PART II

C O N S T R U C T I O N

3. SCOPE OF WORK

Award of Prime Contract

Facilities for the Larson Titan project were adapted to this site for the Air Force by the Ralph H. Parsons Company of Los Angeles from a basic design prepared by Daniel, Mann, Johnson & Mendenhall & Associates. Invitation for bids for construction of three missile launching sites was issued by U. S. Army Engineer District, Walla Walla, on 19 October 1959. The bids were opened on 18 November 1959 at Walla Walla, Washington. There were a total of eight bidders. Contract No. DA-45-164-ENG-3552 was awarded to the low bidder, a joint venture of contractors composed of MacDonald Construction Co., The Scott Co., Paul Hardeman Co., C. H. Leavell Co., F. E. Young Construction Co., and Morrison-Knudsen Co., Inc. Notice to Proceed was issued on 21 November 1959, and the contractor started work on Contract 3552 in the basic amount of $31,600,722.00. The original contract completion date was 1 April 1962, which was subsequently extended to 11 April 1962 as the result of a time extension granted to cover time lost during a strike. Construction was completed on 16 March 1962 and the Using Agency accepted beneficial occupancy on that date.

Subsequent to award of the construction contract, twenty-seven separate supply contracts totaling nearly 5 million dollars were let by the Omaha District for the manufacture and delivery of the pumps, compressors, air conditioning equipment, switchgear, generators, liquid oxygen tanks, and other equipment standardized for the Titan Weapon System. Installation of this equipment was the responsibility of the Prime Contractor. In addition, the administration of the contracts was given to MacDonald-Scott & Associates in accordance with the terms of their contract.

Foundation Investigations

Foundation investigations were conducted at the complexes from March through April 1959. Borings were accomplished with rotary drilling equipment by Lynch Brothers Drilling Company of Seattle, Washington, under the supervision and direction of Shannon and Wilson, Soil Mechanics and Foundation Engineers, Seattle, Washington. Results were submitted to the Walla Walla District in May 1959. The report for each site consisted of a general geological history, types and depths of soil and rock encountered, seismic exploration data, bearing capacities of the soils to be encountered during excavation, and ground water and excavation conditions that could be anticipated.

Well Drilling

Total costs of well drilling operations were as follows:

Contract No. DA-45-164-3481	$ 78,820.98	Well #1 - 1-A
164-3482	115,052.85	Well #1 - 1-B
164-3483	122,017.88	Well #1 - 1-C
164-3510	101,130.95	Well #2 - 1-B
164-3511	232,933.48	Well #2 - 1-A, #2 - 1-C
TOTAL	$649,956.14	

Excavation and Earthmoving Operations

The Contractor broke ground at Site 1-A on 1 December 1959, followed by 1-B on the 3rd and 1-C on the 8th. Analysis of excavation problems by the Contractor indicated that a combination of opencut and shaft excavation could be best utilized to meet the substrata conditions prevalent at the complexes. Accordingly, the opencut excavation plan entailed the following procedures:

a. The opencut excavation, regardless of material encountered, was carried to fixed arbitrary elevations.

b. Within the launcher areas the bottom of the opencut was carried to the "S" line. The "S" line being identified as a plane 116' 10" above finish floor of the missile silos or about 40' below average ground surface.

c. Within the powerhouse and control center areas the opencut excavation was carried to a plane which, within close limits, coincided with the bottom of the air intake and exhaust structures and the top of the finished floor in the power house.

d. Opencut excavation at the antenna silos was cut to a plane coinciding with the bottom of the antenna silo tunnel junction.

e. Opencut excavation along the personnel tunnels was carried to an elevation approximately five feet above the top of the tunnel.

Multiple problems were encountered during opencut and shaft excavation. These problems were attributable to the position of the caliche basalt contact relative to fixed elevations that divided opencut and shaft excavation methods, structural and lithological dissimilarities in basalt, blasting techniques, and excavation methods.

No problems occurred during opencut excavation at Sites 1-A and 1-B. Shafts were collared in the Ringold sediments, commonly referred to as caliche, at Site 1-A. The caliche-basalt boundary generally marked the demarcation between opencut and shaft excavation at Site 1-B. About one-half of the opencut slopes at Site 1-C were composed of basalt. Periodic slope maintenance was required to eliminate dangerous overhangs and produce safe conditions as the caliche slopes deteriorated rapidly by weathering upon exposure.

Serious problems developed at Site 1-C as a result of blasting. Open-cut slopes were cracked up to 15 feet in the caliche and overlying surface loess around substantially large peripheral areas in Launcher Area No. 2. Blasts resulted in predominantly lateral propogation of shock energy into the slopes. The direction of the shot was geologically controlled by a relatively soft, highly weathered stratum of vesicular basalt 15 to 20 feet below the surface of the shot. A slope correction program corrected a safety hazard.

Results of excavation at the base of the ring footing of part of the control center at Complex 1-B indicated that structurally unsound rock contained exceptionally low bearing capacity. An abnormally high quantity of silt, highly altered vesicular basalt, volcanic ash with lesser amounts of caliche, calcium oxide, ferrous oxide and opalite were encountered. A test pit was excavated five feet below the indicated footing base elevation. Dense basalt with adequate bearing was four feet below the footing for a distance of 55 linear feet. The overexcavated area was backfilled with Class "C" concrete to obtain acceptable bearing load capacity. Almost identical adverse lithological conditions were in the powerhouse ring footing at Complex 1-B, Missile Silos Nos. 1 and 2, and Equipment Terminal No. 3 at Complex 1-A. Attainment of adequate bearing load capacities for the ring footings for these structures was accomplished by overexcavating and backfilling with Class "C" concrete.

Shaft excavation imposed several major problems as follows:

a. Blasting techniques had to be cautiously developed to prevent flyrock endangering personnel and equipment outside of the shafts to prevent displaced rock from dislodging or distorting ring beams and associated bracing materials, to preserve the rock outside the prescribed limits of excavation, and to effect optimum breakage of basalt rock to facilitate rock removal operations.

b. Shaft blasting which was first started at Complex 1-A was cautiously initiated. Negligible damage to bracing resulted. Primacord was used in the peripheral holes in blasting for a shattering effect but was soon discarded and replaced with 40% dynamite and sometimes a mixture of 60% and 40% dynamite. The main reason for discarding Primacord was due to the number of misfires. The flyrock from the reliever holes was cutting the wires and the Primacord itself, thereby causing a delay in excavation as the misfires had to be fired off. Very little flyrock out of the missile silos was evident. Milli-second blasting delays were introduced at Complex 1-A about half-way through the excavation of the missile silo. This replaced the full second delay and produced a much better heaving and shattering effect, thereby making for a faster mucking operation. In fairly solid rock devoid of much jointing the rock would shatter to around a 5" minus size and heave toward thecenter of the silo. It could be said that the elimination of Primacord and the advent of milli-second delays increased the contractor's output by about fifty per cent.

