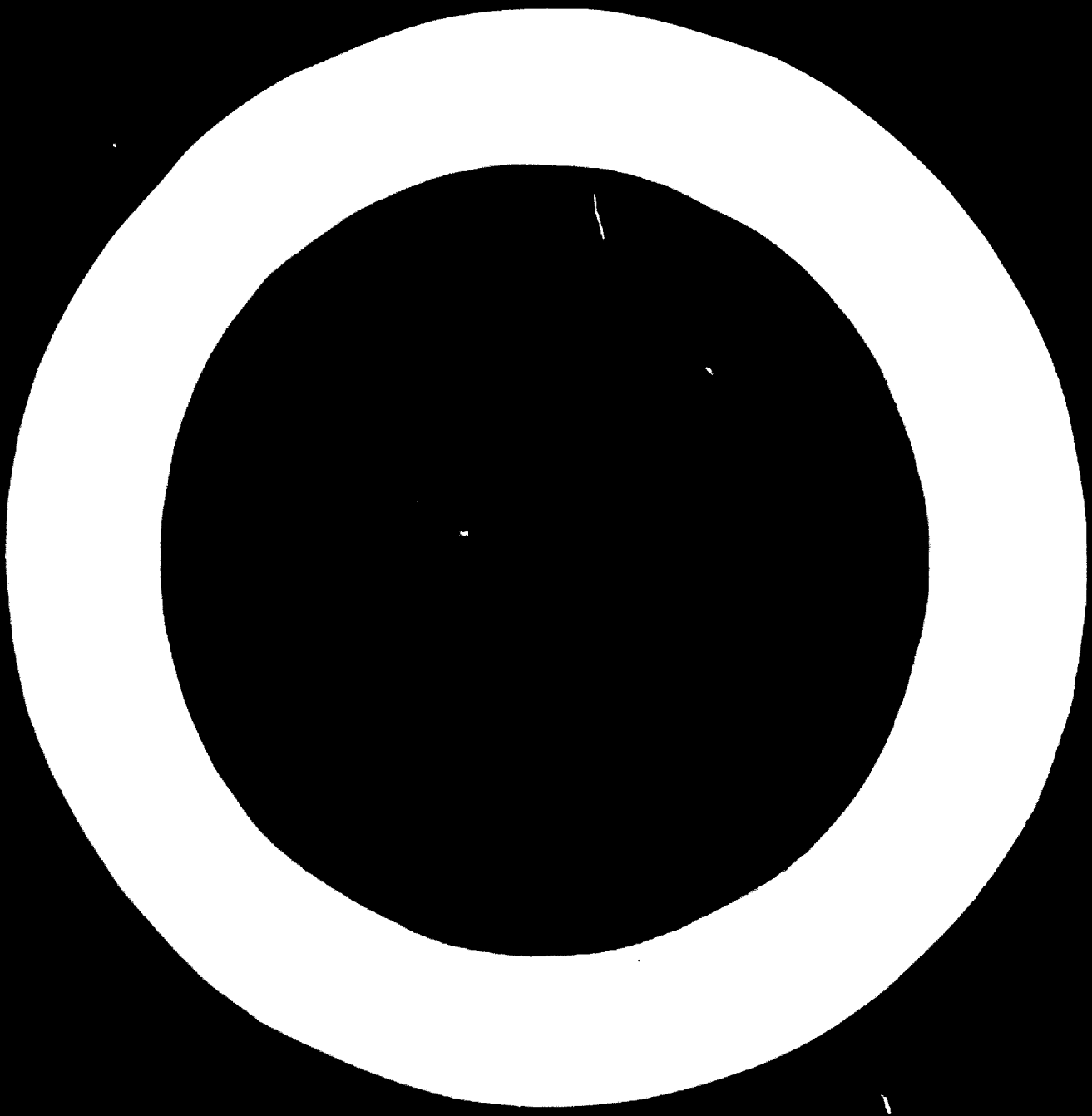


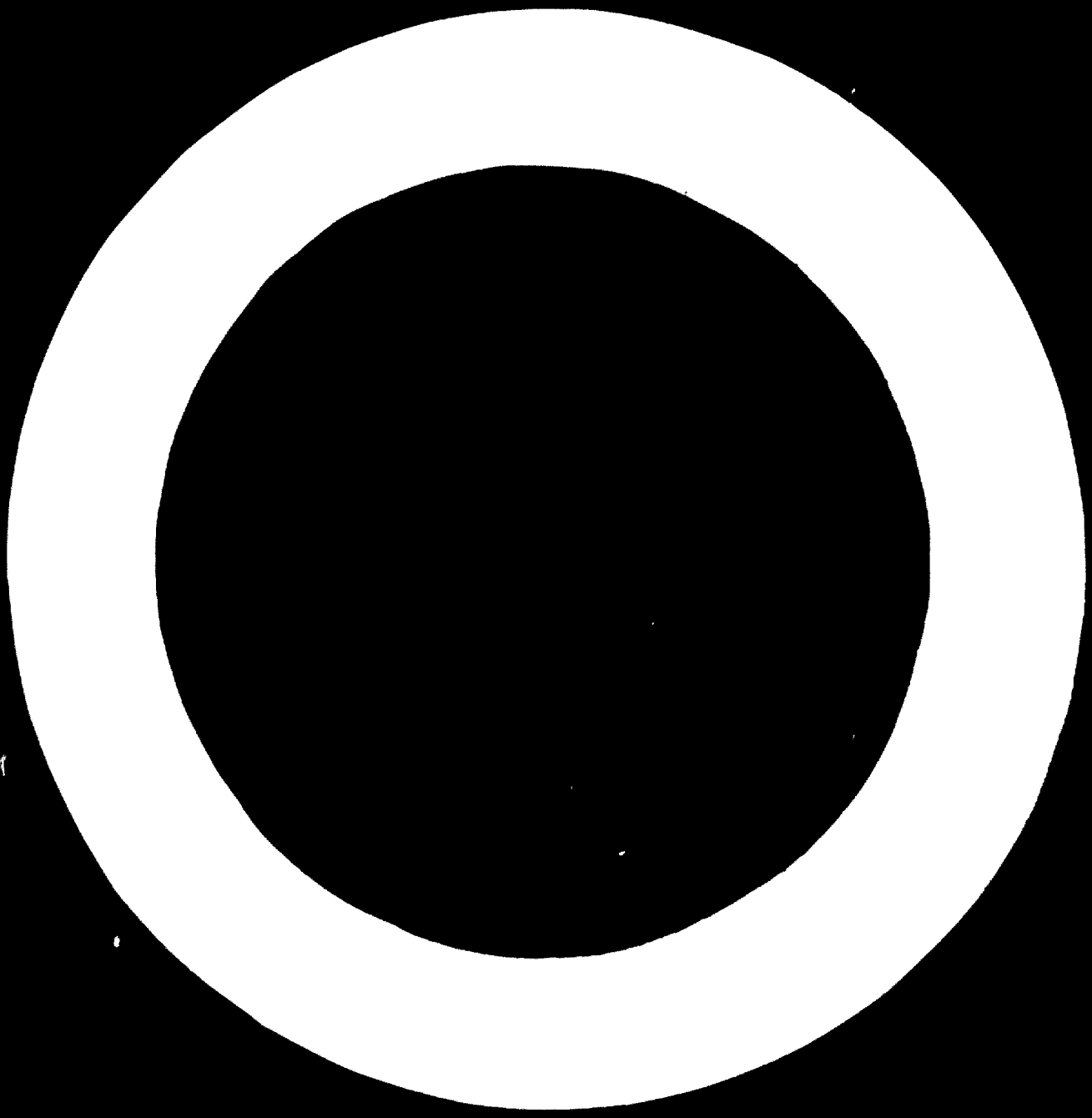
SUMMARY
OF A DISCUSSION PAPER ENTITLED

IRON ORE EXPLORATION AND EXPLOITATION ON A LARGE SCALE

PREPARED FOR
THE UNITED NATIONS IRON AND STEEL SYMPOSIUM

Most developing countries contemplate the rapid exploitation of their mineral resources. Such countries favoured with the presence of large iron ore deposits usually encounter difficulties in raising the necessary capital to develop them. When sufficient capital is found for iron ore exploration and exploitation, the entire economy of these countries receive tremendous benefits.

In Liberia, the Lamco Joint Venture has developed a large scale iron deposit in the Nimba mountain range. Exploration activities commenced using the most modern methods, including photogrammetric and geophysical surveys, diamond drilling and tunneling. Data assembled from these activities enabled engineers to determine the quality of ore and the quantity of ore reserves. After proving the venture an economically feasible undertaking, financing was secured and exploitation began. Parallel with the development of the mine came the survey and construction of the harbour, railroad and all other necessary installations needed for this development and preparation of the ore for export.



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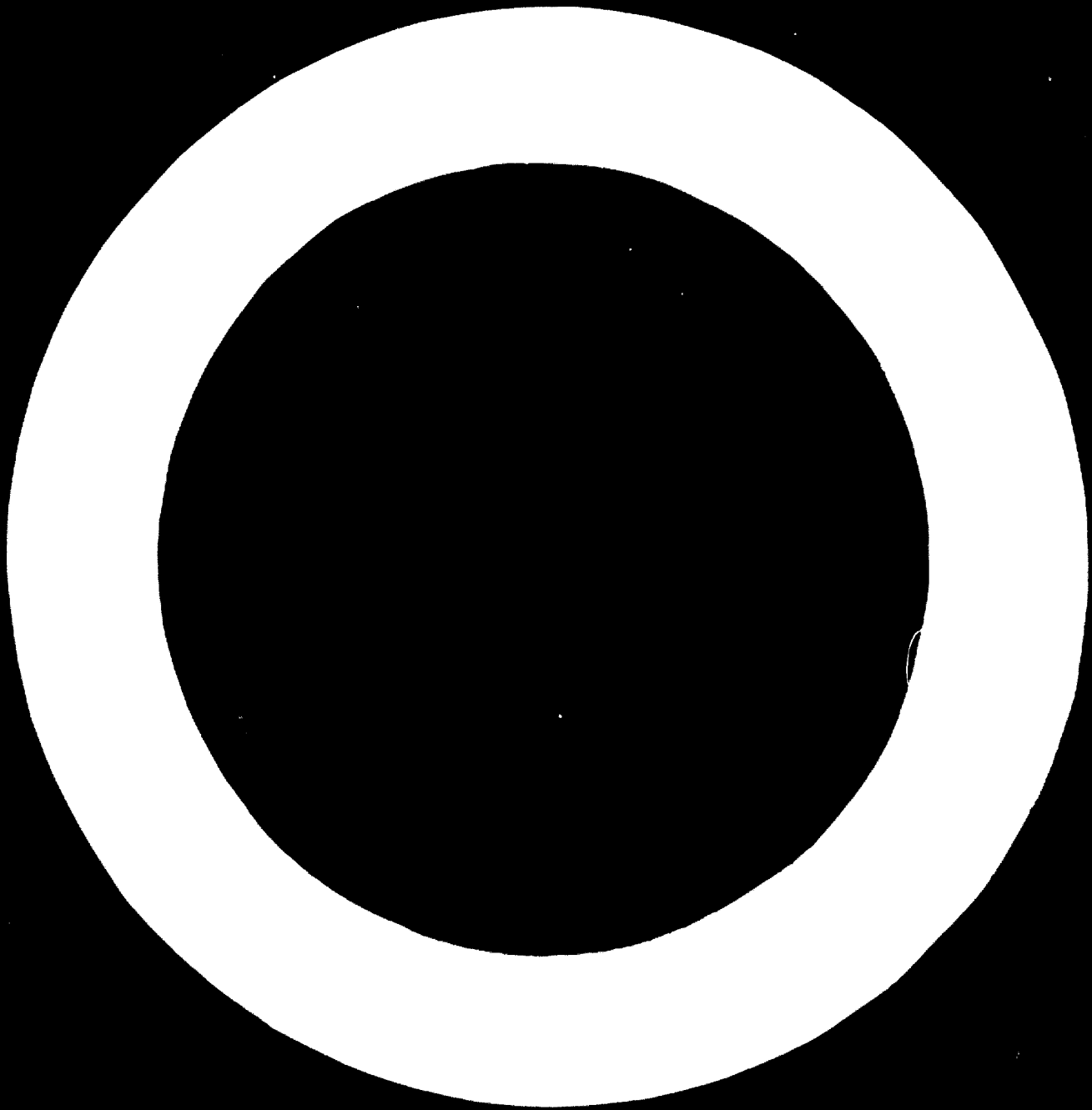


I INTRODUCTION

1. Since the founding of Liberia and until quite recently, except for local small-scale mining of surface exposures, Liberian iron ore deposits remained latent in the earth's lithosphere. Before the introduction of modern industrial methods there existed an old indigenous industry of iron manufacturing based on local small-scale mining of high grade canga and lateritic ironstone deposits. It was not until the establishment of the Bureau of Natural Resources and Surveys (formerly the Bureau of Mines and Geology) in 1948, that increased interest in the mineral resources of Liberia began.

2. The initial reconnaissance mapping and mineral exploration in the country were undertaken by the Bureau of Natural Resources and Surveys. In some cases, knowledge of the surficial deposits of high grade canga and lateritic ironstone mined by the indigenous people led to modern exploration of the underlying iron-bearing formations and to discovery of the areas of current interest. The Bureau of Natural Resources and Surveys was thus able to make available to mining companies preliminary geological information on individual areas of presumptive economic interest.

3. At present, three mining companies are engaged in the commercial exploitation of iron ore in Liberia on a large-scale basis; a fourth is scheduled to come in production in the spring of 1965. The first iron ore mined in the country was at Bomi Hills in 1951. Exploration by other mining companies has been carried out in different parts of the country and some of these companies are now in production. The Bomi Hills deposit is being mined by the Liberia Mining Company; its total proven and probable reserves are estimated at 50 million tons. The Bong Mining Company is

developing the Bong deposit, with estimated reserves of 300 million tons. The National Iron Ore Company is mining the Mano river deposit which has also come into production; it has estimated reserves of 48 million tons.

4. The largest known iron ore deposit in Liberia is located at Mount Nimba and the total proven and probably reserves are estimated to be 300 million tons of high grade iron ore. This deposit is being mined by The Liberian American-Swedish Minerals Company (LAMCO).

