ENGINEERING GEOLOGY PROBLEMS
AT AMBUCLAO DAM SITE
BOKOD, BENGUET, PHILIPPINES

BY

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PLATE I-A

A. View of Ambuclao Dam Site.
(Upstream Side)

B. View on Downstream Side. Note south steep slope of Spillway.

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ABSTRACT

Extensive geological investigations are necessary in the solution of problems related to the construction of a large earth dam with an underground powerhouse. The objects of this thesis are to present some of these problems, using Ambuclao Dam as an example, to explain the methods of investigation, and to demonstrate the control of geology concerning the location and design of the principal engineering structures.

Detailed surface mapping, extensive diamond drilling, trenching, test pitting, test shafts, tunneling, and hydraulic sluicing were the methods used to obtain adequate information regarding the nature of the foundation rocks. Some of the problems required more than one method of investigation, and the techniques varied depending on the object of the examination and the geologic conditions.

The choice of a dam site must be based on both engineering and geological factors. Certain geologic features, indicating an unfavorable location, may be noted early in the investigation and unnecessary delays and high construction costs are thus avoided.

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CHAPTER I

INTRODUCTION

This report outlines the geological studies necessary to enable sound engineering planning and to solve foundation problems more adequately in the construction of dams. The data used in this analytical approach represent a compilation of observations made under the supervision of the writer during the extensive geological investigations at Ambuclao dam site from September 1948 to April 1950.

Ambuclao dam is one of seven dams planned by the government for the development of the Agno river in northern Luzon, Philippines (Plate I). The project involves a high earth- and rock-fill dam, a spillway on the left abutment, an underground powerhouse, three diversion tunnels, and a tail race tunnel about 2.38 kilometers long. The complex geologic structure at the site necessitated very thorough geological studies of the foundation rocks.

The dam at Ambuclao has a drainage area of 686 square kilometers, a storage capacity of 258,000,000 cubic meters, and a net head of 171 meters at full reservoir operating capacity. The plant will develop 75,000 kilowatts at an estimated cost of about $0.01 (U.S.) per kilowatt-hour.

Ambuclao dam, construction of which is now in progress, has two significant features, namely: it is the first major public project in the country which made large scale use of geology to treat engineering problems of design and construction; and this earth- and rock-fill dam is the highest of its type ever attempted in the Far East, a region known to be active seismically. Therefore, the treatment of Ambuclao dam as a case study in "Engineering Geology" is in order.

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The writer is deeply grateful to Mr. Irving B. Crosby, consulting geologist of Boston, Massachusetts, with whom he enjoys a very friendly association and under whom he received extensive professional training

during the geological investigations of the Agno River Projects in Luzon and of the Agus River Projects in Lanao, Mindanao. Thanks are extended to Mr. Earl M. Irving, geologist, United States Geological Survey, who proffered suggestions concerning the conduct of the early work and who studied the thin sections of the different rock types.

I wish to thank the officials of the Philippine Bureau of Mines and of the National Power Corporation for having given me the opportunity to work on the geological investigations of dam sites and the rare privilege of becoming associated with men of such technical distinction.

Location and Accessibility

Ambuclao is approximately 16 kilometers, airline distance, northeast from the city of Baguio (see Plate II). The project lies within the municipal jurisdiction of Bokod, sub-province of Benguet, Mountain Province, in the island of Luzon, Philippines.

The dam site is located at the river's canyon, which is 1.4 kilometers downstream from the village of Ambuclao and 1.63 kilometers, river distance , upstream from the intake of the North Luzon Power Company (Plate III).

Two routes lead to Ambuclao, namely, the provincial highway which passes through the town of Trinidad and the access road through the Pacdal Circle. The latter route has the advantage of controlled traffic by the National Power Corporation in order to facilitate travel of personnel, equipment, and supplies. Air travel is scheduled daily, except Sundays, between Manila and Baguio.

Engineering Studies

The early investigations of the Agno river were conducted by the Philippine Bureau of Public Works which was interested in the construction of several low dams chiefly for irrigation purposes. The river's gorge at Ambuclao was among those considered for power development.

Before the outbreak of World War II, the National Power Corporation, then a division of the National Development Company, took direct charge of the investigation and planning of the river. The object was to construct high dams at suitable sites. Preliminary studies indicated that the constriction of the river at the present site offers good possibilities for economic development. This phase of the investigation was undertaken with the advice of the United States Army engineers, of whom General

Lucius Clay and General Hugh Casey took active part.

Engineering studies continued even during the Japanese occupation period, and drilling was carried out too at the old Itogon dam site. However, the Itogon site was abandoned in 1949.

Positive action for the comprehensive and coordinated development of the Agno river commenced soon after liberation, when the government launched an ambitious program of industrial development. The National Power Corporation was created as a separate government entity, and the act vested the corporation with authority to undertake studies and to outline a program of hydroelectric power development for the entire archipelago. Several power sites were investigated, but the final plans call for seven developments, of which five are located along the Agno river and two on the Toboy river (Plate II). The Ambuclao and Binga Projects were considered for immediate construction. The post-war studies are being undertaken with the advice and assistance of the Harza Engineering Company of Chicago.

Geological Studies

The geological study of the Ambuclao dam site started in September 1948 with a party of three geologists from the Bureau of Mines. The nature of the investigation was both reconnaissance and exploratory for the original plans were already laid out (see Plate V), and drilling was in progress too. Suggestions for the conduct of the early phase of the work was given by Mr. Earl M. Irving, who is a technical consultant for the bureau and who stayed in the project for one week during the later part of 1948.

In March of the following year, Mr. Irving B. Crosby came to the Philippines. Mr. Crosby examined four dam sites along the Agno river in Luzon and all the project sites in the Agus river, Mindanao for a period of two and a half months. It was during this visit that the consulting geologist and the resident geologist outlined a more detailed surface mapping and drilling program to cover areas which have significant bearing on the projected engineering structures at Ambuclao and Binga. About the same time, Mr. C. K. Willey, staff engineer of the Harza engineering firm, required a number of drill holes for design purposes.

Mr. Crosby came back in 1950, and he spent a period of over a month at Ambuclao and one week at the Maria Cristina Falls Project in Lanao, Mindanao. It was during this second trip of the consulting geologist and of the consulting engineer, Mr. Leroy F. Harza, that the designs for Ambuclao dam were finalized. An additional program of investigation was outlined to evaluate the structural feasibility of the new plans.

The writer had direct supervision of all geologic fieldwork until April 1950 for both the Ambuclao and Binga Projects which were concurrently investigated. Periodic visits were also made to Ambuclao in the early part of 1951 during the construction of diversion tunnel number 10 and the tail race tunnel. Moreover, the writer assisted Mr. Crosby in all field trips to the various projects of the National Power Corporation. Up to the present time, Mr. Crosby is retained as the consulting geologist of the corporation.

Previous to 1949 there had been no geological study of the dam site at Ambuclao. The only portion of the Agno river examined was the old Itogon site, which is located below the Twin river junction. In 1940 to 1941 Mr. George H. Kemmer, then geologist of the National Development Company, directed the investigation of the Itogon site and recommended some drill holes on both abutments of the proposed dam. Drilling records are intact, but no geologic maps are available. The writer examined the project in 1949 and observed certain serious foundation problems. A fault, with over 12 inches of gouge, crosses the axis of the dam, and numerous shears traverse the spillway site (Plate IV). In addition, silting of the reservoir from mine tailings will cause added difficulty. The major producing gold mines in the Baguio district dump their mill tailings into the headwaters of the Twin river, which joins the Agno river above the site of the proposed Itogon dam. Thus, the old site was abandoned, and the Binga site, 3.5 kilometers upstream from the former, was adopted instead.

CHAPTER II

METHODS OF INVESTIGATION

General Considerations

The fundamental consideration in all geological studies of dam sites is to evaluate the suitability of the supporting rocks in relation to the projected engineering structures. In essence the appraisal is simply a judicious prediction on how the foundation rocks would react under the new conditions or after the completion of the dam. Methods and techniques vary depending upon the object of the examination and the geologic conditions. It is not unusual to employ related methods to solve a particular problem. For instance, during the drilling of holes 32, 38, and 54 the percentage core recovery was low. Consequently, test shafts were sunk to examine the undisturbed condition of the rock. In another case, hydraulic sluicing was employed to remove the overburden on the steep south slope of the spillway site after drilling failed to yield the required information.

The Tennessee Valley Authority[6] has grouped geological investigations under preliminary, exploration, and construction stages. The scope of the geologic work in each stage is defined. Mr. Irving Crosby[1], on the other hand, has classified three different types based on the object of the examination as follows; reconnaissance, feasibility, and complete investigation. Mr. Crosby mentioned that the objectives are not always clearly defined, and a reconnaissance may pass through the different stages as the project develops. This statement applies particularly to the work at Ambuclao, for the reconnaissance and feasibility studies were made almost simultaneously.

Surface Geologic Mapping

Mapping of the different rock types and of the geologic structures was started at the dam site (Plate VI). This included the canyon walls on both abutments, the spillway site, the diversion tunnels, and the powerhouse site. The base map used has a scale of 1 : 1,000. The work was then extended to cover the area from the rim of the reservoir to the tail tunnel outlet. This latter mapping was carried on transit survey traverse sheets with a scale of 1 : 1,000, and the observations were subsequently transferred to a composite map (Plate III). For purposes of regional correlation, the provincial road towards Baguio was mapped as far as Km. 21[4].

The scale of mapping varied with the details and accuracy demanded. In the vicinity of the dam, many of the maps were made on a scale of 1 : 1,000, others were carried on 1 : 50. Regional mapping was done on scales of 1 : 10,000, 1 : 13,000, and 1 : 20,000; the scale of 1 : 13,000 is based on aerial stereo-comparagraph sheets.

The location of points on the ground was largely determined by pace and compass traverses. The projected engineering structures were first staked on the ground to obtain good control. Compass and tape measurements were used to tie important observations to survey monuments. But on the abutments of the dam and on the north and south slopes of the spillway, the location of contacts, faults, shears, and joints was determined by transit and stadia.

It will be noted that formational contacts on the left bank of the river are very irregular. Furthermore, the hill slopes are unusually steep and the river banks are precipitous. A technique followed in mapping these steeply sloping areas was "contour trailing". Trails were constructed at 15-meter intervals from the level of the river to elevation 756 meters which is the crest of the dam. Change in the type of rock is shown by change in color. Diorite is whitish to yellowish white, while the metamorphics are reddish when weathered.

Trenching

Trenching was frequently used to explore the nature of contacts, faults, joints, or other geologic structures of weathered outcrops. The progressive changes of weathered formations are best studied by trenches. This method is suited to exposures occurring along gentle slopes and lying under a thin soil cover. Hence the vertical range is limited. Trenching is an auxiliary technique to surface geologic mapping.

Test Pitting

Test pitting may be either a primary or an auxiliary technique of examination. This is effective where the vertical rather than the horizontal extent is an important consideration, or where trenching becomes impractical.

Test pits were primarily used in the investigation of decomposed and disintegrated rocks needed for earth-fill in the dam. There were 47 pits excavated in Borrow Areas 1 and 1-B. The distribution of the pits was controlled largely by the topography and the area of influence which a pit will carry in the computation of reserves. Test pits were also sunk along the abandoned river channel that surrounds the "sombrero" (Plate III) and in many river terrace deposits upstream from the dam site.

Depth of bedrock under river gravel was also determined by test pits. Test pitting was an auxiliary method to diamond drilling. It had been the usual procedure to excavate a pit prior to drilling in order to overcome the difficulty of driving standpipes through the gravel overburden.

Test Shafts

Eleven test shafts were sunk to delineate the sheared zone on the left abutment of the dam (Plate VII). The weak zone was first noted in drill hole 26 which showed very poor core recoveries, in addition to thick sludges that accompanied the return water. The sheared zone was encountered again in drill hole 38 where practically no core was obtained throughout the drilling depth.

The areal disposition of the test shafts shows two trends; one set follows the base of the diorite bluff along a northeast-southwest direction, and another set encircles the gully area on the north slope of the spillway site.

Test shafts were employed in conjunction with diamond drilling in order to examine the rocks in their undisturbed state and on a much larger scale than that afforded from the study of drill cores. However, calyx drills[6] are preferable to test shafts when the rocks to be penetrated are hard, particularly the diorite in

TS - 3 and TS - 4 (see Plate VII).

Tunneling

Objectives in tunneling differ. The purpose of the test tunnel on the right abutment, near drill hole 12, was to determine the maximum opening that the metamorphics can stand unsupported and to lay out a scheme of tunnel driving and enlargement to attain a full size which is 7 meters wide at the base, 7 meters high, and 10 meters long. This exploration test was undertaken before the construction of tunnel number 10. A pre-war prospect tunnel, located 40 meters south of the saddle at the first bend of the river below the dam, gave added information on unsupported rock openings through unweathered metamorphics.

The test tunnel in diorite lies 160 meters north of drill hole 66, at contour 675 meters. The objects of the test were to determine the depth of weathering, the type of drill cut, the amount of blasting powder required, and the manner of breaking of the diorite for quarrying operations. Test on the maximum opening that the diorite can stand unsupported was not carried out, for the North Luzon underground powerhouse, 1.63 kilometers downstream from the dam site, is in diorite country rock. The underground chamber was constructed 20 years ago. It has a maximum span of seven meters and the roof is unlined with a very flat arch.

The suitability of test tunnels is restricted to rock outcrops along fairly steep slopes so as to avoid drainage and haulage difficulties. Tunnels may also be used to delineate weak zones or other structures of the rocks at deeper levels.

Diamond Drilling

Foundation exploration at the Ambuclao dam site was chiefly undertaken by diamond drilling (Plate VII). A total of 89 holes, with a footage of nearly 23,000 feet, had been drilled by June 12, 1950. The drill bits used range from EX (1-7/16") to NX-casing bit (4").

The narrowest section of the gorge was explored by two overlapping inclined holes, 24 and 25, and a vertical hole, 40, at the center of the river. Holes were drilled along the axes of the dam, spillway, and coffer dam. Critical areas along tunnel lines were also drilled. In the exploration of a powerhouse site, drilling was usually extended five meters below the lowest elevation of the proposed underground excavation.

Formational contacts and weak zones were explored by both vertical and inclined drill holes. The number, distribution, orientation, and depth of holes are based on previous geologic findings. Hence, no definite drilling pattern was followed.

Four drills were in continuous operation at the peak of the investigations. Three crews worked on 8-hour shifts. Drill inspectors were assigned to take proper care of the cores and to note drilling observations, such as the nature and amount of return water, rate of drill penetration, caving in of the holes, chattering, and various other features which reflect the condition of the formation being drilled. Drilling data are then presented in the form of graphical logs (Plates VIII-A and VIII-B).

Diamond drilling is quite an expensive method of subsurface exploration, and an exhaustive analysis of the problems is required before a drill hole is recommended. It was observed, for example, that the engineers are likely to distribute drill holes along a straight line and at regular intervals due to an incomplete understanding of the geology.

Water Pressure Tests

For the determination of the relative permeabilities or water tightness of the rocks, water pressure tests were performed immediately after a hole had been completed.

The apparatus consists of five- or ten-foot length of perforated G. I. pipe with replaceable rubber seals on both ends. The equipment is attached to water pipes which are lowered into the hole. Water is supplied by a centrifugal pump, with water gages installed at the collar of the hole in order to register the pressure and the amount of water flowing in. A pressure of 50 psi (pounds per square inch) is maintained for the first 10 minutes and 100 psi for the succeeding 10 minutes. For holes that are dry or above the water table, water is pumped continuously for 20 minutes so as to effect saturation of openings in the rocks before the start of the test. The test may progress upward or downward.

Colored Solution Test

Fluorescein solution was used in two tests made to trace the path of leakage from drill hole 25. The tests were undertaken for water table measurements indicate an abnormal relationship between the river level, on one hand, and the elevation of the water table in hole 25, on the other. Under normal conditions, the water table rises gradually above the level of a stream towards a hill. But in the case of hole 25 which lies very close to the edge of the river, the water table is lower than the level of the river. An average difference of 14.48 meters was recorded for the month of July 1949 and 13.41 meters for August of the same year.

The standard solution was prepared by dissolving separately in sufficient amounts of water 0.5 kilogram of fluorescein and 0.7 kilogram of hydrous sodium carbonate. The two solutions were mixed to form a pregnant solution. Afterwards known quantities were diluted to varying proportions so as to establish the different colors at the different concentration ratios for purposes of comparison. The standard solution used for the test had a concentration ratio of 1 : 1,100, with a bright green color.