c. A considerable amount of structural overbreak was encountered in the weathered basalt just above the solid basalt. Basalt columns and masses broke irregularly along joint planes and fracture surfaces and resulted in overbreak behind neat structural lines. Trim shots were used to correct underbreak or basalt masses that projected inside the shaft lines. It required considerable ingenuity on the part of the powder man as to spacing and location of his peripheral holes to minimize the overbreak. Blasting and excavation were normally done in 10-foot lifts. The largest round fired for a 10-foot lift totaled 1100 pounds of dynamite and 180 blast holes which averaged 2.5 to 3 inches in diameter. About 8,500 pounds of dynamite and approximately 2,400 blast holes were used for each missile silo. Primary shaft bracing consisted of steel ring beams placed at five foot intervals for the full depth of the shafts. Rings were hung on tie rods and blocked with wood wedges. Steel collar bearing sets were set and anchored to concrete collars. Caliche surfaces were supported by 2" x 2" galvanized reinforcing mesh and three inches of gunite in addition to ring beams and associated bracing. Two-inch fir lagging was used to shore unsound fractured basalt rock at Complexes 1-A and 1-C. Lagging that was placed inside the flanges of the ring beams is termed "Coeur d'Alene".

Improper blasting operations resulted in broken collar sets and dislodged ring beams at Complex 1-C. The problem embodied the use of too much dynamite with a paucity of holes in dense columnar basalt that was characterized by relatively wide spaced stratification or flow planes. The holes were bottom loaded; consequently, basalt blocks up to 22,000 pounds were blown out of the shafts. Successful remedial blasting techniques incorporated a three fold increase in the number of blast holes and step loading of charges by alternating higher velocity dynamite with small blocks of wood for vertical distribution of charges. Cargo nets were draped from bangboards to intercept flyrock.

A total of approximately 1,700,000 cubic yards of material was removed in opencut and approximately 700,000 cubic yards by shafting and trenching.

Utilities

The Construction Contractor obtained water for his operations from the wells that had previously been drilled at the complexes and under other contracts. Under the specifications, he furnished reasonable amounts of water for use of the Government and other contractors at his own expense.

All electrical current required by the contractor was furnished at his own expense. Temporary primary power was purchased from the Public Utility Districts. Temporary lines were constructed and maintained by an electrical subcontractor, Close Electric Company, Seattle, Washington.

The feeder lines emanated from the adjacent County roads approximately a quarter of a mile from each Complex. Feeder lines were run underground to the complex, brought to 480 volts and distributed throughout the complex by 90 foot overhead lines. These poles also served for exterior lighting, consisting of thirty one 1500 watt, 480 volt mercury vapor lights.

To minimize down time occasioned by primary line power failures, the Air Force furnished a 350 KVA generator at each complex in January 1961. These generators were extremely useful and provided standby service on numerous occasions.

The temporary system was leased by MacDonald-Scott & Associates to the Air Force Associate Contractors for their power needs during their phase of installation work.

Access to Complexes

Access to the complexes was over county roads which were in fair to good condition at the beginning of construction. During the summer of 1961 the county roads were improved by contracts let by the local road commissions, utilizing funds furnished by the Air Force through the Bureau of Public Roads. The contractor's main office was set up in Ephrata, about 15 miles from the Area Office. Figure 5 is a vicinity map indicating the location of Complexes with respect to the Area Office and the Contractor's Office in Ephrata. The contractor utilized a light, 3 passenger airplane in his work and built light plane strips at each site. Corps personnel used vehicular transportation.