5. The corporate structure of LAMCO involves Liberian, Swedish and American participation in a joint venture to exploit the Nimba deposit. The Nimba mountain range is located in the northeastern part of Liberia on the border with Guinea and the Ivory Coast, approximately 267 kilometers (about 170 miles) inland from the Atlantic Ocean. The aggregate length of the Nimba mountain range is 45 kilometers (about 28 miles) of which 25 kilometers (about 16 miles) lie within Liberian territory.

6. The initial annual production of this mine will be 6,000,000 tons and by 1965 it is scheduled to produce 7,500,000 tons annually. An annual productive capacity of 10,000,000 tons or more is expected in later years.

7. The total cost of the expanded 7,500,000 ton capacity project is estimated at $217,500,000.

II GEOLOGY AND ORE DEPOSITS

8. Geologically, Liberia forms a part of the West African shield, which is a large Pre-Cambrian region. The lowland surrounding the Nimba range consists predominantly of granites and partly migmatic gneisses. The range itself is built up by a series of more or less isoclinally folded

and steeply tilted sediments, mainly itabirites, quartzites and phyllites.

9. Deposits of high grade iron ore have been developed within the itabirite formations of the Nimba range by the laterization process, which involves the enrichment of the iron oxides and the removal of silica by leaching. The high grade hematite ore which resulted has excellent characteristics for blast furnace and other uses. It is low in phosphorus, sulphur, alumina, silica and ignition loss. The iron formation runs more or less parallel to the range and extends steeply downward to the northwest. The ore is predominantly a platy, rather fine-grained hematite with minor quantities of magnetite and limonite; it varies from extremely soft and friable to hard, dense and massive material. A detailed description of the three principal types of iron ore in the Nimba deposits follows:

a. Blue Ore (deep orebodies)

This ore makes up the bulk of the main orebody and goes to a depth of more than 600 meters below the present summit. Generally laminated and fine-grained, this dark blue ore is predominantly hematite (martite) ore. It consists of three sub-types: (i) blue medium hard ore; (ii) blue soft ore mostly mixed with platy blue biscuit ore; and (iii) blue recemented hard ore.

b. Brown Ore (shallow orebodies)

This limonite-coated hematite (martite) ore, mostly brown to dull black in colour, is rarely met at greater depths than 75-100 meters below the surface. All orebodies hitherto known outside the main orebody, including marginal parts of the latter, consist of three sub-types: (i) brown soft ore, mostly mixed with brown biscuit ore; (ii) recemented biscuit ore, transitional to laminated crust ore occurring to depths of 10 to 40 meters; and

(iii) hard dense ore occurring in irregular lumps and fissure-fillings of steel grey.

c. Crust Ores

These ores are found to be less than 20 meters in depth and are of hematite cemented by limonite, frequently with large pores having all kinds of gel structures. There are three sub-types: (i) lateritic ironstone, both laminated and unlaminated varieties; (ii) canga-breccia to fanglomerate of ore and/or itabirite boulders and pebbles, cemented by hematite-limonite matrix; and (iii) float ore in loose boulders and pebbles of all types of ore as cover on slopes, in creek and river terraces, etc.

III EXPLORATION ACTIVITIES

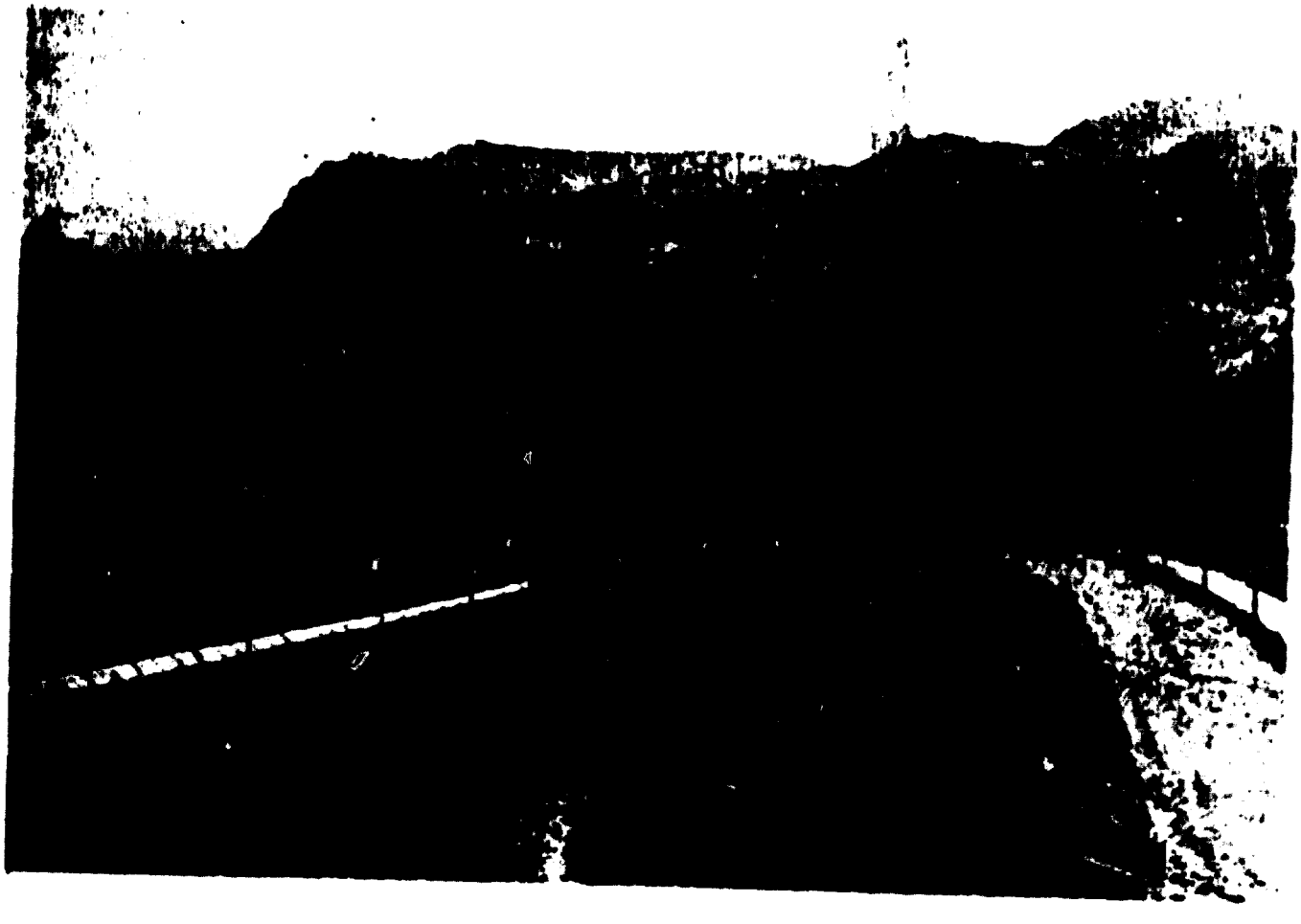
10. In exploring the Nimba, Bassa Hills and Putu areas, LAMCO has done geological mapping, photogrammetric surveying, diamond drilling, trenching, pitting, tunneling, and geophysical surveying. As a result of these activities, substantial proven and probably reserves of high grade iron ore have been established in the Nimba range, and smaller deposits of iron mineralization in the Bassa Hills.

11. The Bureau of Natural Resources & Surveys investigated the Nimba range in 1954. Information obtained was later made available to LAMCO which had in the meantime secured an option to exploit the deposit. The company began its exploration programme in 1956.