The colored solution was pumped into the hole at the rates of 55 and 75 liters per minute under respective pressures of 60 and 100 psi for the first test, and 50 liters per minute at 50 psi for the second test. The limited amount of fluorescein solution prevented continuous pumping for a duration of 24 hours recommended by the consulting geologist. Instead, water was pumped for the remaining portion of the time so as to displace whatever fluorescein solution might have been retained in the crevices of the rocks.

Water Table Measurements

Daily observations are made on the elevation of the water table. Measurement is usually accomplished by lowering into a hole a one-quarter inch Manila rope with a lead weight at its end. For more accurate measurements an electrical apparatus is used. Two terminals of a 220-volt line are encased in a G.I. pipe, and this instrument is lowered into the hole. As soon as water is reached, a closed-circuit results, thereby lighting a 50-watt lamp provided for at the collar of the hole.

The elevation of springs on both abutments and along the trail to Bisal was established by transit and stadia. Furthermore, variation in the volume of flows was recorded to note the effect of climate.

Hydraulic Sluicing

Poor core recoveries at the spillway site necessitated other means of examining more fully the character of the underlying rocks. A test pit was sunk on the north slope and "contour trailing" was employed on the south steep slope to delineate contacts. In addition, hydraulic sluicing was undertaken in two sections where the spill water has been designed to course through (Plate VII).

Hydraulic operations started from the highest point on the south slope, and a channel was cut down to relatively fresh exposures. The weathered mantle was thus removed and a continuous outcrop from the top of the left abutment ridge to the level of the river was exposed to detailed study.

Soil Testing

During the early phase of the investigation, soil samples were shipped to the National Power Corporation's laboratory at Caliraya, Laguna, where the first earth dam was constructed by the corporation. Before the close of 1950, however, all soil tests were being conducted at the project site.

CHAPTER III

GENERAL GEOLOGY

Physiography

The Agno valley occupies the southwestern flank of the Central Cordillera of northern Luzon. The region is characteristically rugged, with the higher ranges lying between 6,000 and 8,000 feet above sea level. The highest peak, Mt. Pulog, has an elevation of 9160 feet. It is located 25 kilometers northeast of the project site. The river elevation at the dam site is slightly over 2,000 feet so that the relief of the region varies approximately from 4,000 to 6,000 feet.

The Agno river system, comprising the main drainage trunk of the region, has a general southerly course for a distance of 110 kilometers and emerges from the mountainous area at San Manuel, Pangasinan on the northern extremity of the Central Plain of Luzon. From San Manuel, the river courses through alluvial deposits in a roughly semicircular arc, for an additional stretch of over 150 kilometers, to Lingayen Gulf on the west coast of Luzon.

Streams tributary to the Agno river possess high gradients, precipitous banks, and numerous cascades and waterfalls. Many of the tributary streams display cirque-like depressions at the headwaters which resulted from flushing by mud flows and rock slides. Deep tropical weathering, very steep slopes along valley walls, and heavy precipitation are the principal factors which cause the transportation of considerable quantities of detritus. The maximum rainfall on record for the Baguio district is 48 inches for a period of over 24 hours and 109 inches in four days during one of the severe typhoons.

According to Dickerson (1923)[3], Willis (1937)[9], Leith (1937)[5], and others, the topographic development of the region resulted from the combined effects of at least four factors, namely, the fractured nature of the different rock units, high elevation relative to the surrounding areas, geologically recent uplift, and exceptionally high annual rainfall with maximum precipitation from August to January.

The city of Baguio, elevation 4500 feet, is situated upon a high level surface that was called a peneplain by Dickerson. Willis described this erosion surface as an "oldland" for a number of high peaks rise above it. The Trinidad valley and the Baguio airport are two of several terrace levels that lie below the "oldland" surface. Poorly consolidated clays, silts, sands, and gravels occur as discontinuous deposits on the different erosion levels. These terrestrial sediments were not encountered in the vicinity of the dam site at Ambuclao.

A matureland surface is clearly recognizable from the accordant ridge summits at Ambuclao (Plate III). Thus, it indicates that the Agno river previously flowed in a mature river valley whose floor elevation is approximately 1,000 feet above the level of the river at the dam site. It was probably during the aggradational stage in the development of the mature valley that the river acquired a meandering course, which became entrenched into the underlying rocks as a consequence of later uplift and renewed erosion. Certain modifications of the meander pattern may have occurred during the process of entrenchment, but the present course of the river appears to have no significant relation to major geologic structures. For instance, at the bend of the river just below the axis of the dam, bedding and cleavage in the metamorphics trend northeast-southwest while the downstream flow of the river is northwest or at right angle to the structures.

Regional Geology

The region is underlain by an unknown thickness of metamorphosed volcanics and sediments, with intrusions of diorite, granodiorite, dacite, and basic dikes. The basement rocks upon which the metamorphics must have been laid are not recognized in the area. Fossils are absent in the sediments intercalated within the metavolcanics, and the exact geologic age, therefore, is not known. On the other hand, the relative age of the intrusives is determined by geologic relations. In the absence of direct or crosscutting evidence, correlation has been tentatively inferred from igneous textures based on the Rosenbusch classification and from mineralogical composition based on the reaction principle in a given igneous cycle.

It is often difficult to distinguish the metamorphosed sediments, particularly the meta-graywackes, from the metavolcanics. Thus, the metamorphics were mapped as one formational unit. Basic dikes, too, may not be easily differentiated from the metavolcanics unless structural and hydrothermal criteria are used.

Metamorphics

The series consists of a thick metavolcanic sequence with interbeds of metagraywackes, quartzites, reddish shales, and cherts. The metavolcanics are chiefly andesitic in composition, but basaltic and gabbroic types are also noted. Agglomerates and tuffs are occasionally represented in the metamorphosed volcanics. Fracturing is a prominent feature of the series, and the rocks break upon disintegration into polygonal fragments of highly variable dimensions. Epidotization is another characteristic feature. Epidote occurs as criss-crossing veinlets, disseminations, clots, and irregular masses that measure up to several feet. A reddish brown soil of varying thickness mantles weathered exposures, and the recognition of this type of alteration products is a useful guide in mapping the different formations in the tropics.

The metavolcanics display various shades of green, gray, brown, and red depending upon the state of weathering. Dense, fine-grained varieties with a fairly uniform composition are common, but certain of the recrystallized metavolcanics, particularly those found adjacent to the plutonic intrusives, show a coarse-grained to porphyroblastic texture. Banding is uncommon, and fresh outcrops of the dense varieties exhibit a fairly uniform aspect. Relict amygdaloidal structures are sometimes noted. Pillow lavas, measuring from 6 to 30 inches, are seen in two localities, namely, along the north fork of Siwisiwan creek, about 1 kilometer east of the mountain trail at Km. 21, and on the left bank of the Agno river, four kilometers upstream from the suspension bridge at Barrio Langayan.

The metasediments occur as narrow outcroppings in widely separated areas. In general, they lack areal continuity and lose identity even for short distances along their strike. With the exception of the red shales and cherts, the recrystallized graywackes are not unlike those of the finely porphyritic metavolcanics. Varicolored, thin-bedded sediments outcrop along the left steep bank of the river, one kilometer east of Ambuclao. The rocks are composed of red and green cherts, impure quartzites, recrystallized tuffs, and metagraywackes. Under direct sunlight, an observer notes a spectacular display of colors. The sediments strike N 10° - 30° E and dip 60° to 80° E. Red shales crop out along Langayan river, an easterly tributary which joins the Agno river just above the Barrio of Ambuclao. The shales are regularly bedded with a uniform thickness of about one inch. The beds are folded along a NE-SW axis. A third exposure of the metasediments is seen on the right bank of the river above the North Luzon Power intake. The rocks are principally metagraywackes which are easily confused with the enclosing metavolcanics. Bedding shows as faint traces but becomes well discernible by standing at a convenient distance away from the outcrop. The strike is N 10° - 20° E and the dip varies from 40° to 60° W. On the Laboy river, the sediments consist of dark gray, fine-grained quartzites which are occasionally pyritiferous. In this area the sediments strike N 25° - 45° E, dipping 30° to 50° SE. Along the provincial road between Laboy and Km. 21, the sediments trend a few degrees east or west of north and dip gently to moderately on either side. In some of the exposures near the diorite contact at the dam site, the sediments are rendered slightly schistose within very limited sections. The cleavage strikes N 40° E and dips 45° to 65° NW.

Diorite

Diorite is the oldest recognizable intrusive in the area. Basic dikes and aplites of granodiorite type cut the diorite at the dam site. The rock is greenish-gray when fresh and possesses a medium-grained texture. A porphyritic texture has been noted along contact zones and in smaller diorite bodies. In these localities quartz may be wanting. Diorite weathers to a creamy white clayey mass, and this type of alteration product serves as a valuable criterion in mapping concealed diorite exposures.

"Under the microscope[4], the rock possesses a hypidiomorphic to allotriomorphic granular texture and is estimated to be composed of 50 per cent plagioclase (An_{45}); 20 to 36 per cent brownish green hornblende (Z= blue green, X = tan) or its alteration products, chlorite; 10 to 18 per cent anhedral quartz; and 2 per cent accessory iron ore minerals, and secondary sphene, epidote, and calcite."

Diorite occurs in three more or less linearly-arranged zones and consequently separates the metamorphics into three northeasterly trending belts. Two of these belts lie very far from the dam site and are not shown in the composite map. The largest body underlie the major part of the project area (Plate III). The second belt, which has a maximum width of two kilometers, outcrops along the road to Barrio Laboy, 3 kilometers east of the dam site. The third belt comprises a dike complex near the summit of the ridge at Km. 21. Contacts with the metamorphics, as a general rule, are sharp but very irregular. Engulfed blocks of the intruded rocks are abundant. Migmatites are common along contact zones with the bedding and cleavage structures usually preserved. Metamorphism of the volcanics and sediments is mainly due to the diorite intrusion.

The diorite is quite susceptible to weathering, but below the water table the rock is massive and strong. An understanding of this phenomenon has very important engineering implications especially in the design of underground structures that require excavations of considerable dimensions.

Granodiorite

A northeasterly trending, lens-shaped granodiorite dike cuts the metamorphics west of the dam site. It is approximately three kilometers long and attains a maximum breadth of 500 meters at the road cut west of Barrio Ambuclao. The extension of the dike to the north is not shown on the map. The lens tapers gradually and its southern portion terminates at the hill on the right abutment of the dam. In this locality, the contact with the metamorphics is marked by a spring (Plate VI). Along the Laboy river, about one kilometer upstream above its confluence with the Agno river, several dikes of granodiorite, with knife-edge contacts, traverse the metamorphics. The granodiorite, in turn, is cut by basic dikes that follow major joint systems in the host rock.

"Under the microscope[4] the rock is coarse-grained and possesses a hypidiomorphic-granular texture. The minerals occur in the following proportions: plagioclase (An_{36}), 50 to 60 per cent; quartz, 25 to 30 per cent; orthoclase, 5 per cent; brownish green hornblende, in part altered to chlorite, 4 per cent; biotite, 3 per cent; iron ores, sphene, calcite, epidote, and decomposition products, 2 per cent. The plagioclase is of particular interest because most of the grains possess a pronounced inner core which is markedly euhedral. The more basic cores are partially altered and are surrounded by a dark sheath containing minute inclusions at their outer edges. Surrounding the cores is a thick layer of optically continuous younger plagioclase that is subhedral to anhedral with respect to the other minerals, and is of slightly more albitic composition. The quartz exhibits undulatory extinction and some feldspar laths are slightly bent."

The areal disposition of the granodiorite conforms to the regional trend of major geologic structures. The principal engineering implication of the dike is the possible leakage that may occur along its contact with the metamorphics.

Dacite Porphyry

Dacite porphyry is composed of feldspar and quartz phenocrysts in a very fine-grained matrix. The most distinctive feature, which permits easy identification in the field, is the prominent development of bipyramidal quartz, i.e., two hexagonal quartz prisms which are joined at the bases. A single crystal may measure as much as 18 mm. along the c axis and up to 12 mm. across. The feldspar phenocrysts are also well developed but are much smaller than the quartz crystals. The fine-grained groundmass suggests rapid cooling, and this is interpreted to be the result of emplacement under a shallow cover.

"Under the microscope[4] the quartz phenocrysts are slightly resorbed and the crystals are bordered by a reaction rim of minute plagioclase grains. The quartz contains curved lineal trains of bubbles but in general the crystals are fairly free of other mineral inclusions. In fresh specimens the feldspar phenocrysts are sharply defined and quite glassy. Many show strong zoning, and occasional bands of reversed zoning are noted. The basic cores are determined to be An_{33} but the outer rims and much of the unzoned plagioclase are An_{28}. The rock formerly possessed small phenocrysts of hornblende, but these are now completely altered, commonly in parallel orientation, to brownish green chlorite which contains numerous inclusions and some irregular patches of calcite. The groundmass is composed of fine overlapping and mutually interfering grains of plagioclase and quartz through which small grains of chlorite and abundant iron ore minerals, some of which under reflected light prove to be pyrite, are interspersed."

Dacite porphyry outcrops along two ill-defined, northeast trending belts west of the project area. Only the eastern section of one of these belts is shown on the map (Plate III). Blocks of the metamorphics are included in the dacite porphyry, and the latter, in turn, is intruded by basic dikes. The summits of the ridges underlain by dacite porphyry show clay accumulations which are excellent materials for the impervious core of the dam.

Basic Dikes

Basic dikes occur as thin bodies which filled major joint systems in diorite, granodiorite, and dacite porphyry and cleavage planes in the metamorphics. Their continuity and attitude are controlled, therefore, by the pre-existing openings in the country rocks. The dikes seldom measure over five feet thick. Although the borders are characteristically chilled, texture shows a gradual transition from glassy at the edges to finely porphyritic at the central portion.

"Under the microscope[4] the rock consists of small, strongly altered, feldspar phenocrysts which are imbedded in an intergranular groundmass of augite and feldspar microlites. The plagioclase phenocrysts (An_{72}) show resorption by development of feldspar microlites and pyroxenes, and contain secondary chlorite, calcite, and occasional epidote grains. The augite possesses an estimated 2V of 15° and is therefore pigeonitic in composition. Although the groundmass contains considerable alteration products, the ferromagnesian minerals are essentially free of alteration. Besides sparse opaque minerals, the groundmass contains a generous sprinkling of chlorite, calcite, and epidote. The rock is basalt."

<u>Summit Sediments</u>

Tertiary sedimentary rocks have not been recognized in the area studied. Of particular interest, however, are the horizontally bedded clays, silts, arkosic sands, and gravels that lie on diorite and metamorphics along the summits of the ridges at Km. 21.

Cobbles of both basement and young volcanic types are represented. This would indicate that the summit deposits are younger than the later Tertiary volcanics. The sediments are of terrestrial origin and may have been deposited upon a flood plain related to the development of the Baguio "oldland" surface.

Geologic Structure

The bedding structures observed from widely separated outcrops of the metamorphosed sediments show a general northeasterly trend and may dip gently to steeply to the east or west. Cleavage, faults, and shears show slight deviations from the regional strike of the bedding. The diorite and granodiorite are areally disposed along belts more or less paralleling the NE-SW structure. Furthermore, the dacite porphyry, which appears to be related to a much later igneous activity than the plutonics, occurs also in rudely-defined belts that conform to the major geologic structures. It appears that the metamorphics were subjected to orogenic compression that developed folding along N 15° E to N 30° E axes, and judging from the areal distribution of the igneous rocks, intrusions of the diorite, granodiorite, and dacite porphyry may have been largely controlled by the weak zones developed during the orogeny.

Numerous shears traverse the metamorphics, particularly those which underlie the abutments of the dam. However, the magnitude of displacements can not be determined for lack of any reliable reference plane. Two major faults, one striking nearly N-S and another trending N 35° W, were delineated by an extensive drilling and test pitting program on the left abutment of the dam (Plates VI and VII). The faults apparently intersect at hole 38 where the rocks are ground up to a gougy mass.