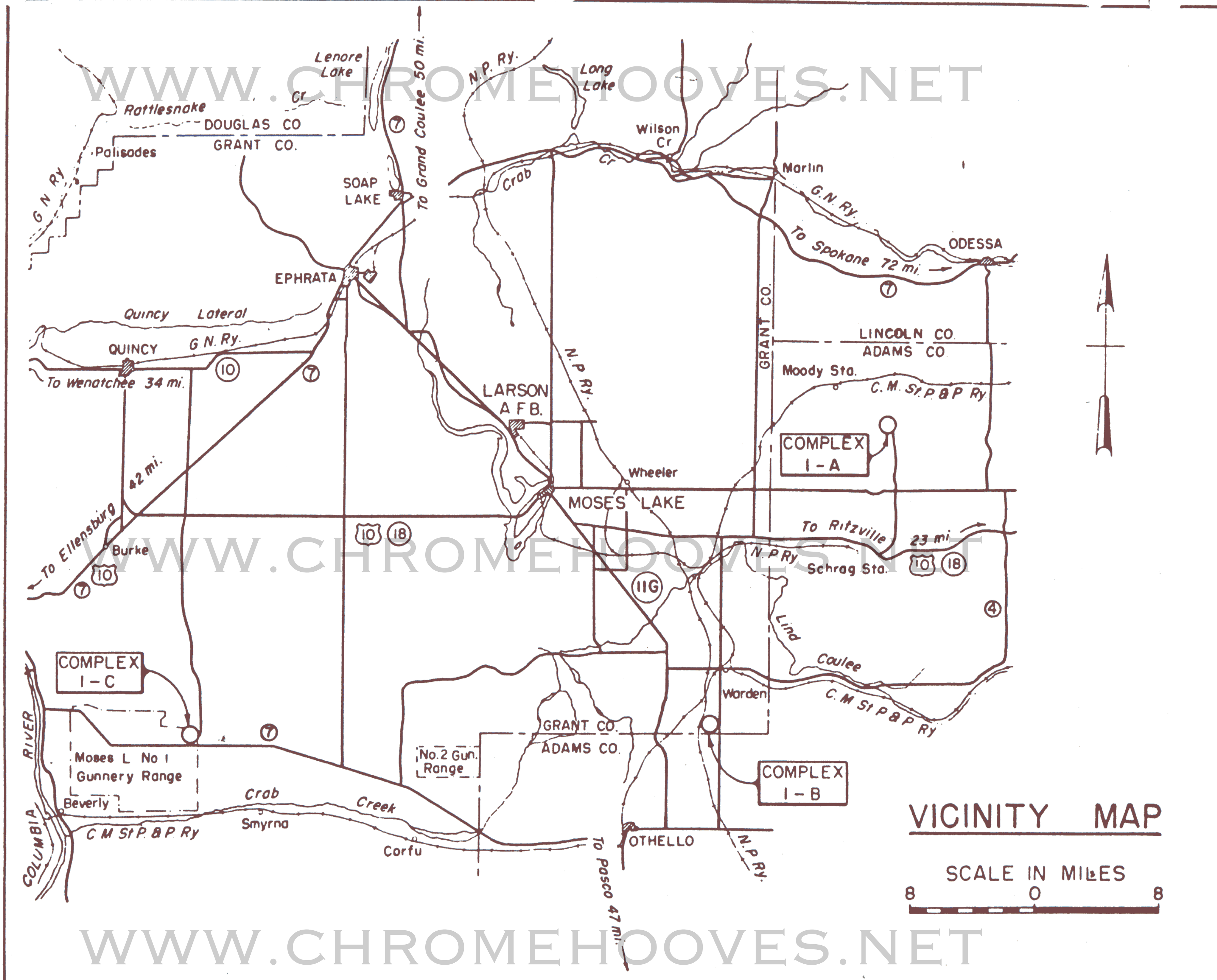

VICINITY MAP
SCALE IN MILES
8 0 8
Lenore Lake
Rattlesnake Cr
DOUGLAS CO
GRANT CO.
Palisades
G N Ry
SOAP LAKE
To Grand Coulee 50 mi.
N.P. Ry.
Long Lake
Wilson Cr
Crab Cr
Marlin
G.N. Ry.
To Spokane 72 mi.
ODESSA
EPHRATA
Quincy Lateral
QUINCY
G.N. Ry.
To Wenatchee 34 mi.
LINCOLN CO.
ADAMS CO.
GRANT CO.
Moody Sta.
C. M. St. P. & P. Ry
LARSON A.F.B.
N.P. Ry.
COMPLEX I - A
42 mi.
Wheeler
MOSES LAKE
To Ellensburg
Burke
To Ritzville 23 mi
N.P Ry
Schrag Sta.
11G
Lind Coulee
COMPLEX I - C
Warden
C M St P & P Ry
GRANT CO.
ADAMS CO.
Moses L No 1 Gunnery Range
No.2 Gun. Range
COMPLEX I - B
COLUMBIA RIVER
Beverly
Crab Creek
C M St P. & P Ry
Smyrna
Corfu
To Pasco 47 mi.
OTHELLO
N.P. RY.