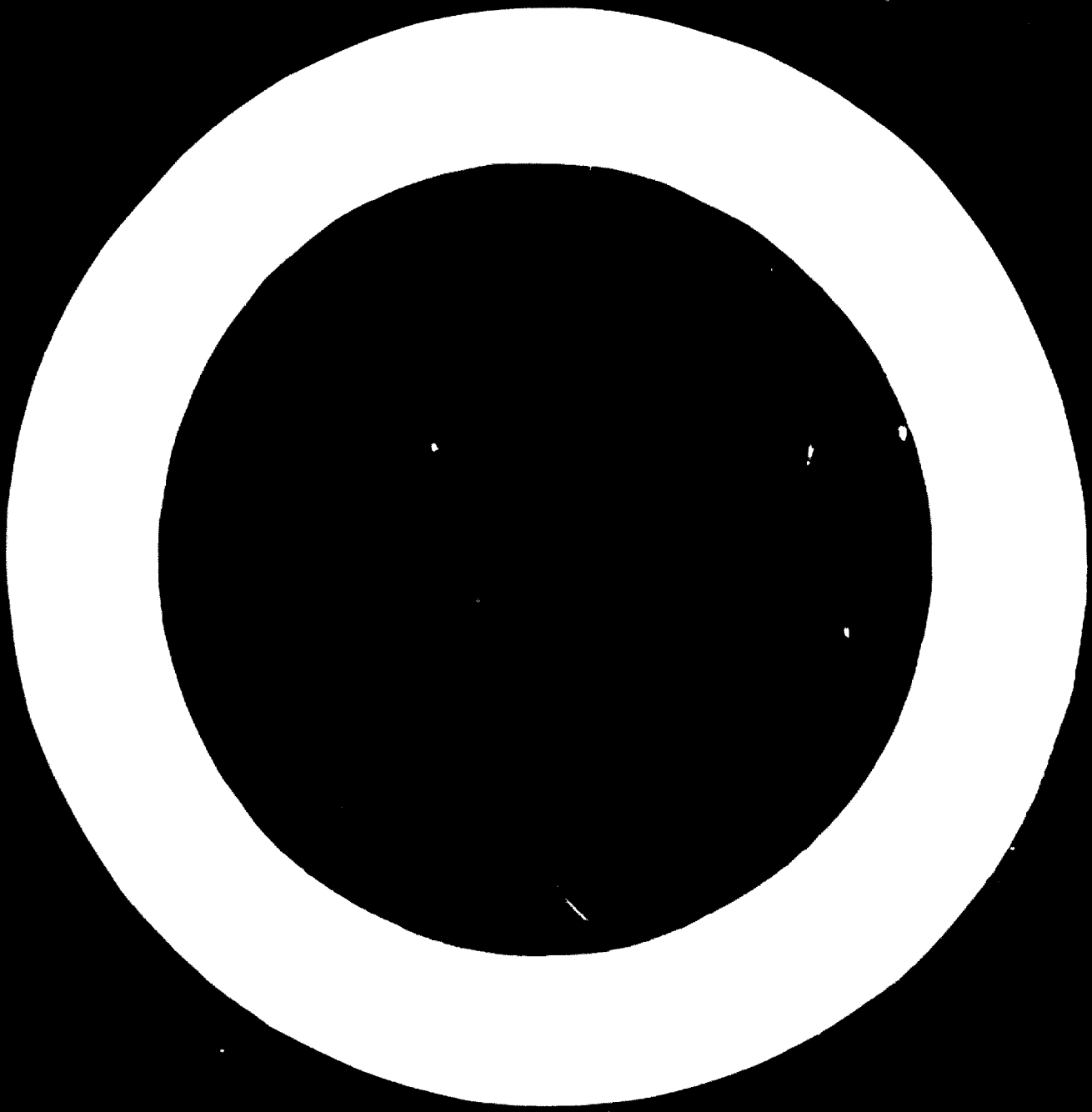
IV SURVEYING AND MAPPING

12. The topography of the Nimba range was surveyed by traverses along lines cut through the vegetation. During

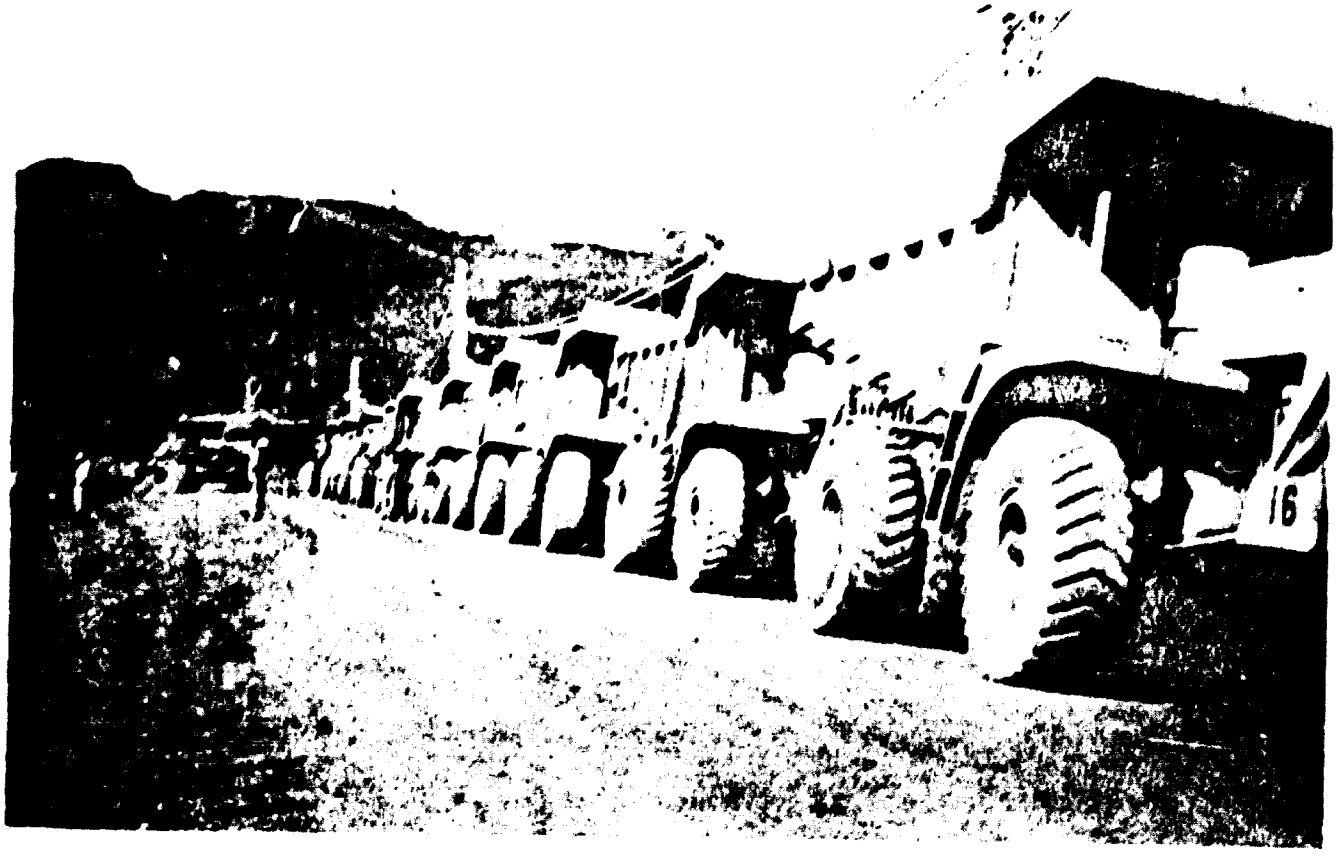
1. Nimba--Main Orebody



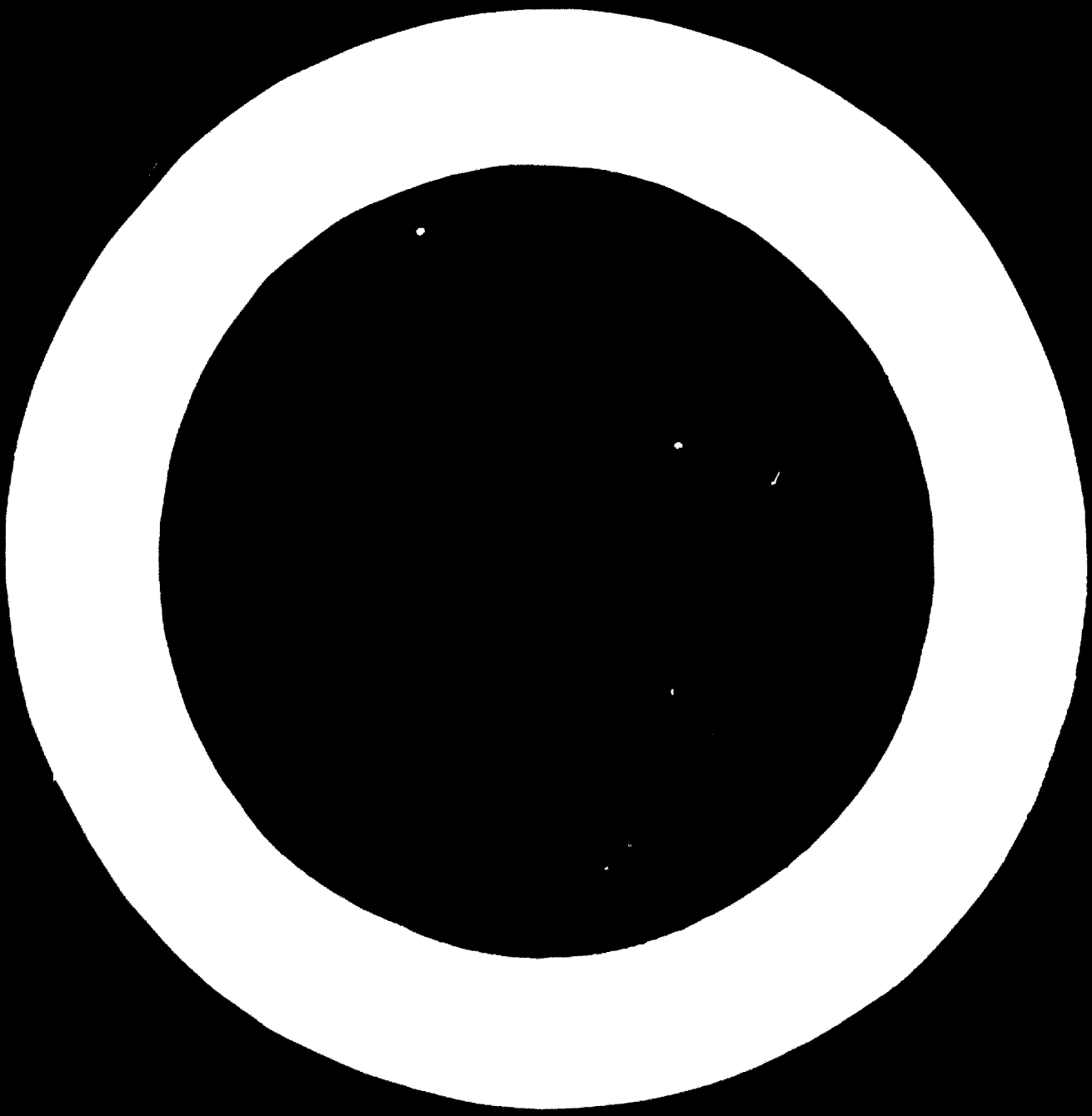
2. Nimba--Main Orebody

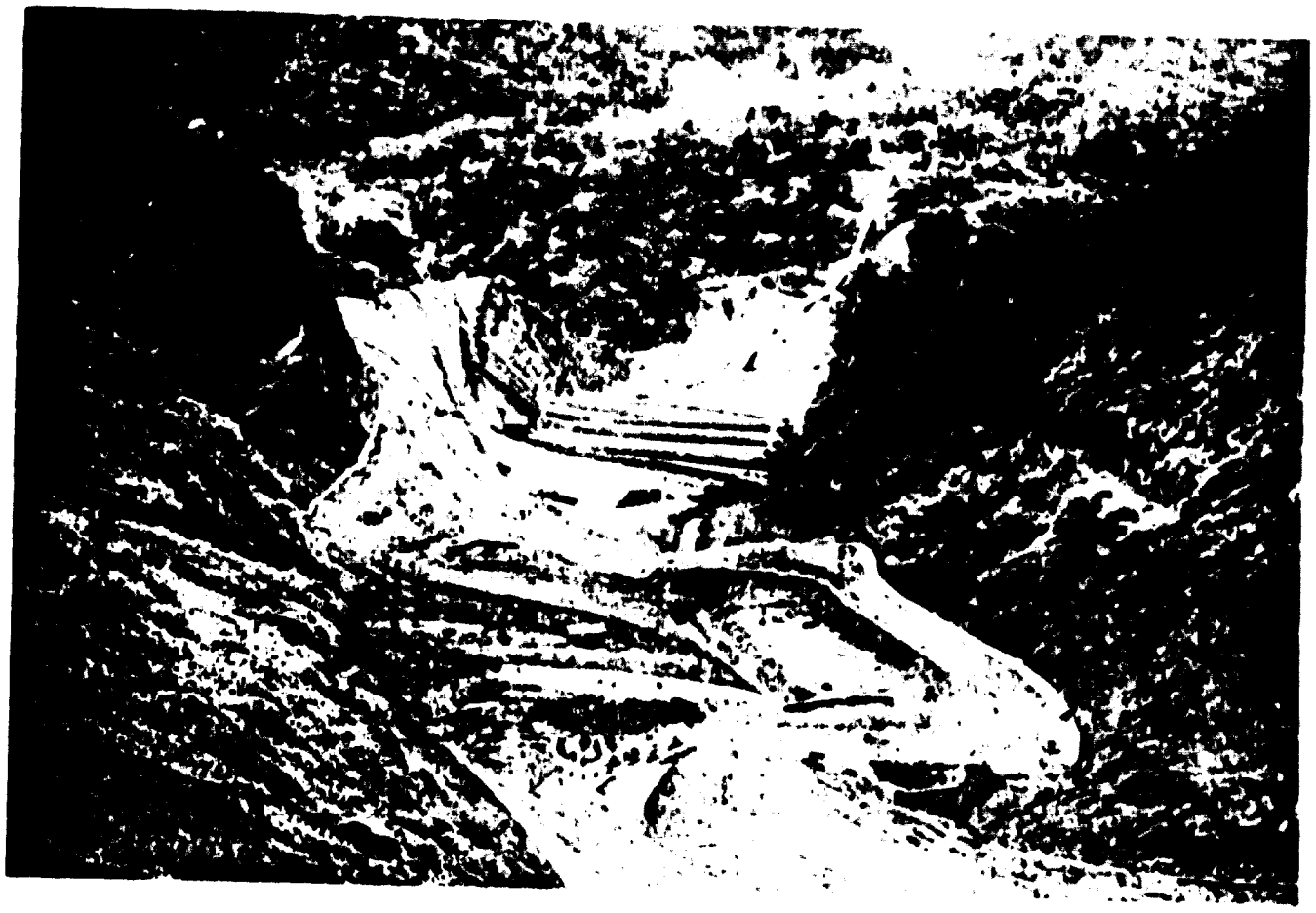