Contacts between the metamorphics and the intrusives are usually sharp but very irregular. The plutonics send numerous dikes and tongues into the metamorphics. Blocks of metamorphics occur as xenoliths in the diorite, granodiorite, and dacite porphyry. Diorite bodies which completely surround fragments of the chloritized metamorphics usually display a greenish-tinged rim along the contact zone. This probably resulted from the partial melting of the xenoliths at the borders. Lit-par-lit injection gneisses characterize the metamorphics especially near the contact with the diorite at the banks of the gorge.

The flat-lying attitude of the summit clays, sands, and gravels suggests that major uplifts which elevated the ranges of the region are essentially vertical.

Geologic History

It was pointed out that fossils are absent in the sediments interbedded with the metavolcanics. Moreover, it seems very unlikely that any contained fossils could have remained unaltered when subjected to tremendous pressure and heat accompanying orogenic movements and plutonic intrusions. At best, therefore, the events can only be stated in a chronological order.

First, one must assume the existence of basement rocks upon which the older volcanics and sediments were deposited.

The next event was extensive, periodic eruptions of lavas. Sediments were deposited during intervening periods of quiescence. Although volcanism appears to be dominantly of the quiet type, explosive outbursts are indicated by the presence of occasional agglomeratic and tuffaceous beds. Interbedded cherts and pillow lavas suggest subaqueous deposition of some of the volcanic rocks.

The third episode is represented by orogenic movements with folding along a general NE-SW axis. Intense fracturing and major faulting in the metamorphics probably took place during this period.

Orogenic disturbance was followed by diorite intrusion along the deformed belts. The volcanics and sediments must have been hydrothermally altered during and after the diorite intrusion.

Intrusion of the granodiorite dike followed. Its attitude may have been controlled by strong NE-SW shears in the deformed metamorphics.

Surface irregularities which resulted from the orogenic disturbances and the plutonic intrusions were rapidly eroded.

Following this period of erosion, dacite porphyry was intruded presumably under a relatively thin cover. This intrusion is interpreted as the start of the late Tertiary volcanism in the region.

The last episode of volcanic activity is represented by the intrusion of basic dikes. Elsewhere in the Baguio Gold District, this period is marked by basalt flows.

Extensive land degradation following the last phase of volcanic activity developed a relatively low-level area, which may be correlated with the Baguio "oldland" surface. The unconsolidated gravels, sands, and clays must have been deposited during the later part of this erosion cycle.

A sharp vertical uplift of at least 4,000 feet took place, with the formation of consequent streams. Increased stream gradients promoted vigorous erosion that subsequently developed a matureland topography. The Agno river must have acquired a meandering course late in this stage.

The matureland was then uplifted by at least 1,000 feet in the present section of the dam. The Agno river incised its meander pattern into the underlying rocks. Elevation of the area enhanced weathering processes. Streams acquired greater erosive capacity, and, even today, the Agno river carries a considerable load of detritus especially after torrential downpours.

The metamorphics of the Ambuclao area show very striking similarities to the metavolcanics and metasediments associated with the basement complex that underlies the Sierra Madre range east of the Marikina graben, a few kilometers northeast of Manila. In the latter locality, lower Miocene clastics and limestones unconformably overlie the basement complex. In the island of Marinduque, the metavolcanics and associated quartzites lie under early Tertiary limestones. In the Surigao Gold District, the metamorphosed volcanics and seimentary rocks are overlain by Eocene Limestone. The metamorphics at Ambuclao are tentatively dated as pre-Tertiary. It is understood, however, that lithologic similarity and degree of metamorphism are unreliable criteria for regional correlation.

Geology at the Dam Site

Four rock types, namely, metamorphics, diorite, granodiorite, and basic dikes, underlie the dam site and vicinity (Plate VI). The west wall of the gorge consists principally of metamorphics, with diorite and basalt at the downstream end. The left abutment is underlain by a very complex contact zone of metamorphics and diorite. Granodiorite dike, striking N 25° E and dipping 40° to 50° W, cuts across the saddle of the right abutment ridge.

Fracturing is characteristic of the metamorphics and may range from microscopic to large scale. Fractures and slips have a prevailing NE-SW trend and dip steeply to the northwest (Plate VI). Bedding and cleavage, although these are not prominently developed, follow the same orientation, so that the magnitude of any displacement is difficult to ascertain. Joints and slips in the diorite, on the other hand, are well developed along a NW-SE direction and dip either NE or SW. Thus, the geologic structures at the dam site form two principal trends which are areally disposed at almost right angle to one another. The NE-SW set, which is usually associated with the metamorphics, probably represents a comparatively older system than the NW-SE set commonly observed in the diorite.

A complete cross-section of the rocks underlying the gorge was obtained by two overlapping inclined holes. A study of the cores show that no fault of importance crosses the axis of the dam (Plates IX-A and IX-B).

The spillway structure is located on fractured and partly disintegrated metamorphics (Plate IX-B). A swarm of diorite dikes traverse the metamorphics (Plate IX-E). Highly sheared metamorphics underlie the gully area north of the spillway site. This partly disintegrated zone measures 130 meters wide and extends down as far as the depth of drilling (Plate X).

Two major faults have been inferred from drilling data. The faults are located at the upstream toe of the dam and seem to intersect in the neighborhood of drill hole 38. The NW-SE fault is terminated by a cross-fault at the head of the gully where the stream makes a sharp turn towards the north. The other fault, trending almost N - S, appears to have terminated as parallel shears in the metamorphics at the spillway site. Another fault of importance, which shows eight inches of gouge, was seen on the west wall of diversion tunnel number 10. It strikes N 50° W and dips vertically.

Hill slopes are commonly very steep. Undercutting by the river produced declivities of 45° to 90°. Weathering of the diorite develops a more or less even surface, but the metamorphics, by contrast, display a jagged surface. It is well to emphasize the fact that weathering proceeds at a relatively faster rate along the joints or other structural planes. This explains the irregular thickness of the soil mantle.

Fractures or other openings situated within the zone of oxidation are usually filled with clay and are fairly water tight. Joints and faults intersected by diversion tunnel 10 do not show any serious leakage. Both the diorite and metamorphics are hard and sound, even if fractured, below the water table where they are protected from chemical decomposition.

Of special physiographic interest is the meander cut-off around the "sombrero" area southeast from the dam site. This ox-bow has a thick accumulation of loosely-compacted clay, silt, sand, and gravel. It is listed as one of the possible sources of the earth fill.

CHAPTER IV

ENGINEERING PLANS AND GEOLOGICAL CONSIDERATIONS

Early Development Plans

The original plan was for an earth- and rock-fill dam with an inclined clay core, one diversion tunnel, a spillway on the right abutment, and a tunnel intake to a downstream powerhouse (Plate V).

The tunnel intake for the power units starts from the granodiorite at an elevation of 720 meters and crosses the right abutment ridge in a southwesterly direction up to a point west of the camp site. From the last point, the tunnel has a southerly course as far as the powerhouse site, which was to be located on the right bank of the river below the outlet of the North Luzon Power plant.

After a preliminary geological investigation of the abutment areas and the tunnel routes, modifications of the original design were recommended, namely: to re-orient the axis of the dam in order to have a maximum shoulder area at the right abutment; and to extend the impervious core on the fractured abutments so as to prevent leakage. Two significant features were pointed out. First, the tunnel intake, measuring about 1,400 meters long, will cross the highly broken metamorphics rather near the surface west of the camp site. Inasmuch as this is a pressure tunnel, steel liners set in heavy concrete are to be prescribed for the entire length of the intake structure. Hence, the cost will be quite high. Second, the left abutment ridge, which is underlain by diorite and metamorphics, appears to be a comparatively better site for the spillway.

The original plan was abandoned upon the recommendation of Mr. Leroy F. Harza, consulting engineer, and Mr. Irving B. Crosby, consulting geologist.

Present Development Plans

The outlay of the proposed engineering structures is shown in Plate III, and the construction details for the dam and the powerhouse are shown in Plate XI. The project involves an earth and rock fill dam, a spillway on the left abutment, an underground powerhouse, three diversion tunnels, and a tail race tunnel.

The top elevation of the dam is 756 meters. Since the bedrock elevation is 631 meters, the height of the dam is 125 meters. The maximum and minimum pool elevations are 752 and 694 meters respectively. This gives a maximum drawdown of 58 meters.

The impervious core will consist of clay and weathered rock with an upstream face composed entirely of clay material. Horizontal filters are provided through the rolled clay and weathered rock which are connected by an incline drain on the downstream end. The upstream face of the dam will be covered by a first layer of gravel extending from the coffer dam to elevation 752 meters and a second layer of random rock to about half of the inclined length from the base. The downstream face will be paved entirely with random rock.

The spillway will be provided with seven tainter gates, each 15 meters wide and 11 meters high, whose crest elevation is 752 meters. Since the river elevation at the south slope is a little less than 620 meters, the spill water will have a vertical drop of over 132 meters.

The power units will consist of 3 - 34,500 horsepower turbines coupled with 3 - 28,000 kilovolt-ampere generators. The centerline of the power units in the underground powerhouse is at elevation 574.10 meters. Therefore, the maximum and minimum heads available are 177.90 and 117.90 meters respectively. The plant will develop a capacity of 75,000 kilowatts at an estimated cost of $0.01 (U.S.) per kilowatt-hour. The excavation for the underground structures has a maximum cross-section which is 53 meters long, 9 meters wide, and 19.3 meters high.

The inlet portals of the three diversion tunnels are on the right abutment. The outlet of tunnel 10 is on the south slope of the right abutment. Tunnels 11 and 12 will cross under the river and their outlet portals will be on the southeast slope of the saddle just below the dam site. Tunnel 10 has an inner diameter of 4 meters. Its outside diameter may be as much as 7.20 meters. This tunnel will be kept in use after the completion of the dam in order to serve as an auxiliary outlet for flood waters and to contain a Bunger-Howell valve. The valve will be used to draw silt and other fine materials from the reservoir. Diversion tunnel 11 will be plugged eventually. Tunnel 12 will finally be used as the intake for a vertical penstock to the power units. The minimum height of excavation for the latter two tunnels is 8.5 meters.

The tail race tunnel is about 2.38 kilometers long (Plate XII). The inner diameter is 5.00 meters, and the minimum height of excavation will be 6.3 meters with a gothic arch. The tunnel will cross the river thrice before reaching the outlet.

Engineering Geology Problems

Each engineering structure has its own problems. The various structures will be dealt with in the following order:

A. Dam Proper

B. Spillway Site

C. Powerhouse Location

D. Diversion Tunnels

E. Tail Race Tunnel

F. Water Tightness of the Abutment Ridges

A. Dam Proper

It was pointed out that the metamorphics at the right abutment are severely fractured and those in the gully area are sheared and partly disintegrated (Plates IX-A to IX-E). The sheared zone has a maximum breadth of 130 meters (see Plate X) and extends from the upstream toe on the right bank of the river to the gully and spillway areas on the left abutment ridge (Plate III). Undisturbed specimens obtained from the test pit in drill hole 38 slake in water at a very slow rate and crumble easily under a slight pressure after the specimen had been exposed to the atmosphere.

It will be necessary, therefore, to protect the fractured abutment and the sheared zone under the impervious clay core. Long exposure to the atmosphere should be avoided during construction. It is not known whether the sheared metamorphics possess sufficient bearing strength to sustain the combined load of the fill materials and the overlying column of water. Tests should be made to determine the compressibility and plastic properties of the gougy material in drill hole 38.

Grouting operations at the base and abutments of the dam should follow the pattern adopted by the Tennessee Valley Authority[6]. The method consists of three sets, namely, consolidation grout, low-pressure grout cut-off, and high-pressure grout cut-off. The spacing and depth of the grout holes should be determined by field tests. For the TVA, consolidation grout holes are from 10- to 15-foot centers and 20 to 40 feet deep along 10-foot center-lines. Pressures applied range from 20 to 40 psi (pounds per square inch). Low-pressure grout cut-off holes are in staggered position with the first set, 40 to 60 feet deep, and using 40 to 60 psi. High pressure grout cut-off holes are deeper and may be spaced farther apart than the low-pressure grout holes. Pressures of 75 to 100 psi are applied.

<u>B. Spillway Site</u>

The metamorphics at the spillway site are deeply weathered, particularly along the north slope of the ridge. However, diorite crops out high up on the south slope (Plate IX-E). The diorite is a stronger foundation rock for it is less weathered than the metamorphics.

It was calculated that the spill water has a vertical drop of at least 132 meters, and unless the south slope of the ridge is provided with a pavement, the bedrock is likely to be scoured. Hence, it is recommended that a concrete pavement be provided which will act as a cushion for the overflowing water. It is also important to anchor the concrete sufficiently deep into the diorite, and to safeguard against sliding, concrete dowels should be provided. In addition, the upstream slope of the spillway must be water tight in order to prevent undermining or piping at the base of the concrete pavement. Grouting procedure to be followed is the same as outlined for the dam proper.

C. Powerhouse Location

The underground powerhouse requires the excavation of a single chamber which is 53 meters long, 9 meters wide, and 19.3 meters high. The problem involved is to select the right type of rock at a convenient site which requires a minimum of construction difficulty. A key to the solution of the problem is seen at the underground hydroelectric plant of the North Luzon Power Company, which is located a short distance below the Ambuclao dam site. The powerhouse was constructed in diorite 80 feet below river elevation at the intake. The chamber has a maximum span of seven meters and an unlined roof with a very flat arch. No serious maintenance problem has been encountered for the last 20 years. Consequently, the left bank of the river which is composed mostly of diorite was considered for exploration. Seven sites were investigated, of which six are on the left bank and one on the right bank of the river.

Three upstream locations on the left bank were explored by the following drill holes: (1) hole 66; (2) holes 91, 92, 93, and 94; and (3) holes 58 and 64. These three locations were abandoned because the diversion tunnels and the tail race tunnel would have had to cross the weak zone of the gully area. A fourth upstream location, drilled by holes 48 and 51, has the disadvantage of longer tunnel routes. In addition, several sections of the diorite show intense fracturing and kaolinization. Two downstream locations were examined; one of which was explored by hole 59-A and the other by hole 60. In these downstream sites, the diorite at the elevation of the powerhouse is highly fractured. Moreover, water pressure tests show unfavorable results.

The diorite exposure immediately downstream from drill hole 25 was the first site recommended by the geologists based on the good core recoveries from drill holes 24 and 25. However, the recommendation was not received with favor because of the location. Any site selected below the axis of the dam necessitates the construction of an access tunnel with a relatively steep grade. The access tunnel would subsequently be used to transport equipment into the underground powerhouse.

A comparative study of drilling and water pressure data indicates that the diorite on the right bank of the river is strong and massive. This was proven by holes 81, 97, 99, and 100.

It will be noted that the control chamber has a minimum back of only 10.5 meters of diorite below its contact with the metamorphics (Plate XI). This will require strong provisions for support of the roof of the chamber. Extreme care must be exercised during excavation to avoid undue shattering of the rock at the roof and sides of the chamber. Grouting operations should follow the procedure outlined under "Diversion Tunnels".

D. Diversion Tunnels

It was stated that the scheme of development requires the construction of three diversion tunnels, and the intake shaft will take off from one of the tunnels. The diversion tunnels are numbered 10, 11, and 12 (Plate III). At an early stage of the planning, two of the tunnels, 11 and 12, were proposed on the left bank of the river and would have had to cross the weak zone of metamorphics underlying the gully area. Since one of the tunnels will be a pressure tunnel and that the weak zone is an unfavorable location, the proposition was not adopted.

Diversion tunnel number 10 was completed in 1951. The constuction of the tunnel has proven that unweathered metamorphics, although fractured, can stand unsupported within the maximûm span of the tunnel excavation. Only the sections traversed by faults or shears require permanent timber supports during construction. This tunnel will be kept in continuous operation. A desilting valve will be provided near the outlet portal and this will require the excavation of a chamber above the roof of the tunnel for the control works. The practical problem is to select a suitable location along the tunnel line close to the outlet. Sound metamorphics were noted for a stretch of over 40 meters, whose near and far ends are respectively 50 and 90 meters away from the outlet portal. But the most important factor in the selection of the site is the consideration of the column of rock above the tunnel. To counteract uplift pressure, the vertical height of rock above the control chamber shall not be less than half the height of water that represents the difference between the maximum pool elevation and the elevation of the roof of the chamber. By this method, the water pressure will be resisted by the dead weight of the metamorphic rocks which have been conservatively assigned a specific gravity of two, taking into consideration the fractures and slips present in the metamorphics.