Fig 5

ARTIST CONCEPTION

TITAN MISSILE COMPLEX

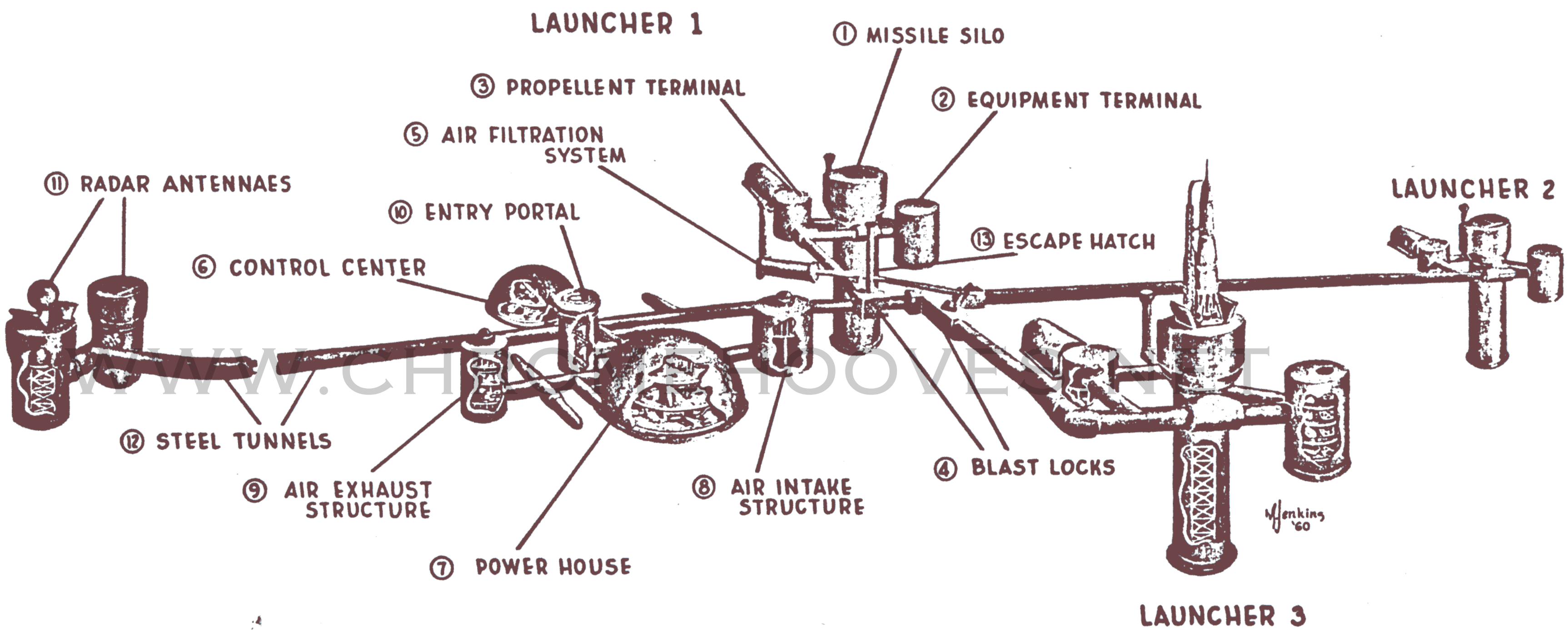
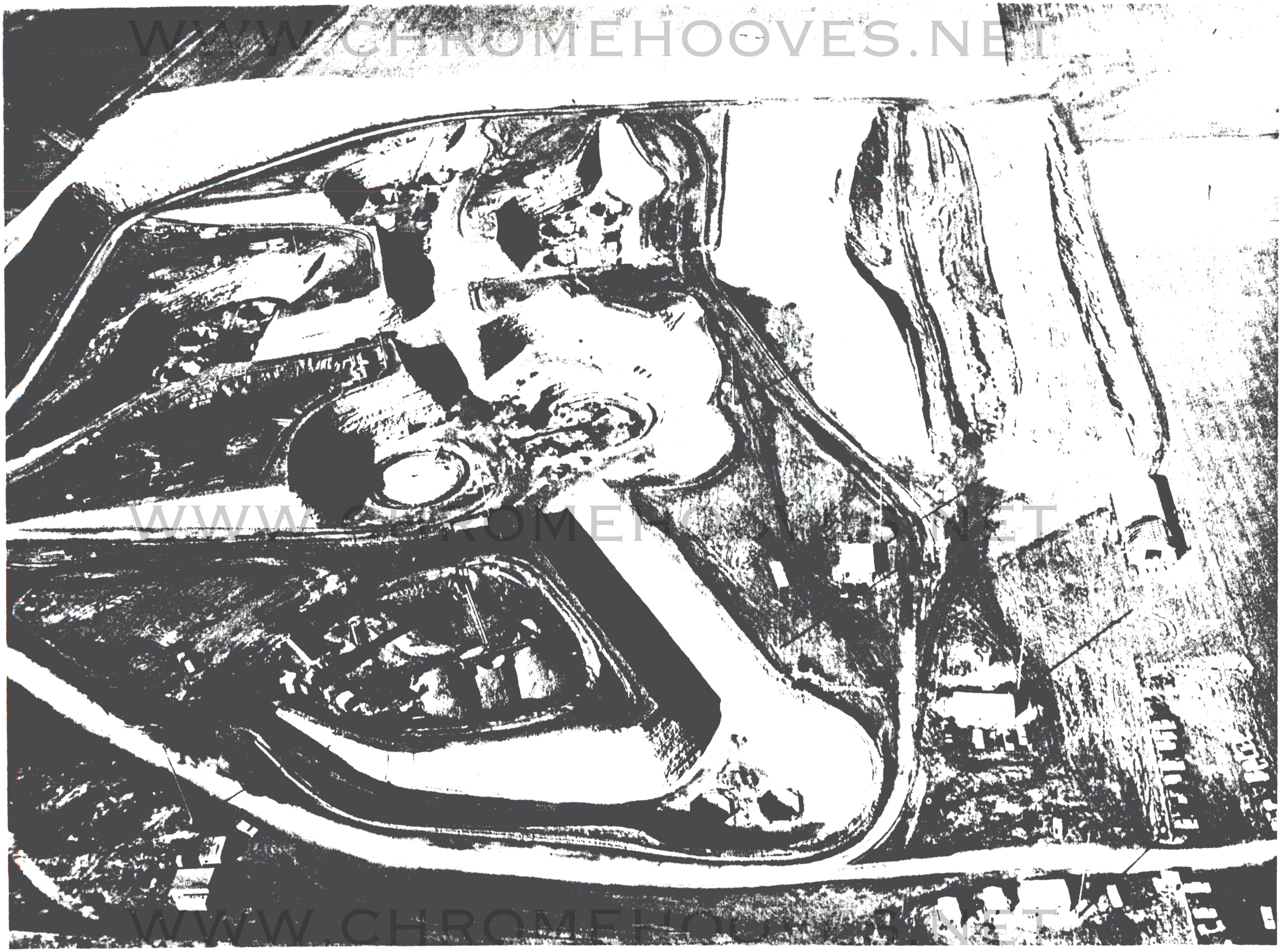
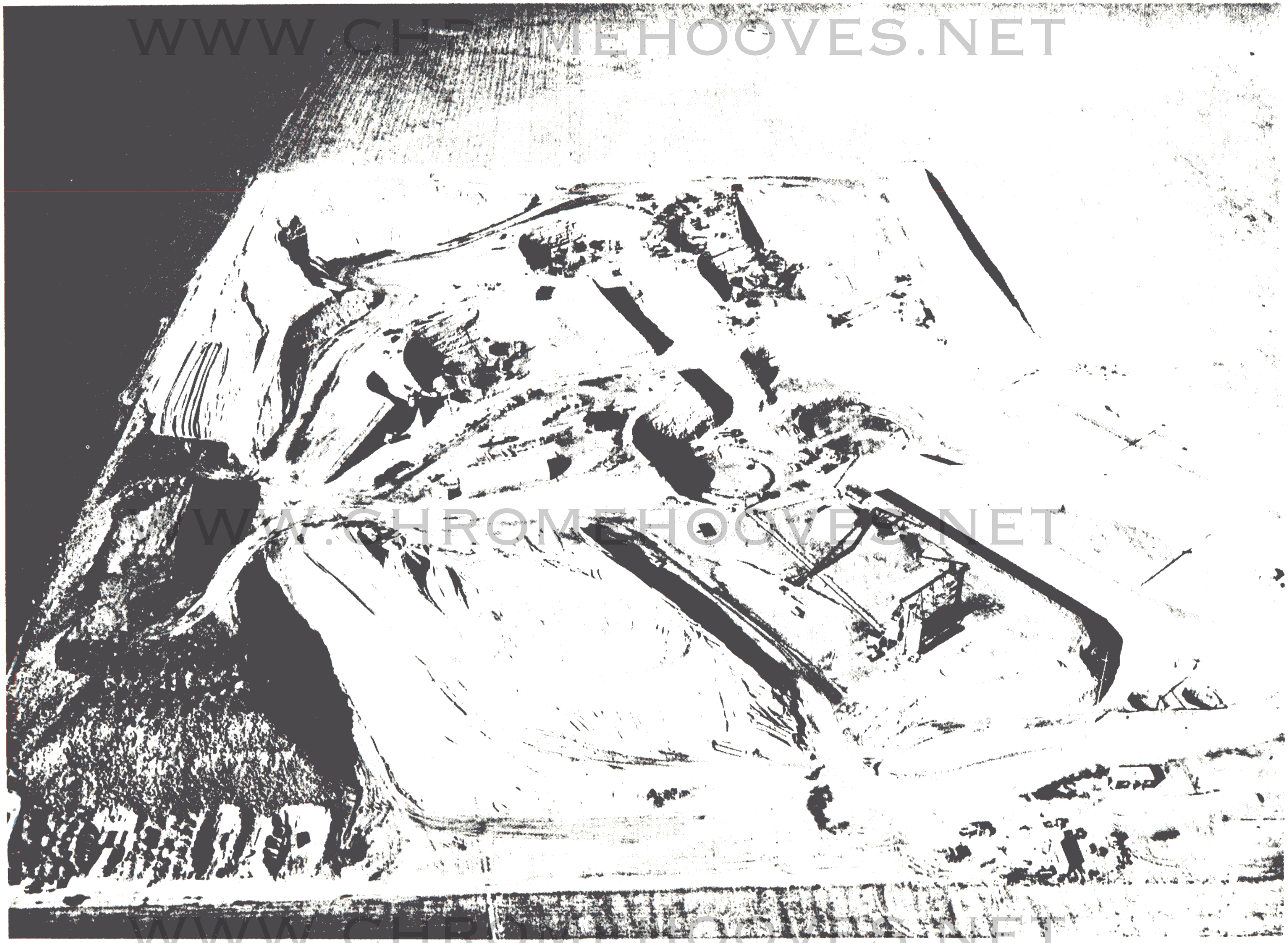