Nimba-Footwall road leading to Main Orebody and mine workshop

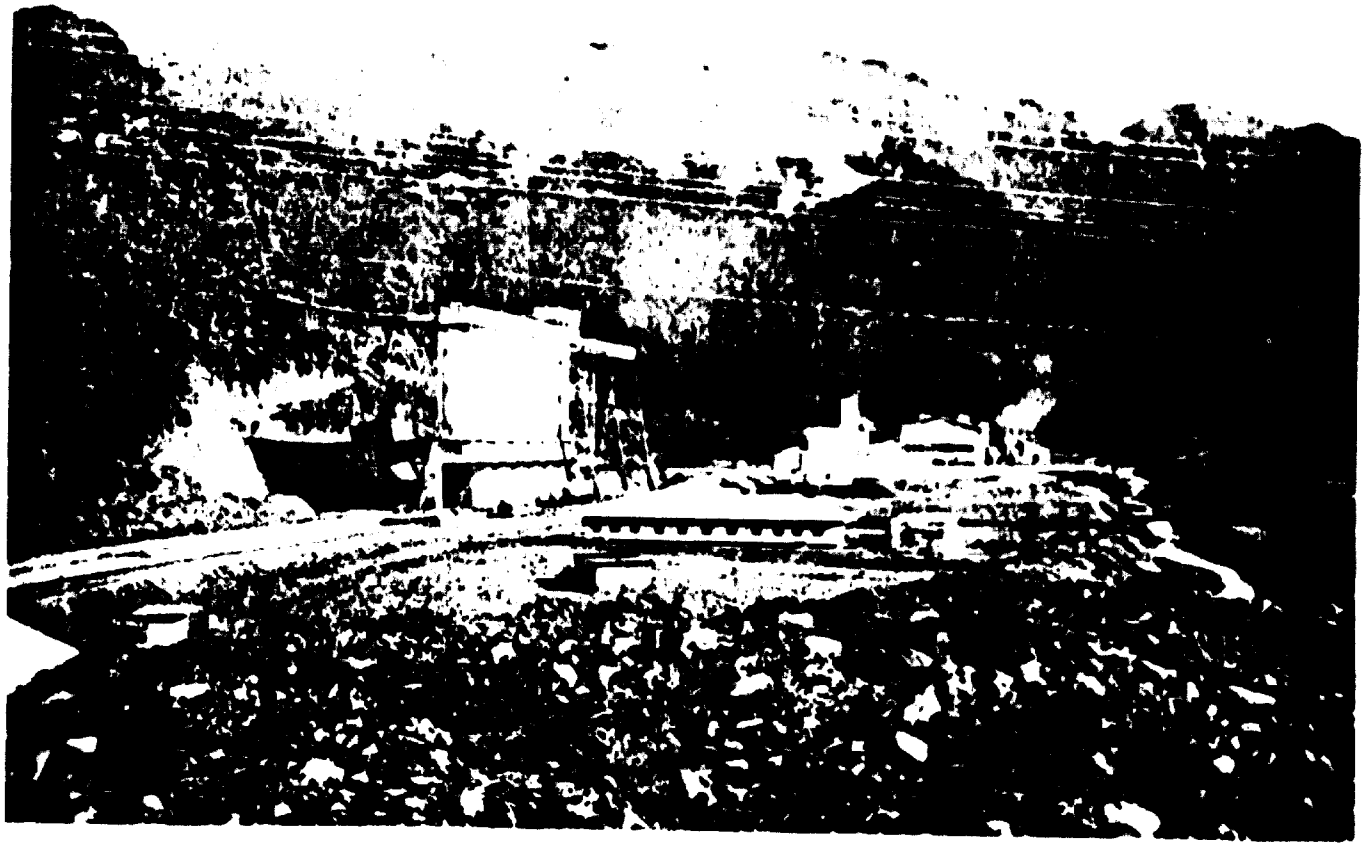


4. Nimba--Haulpacks

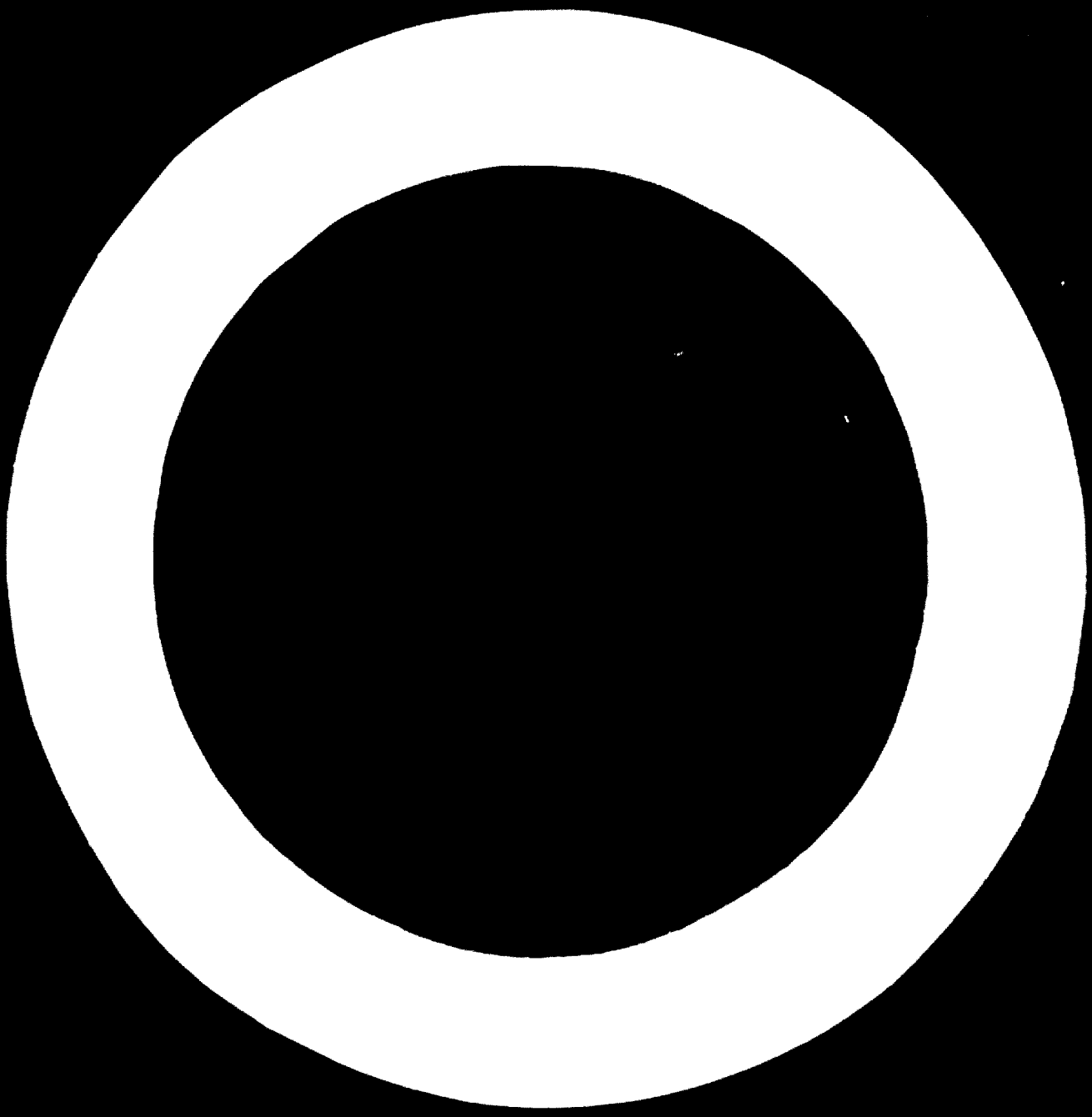


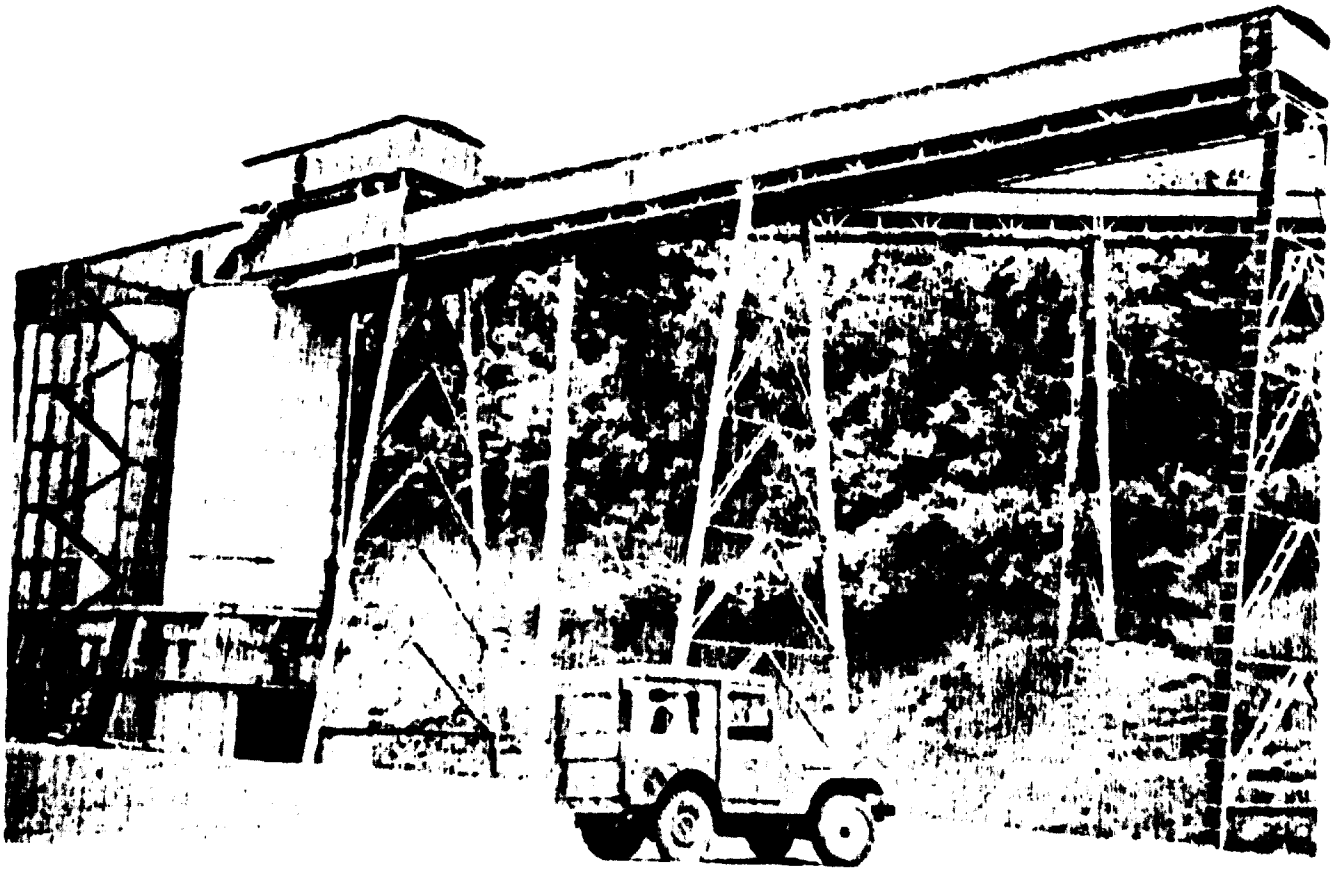


5. Nimba--Conveyor belt

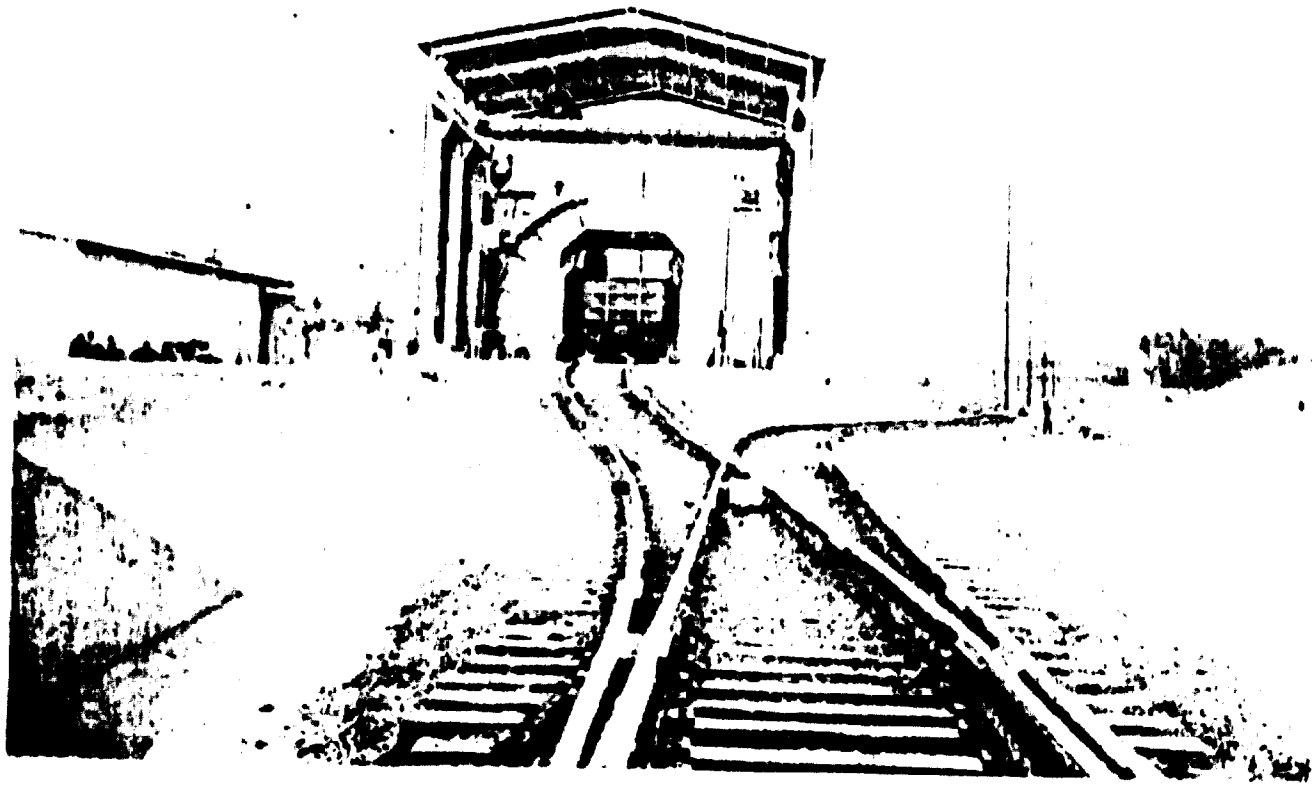


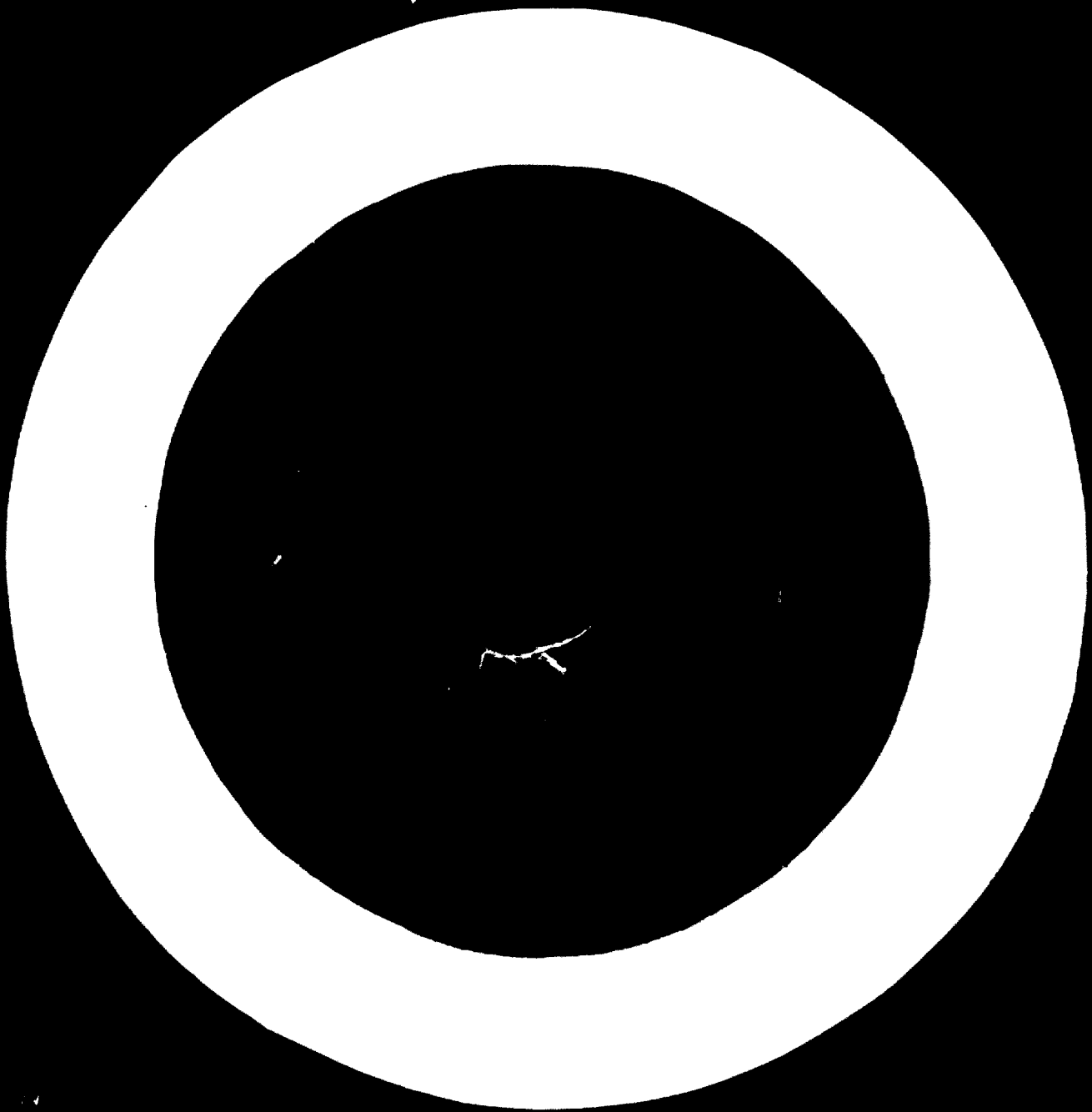
6. Nimba--Orebins, power station and laboratory