As stated before, diversion tunnel number 11 will be plugged after the completion of the dam, while tunnel number 12 will serve as the intake for a vertical penstock to the power units. Both tunnels will go through the contact between the diorite and the metamorphics and will cross under the river at the dam site. At a certain point under the river crossing, the tunnels have 10.5 meters of diorite back. Strong supports are to be prescribed in these sections, particularly tunnel number 12 which will be under high water pressure. It is also necessary that blasting operations during construction must not cause fragmentation of the rocks above the roof of the tunnels. Consequently, the method of tunneling must be carefully considered before the start of operations.

Grouting will also be an important consideration. Grout holes are to be spaced at 10-foot centers along the tunnel line and not more than five feet apart along the circumference. Depth of grout holes may range from 10 to 40 feet depending on the nature of the fractures present in the rock. Pressures of 75 to 100 psi are to be applied. Greater depths and maximum pressures are recommended for all pressure tunnels. Inasmuch as concrete has a very low tensile strength, the concrete lining should be tightly wedged into sound rock, or steel reinforcing bars must be provided.

E. Tail Race Tunnel

The present location of the tail tunnel is shown in Plate III. Three other locations were investigated. Alignments 1 and 2 were proposed by the engineers when they considered the upstream and downstream locations of the underground powerhouse on the left bank of the river. The first alignment crosses under the abandoned river channel in the "sombrero" area. Alignment 2 lies too close to the edge of the deep channel and to the metamorphics at the right bank of the river below its confluence with the Lebung river. Thus, alignment 3 was recommended. After the final selection of the powerhouse site at the right bank of the river, location number 3 was re-oriented to the present location.

The tail tunnel will not be under pressure since it will conduct discharge water from the turbines. It is possible, therefore, that a large section of the tunnel may be left unlined if sound country rock can be found. On this assumption, areas underlain by diorite were investigated. Contact zones and areas underlain by metamorphics were avoided as much as practicable. Furthermore, the centerline of the tail tunnel was made to follow high ridges and peaks of diorite (Plate XII).

At the three crossings under the river, the entire section of the tunnel must be lined with concrete. Faults and joints will have to be grouted.

F. Water Tightness of the Abutment Ridges

Of the several holes drilled on the left abutment, water pressure tests were conducted only in holes 43, 48, and 60. Hole 51 was partially tested. The main difficulty in testing a hole arose from caving in of the walls and drill "stuck-up" which necessitated reaming the hole and extending the casing pipes. The diameter of the enlarged holes were much bigger than that of the seals provided in the pressure testing device.

Although core recoveries from drill holes at the left abutment ridge are commonly poor, the return water has always been considerable. Moreover, two springs occur a short distance east of the spillway site. One spring emerges at elevation 769.57 meters, and the other at elevation 764.29 meters. The crest elevation of the spillway is 752 meters. Thus, a fairly water tight condition of the rocks at the spillway area is indicated. The only section of the left abutment which requires further study is the diorite in hole 60. Water pressure tests showed higher rates of flow and, in addition, the rock is highly fractured. These findings have important bearing on the abnormal condition of the water table in hole 25. Drill hole 25 is inclined towards hole 60.

It is unfortunate that no EX-pressure testing apparatus was at hand during the drilling at the right abutment ridge. Test can not be made for many of the holes are clogged. It was stated earlier that joints and slips intersected by diversion tunnel number 10 have only minor flows of water. Furthermore, fractures in the unweathered metamorphics are free from clay and grouting operations can be carried out effectively. The only possible problem is that leakage may occur along the contacts of the granodiorite dike with the metamorphics. A spring, whose elevation is 665 meters, marks the contact between the two formations on the south slope of the ridge. It was noted that higher rates of flow occur during the rainy months. It is to be expected, therefore, that when the water in the reservoir is raised to its maximum pool elevation, the spring will also register larger flows. Another problem related to the seepage at the contacts is the possible build-up of water pressure. The provision of drain holes may be a remedial measure.

CHAPTER V

BORROW PITS AND QUARRY SITES

Borrow Pit Investigation

The first area investigated was the residual clay deposit at Bisal, 6.5 klometers, airline distance, southeast of the dam site. On account of the unfavorable location, which requires costly road construction, search for the clay fill was made among the river bar deposits. The abandoned river channel around the "sombrero" was recommended for investigation by Mr. Crosby early in 1949. Test pits were sunk to as much as 30 feet deep where cobbles and boulders were encountered. The deposit consists of unconsolidated clays, silts, sands, and gravels. It was estimated that about half of the fill materials needed in the original design may be obtained from this meander cut-off.

During the middle part of 1949, a revised plan of the dam was submitted by the Harza Engineering Company. Based on the new design, decomposed and disintegrated rocks are suitable fill materials for the central core of the dam (Plate XI).

Two borrow areas were examined (Plate III). Borrow Area No. 1 is on the northwesterly extension of the right abutment ridge, with the lower limit set at 800 meters contour. Borrow Area No. 1-B lies west-southwest of Borrow Area No. 1 and has the lower limit at contour 850 meters. The greater part of Borrow Area No. 1-B occupies the ridge above the road to the plant of the North Luzon Power Company. Contours 800 and 850 meters were chosen arbitrarily for two reasons: first, to limit the area where a sufficient number of test pits may be excavated without much difficulty; and, second, to include only areas which are elevated enough such that a convenient grade can be had for transporting fill materials to the dam.

Forty seven test pits were excavated in the two areas. The depth of weathered rocks ranges from 3.40 to 27.90 meters. Blocks and lenses of unweathered metamorphics were often encountered. Extension in depth was carried on as far as the ordinary pick and shovel method of excavation was deemed feasible. Use of blasting powder was not allowed.

The mantle of weathered rock varies in thickness. It sometimes disregards topographic similarity even in areas of the same rock type. Such factors as the type of rock, orientation and magnitude of fracturing, and topography exercise varying degrees of influence on the resulting thickness of the residual clay. These factors were carefully considered in the computation of reserves.

In estimating reserves, calculation was based on the "area of influence" method. The depth of a single test pit is used in the computation of average depth as many number of times as there are pits around it. Such a procedure avoids either over- or under-valuation of the deposit. This is due to the fact that most of the test pits were located on top of ridges where the thickness of the clay is greater than the average for the area which an individual pit represents. Moreover, the soil profile shows a very irregular bottom on account of the difference in the attitude and degree of fracturing of the underlying rocks.

Borrow Areas 1 and 1-B are estimated to contain 9,000,000 cubic meters of clay and weathered rock. The volume available exceeds the requirement for the central core of the dam.

Quarry Site Investigation

One upstream and two downstream locations of rock quarries were investigated. The site upstream from the dam is approximately 160 meters north of drill hole 66. The two downstream sites are located above the right bank of the river past the intake of the North Luzon Power Company. The selection of upstream and downstream sites was based on the premise that simultaneous quarrying operations may be carried on and that transport of quarry rock to either face of the dam will not interfere with any construction operations that may be in progress at the central portion of the dam.

The three quarry sites are underlain by diorite with very steep slopes, so that much of the weathered surface had already been eroded. At least one meter thick of the diorite face would be removed before the start of quarrying operations.

Part of the random or ungraded rock may be obtained from the river boulders. Selective mining is to be made due to the presence of boulders of shale.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The most important problems involved in the construction of Ambuclao dam are as follows:

(1) Partly disintegrated, highly sheared metamorphics underlie the spillway site and the gully area on the left abutment of the dam. Inclined holes 44 and 45 disclosed that the weak zone in the gully has a maximum width of 130 meters. Drill hole 38 revealed that the gougy material extends down to elevation 558.90 meters, which is the bottom of the drill hole. The gougy material slakes slowly in water and disintegrates under a slight pressure upon dehydration.

The gougy material should be subjected to compaction, shear, and compression tests. The plastic behaviour is a major consideration with respect to the amount of allowable settlement.

(2) Fractured metamorphics occur at the right abutment, along the upstream toe of the dam, and at certain sections below the coffer dam. An extensive grouting program must be undertaken to protect the foundation rocks from scour and to prevent leakage.

(3) On the right abutment ridge, the principal problems are seepage and possible build-up of water pressure on the south slope of the ridge along the contacts between

the granodiorite dike and the metamorphics. Drain holes may be provided in order to relieve water pressure.

(4) Tunnel lines along contact zones and under river crossings with comparatively thin backs, particularly diversion tunnels 11 and 12 and the tail race tunnel, will require very strong supports.

(5) The diorite explored by holes 81, 97, 99, and 100 is considered the most favorable location for the underground powerhouse.

(6) The diorite and metamorphics are quite susceptible to weathering. Below the water table, however, both rocks are sound even if fractured and can stand unsupported for a considerable span. Diorite is usually homogenous and massive and possesees a comparatively greater competency than the metamorphics. Therefore, underground structures should be located in diorite.

The foregoing description of the Ambuclao dam site illustrates the various problems involved in constructing a high earth dam on metamorphic rocks and diorite. These rock types are common in the Agno river valley and underlie, too, the principal structures of the proposed Binga development.

The investigation of the foundation rocks of Ambuclao dam has involved both local and regional geological mapping. Aerial photos were very useful in the delineation of formational contacts and in the study of the geologic structures of the region. Detailed study of the geology of the dam site required an extensive drilling program, hydraulic sluicing, and the excavation of several trenches, pits, shafts, and tunnels.

The design of all engineering structures was not finalized until sufficient geologic data had been obtained from surface and subsurface investigations. This procedure demonstrates the practical application of geologic principles to treat engineering problems.

Diamond drilling is the most convenient method usually employed in subsurface explorations. Large diameter drill holes, however, are preferable to test shafts in the study of certain critical areas that are underlain by hard rocks.

The distribution, orientation, and depth of drill holes should be left to the judgement of the geologist. Distribution of drill holes along a straight line and at pre-determined intervals, a pattern which engineers commonly adopt, is not always effective in subsurface studies of the foundation rocks.

In the planning and investigation for the power development of a region, the study of aerial photos is one of the most valuable sources of information. The cost of preliminary surveys may be greatly reduced. Moreover, certain geologic structures are usually recognizable on the relief map of a region. These major structures may easily escape notice in the study of restricted areas.

The choice of a dam site must be based on both engineering and geological factors. Unnecessary delays and high construction sosts result from an incomplete understanding of the geology.

Finally, the writer wishes to emphasize the necessity of an atmosphere of cooperation and mutual respect in the relations between the geologist and the engineer. The geologist should understand that there are other important factors besides a consideration of the geology in the development of hydroelectric projects. It is the duty of the geologist to present to the engineer as clearly as possible the geologic problems involved. On the other hand, the engineer should consult the geologist whenever changes are made in the plans. Over-conservatism in the design, which means high cost of construction, is thus prevented.

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4, Irving, E. M. and Oca, G. R., 1950, "Notes on the Geology of the Basement Complex along the Bokod Trail, Mt. Province, Luzon," Philippine Geologist, Vol. 4, No. 3, pp. 11 - 23.

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6. Tennessee Valley Authority, 1949, "Geology and Foundation Treatment," Tech. Report No. 22, U. S. Gov't. Printing Office, Washington, 548 pp.

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8. __________, 1924, "Geology and Mineral Resources of the Philippine Islands," Philippine Bureau of Mines, 559 pp.

9. Willis, Bailey, 1937, "Geologic Observations in the Philippine Archipelago," National Research Council Bulletin No. 13, pp.1-127.

BIOGRAPHICAL NOTE

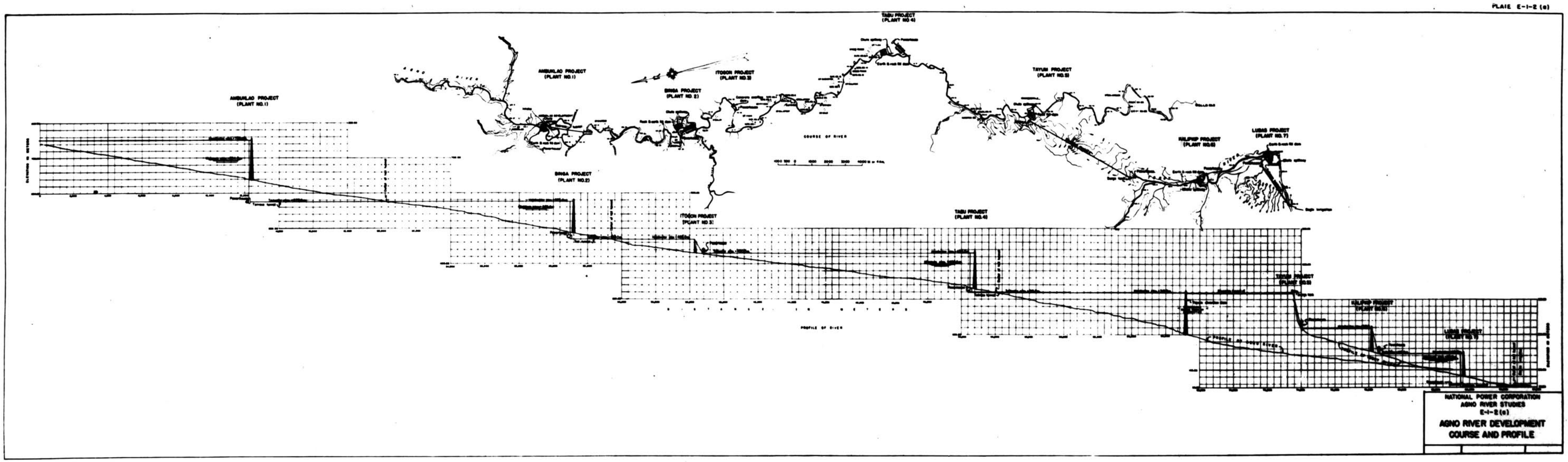
Born on February 18, 1917 in Pila, Laguna, Philippines, of Evaristo R. Oca and Maria Rebong (deceased). Married Constancia Madlansacay of Indang, Cavite in 1942. Marriage blessed with three children, namely, Nevin - 10 years, Liberty - 7 years, and Sandra - 3 years.

Finished the elementary course in 1930, graduated from the Laguna Public High School in 1934, and obtained a B. S. at the Mapua Institute of Technology in 1938.

Appointed as Surveyor's assistant by the Philippine Bureau of Mines in February 1939. Passed the licensed Mining Engineer's examination, 4th place, in February 1939, and the Geologic Aide examination, 3rd place, in May 1939. Promoted to Geologic Aide in July 1939.

Joined the resistance movement (1st Lt., Intelligence Officer) during the Japanese occupation, and assisted in the liberation of the Americans from the Los Banos internment camp in 1945.

Reported to the Bureau late in 1945. Promoted to Assistant Geologist in 1946. Passed the "Pensionado" competitive examination in Economic Geology, 1st place, in 1947. Promoted to Geologist in 1947. Passed the Geologist examination, 2nd place, in 1948. Loaned to the National Power Corporation from June 1947 to July 1950 to undertake foundation investigations of dam sites. Recalled to the Bureau in July 1950 and appointed as Senior Geologist. Selected as a trainee in Engineering Geology for advanced studies and in-service training by the United States Mutual Security Agency.