Fig6



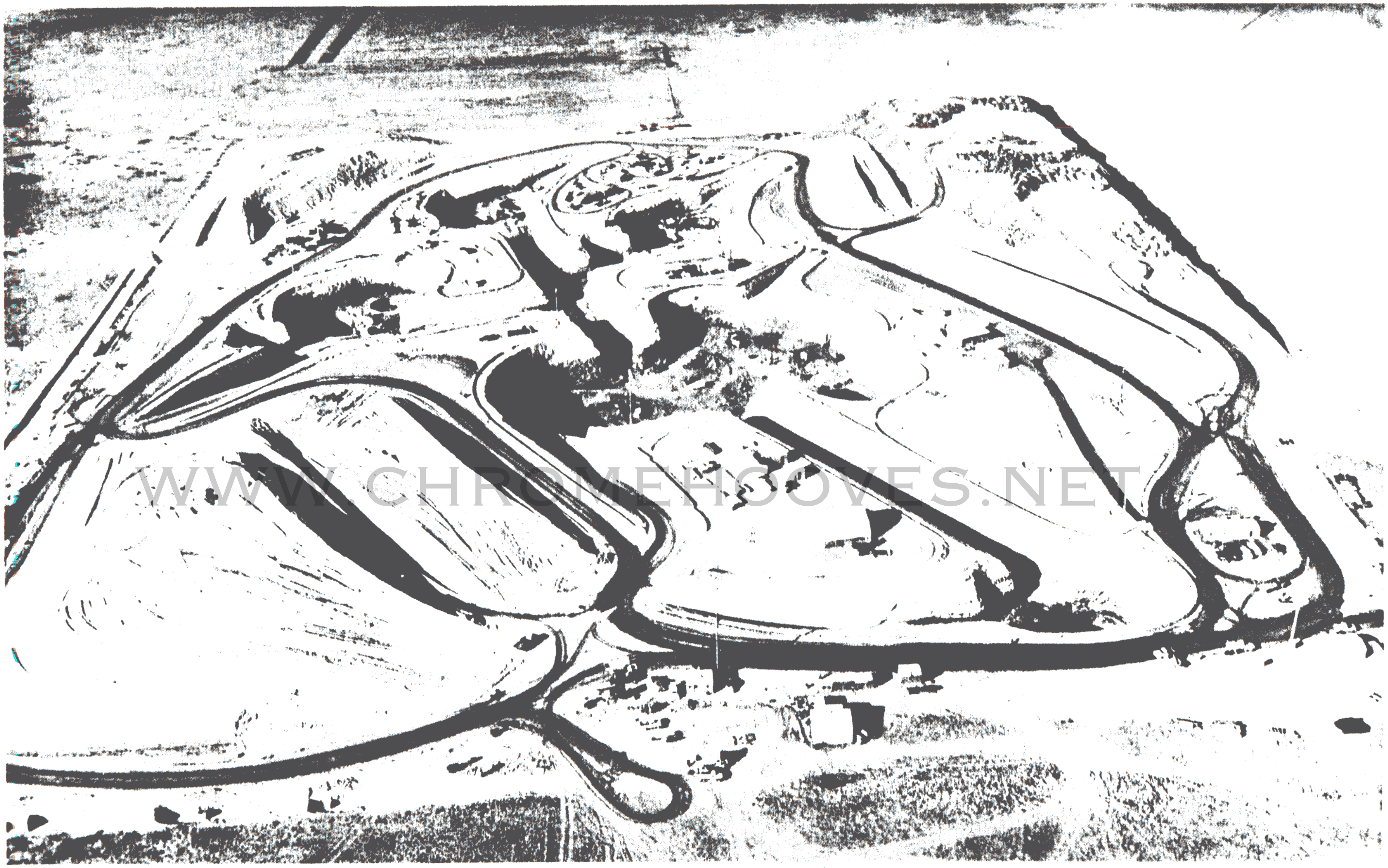
LARSON MISSILE COMPLEX 1 - A Fig 7 11 MARCH 1960

LARSON MISSILE COMPLEX 1-A Fig 8 16 SEPT. 1960



LARSON MISSILE COMPLEX 1 - B   Fig 9   11 MARCH 1960

LARSON MISSILE COMPLEX 1-B Fig 10 16 SEPT. 1960



LARSON MISSILE COMPLEX 1 - C Fig 11 11 MARCH 1960

LARSON MISSILE COMPLEX 1-C Fig 12 16 SEPT. 1960

4. GEOLOGY AND SOILS

General Regional Characteristics

The three missile complexes are underlain by loess and caliche covered basaltic lava flows in the Yakima group of Miocene Age included in the Columbia Plateau physiographic province. This distinctive province is designated as the locally-important Columbia Basin. The presence of the Columbia River to the west has made possible an extensive irrigation project under the U. S. Bureau of Reclamation. Topographically, the area is moderately rolling to gently undulating farm land as glacial flood waters incised the broad, relatively flat lava plains and superjacent caliche and loess mantle into an intricate network of coulees and stream valleys.

The basalt is the oldest formation. Disconformably overlying the lava is the Ringold formation of Pleistocene Age which varies in thickness from 15 feet at Complex 1-C, to 23 feet at Complex 1-B, and 55 feet at Complex 1-A. Surfaces at all complexes are composed of Palouse formation silt and sand--a loessial sediment of Pleistocene to Recent Age which averages about 6 feet in thickness.

Structurally, the lava plains are essentially flat-lying with a slight regional dip to the southwest. Structural entities such as faults, joints, fractures, and anticlines and syclines are found only in the lava flows.

General Characteristics - Complex 1-A

Stratigraphy: The bedrock consists of basaltic lava of Miocene Age. Excavation for the foundation footing ring and slab of the missile silos penetrated about 100± feet of the Yakima basalt. Generally, basalt flows are hard, dense, fine-grained and structurally competent. However, much of the shaft walls and foundation in Missile Silo No. 1 and Equipment Terminal No. 3 consisted of weathered, unkeyed, vesicular, nontronitic clay and sporadic gas bubble voids at several intervals, whereas the basalt

(Missile Silo No. 3 and Equipment Terminal No. 1) correlated with the general type of lithology described above. No clearly defined sedimentary interbed was exposed throughout the excavation limits of the complex. The Ringold formation is composed of sand and silt and contains locally up to six caliche beds. The stratigraphic unit disconformably overlies the basalt and attains a thickness of about 55 feet. The formation is of middle to late Pleistocene Age and is horizontally bedded continental sediment. Opencut slopes were terminated in the Ringold formation.

The surface is thinly veneered with up to six and one-half feet of very fine-grained sandy silt of the Palouse formation.