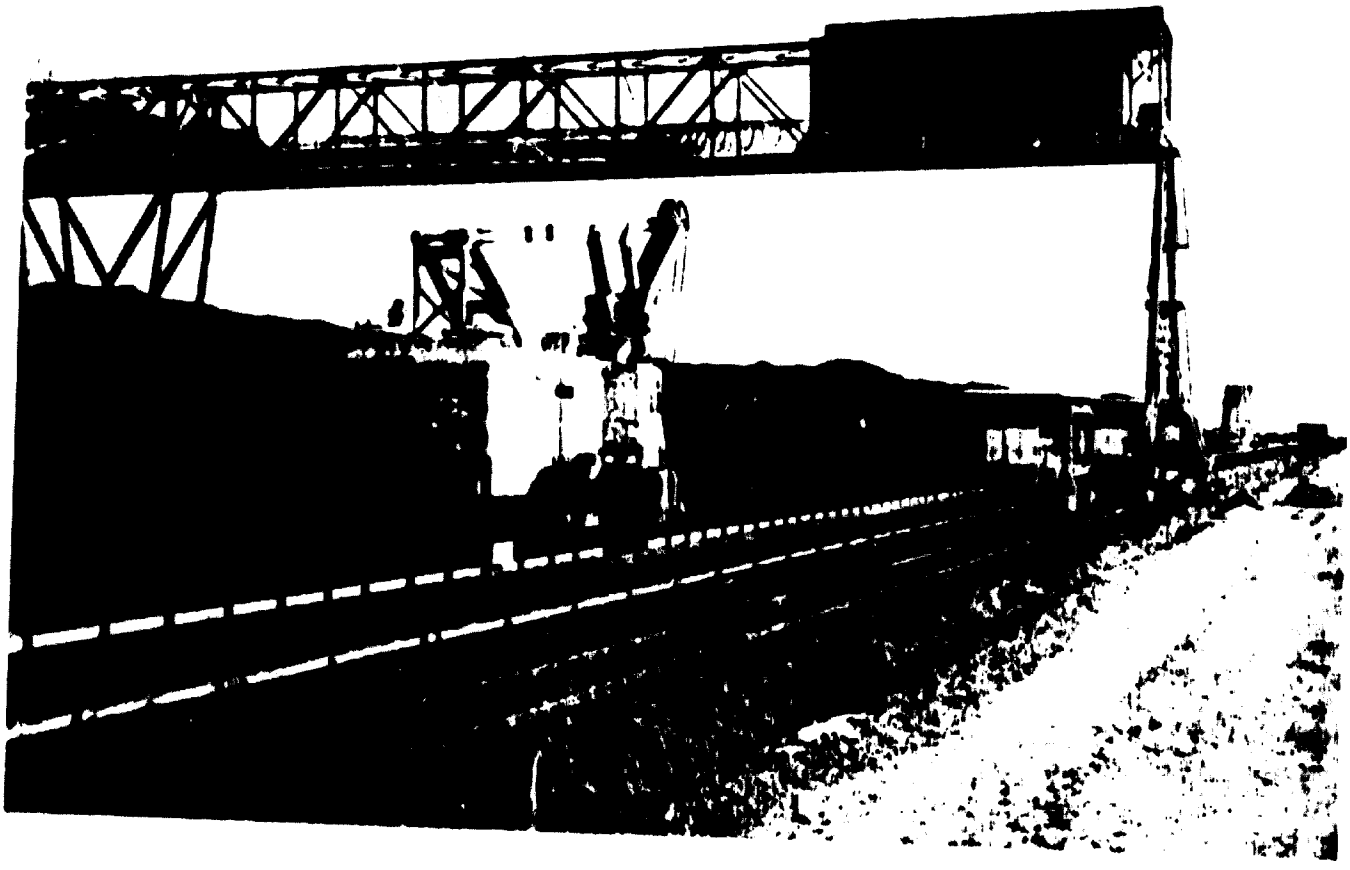




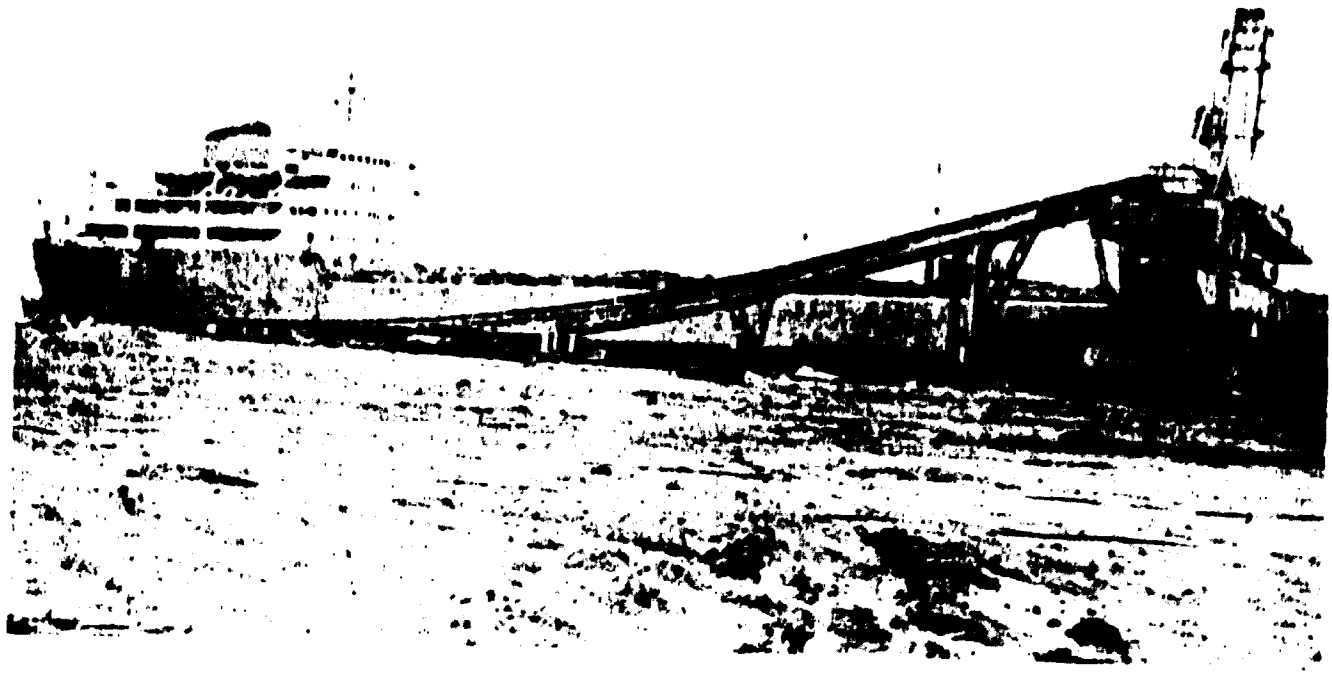
7. Nimba--Close view of Orebins



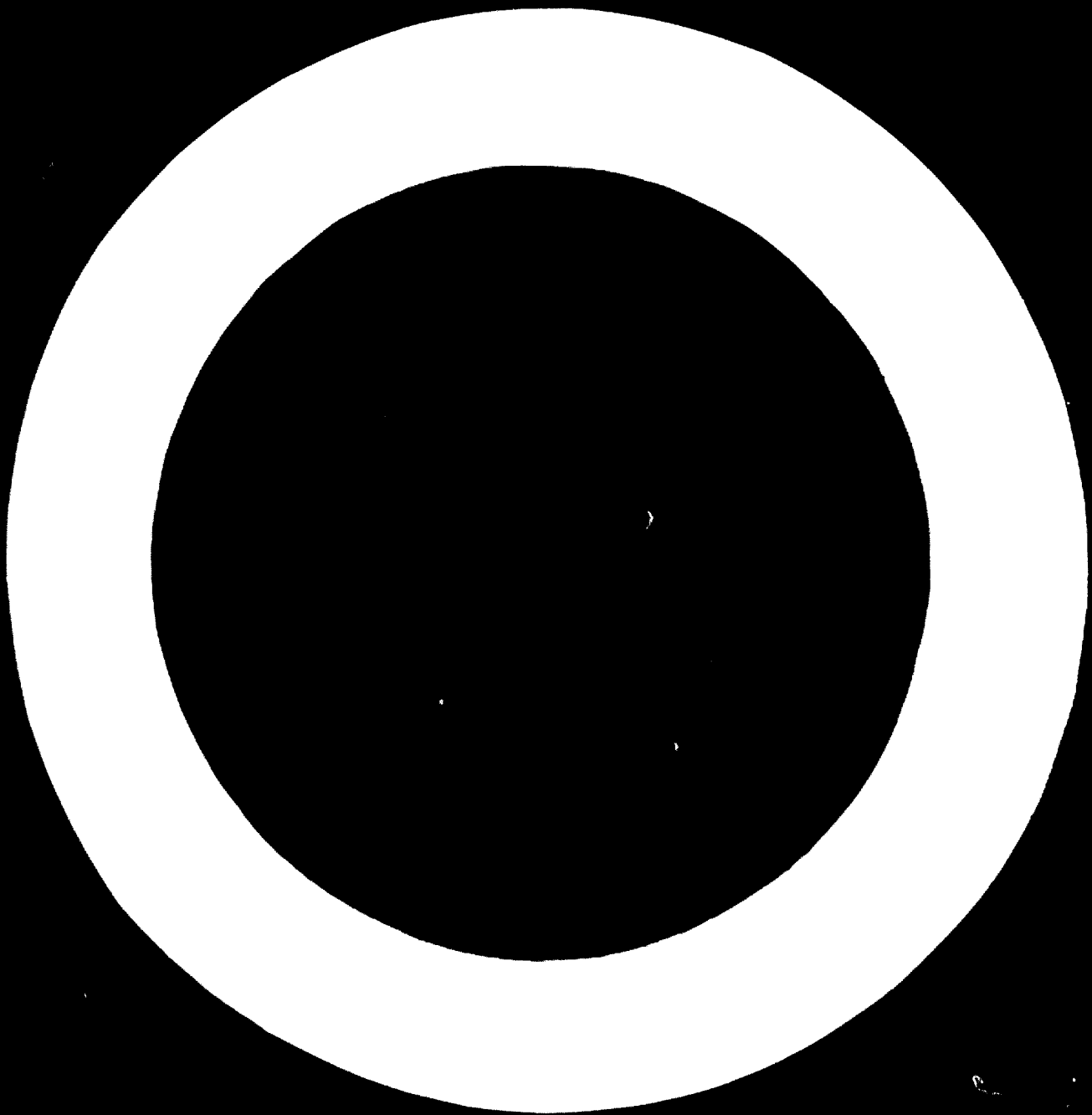


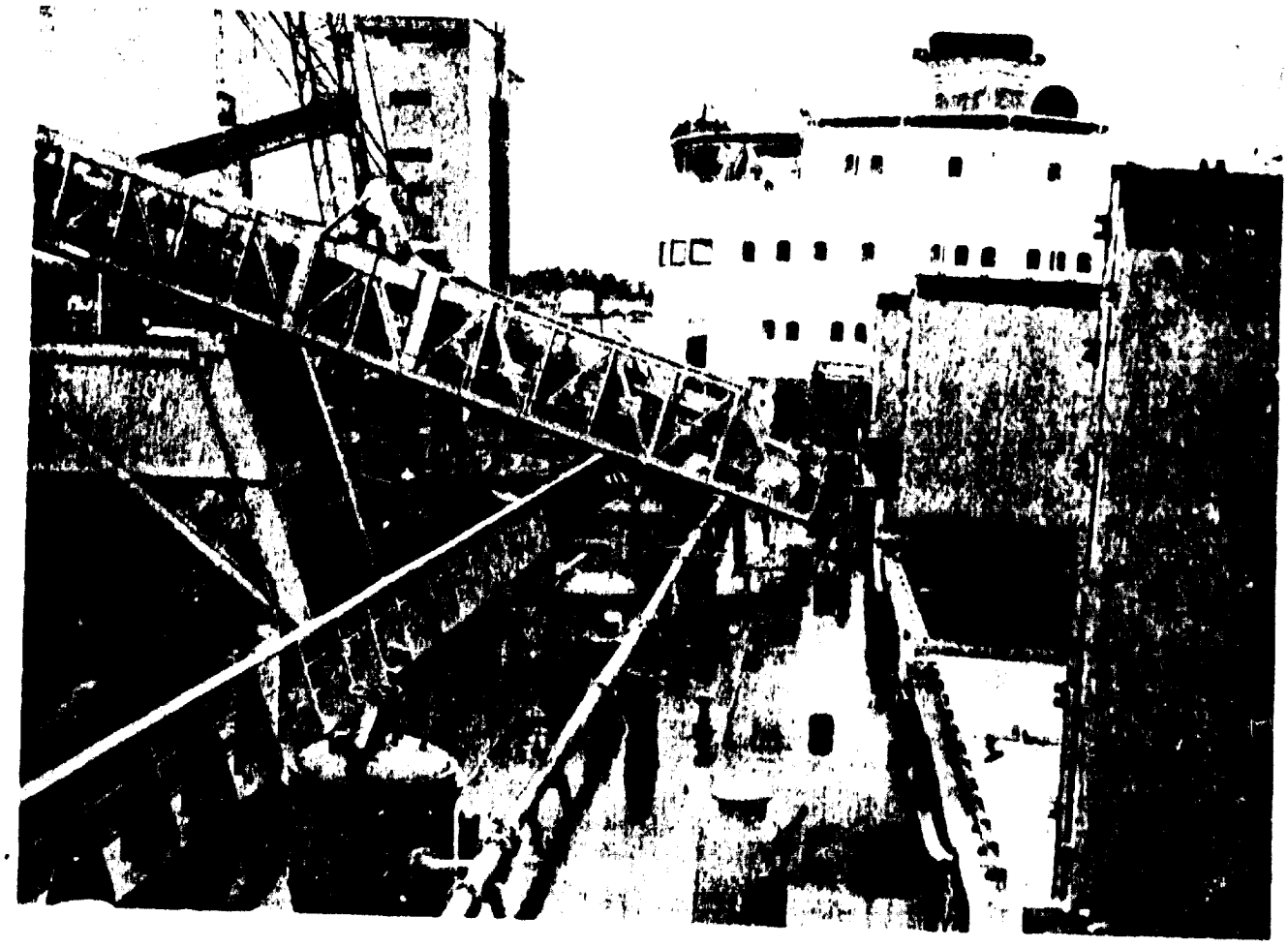


9. Buchanan--Conveyor bridge and shovel at stock pile. In the foreground conveyor belt with travelling hopper.