PLAIE E-1-2 (a)
TABU PROJECT
(PLANT NO.4)
AMBUKLAO PROJECT
(PLANT NO.1)
ITOGON PROJECT
(PLANT NO.3)
BINGA PROJECT
(PLANT NO.2)
TAYUM PROJECT
(PLANT NO.5)
COURSE OF RIVER
KALIPKIP PROJECT
(PLANT NO.6)
LUBAS PROJECT
(PLANT NO.7)
AMBUKLAO PROJECT
(PLANT NO.1)
BINGA PROJECT
(PLANT NO.2)
ITOGON PROJECT
(PLANT NO.3)
TABU PROJECT
(PLANT NO.4)
PROFILE OF RIVER
NATIONAL POWER CORPORATION
AGNO RIVER STUDIES
E-1-2 (a)
AGNO RIVER DEVELOPMENT
COURSE AND PROFILE

PLATE I

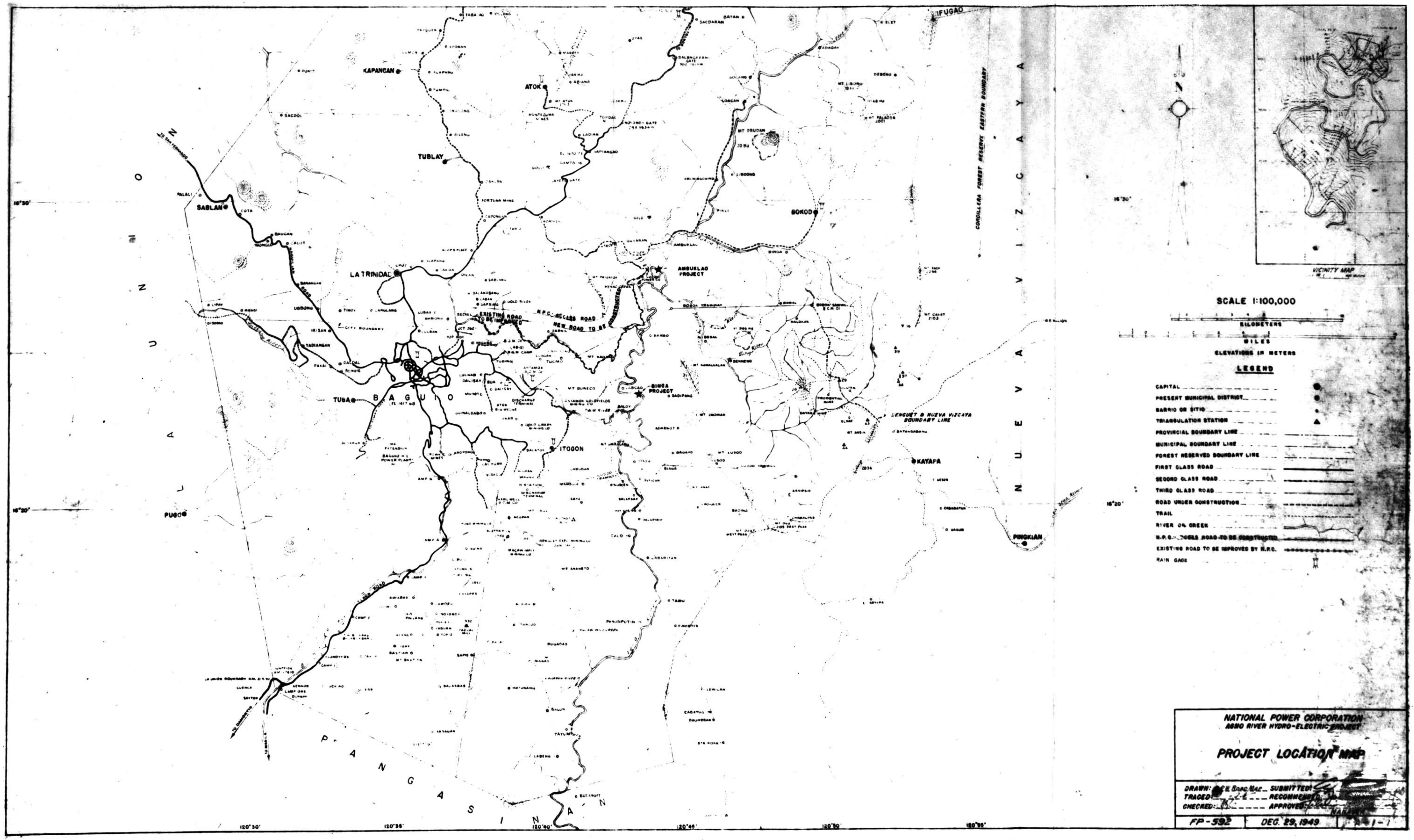
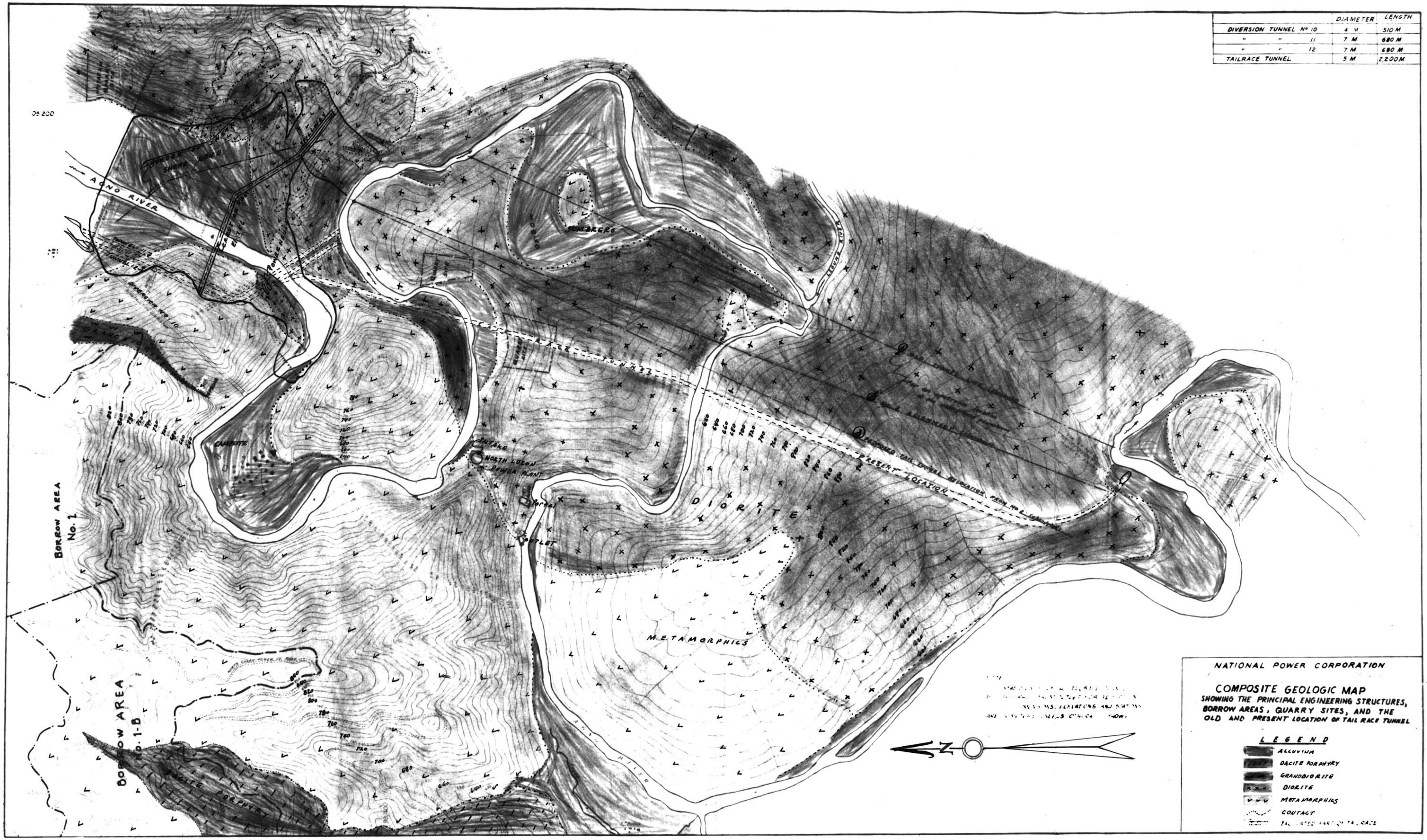

NATIONAL POWER CORPORATION
AGNO RIVER HYDRO-ELECTRIC PROJECT
PROJECT LOCATION MAP
DRAWN:
TRACED:
CHECKED:
SUBMITTED:
RECOMMENDED:
APPROVED:
FP-592
DEC. 29, 1949
SCALE 1:100,000
KILOMETERS
MILES
ELEVATIONS IN METERS
LEGEND
CAPITAL
PRESENT MUNICIPAL DISTRICT
BARRIO OR SITIO
TRIANGULATION STATION
PROVINCIAL BOUNDARY LINE
MUNICIPAL BOUNDARY LINE
FOREST RESERVED BOUNDARY LINE
FIRST CLASS ROAD
SECOND CLASS ROAD
THIRD CLASS ROAD
ROAD UNDER CONSTRUCTION
TRAIL
RIVER OR CREEK
EXISTING ROAD TO BE IMPROVED BY N.P.C.
RAIN GAGE
VICINITY MAP
IFUGAO
NUEVA VIZCAYA
LA UNION
PANGASINAN
CORDILLERA FOREST RESERVE EASTERN BOUNDARY
BENGUET & NUEVA VIZCAYA BOUNDARY LINE
KAPANGAN
ATOK
TUBLAY
SABLAN
LA TRINIDAD
BAGUIO
TUBA
ITOGON
BOKOD
KAYAPA
PUGO
PINGKIAN
AMBUKLAO PROJECT
BINGA PROJECT
EXISTING ROAD TO BE IMPROVED
N.P.C. ACCESS ROAD
NEW ROAD TO BE
16°30'
16°20'
120°30'
120°35'
120°40'
120°45'
120°50'
120°55'

PLATE-II



DIAMETER
LENGTH
DIVERSION TUNNEL Nº 10
4 M
510 M
" " 11
7 M
680 M
" " 12
7 M
680 M
TAILRACE TUNNEL
5 M
2,200M
AGNO RIVER
CAMPSITE
NORTH LUZON
POWER PLANT
OUTLET
DIORITE
METAMORPHICS
PRESENT LOCATION
BORROW AREA
No. 1
BORROW AREA
No. 1-B
NATIONAL POWER CORPORATION
COMPOSITE GEOLOGIC MAP
SHOWING THE PRINCIPAL ENGINEERING STRUCTURES,
BORROW AREAS, QUARRY SITES, AND THE
OLD AND PRESENT LOCATION OF TAIL RACE TUNNEL
LEGEND
ALLUVIUM
DACITE PORPHYRY
GRANODIORITE
DIORITE
METAMORPHICS
CONTACT

PLATE III

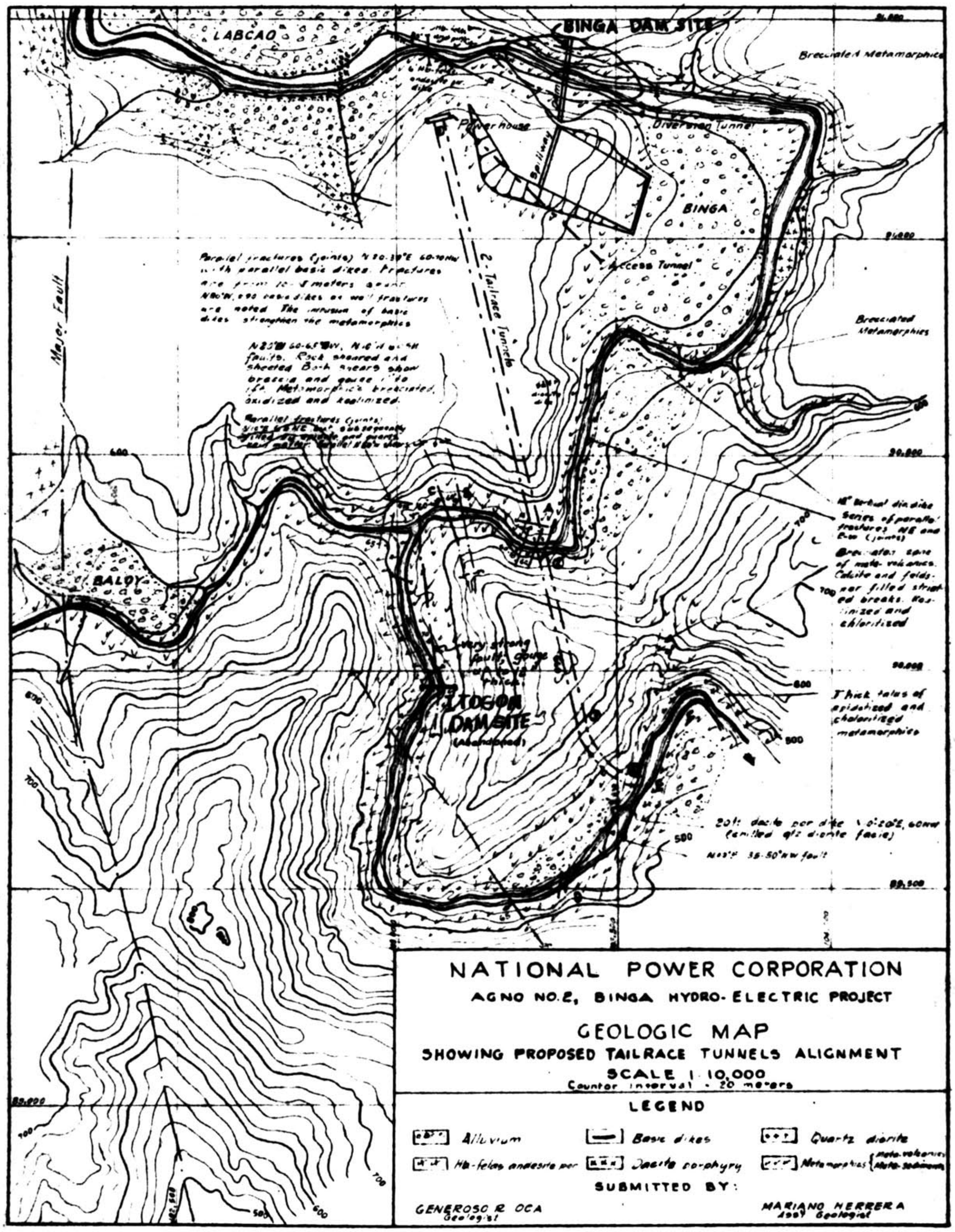

LABCAO
BINGA DAM SITE
Brecciated Metamorphics
Powerhouse
Spillway
Diversion Tunnel
BINGA
Access Tunnel
Tailrace Tunnels
Major Fault
Brecciated Metamorphics
Parallel fractures (joints) N 20-30°E 60-70NW with parallel basic dikes. Fractures are from 10-5 meters apart.
The intrusion of basic dikes strengthen the metamorphics
Rock sheared and sheeted
brecciated, oxidized and kaolinized.
Parallel fractures (joints)
Series of parallel fractures NE and E-W (joints)
Calcite and feldspar filled breaks.
chloritized
Thick talus of epidotized and cholorotized metamorphics
BALOY
ITOGON DAM SITE
(Abandoned)
N 03°E 35-50° NW fault
600
700
800
900
500
NATIONAL POWER CORPORATION
AGNO NO. 2, BINGA HYDRO-ELECTRIC PROJECT
GEOLOGIC MAP
SHOWING PROPOSED TAILRACE TUNNELS ALIGNMENT
SCALE 1:10,000
Countor interval - 20 meters
LEGEND
Alluvium
Basic dikes
Quartz diorite
Hb-feldspar andesite por
Dacite porphyry
Metamorphics
Meta-volcanics
Meta-sediments
SUBMITTED BY:
GENEROSO R. OCA
Geologist
MARIANO HERRERA
Asst. Geologist