Geological Characteristics: Dense basalt from the foundation in Missile Silo No. 3 has the following characteristics: Specific gravity 2.89, 180.81 pounds per cubic foot, 2.444 tons per cubic yard, and 11.06 cubic feet per ton.

A sample of caliche from the Ringold formation in Launcher No. 1 has a specific gravity of 2.13, 133.13 pounds per cubic foot and 15.02 cubic feet per ton. An insoluble resudue analysis revealed 35% carbonate and 65% residue.

A mechanical analysis of a sample of the Palouse formation revealed 97% and 91.3% passed the 100 and 200 screens respectively. The sediment may be classified as a very fine-grained sandy silt. (ML)

Structure: Structural variations are small (up to six feet) between Launchers No. 1 and No. 2 despite the presence of faulting in the lower reaches of Missile Silo No. 2 where weathered vesicular clay bearing basalt was down-faulted in relation to hard, dense basalt. Many fracture and joint surfaces were recorded on the geologic shaft maps.

Foundation Geology - Complex 1-A

Missile Silo No. 1: Dense, jointed and fractured basalt, highly weathered between S-24 and S-49 feet. Highly vesicular and weathered basalt with disseminated bentonite or nontronite (clay-like rock material), scoria, devitrified volcanic glass, and 10 gas bubble voids between 0.5 and 15$\pm$ cubic yards were found between S-49 feet and S-71 feet. Dense, hard fractured and jointed basalt was between S-71 feet and S-91 feet. Weathered, soft basaltic material, as above, was between S-91 feet and S-123 feet, the footing ring elevation. Excavation of structurally-incompetent rock, which consisted of bentonite and highly weathered, unkeyed, vesicular basalt, below the indicated final grade elevation 1582.00 was concluded 8 March 1960. Over-excavation which was field-supervised by the geologist, was accomplished by pavement breakers, hand shovels, and air hoses. Based on the Contractor's elevations, final footing elevations are between 1582.00 and 1579.00.

Equipment Terminal No. 1: Excavation penetrated about 18 feet of basalt which was weathered, dense, jointed and fractured whose planes contained iron oxide silt and clay, calcium carbonate or caliche, and calcium oxide. With the exception of delineating secondary minerals along joint and fracture surfaces, the soil boring log adequately described the geological conditions which were encountered during excavation.

Propellant Terminal No. 1: The structure was excavated almost entirely in the Ringold caliche. Only 0.5 foot of basalt was removed to satisfy foundation requirements.

LOX Tank Bay No. 1: The foundation slab was excavated in caliche.

Missile Silo No. 2: The Ringold formation basalt boundary is at S-24.5 feet. Weathered, dense to vesicular basalt with joints and fractures was replaced at S-50 feet by fresh, dense, hard basalt with fractures and joints that continued to S-95 feet. Two small scale faults divided the vertical interval between S-95 feet and the footing ring into dense, hard, stratified basalt and highly weathered, vesicular, amygdaloidal basalt with bentonite or nontronite and iron stained clay. This material was identical to that encountered in the foundation of Missile Silo No. 1. Generally, structurally sound gray, dense basalt was encountered at the indicated footing base elevation 1576.00 in the east one-half of the silo in quadrants III and IV. This basalt was apparently in a down-thrown fault block. The up-thrown fault block in the west one-half of the silo in quandrants I and II consisted of highly weathered, unconsolidated vesicular basalt with heavily disseminated bentonite. Consequently, pockets of objectionable rock were overexcavated to depths up to 3± feet below the base of the footing ring in this area. Authorized overexcavation was concluded 18 February 1960.

Equipment Terminal No. 2: About 20 feet of basalt were excavated to the foundation. This interval was equally divided between dense, weathered, hard jointed and fractured basalt and underlying dense, hard, columnar basalt containing fractures and joints.

Propellant Terminal No. 2: Same as reference rock description under Propellant Terminal No. 1.

LOX Tank Bay No. 2: The foundation slab was excavated in white, thin-bedded caliche layers and calcite-cemented sandy silt.

Missile Silo No. 3: Excavation of shaft revealed basalt comprised of altered, weathered, vesicular, secondarily mineralized material between caliche contact of S-29 feet; weathered, vesicular, nontronite-bearing basalt to S-40 feet; dense to slightly vesicular basalt with random nontronite pockets to S-60± feet exceptionally dense, hard, fresh basalt with little overbreak to the base of the footing ring excavation except for a faulted zone of highly weathered vesicular, nontronite-bearing zone between S-60± feet, and S-92± feet in the northwest one-fourth of the silo.

__Equipment Terminal No. 3:__ About 20 feet of basalt were excavated below the caliche contact. Excavation of undesirable foundation rock below indicated grade elevations was as follows: About 20 c.y. were overexcavated in the south part, Quadrant II, of the shaft. Several additional smaller areas were overexcavated; 2 to 3 c.y. in slab at north part of Quadrant IV, 2-1/2 c.y. pocket in footing in Quadrant IV, 1 c.y. pocket in footing in Quadrant I, and 1.5± c.y. in a gas bubble void in Quadrant II.

__Propellant Terminal No. 3:__ Description of lithologies and structural conditions same as other Propellant Terminals at Complex 1-A. No over-excavation of walls or foundation was authorized.

__LOX Tank Bay No. 3:__ A white caliche bed is the foundation medium.

__Antenna Silos:__ Less than 15 vertical feet of basalt were excavated from each silo. The rock is dense, fractured, jointed, weathered, secondarily mineralized, thin bedded, somewhat diced, and contains basalt boulders in the East Silo. The rock description in Log L-1F does not reflect any significant departure from the rock encountered in the silos.

__Powerhouse:__ Footing ring is at least six inches in basalt to meet design specifications. Rock is composed of highly weathered, dense basalt with calcite, calcium oxide, limonite iron and silt along fractures and thin stratification planes. The foundation slab is in caliche.

__Air Intake:__ Foundation is in caliche.

__Air Exhaust:__ Foundation was excavated in predominantly uncemented silty sand and thin caliche layers.

__Entry Portal:__ Foundation is in basalt whose characteristics are the same as described under the section on the Powerhouse.

__Control Center:__ A minimum of six inches of weathered, dense basalt in the footing ring. The slab was founded in caliche. Results of geological investigations made between 16-23 February 1960 indicate:

a. Elevations and thicknesses of the ring footing vary between 1680.84 and 1678.00 and from 9.96 to 12.80 feet respectively.

b. The average thickness of the ring footing is about 11 feet.

c. The footing is in a minimum of six inches and a maximum of 1.18 feet of dense basalt.

d. Six inches into dense basalt vary between elevations 1678.68 and 1681.30.

Excavation was completed on 23 February 1960. On 9 March 1960, 77 c.y. of Class "A" concrete and 15 c. y. of grout were poured in the footing.