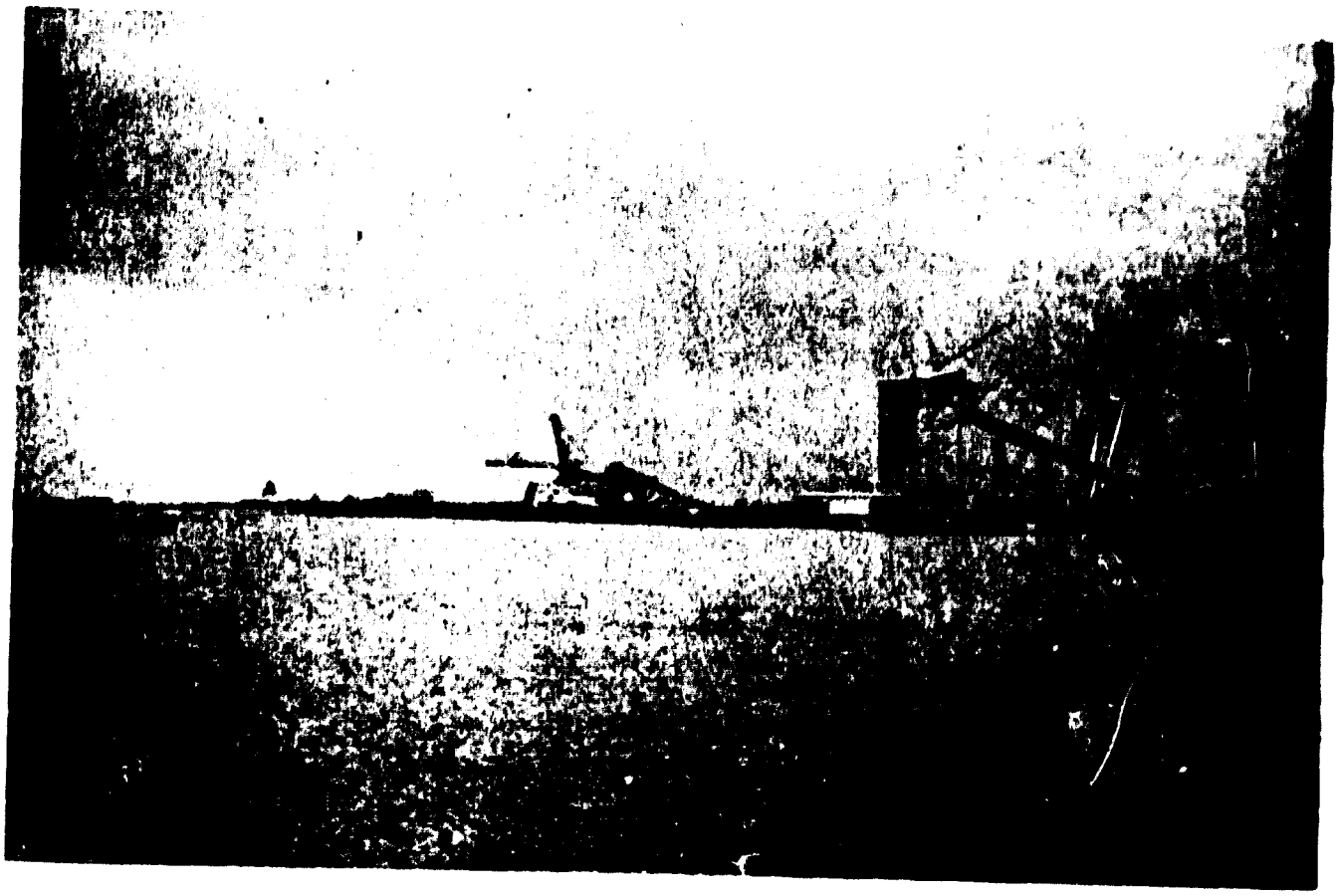


10. Buchanan--Oreloading tower

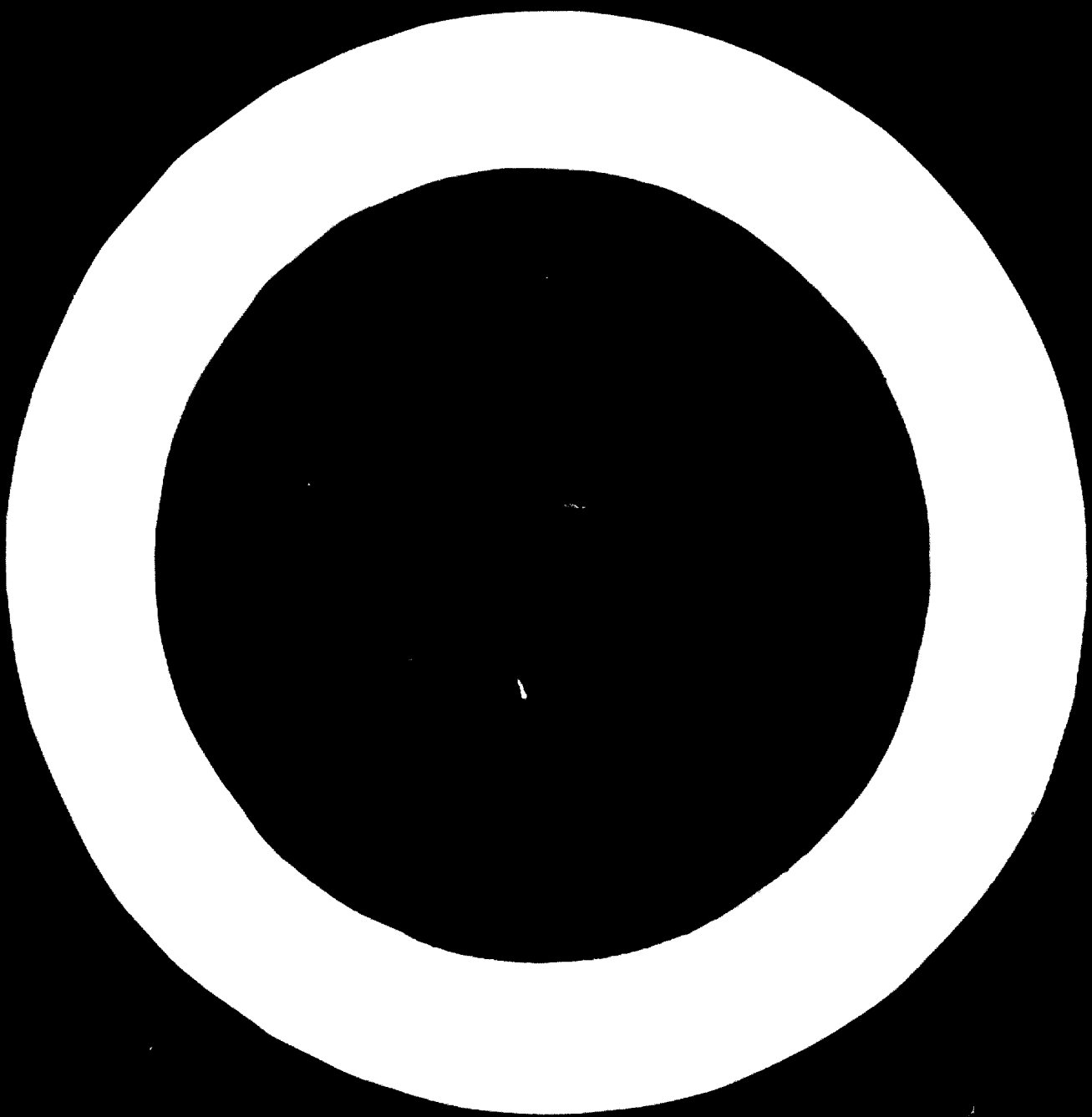




11. Buchanan--Ship loader on quay

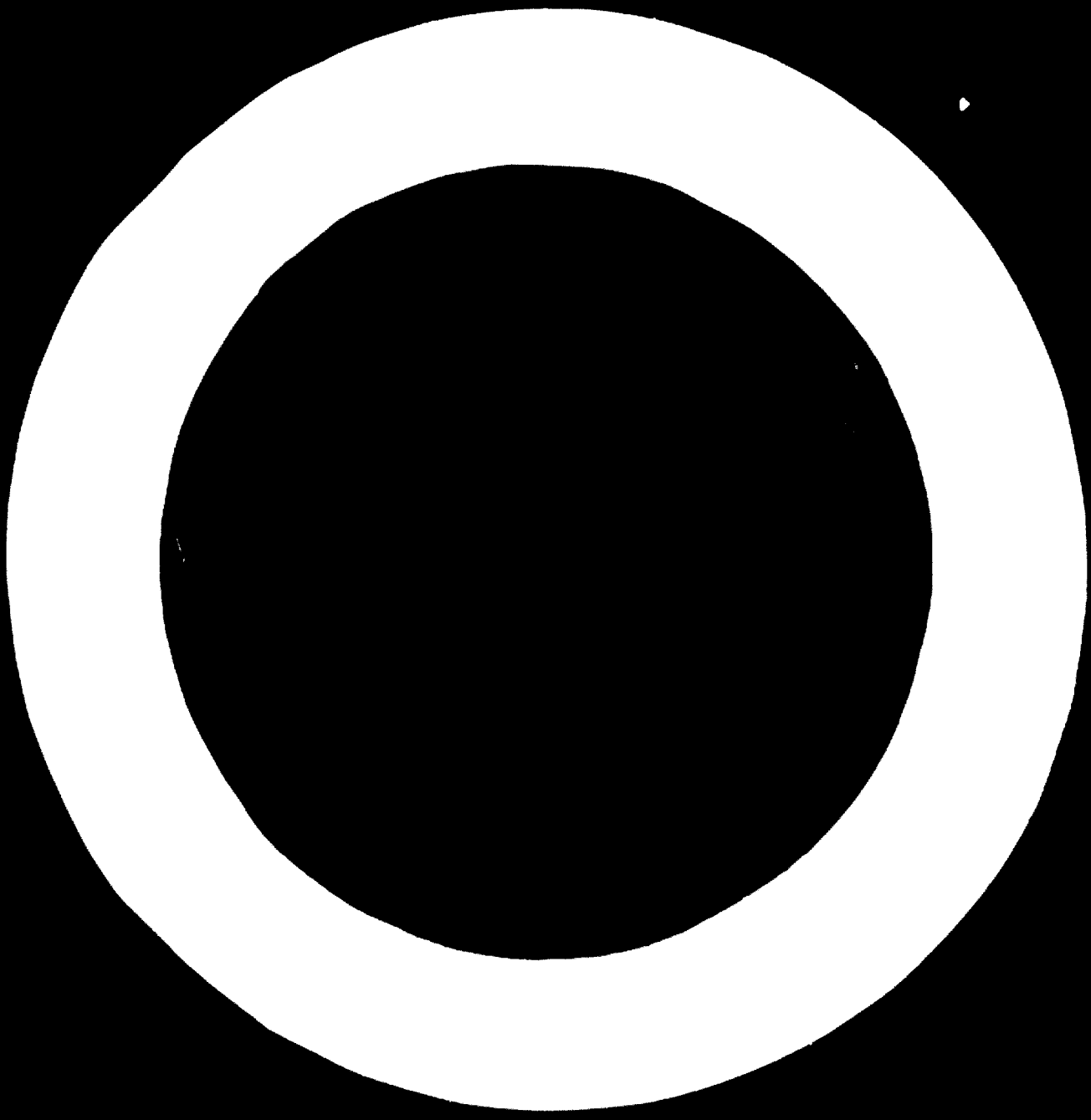


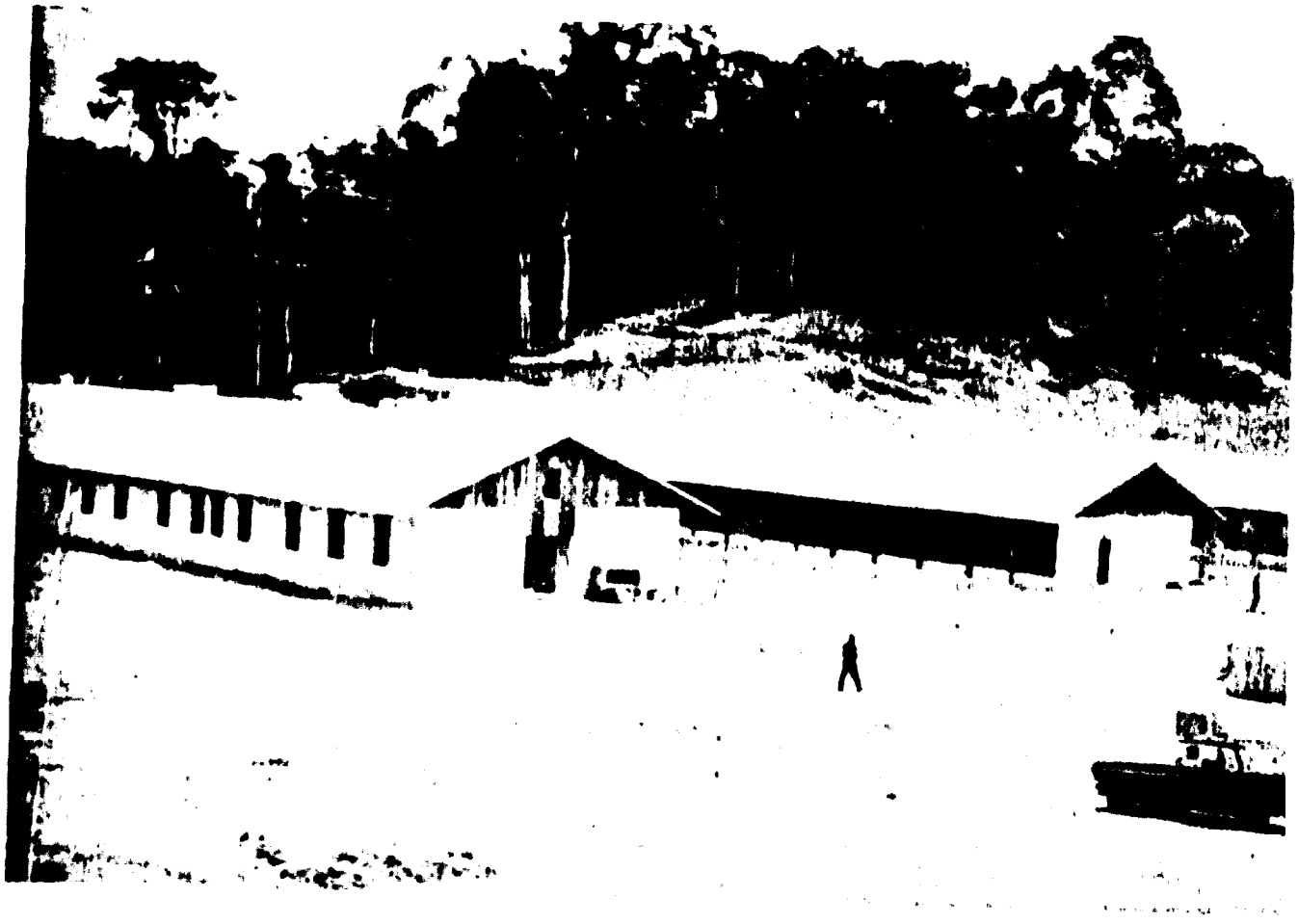
12. Buchanan--Ship loader, surge bin and conveyors