PLATE IV

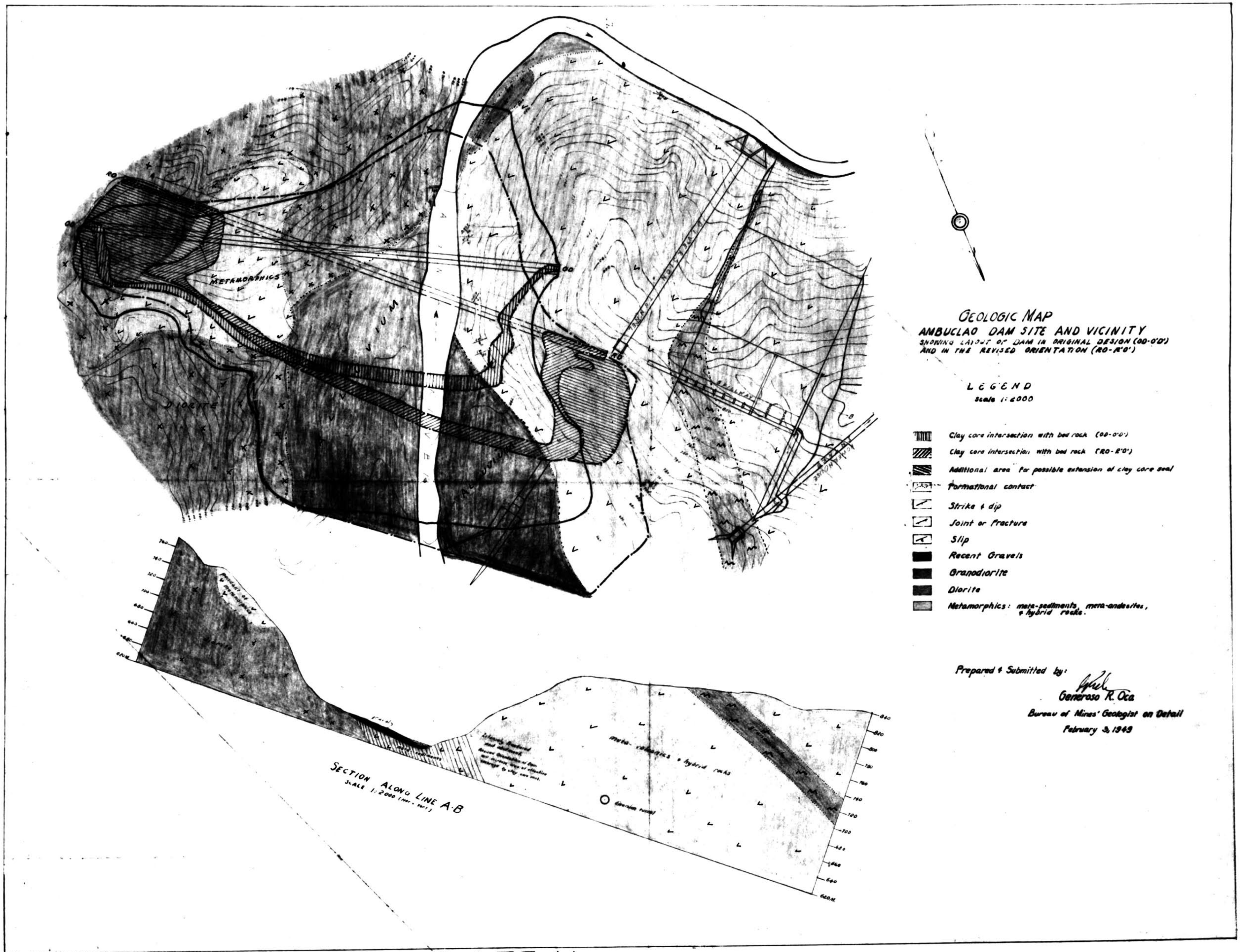

GEOLOGIC MAP
AMBUCLAO DAM SITE AND VICINITY
SHOWING LAYOUT OF DAM IN ORIGINAL DESIGN (OD-O'D')
AND IN THE REVISED ORIENTATION (RO-R'O')
LEGEND
Scale 1:2000
Clay core intersection with bed rock (OD-O'D')
Clay core intersection with bed rock (RO-R'O')
Additional area for possible extension of clay core seal
Formational contact
Strike & dip
Joint or Fracture
Slip
Recent Gravels
Granodiorite
Diorite
Metamorphics: meta-sediments, meta-andesites, & hybrid rocks.
METAMORPHICS
DIORITE
SECTION ALONG LINE A-B
SCALE 1:2000 (HOR. - VER.)
meta-volcanics & hybrid rocks
Prepared & Submitted by:
Generoso R. Oca
Bureau of Mines' Geologist on Detail
February 3, 1949

PLATE V

PLATE VI

NATIONAL POWER CORPORATION
AGNO RIVER No. 1 HYDROELECTRIC PROJECT
AMBUKLAO DEVELOPMENT

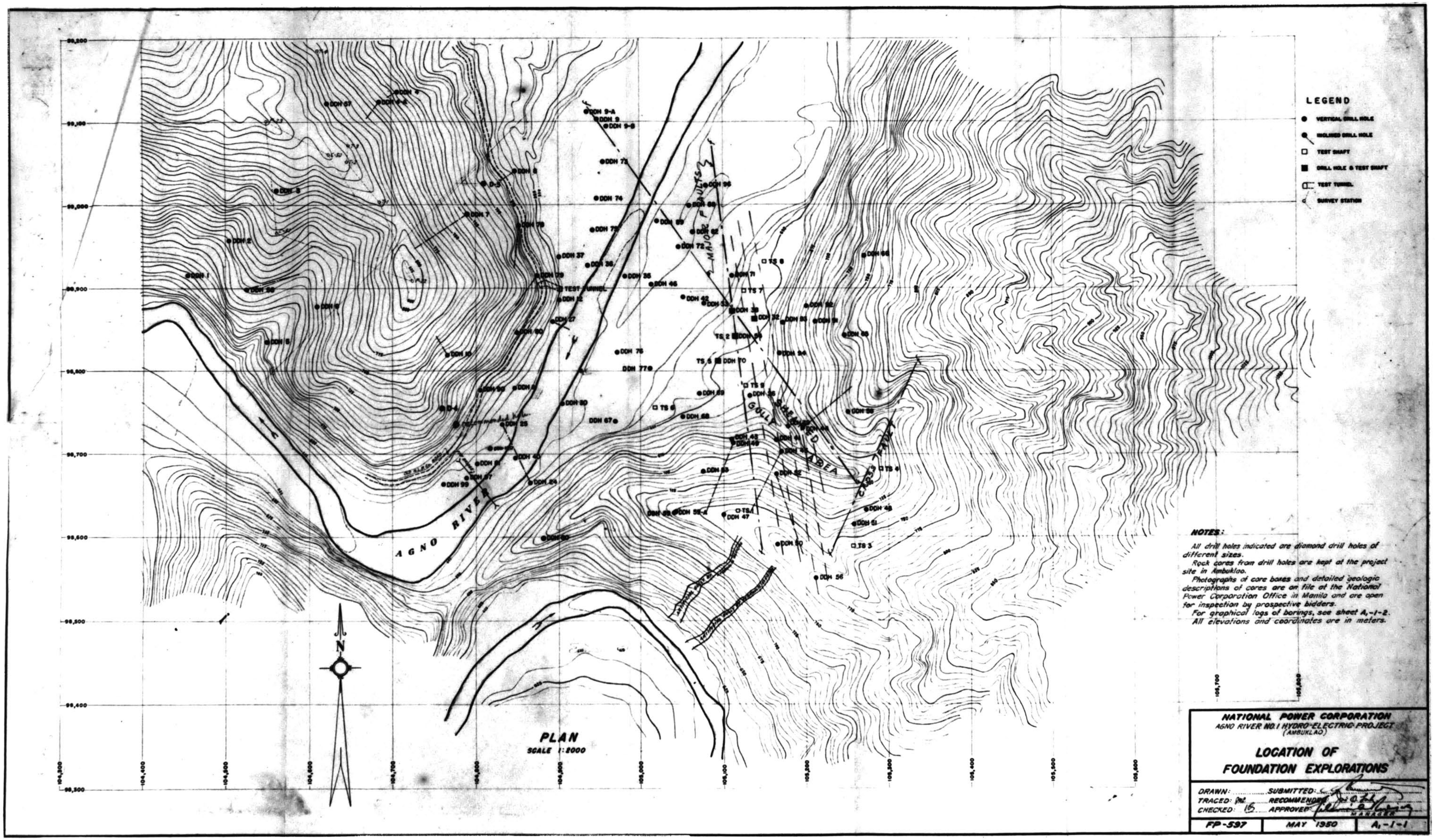

LEGEND
VERTICAL DRILL HOLE
INCLINED DRILL HOLE
TEST SHAFT
DRILL HOLE & TEST SHAFT
TEST TUNNEL
SURVEY STATION
NOTES:
All drill holes indicated are diamond drill holes of different sizes.
Rock cores from drill holes are kept at the project site in Ambuklao.
Photographs of core boxes and detailed geologic descriptions of cores are on file at the National Power Corporation Office in Manila and are open for inspection by prospective bidders.
For graphical logs of borings, see sheet A,-1-2.
All elevations and coordinates are in meters.
AGNO RIVER
TEST TUNNEL
PLAN
SCALE 1:2000
N
NATIONAL POWER CORPORATION
AGNO RIVER NO.1 HYDRO-ELECTRIC PROJECT
(AMBUKLAO)
LOCATION OF
FOUNDATION EXPLORATIONS
DRAWN:
TRACED:
CHECKED:
SUBMITTED:
RECOMMENDED:
APPROVED:
MANAGER
FP-597
MAY 1950
A,-1-1

PLATE VII

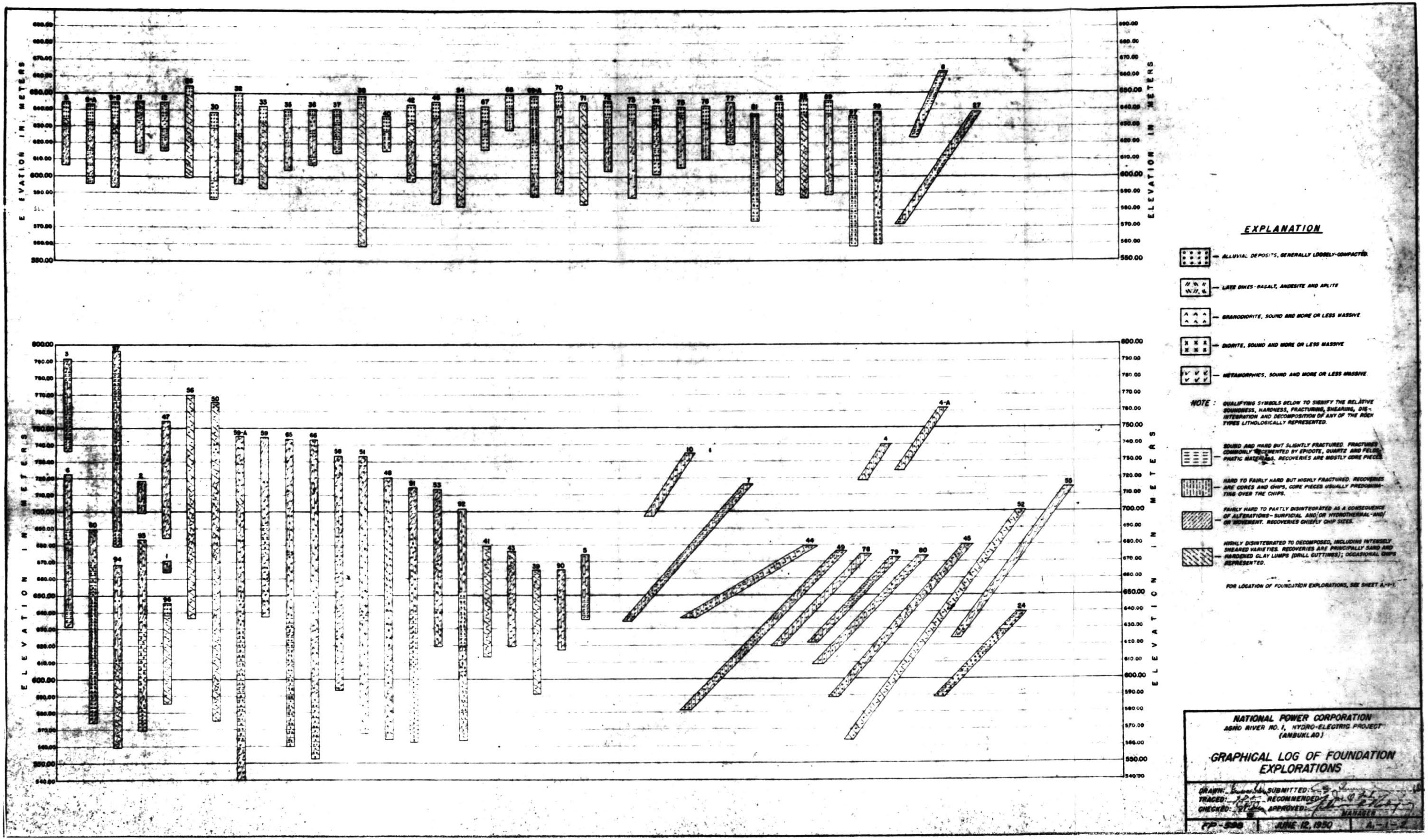
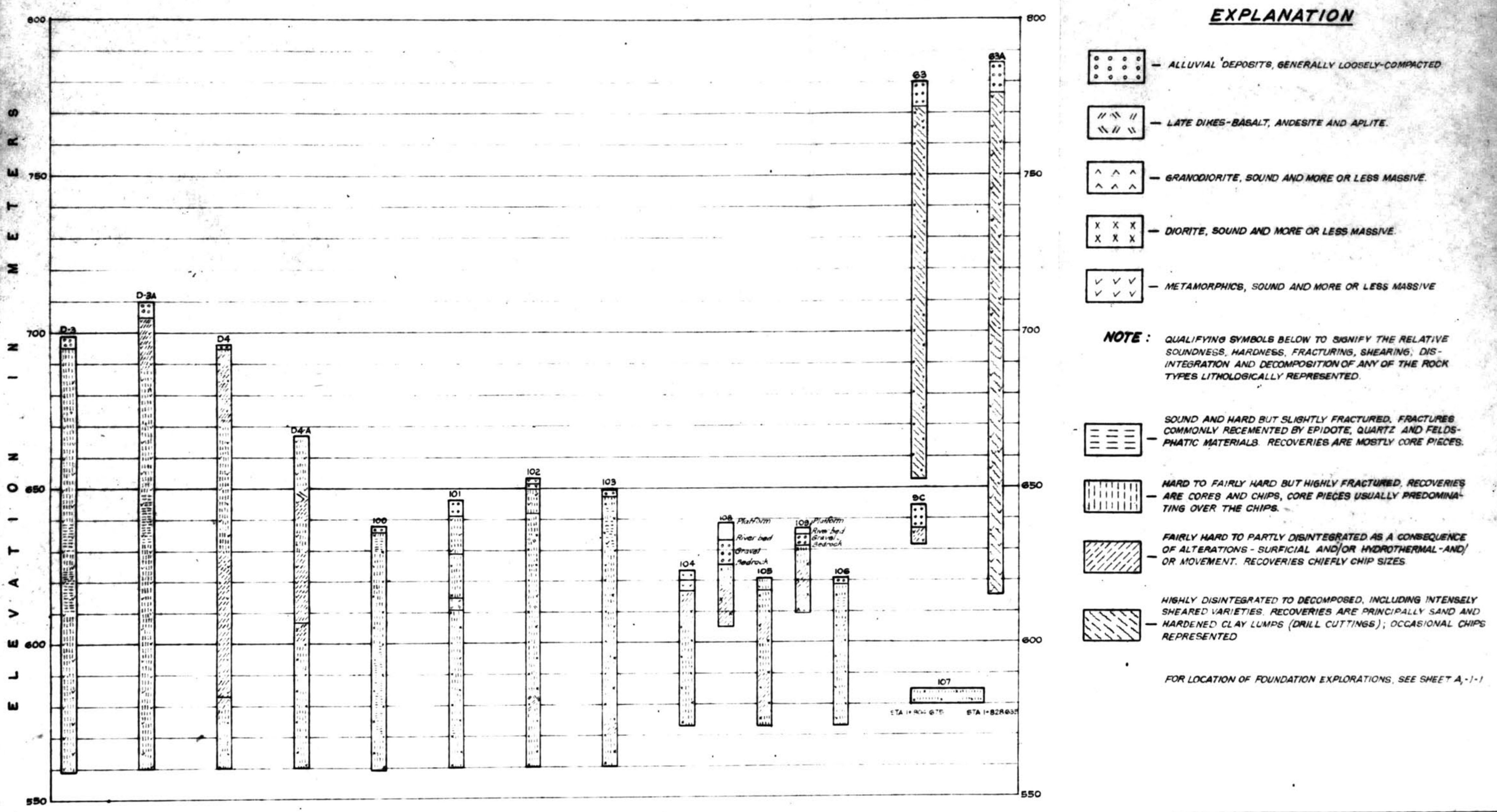