Blast Locks Nos. 1 and 2: Foundation slabs were excavated in thin-bedded caliche layers and loosely cemented silty sand.

Air Filtration: Class "C" leveling course was placed on caliche of the Ringold formation. A portion of the north end wall of the structure was undercut to facilitate excavation for the foundation slab of Blast Locks No. 2. Class "C" concrete was used for backfill and stabilized the undercut area.

Tunnels: All tunnels were excavated in either caliche or silty sand in the Ringold formation.

Foundation Geology - Complex 1-B

Missile Silo No. 1: Dense to slightly vesicular, jointed and fractured, altered, weathered, and secondarily mineralized basalt to S-30 feet, and dense, hard, fractured and jointed basalt to S-50 feet. Dense, fresh gray, hard, jointed, columnar basalt is between S-50 feet and the footing ring and foundation slab. A cave-in was noted on the log at elevation 1238.49 or S-65 feet. The principal rock fall areas are between S-50 and S-80 and the bottom of the shaft. Some overbreak areas were 8 to 10 feet beyond the neat structural lines of the shaft. The columns of basalt did not fall simultaneously. Actually, the rock was jointed and fractured or closely to slightly broken, and was not supported adequately during excavation operations. Various rock falls occurred intermittently.

Equipment Terminal No. 1: The soil boring log indicated closely to slightly broken altered, very fine grained, dense, dark gray basalt within the limits of excavation. The lithological and structural conditions mapped were identical with those depicted in the log.

Propellant Terminal No. 1: The rock that was penetrated during excacavation correlated favorably with that shown on the soil boring log. The log also showed that the drill hole was cased to retain broken rock at S-13 feet. The foundation slab was excavated in hard, dense basalt.

Lox Tank No. 1: Excavation for the foundation slab began 10 June 1960 and was completed 17 June 1960. On 13 June 1960, structurally unsound rock was encountered at the design elevation for the foundation slab in the north one-half of the structure. Objectionable material was composed of highly weathered, dense and vesicular basalt, devitrified volcanic ash or bentonite, opalite, caliche, calcium oxide, brown iron or limonite. The rock was, in fact, unkeyed, soft and powdery. The Contractor was authorized to over-excavate objectionable material and to attain acceptable foundation rock. On 17 June 1960, 92 c.y. of Class "C" backfill concrete were placed.

Missile Silo No. 2: A dense, gray, fractured and jointed basalt with columnar characteristics was encountered. The rock displayed a large quantity of joints and fractures to S-65; basalt was less fractured below this point where the largest rock fall areas are found. Excavation in this silo was at approximately S-65 feet where major overbreak began.

Equipment Terminal No. 2: Fractured, jointed, closely to slightly broken rock occurred in the footing ring. The width of the footing ring, which is between the rock wall and the slab averages about 10 to 12 feet or approximately twice the design distance of 6.3 feet.

Propellant Terminal No. 2: Greatly altered, closely broken basalt. Considerable overexcavation resulted in the foundation slab area due to excavation methods.

LOX Tank No. 2: Basaltic rock in foundation is weathered, dense, fractured, and slightly jointed.

Missile Silo No. 3: Geological conditions did not markedly deviate from those described under Missile Silos Nos. 1 and 2. Dense, gray, slightly broken or fractured, jointed basalt was excavated between S-70± feet and the base of the silo. Subsequent to blasting in the silo, two rock slides occurred in the east wall at an average depth of 70 to 95 feet below the "S" line. The slides are identified herein as Numbers 1 and 2. No. 1 in Quadrant III, and No. 2 is in Quadrant IV. Slide No. 1, which contained broken rock in a wedge or prism shape was held in place by distorted ring beams. Slide basalt was removed by explosives on 1 March 1960; ring beams were restored to position. On 3 March additional slide material was cleaned out, and rock bolts and wire mesh were installed and gunite was applied in the roof area of both slides to prevent further sliding. Results of geological study indicated that additional sliding would be imminent without roof stability. The basalt in the wall around the entire periphery of the silo was dense, fractured, and jointed. Both slides were on fracture surfaces that dipped 45°-60° and 60°-75° in Slides Nos. 1 and 2, respectively, toward center of the silo. Subsequent minor sliding in the toe areas of the slides, which resulted in no damage, added about five feet in length to the dimensions. Slide No. 1 was 30 feet long, 8 feet wide, and an average of 6 feet deep. The cavity constituted about 28± c.y. based on a prism shape. Slide No. 2, which approximated a rectangular shape, constituted a cavity of about 57± c.y. with average dimensions of about 30 feet long, 13 feet wide, and 4 feet deep.

An irregular shaped slide area, which consists of coalescing prisms, occurred intermittently on the north side of the silo in Quadrants I and IV. This area, about 40± c.y., attained a maximum dimension of about 20 feet long, 25 feet wide and 4± feet deep, on 12 March 1960. The top of the slide was about 100 feet below the "S" line; the base was at the rock footing.

Equipment Terminal No. 3: Geologically, the excavated basalt rock was brown, weathered, jointed, fractured, bedded with joint and fracture planes cemented with calcium carbonate or caliche, calcium oxide, iron oxide or limonite, and silt and clay to S-30 feet. The remainder of the shaft was excavated in the same type of rock containing less fractures and joints.

Propellant Terminal No. 3: Rock conditions contacted in the silo during excavation were identical with those described under Equipment Terminal No. 3.

LOX Tank No. 3: Basalt in foundation was weathered, dense to slightly vesicular with small amounts of well-keyed caliche along fracture surfaces.

Antenna Silos: Foundation rock is dense, fractured basalt.

Powerhouse: An exorbitant quantity of silt, nontronitic clay, opalite, devitrified volcanic ash, and highly weathered vesicular basalt comprised much of the foundation footing ring and slab. Rough excavation for the foundation slab was completed on 29 February 1960. On 4 March 1960, trench excavation for the ring footing revealed objectionable rock for about 40± linear feet in the south part of Quadrants II and III. Subsequent authorized overexcavation to an undetermined depth by a backhoe at the Contractor's expense was concluded on 4 March 1960. The north one-half of the ring footing was underlain by structurally competent dense basalt that did not require overexcavation. Guniting of the wall of the ring footing was accomplished on 11 March 1960. A total of 48 c.y. of backfill concrete and one c. y. of grout was placed in the overexcavated are in the south part of the ring footing between 12 and 16 March 1960.

Air Intake: Rock in the foundation was weathered, dense basalt.