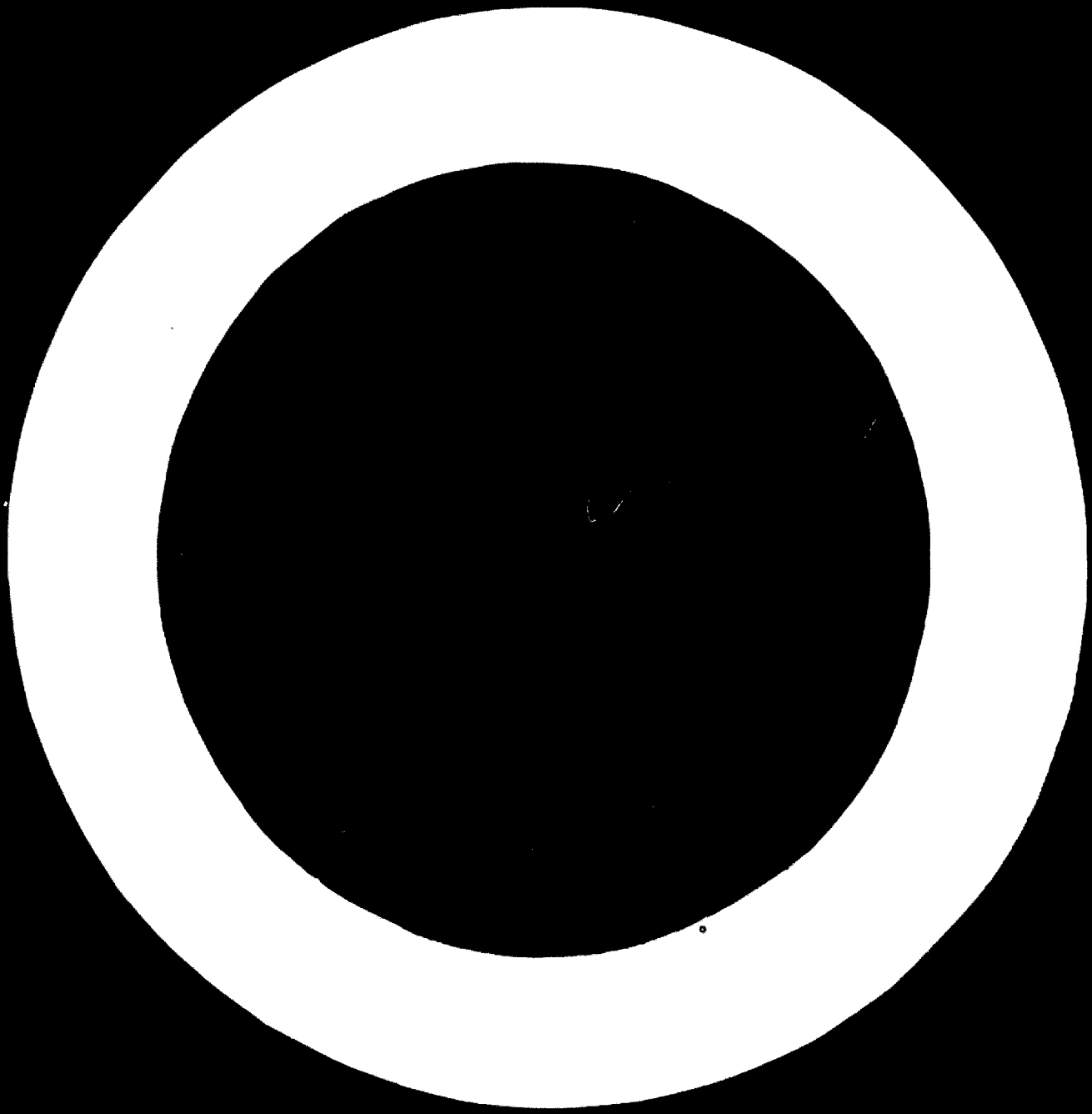
13. Nimba Community with administrative building

14. Nimba Community housing





15. Nimba--Hospital

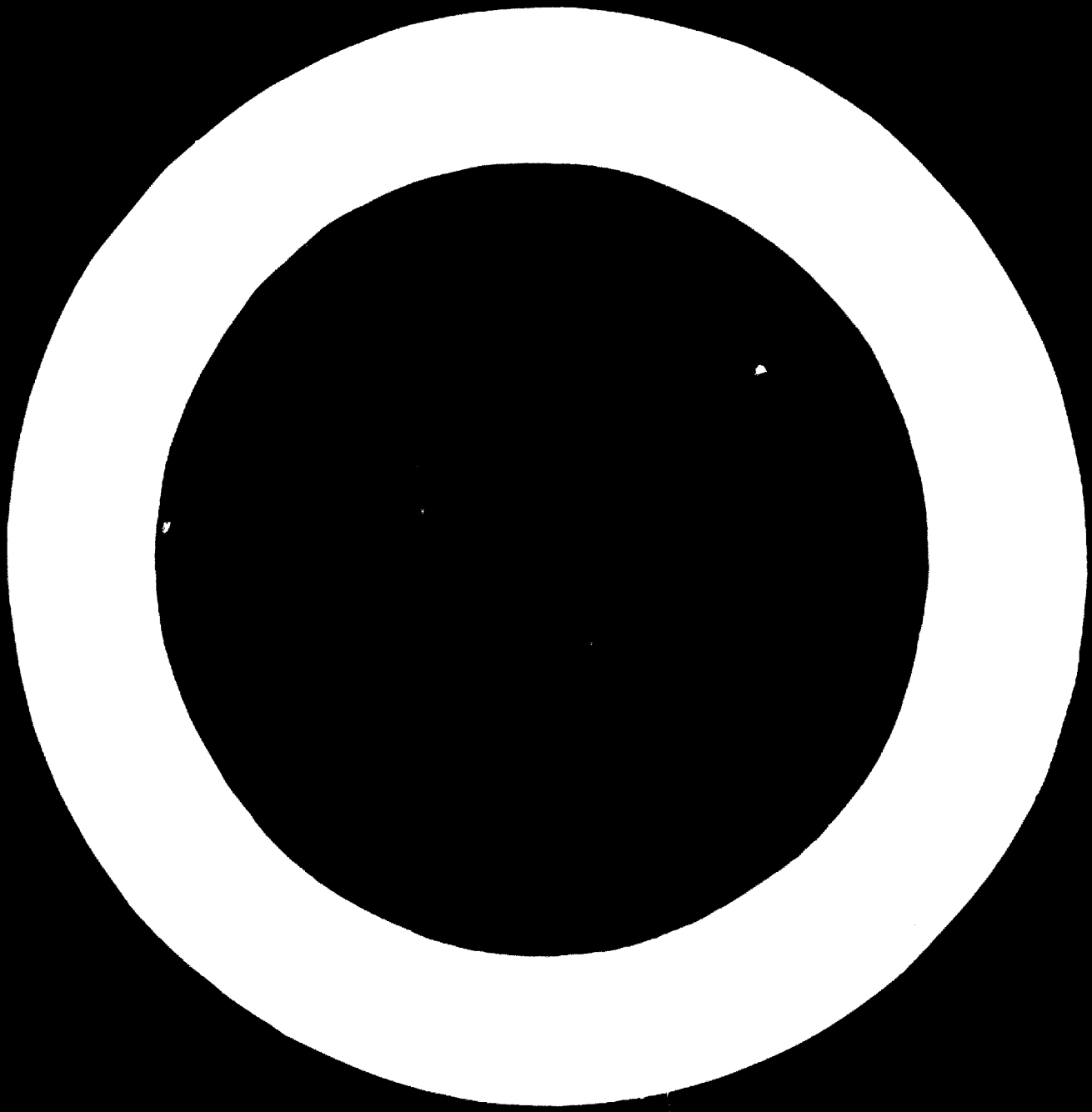


this survey, geological samples were taken. A base line was first established on the main ridge; other survey lines followed the crests of ridges or the valley bottoms across the general direction strike, originating from this base line. Many outcrops occur in the upper parts of the range along the ridge, down slopes, and in the gullies which dissect the ridge. Good outcrops are also found on the plateaux, along the escarpments immediately below the lateritic ironstone cover.

13. Pits and trenches were dug to furnish additional geologic information between outcrops. In most instances these pits and trenches were shallow and hardly penetrated the crust. In most cases this depth (1.5 to 2 meters) was sufficient to determine the nature of the underlying rock. However, in soft ore, phyllites and decomposed itabirites, it was necessary to go consideraly deeper in order to reach fresh exposures.

14. Geological reconnaissance was conducted in the Nimba range after the discovery of the Main Orebody in 1955. This was followed by detailed geological mapping in 1955, carried out at the scale of 1:2,000. A smaller scale geologic map of 1:20,000 with 5 m. contours was later prepared from aerial photographs taken by the Aero Service Corporation of Philadelphia. This survey covered the entire portion of the Nimba range located within Liberian territory. A photogrammetric survey of the Bassa Hills was also made. The most recent geological map to be prepared was that in the scale of 1:5,000, from air photographs of the region around the Main Orebody at Nimba. This map currently serves as a base map for planning further geological and technical operations.

15. A geophysical survey was carried out in the center of the Nimba range in early 1957 by Lundberg Exploration



the observations made on the drill cores, especially from the soft ore sections. This tunnel was also necessary in order to get an impression of the physical and chemical properties of the ore along a representative section. The tunnel began in a valley, making a crosscut into the hanging wall side and penetrating the Main Orebody at right angles to the strike. It goes through 384 meters of ore and 267 meters of itabirite and phyllite.

VI DETERMINATION OF ORE QUALITY

19. Chemical and physical testing of outcrop samples, core samples, tunnel samples and samples selected from surface excavations were performed by LAMCO in a field laboratory located at Nimba. During field mapping and borehole logging the ores were distinguished from the itabirites by their iron content being above or below 60 percent respectively, as estimated by ocular examination. The average assays of iron in drill cores from the blue ore which predominates in the main orebody, and from boreholes in the shallow orebodies, including both crust and brown ore, are shown in the following table.

TABLE 1

Name of Orebody	Meters of drill core assayed	Average % Fe
Main Orebody	4,431	62.02
N 74	296	61.90
Tail	87	58.90
Central Gbham	675	61.40
North Gbahm	58	62.00

20. Tunnel sampling and testing have been the most important and reliable source of information regarding the chemical and physical characteristics of the ore, with the exception of iron content. The Main Orebody tunnel was sampled throughout its entire length in ore by taking channel samples of ore of two meter lengths. In general, the results of the Main Orebody tunnel tests agree with results obtained from chemical and physical testing of samples selected from drill holes and surface excavations at widespread locations. The tunnel samples have been chemically analyzed for all of the elements and minerals affecting the chemical quality of the ore. The following table shows in percentage figures the average chemical composition of the itabirite and hematite penetrated by the tunnel, as obtained by dry analysis:

TABLE 2

	Itabirite	Hematite
Fe	48.13	66.38
P	0.023	0.029
S	0.005	less than 0.005
Mn	0.20	0.08
TiO_2	less than 0.01	less than 0.01
V_2O_5	0.00	0.00
Cr	less than 0.01	less than 0.01
Cu	No trace	No trace
Ni	No trace	No trace
Fe_2O_3	9.05	94.71
Fe_3O_4	57.73	0.88
P_2O_5	0.06	0.06
Mno	0.27	0.10
SiO_2	31.15	2.66
Al_2O_3	1.01	0.78
MgO	0.07	0.05
CaO	0.06	0.10
H_2O	0.33	0.53
Oxides	99.73	99.87

The average moisture content of the ore in the tunnel is 2.3% for the itabirite and 5.7% for the hematite.

VII ESTIMATION OF ORE RESERVES

21. The ore reserves at Nimba have been estimated on the basis of information and data obtained from surface geological mapping combined with shallow surface excavations, exploratory drilling in depth and tunneling. The classification of these reserves as "proven" or "probable" by Russell Bryan & Associates of San Francisco, is based on the following criteria:

> "Proven reserves" are those for which tonnage is computed from dimensions revealed in outcrops, trenches, workings and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling and measurement are so closely spaced and the geologic character is so well defined that the size, shape and mineral content are well established. The computed tonnage and grade are judged to be accurate within stated limits, and no such limit is judged to differ from the computed tonnage or grade by more than 20 percent."
>
> "Probable reserves" are those for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement and sampling are too widely or otherwise inappropriately spaced to outline the ore completely or to establish its grade throughout."

22. The ore estimates were made by both LAMCO and Russell Bryan & Associates after these groups had made independent field investigations. The entire exploration, however, was conducted by LAMCO, which later supplied Russell Bryan & Associates with data obtained from the drilling and tunnelling activities. The estimates made independently by the two groups do not show marked discrepancies. However, there were some differences of opinion in the classification of certain reserves as "proven" or "probable". This was due to differing judgements regarding the number and spacing of drill holes required to give sufficient data for the classification of such reserves as proven.

23. In the Main Orebody, 41 diamond drill holes have given data for the estimation of 196 million tons of proven reserves and 32 million tons of probable reserves with an average dry iron content of 65.1 percent. Diamond drilling on the other orebodies of the Liberian part of the Nimba range has disclosed 68 million tons of proven reserves and 4 million tons of probable reserves with an average dry iron content of 63 percent. The official estimates given by LAMCO are shown in the following table:

TABLE 3

Orebody	Percent Iron (Dry)	Millions of Tons	
		Proven Reserves	Probable Reserves
Main Orebody	65.1	196	32
N 74	64.1	8	3
Central & North Gbahm	61.5	36	-
South Nimba	65.0	7	1
Mt. Alpha	64.3	9	-
NE Extension	62.7	8	-
Total proven	64.6	264	-
Total probable	64.6	-	36

Attention is invited to the fact that the proven and probable Nimba reserves of 300 million tons represents only high grade ore above 60% Fe. Reserves of ore under 60% Fe. are calculated to exceed a billion tons.