ELEVATION IN METERS
EXPLANATION
ALLUVIAL DEPOSITS, GENERALLY LOOSELY-COMPACTED.
LATE DIKES-BASALT, ANDESITE AND APLITE
GRANODIORITE, SOUND AND MORE OR LESS MASSIVE.
DIORITE, SOUND AND MORE OR LESS MASSIVE
METAMORPHICS, SOUND AND MORE OR LESS MASSIVE.
NOTE: QUALIFYING SYMBOLS BELOW TO SIGNIFY THE RELATIVE SOUNDNESS, HARDNESS, FRACTURING, SHEARING, DISINTEGRATION AND DECOMPOSITION OF ANY OF THE ROCK TYPES LITHOLOGICALLY REPRESENTED.
SOUND AND HARD BUT SLIGHTLY FRACTURED. FRACTURES COMMONLY RECEMENTED BY EPIDOTE, QUARTZ AND FELDSPATHIC MATERIALS. RECOVERIES ARE MOSTLY CORE PIECES.
HARD TO FAIRLY HARD BUT HIGHLY FRACTURED. RECOVERIES ARE CORES AND CHIPS, CORE PIECES USUALLY PREDOMINATING OVER THE CHIPS.
FAIRLY HARD TO PARTLY DISINTEGRATED AS A CONSEQUENCE OF ALTERATIONS- SURFICIAL AND/OR HYDROTHERMAL- AND/OR MOVEMENT. RECOVERIES CHIEFLY CHIP SIZES.
HIGHLY DISINTEGRATED TO DECOMPOSED, INCLUDING INTENSELY SHEARED VARIETIES. RECOVERIES ARE PRINCIPALLY SAND AND HARDENED CLAY LUMPS (DRILL CUTTINGS); OCCASIONAL CHIPS REPRESENTED.
FOR LOCATION OF FOUNDATION EXPLORATIONS, SEE SHEET A,-1-1.
NATIONAL POWER CORPORATION
AGNO RIVER NO. 1, HYDRO-ELECTRIC PROJECT
(AMBUKLAO)
GRAPHICAL LOG OF FOUNDATION EXPLORATIONS
DRAWN:
SUBMITTED:
TRACED:
RECOMMENDED:
CHECKED:
APPROVED:
MANAGER
FP-598
JUNE 12, 1950
A,-1-2

PLATE VIII-A



NATIONAL POWER CORPORATION
AGNO RIVER NO. 1 HYDRO-ELECTRIC PROJECT
(AMBUKLAO)

GRAPHICAL LOG OF FOUNDATION EXPLORATIONS

DRAWN .... SUBMITTED ....
TRACED .... RECOMMENDED ....
CHECKED .... APPROVED ....
ACTG. GENERAL MANAGER

MAY 2, 1952 | A,-1-2A

PLATE VIII-B

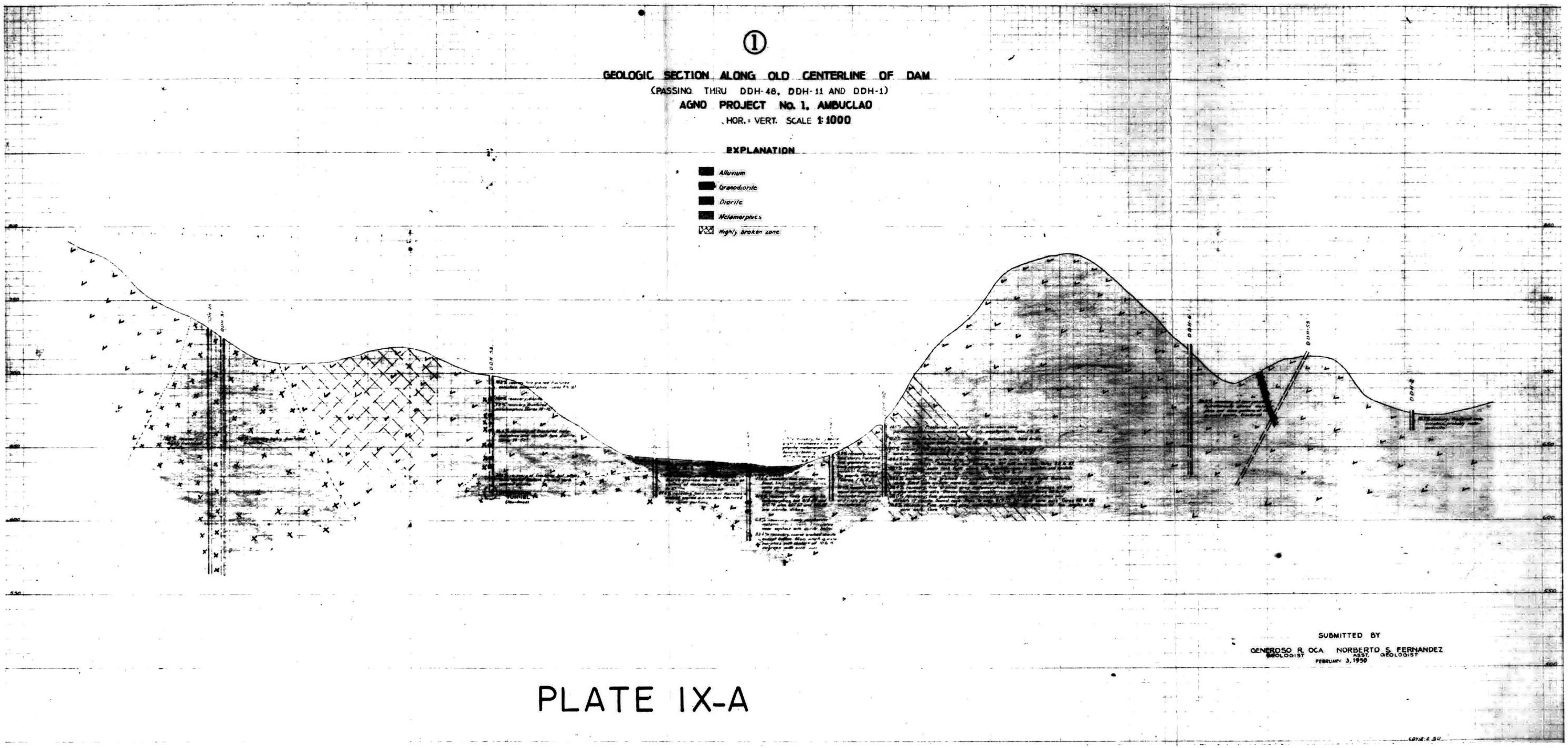
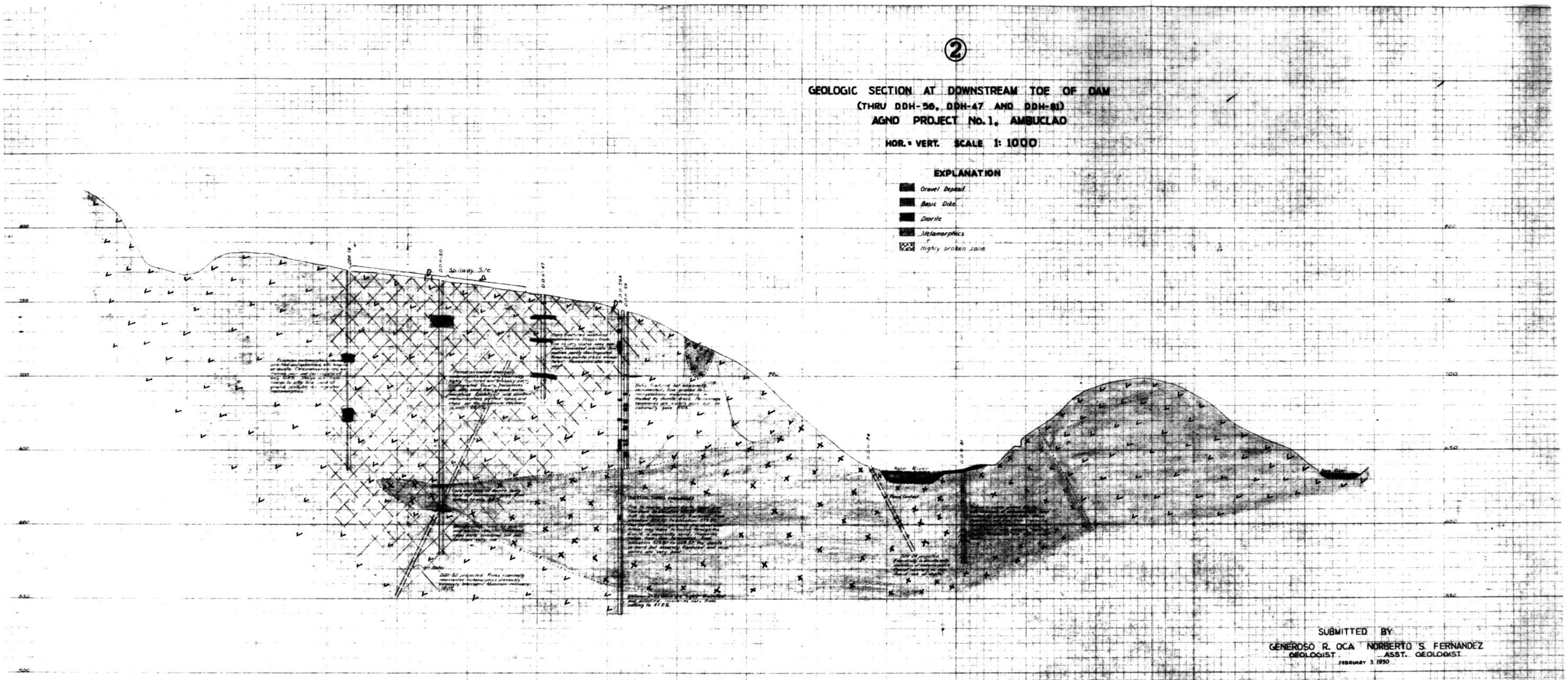
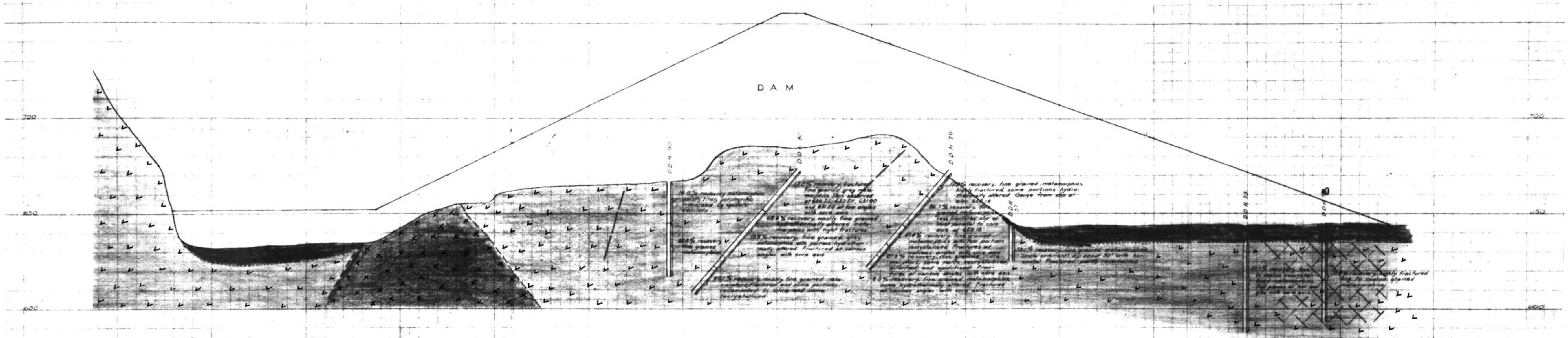

①
GEOLOGIC SECTION ALONG OLD CENTERLINE OF DAM
(PASSING THRU DDH-48, DDH-11 AND DDH-1)
AGNO PROJECT No. 1, AMBUCLAO
HOR. = VERT. SCALE 1:1000
EXPLANATION
Alluvium
Granodiorite
Diorite
Metamorphics
Highly broken zone
SUBMITTED BY
GENEROSO R. OCA
GEOLOGIST
NORBERTO S. FERNANDEZ
ASST. GEOLOGIST
FEBRUARY 3, 1950

PLATE IX-A



②
GEOLOGIC SECTION AT DOWNSTREAM TOE OF DAM
(THRU DDH-56, DDH-47 AND DDH-81)
AGNO PROJECT No. 1, AMBUCLAO
HOR. = VERT. SCALE 1: 1000
EXPLANATION
Gravel Deposit
Basic Dike
Diorite
Metamorphics
Highly broken zone
Spillway Site
Agno River
SUBMITTED BY:
GENEROSO R. OCA
GEOLOGIST
NORBERTO S. FERNANDEZ
ASST. GEOLOGIST
FEBRUARY 3, 1950

PLATE IX-B



③

GEOLOGIC SECTION AT WEST ABUTMENT
(THRU DDH-73 AND 90)
AGNO PROJECT No. 1, AMBUCLAO
HOR. = VERT. SCALE 1:1000

EXPLANATION

- *Gravel or Alluvium*
- *Basic Dikes*
- *Diorite*
- *Metamorphics*
- *Highly broken zone*

SUBMITTED BY:
GENEROSO R. OCA — GEOLOGIST
NORBERTO S. FERNANDEZ — ASST. GEOLOGIST
FEBRUARY 3, 1950

PLATE IX-C

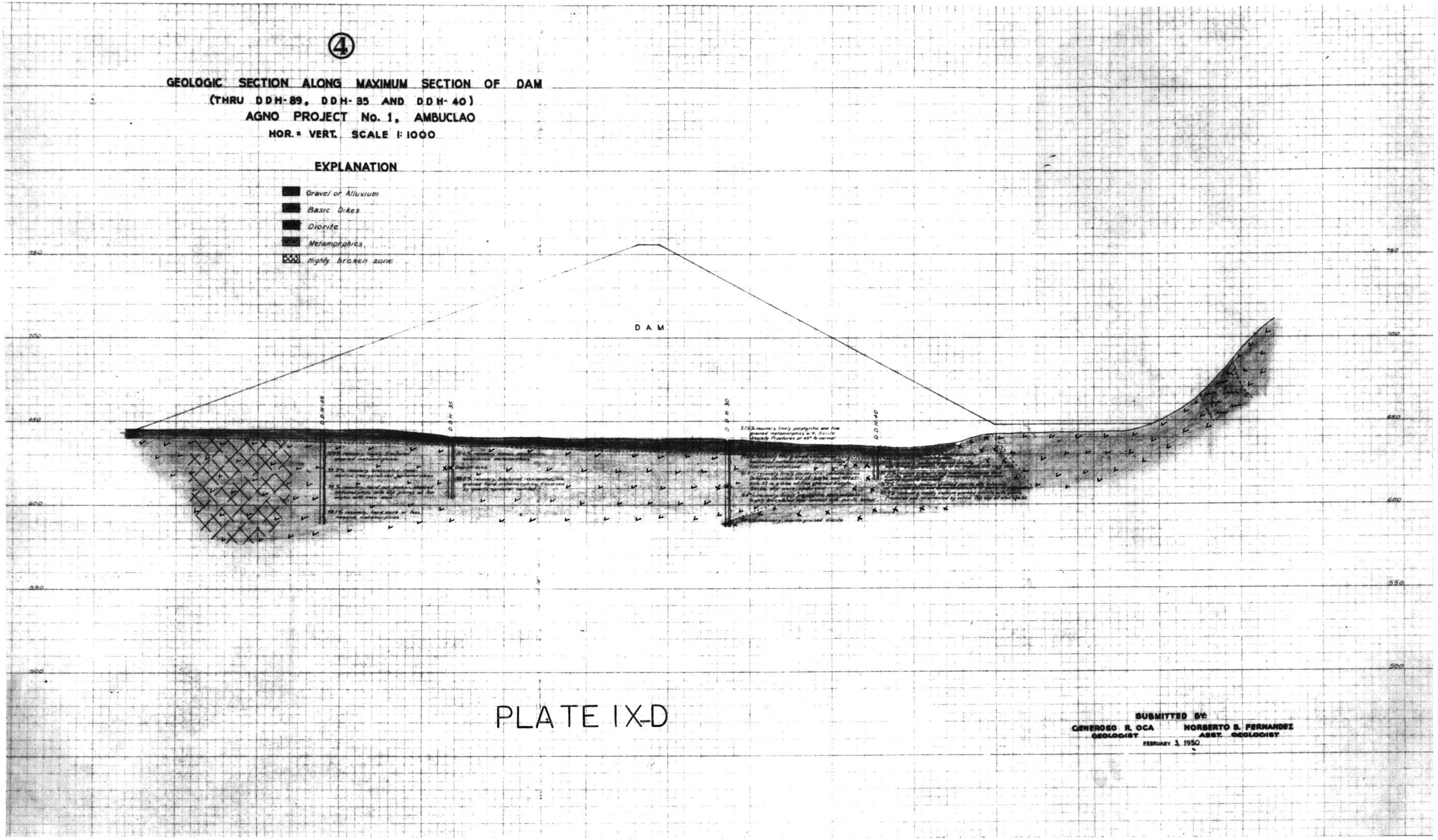

④
GEOLOGIC SECTION ALONG MAXIMUM SECTION OF DAM
(THRU DDH-89, DDH-35 AND DDH-40)
AGNO PROJECT No. 1, AMBUCLAO
HOR. = VERT. SCALE 1:1000
EXPLANATION
Gravel or Alluvium
Basic Dikes
Diorite
Metamorphics
Highly broken zone
750
700
650
600
550
500
DAM
DDH-89
DDH-35
DDH-30
DDH-40
SUBMITTED BY:
GENEROSO R. OCA
GEOLOGIST
NORBERTO S. FERNANDEZ
ASST. GEOLOGIST
FEBRUARY 3, 1950

PLATE IX-D

⑤

GEOLOGIC SECTION AT EAST ABUTMENT

(THRU DDH-54 AND DDH-59)

AGNO PROJECT No. 1, AMBUCLAO

HOR. = VERT. SCALE 1:1000

EXPLANATION

- *Gravel or Alluvium*
- *Basic Dikes*
- *Diorite*
- *Metamorphics*
- *Highly broken zone*

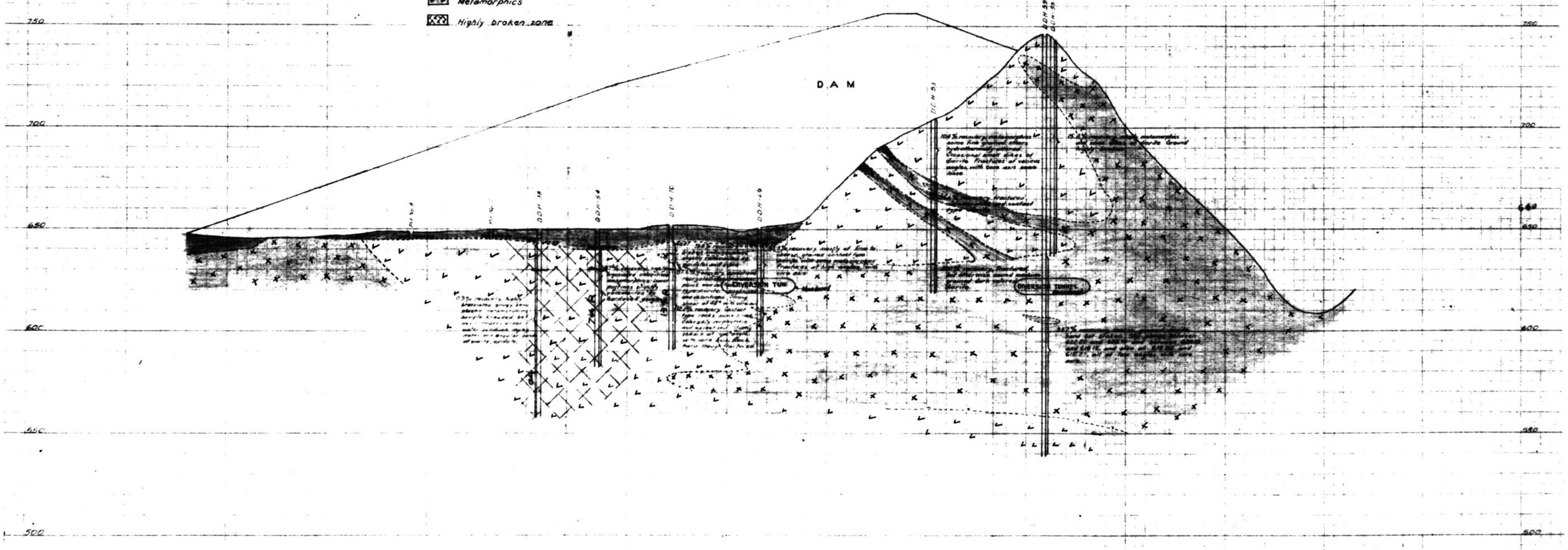


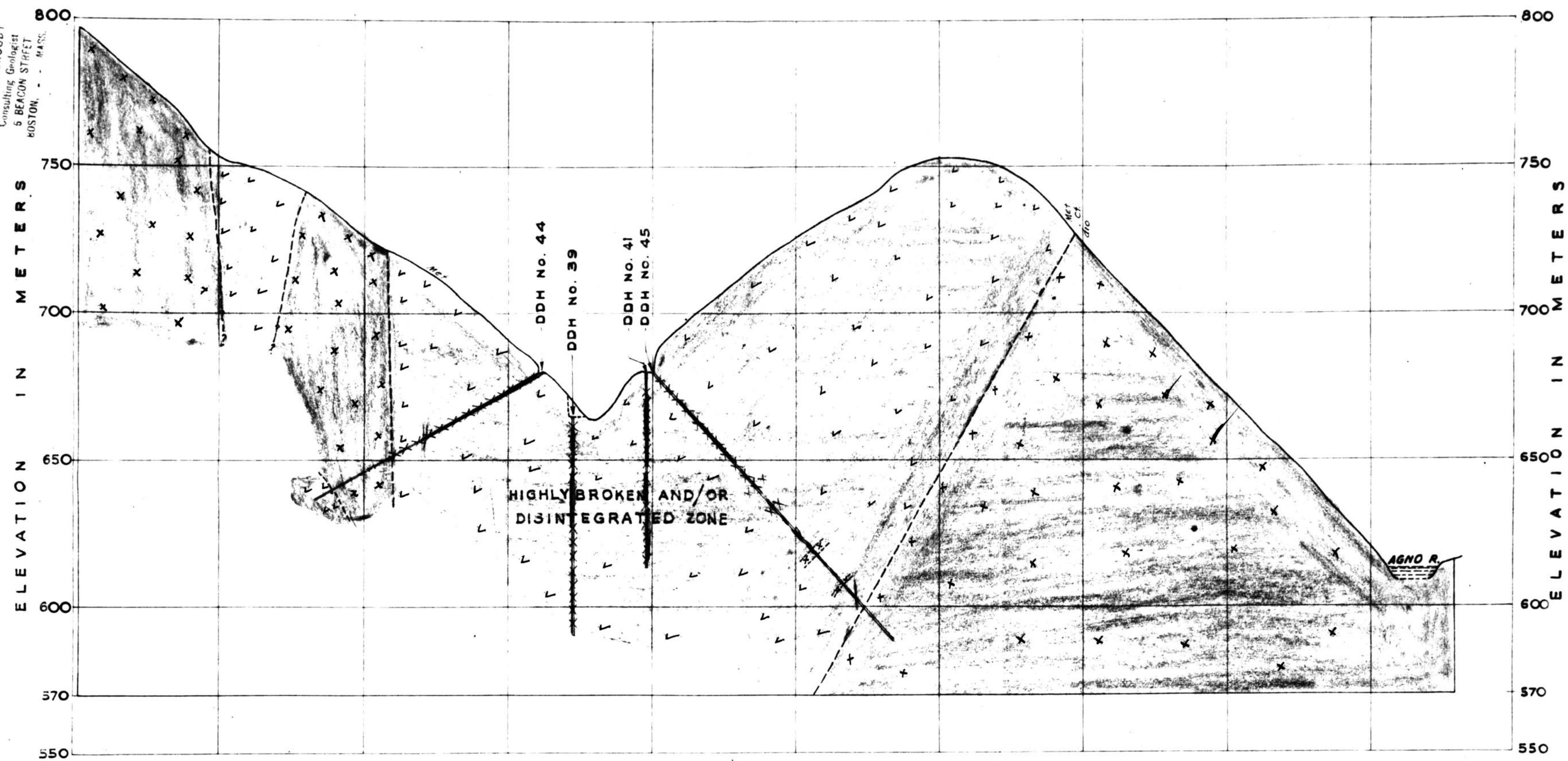
PLATE IX-E

SUBMITTED BY:

GENEROSO R. OCA, GEOLOGIST

NORBERTO S. FERNANDEZ, ASST. GEOLOGIST

FEBRUARY 3, 1950



DIORITE

METAMORPHIC { META-VOLCANIC, META-SEDIMENTS }

SECTION ALONG LINE N. 45°00'E. PASSING THRU COLLARS OF DDH Nos. 44 & 45. DDH Nos. 39 & 41 WERE PROJECTED ON SECTION

HOR. & VERT. SCALE 1:1,000
(AS OF JUNE 14, 1949)

PLATE X

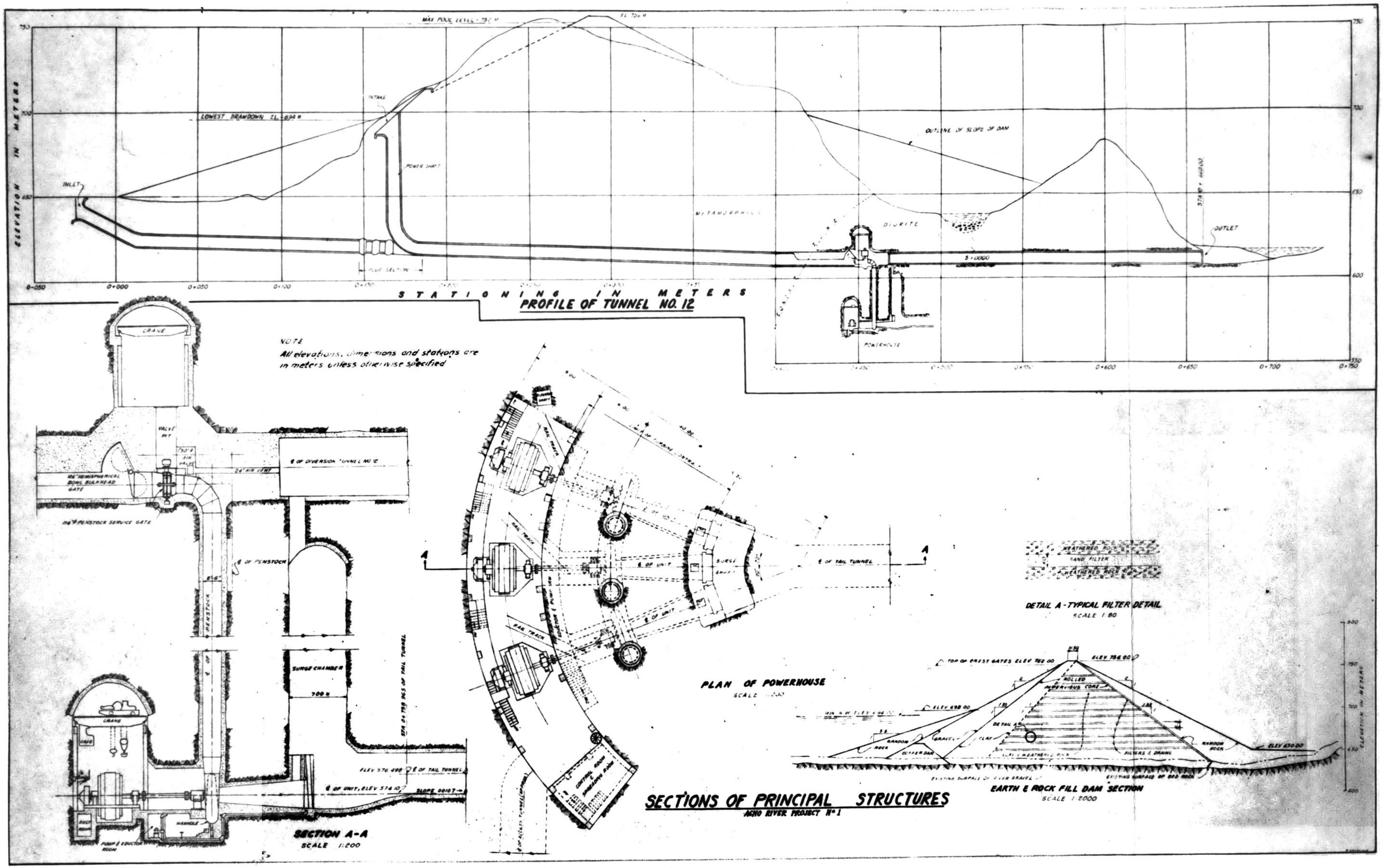

PROFILE OF TUNNEL NO. 12
STATIONING IN METERS
ELEVATION IN METERS
MAX POOL LEVEL
LOWEST DRAWDOWN
INTAKE
INLET
POWER SHAFT
PLUG SECTION
METAMORPHICS
DIORITE
OUTLINE OF SLOPE OF DAM
OUTLET
POWERHOUSE
NOTE
All elevations, dimensions and stations are in meters unless otherwise specified
CRANE
VALVE PIT
HEMISPHERICAL BOWL BULKHEAD GATE
PENSTOCK SERVICE GATE
℄ OF DIVERSION TUNNEL NO. 12
24" AIR VENT
℄ OF PENSTOCK
PENSTOCK
SURGE CHAMBER
℄ OF TAIL TUNNEL
℄ OF UNIT
MANHOLE
PUMP & EDUCTOR ROOM
SECTION A-A
SCALE 1:200
RAIL TRACK
SURGE SHAFT
CONTROL ROOM
PLAN OF POWERHOUSE
WEATHERED ROCK
SAND FILTER
DETAIL A - TYPICAL FILTER DETAIL
SCALE 1:80
TOP OF CREST GATES ELEV 752.00
ELEV 756.00
ROLLED IMPERVIOUS CORE
ELEV 698.00
DETAIL A
GRAVEL
CLAY
RANDOM ROCK
COFFER DAM
FILTERS & DRAINS
ELEV 650.00
EARTH & ROCK FILL DAM SECTION
SCALE 1:2000
SECTIONS OF PRINCIPAL STRUCTURES
AGNO RIVER PROJECT No. 1

PLATE XI

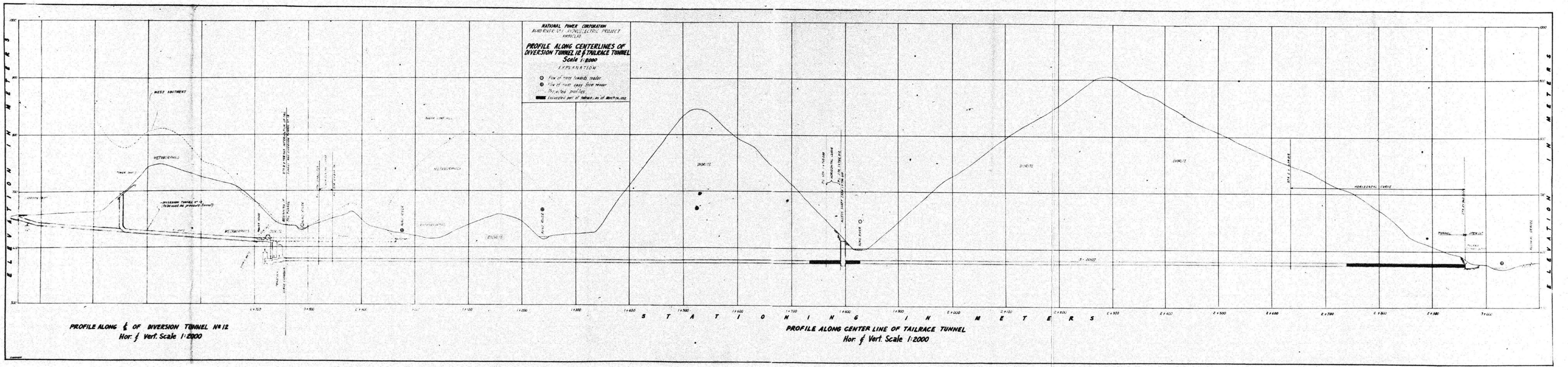

NATIONAL POWER CORPORATION
AGNO RIVER Nº1 HYDROELECTRIC PROJECT
AMBUKLAO
PROFILE ALONG CENTERLINES OF DIVERSION TUNNEL 12 & TAILRACE TUNNEL
Scale 1:2000
EXPLANATION
Flow of river towards reader
Flow of river away from reader
Projected profiles
Excavated part of tailrace, as of March 20, 1952
ELEVATION IN METERS
DIORITE
METAMORPHICS
STATIONING IN METERS
PROFILE ALONG ℄ OF DIVERSION TUNNEL Nº 12
Hor. & Vert. Scale 1:2000
PROFILE ALONG CENTER LINE OF TAILRACE TUNNEL
Hor. & Vert. Scale 1:2000

PLATE XII