VIII DEVELOPMENT PROGRAMME

Nimba Mine Area:

24. Construction and installations at the Nimba mine area must include all facilities for the extraction of the iron ore by open-pit methods. These methods involve the cutting of a series of benches in the orebody and removing ore, after light blasting, by power shovels. LAMCO does not plan to process the ore other than by crushing.

25. The largest part of the Nimba orebody is located at elevations varying from 3,000 to 4,525 feet. The ore is carried by truck down to a crushing plant with an annual capacity of 7,500,000 tons. This plantis located at an elevation of about 3,800 feet on the western slope of the mountain. A conveyor belt carries the ore to one of six storage bins at a switchyard in the valley below. The ore is then loaded on cars from the storage bins through pneumatic discharge chutes. Electricity is supplied from a power station of approximately 9,000 kilowatts capacity.

Railroad Construction:

26. A single-track railroad of standard gauge runs from the mine switchyard area at Nimba to the harbour area at Lower Buchanan for a distance of 165 miles. Two rail bridges of the steel girder type have been mounted on concrete piers across the St. John River. The minimum radius of curvature of the railroad is normally 1,475 feet,

and ruling grades are 0.5% and 1.35% against loaded and empty trains, respectively. The track has been laid to permit a maximum speed of 50 miles an hour, and an average speed of 30 miles an hour. The rolling stock includes 1950 h.p. diesel electric locomotives, and flat-bottomed ore cars of 90-ton capacity. The railroad is provided with a radio-operated centralized traffic control system, requiring from three to ten passing stations at an annual capacity of six to ten million tons of ore, respectively.

Buchanan Harbour Area:

27. The construction of a harbour of approximately 42-foot depth is nearing completion at Lower Buchanan. The harbour will be capable of accommodating ore ships of 45,000 tons cargo capacity, and of loading ore at the maximum rate of approximately 6,000 tons per hour. Underwater blasting is scheduled to be completed by the end of 1963. The harbour entrance between two breakwaters is 720 feet in width. The major breakwater is 6,200 feet in length and the secondary breakwater 1,880 feet in length; the harbour basin is approximately 3,700 feet long and 1,400 feet wide. Navigation aids, including a flashing coastal light, have been constructed.

28. An ore loading dock or quay of 787 feet is provided at the harbour. This quay is connected with the railroad and the mainland by a causeway and an embankment. Vessels awaiting loading are accommodated at a landing stage of 591 feet, which is equipped with a fixed derrick crane of 150 tons capacity for unloading railroad locomotives. A 20-ton luffing crane travelling along the loading quay and the landing stage is also being provided. Other harbour

facilities will include equipment for handling, storing and loading iron ore at a maximum rate of approximately 6,000 tons per hour. Equipment is being provided for unloading the ore cars by a conveyor belt system directly to the loading quay or tc an ore storage yard capable of stock-piling 1,300,000 tons of ore. A power plant of about 8,500 kilowatt has been installed in the harbour area, and a warehouse is nearing completion.

29. Auxiliary facilities which have been constructed or installed at the mine and harbour areas include maintenance and repair shops, staff housing, recreation centers, schools, churches, hospitals, commissaries, communication facilities, water supply and sewage treatment plants, airports and service roads to accommodate the working forces. Approximately 30 miles of permanent roads and 167 miles of temporary access and service roads have been built as part of the Nimba project. The housing and related facilities mentioned above have been provided for approximately 1,900 employees and their families at the Nimba community, and approximately 500 employees and their families at the Buchanan community.

IX LABOUR

30. Under its Concession Agreement, the LAMCO Joint Venture is required to use Liberian citizens for unskilled labour, if sufficient numbers are available, and to give preference to qualified persons of Liberian nationality for skilled labour. The Liberian Workman's Compensation and Protection Act provides that foreign labour can be imported if the employer receives permission from the Department of Interior upon showing that a shortage of Liberian labour exists. As a result, LAMCO has employed

sufficient numbers of unskilled Liberian workers to satisfy its needs, but has found it necessary to import some skilled and semi-skilled labour. The number and description of personnel employed by LAMCO at the middle of 1963 are given below:

TABLE 4

	EMPLOYEES	LIBERIANS	ALIENS
Staff	560	110	450
Clerical Non-staff	90	90	-
Workers	3400	3400	-
Grand Totals	4050	3600	450

X THE LAMCO JOINT VENTURE

31. The Nimba Project is being undertaken by a Joint Venture between LAMCO and Bethlehem Steel Corporation, in which LAMCO has a 75% interest and Bethlehem a 25% interest. The Liberian Government owns half of the LAMCO shares and a Canadian company, Liberian Iron Ore Limited, owns the other half. A Syndicate of Swedish companies, headed by the Grangesberg Company, in turn owns approximately 70% of the shares of the Canadian company.

32. The Grangesberg Company is also acting as manager of the Project on behalf of both LAMCO and Bethlehem. It brings to this task extensive experience in the field of iron ore mining, transportation and sales. The principal contractor for the construction of the facilities has been Raymond International.

XI FINANCING PROGRAMME

33. As of January 1, 1963 the estimated total cost of the 7,500,000 t[illegible]n capacity Project was $217,500,000. Under the Joint Venture Agreement LAMCO must furnish 75% and Bethlehem 25% of the total cost.

34. To furnish its share, LAMCO will incur long term mortgage debt of approximately $100,000,000 and debenture indebtedness of approximately $46,000,000. The balance will be in the form of equity and the proceeds of short term bank borrowings in anticipation of actual sales of ore. The lenders of the mortgage money are Kreditanstalt fur Wiederaufbau of Frankfurt, Germany, Export-Import Bank of Washington, D.C. and First National City Bank of New York City. The Swedish Syndicate is the purchaser of the debentures and also the principal source of the equity funds.

XII CONCLUSION

35. Developing the Nimba Project to its greatest production will be of mutual benefit in that it will bring economic gains to the concessionaires and have a substantial effect upon the Liberian economy since the Liberian Government owns 50 percent of the capital stock of LAMCO.

36. It is believed that the known and proven deposits of iron ore represent only the beginning of the iron ore industry in Liberia as there is much evidence of numerous other deposits not yet fully investigated.

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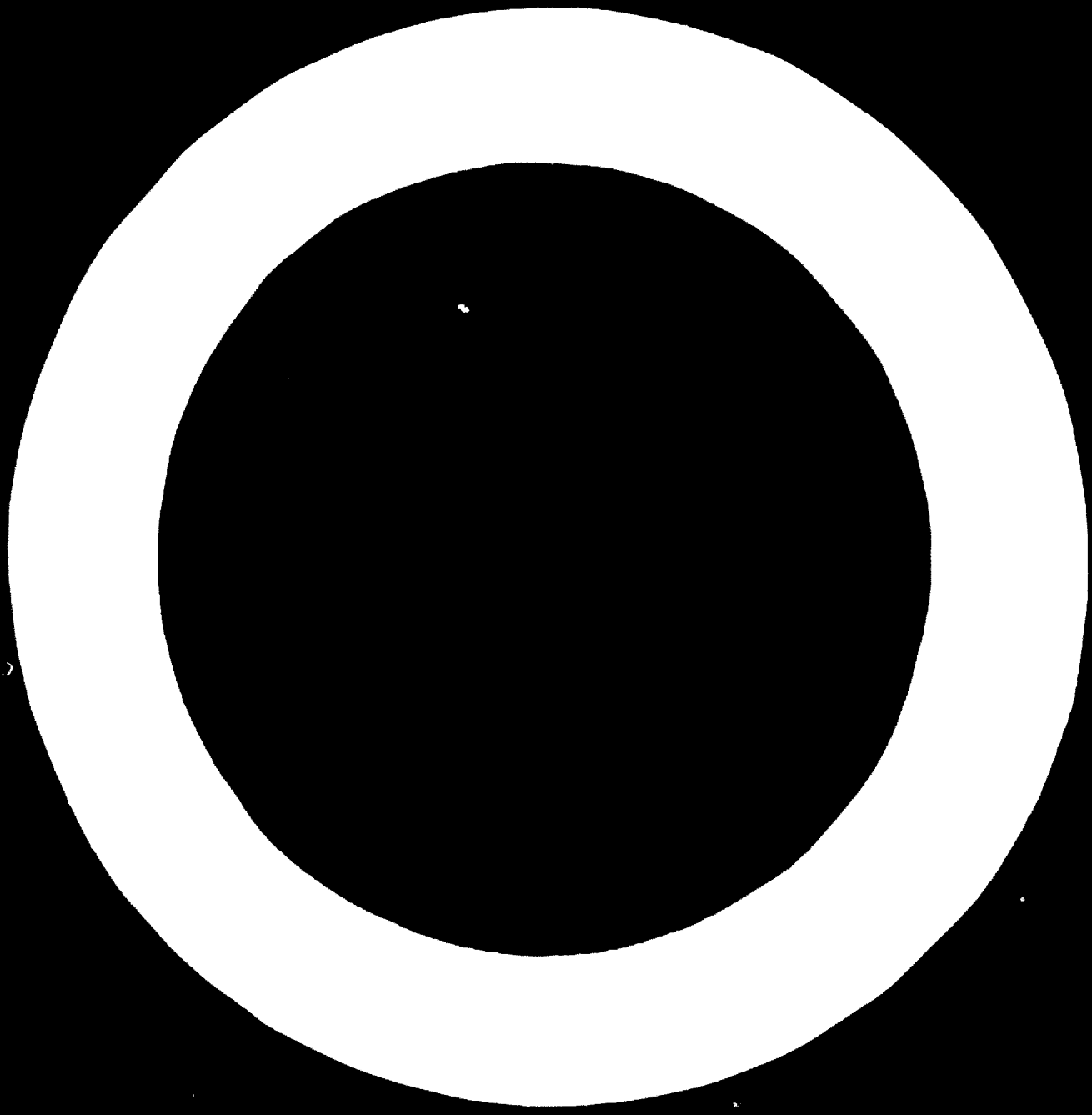

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PROGRESS IN ELECTRIC PIG IRON SMELTING

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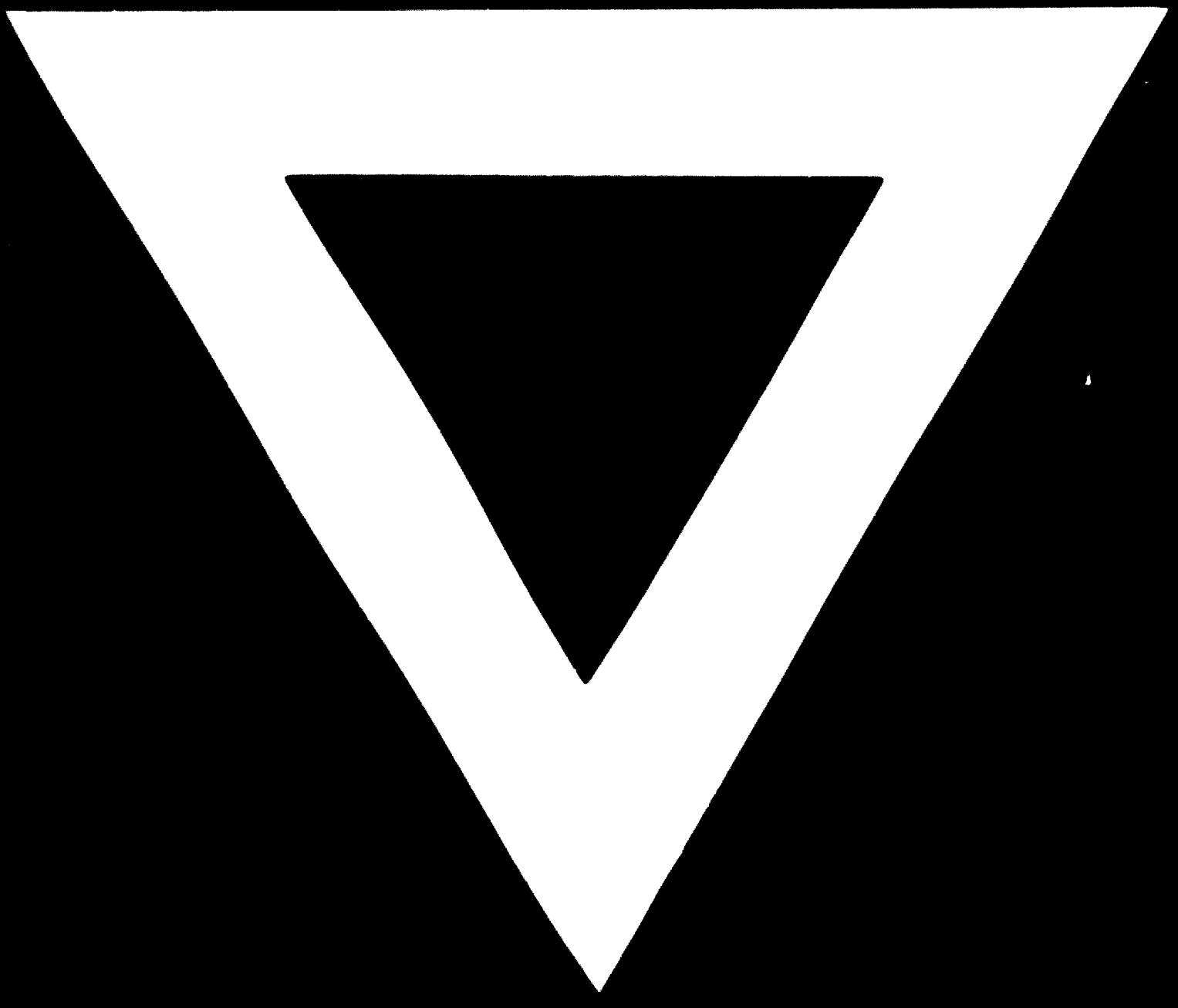

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