Air Exhaust: Excavation for the foundation began 14 April 1960. Overexcavation was authorized to remove objectionable rock from the footing rings and foundation slab. This rock was identical to that described under the Powerhouse. On 9 May 1960, excavation of loose, unkeyed, structurally incompetent rock was completed and 195 sacks of pneumatically placed concrete or gunite was applied to the footing ring slab and walls. Gunite was used to stabilize the spalling walls and to prevent leaching of moisture from concrete.

Entry Portal: Foundation rock was weathered, dense to slightly vesicular basalt.

Control Center: Results of overexcavation near the footing ring indicated that structurally unsound rock would be encountered in the east and west sections of the ring. Sufficient excavation on 29 February 1960 revealed that rock at the base of the ring contained exceptionally low bearing. An abnormally high quantity of silt, nontronite, devitrified volcanic ash and highly altered vesicular basalt with lesser amounts of caliche, calcium oxide and opalite were encountered. The Contractor was authorized to excavate a 6'x4'x5' test pit for geological examination. Subsequent examination indicated that rock of adequate bearing was about 4 feet below the indicated footing base for possible 50± linear feet. This area was overexcavated to a maximum of 5.6± feet by a backhoe on 3 March 1960. Due to the large quantity of unsuitable rock in the footing walls, the Contractor gunited on 10 March 1960 to facilitate the footing pour. The footing floor in the large overexcavated area cited above was also gunited. This area was backfilled with 53 c.y. of Class "C" concrete on 11 March 1960. About 60 linear feet of dense, well keyed basalt forms the indicated footing base in Quadrants I and II. This area required no overexcavation. On 11 March 1960, an elevation investigation was made of the footing ring. Preliminary results disclosed that the footing in parts of Quadrants III and IV was excavated 0.9 foot above the indicated footing elevation 1285.75. This conditions was corrected.

<u>Blast Locks Nos. 1 and 2:</u> Foundation rock is brown, weathered, dense basalt.

<u>Air Filtration:</u> The slab rock composed of weathered, dense, secondarily mineralized basalt. Highly weathered, unkeyed rock is in walls.

<u>Tunnels</u>: All tunnels were excavated in basaltic rock.

<u>Foundation Geology - Complex 1-C</u>:

<u>General</u>: The foundation footings and slabs of all structures were excavated in suitable basaltic rock at design elevations. No overexcavation was authorized. The geological aspects of the basalt encountered during excavation are described below.

<u>Missile Silo No. 1</u>: Basalt rock was between the S-line and the foundation. Brown, weathered, dense, "diced" or "brick-bat" basalt was excavated between the S-line and S-15± feet. Dense, hard, stratified in the upper reaches of the shaft, basalt was found between S-15 and S-25±

feet, while dense, jointed, and fractured gray columnar basalt was between S-25± and S-82 feet. A sedimentary interbed was between S-82 and S-90 feet. It is composed of scoria, volcanic ash, highly weathered, altered vesicular basalt of sand, pebble, and cobble sizes, nontronite. This stratigraphic unit contained no free water. It formed structurally competent shaft walls. Columnar basalt extended between the interbed and the foundation. No critical deviation of the actual conditions encountered during excavation was implied by the soil boring log.

<u>Equipment Terminal No. 1</u>: Closely to slightly broken, altered basalt to S-10 feet, and columnar, fractured and jointed basalt between S-10 feet and the foundation.

<u>Propellant Terminal No. 1</u>: Diced basalt that contained fractures extended to about S-6 feet. Fractured, jointed, stratified, columnar basalt occupied the interval between S-6 feet and the foundation.

<u>LOX Tank Bay No. 1</u>: Foundation is in weathered, fractured and jointed columnar basalt.

<u>Missile Silo No. 2</u>: Lithologic and structural entities of the excavated basalt correlates with the description under Missile Silo No. 1. Effectively, rock conditions were duplicated.

<u>Equipment Terminal No. 2</u>: Opencut excavation to facilitate the installation of the top ring beams and collar set was in "diced" basalt. Jointed and fractured, columnar basalt was excavated below the top set of shaft bracing.

<u>Propellant Terminal No. 2</u>: "Diced" basalt to about S-10 feet, and fractured and jointed, weathered basalt between S-10 feet and the foundations. Dense, hard stratified, fractured and jointed basalt in the foundation footing.

<u>LOX Tank Bay No. 2</u>: Foundation slab is in columnar basalt with highly adequate bearing capacity.

Missile Silo No. 3: Detailed geologic description correlate with those under Missile Silo No. 1. The sedimentary interbed, which is inclosed within columnar basalt flows, is an extension of that penetrated in the other missile silos. The soil boring log shows the interbed occasional to slightly broken altered to fresh basalt with core lengths up to 3 feet. These data correspond favorably with those conditions met during excavation. Basalt in outer periphery of the footing ring is gray, fresh, dense, hard, jointed, and fractured.

Equipment Terminal No. 3: "Diced" basalt between S-line and S-10± and fractured, jointed, dense, hard gray columnar basalt below. The soil boring log shows slightly broken, fresh to altered basalt. This was encountered during excavation. Foundation rock composed of hard, dense, jointed, and fractured columnar basalt.

Propellant Terminal No. 3: Northwood-Mannix initiated shaft type excavation on about 18 March 1960. Because of improper blasting tactics, the original shaft collar set was demolished. Overexcavation was incurred by the Contractor as a result of a combination of blasting by Northwood-Mannix and opencut by Murphy Brothers, Inc. Overbreak attained dimensions up to 7± feet. Overexcavation was not authorized.

LOX Tank Bay No. 3: Hard, dense, columnar basalt in the foundation slab. Solidification and shrinkage joints, which resemble exfoliated surfaces, are weathered and contain limonite iron.

Antenna Silos: The West Antenna Silo whose foundation rock, which is identical to that in the East Antenna Silo, is composed of hard, dense columnar basalt. Residual shot holes were drilled below the design elevation of the footing ring.

Powerhouse: Exceptionally hard, dense, columnar basalt. During blasting operations to attain grade, it was noted that the pronounced columnar joint patterns controlled the breakage. Consequently, very closely-spaced drill holes were necessary to attain optimum size to facilitate mucking operations.

Air Intake: The foundation was excavated in columnar basalt, directly subjacent to diced basalt.

Air Exhaust: This foundation approximated that encountered in the Air Intake.

Entry Portal: Foundation rock is hard, dense, fractured and jointed columnar basalt.

Control Center: Foundation footing and slab were excavated in very hard, dense columnar basalt.

Blast Locks Nos. 1 and 2: The foundation slabs were excavated in slightly weathered, dense, hard columnar basalt. The rock is structurally competent columnar basalt with limonite or hydrous iron oxide weathering along joint planes whichare demarcation surfaces between basalt columns. Many holes (for blasting) were drilled between 1.0 ft. and 2.5 ft. below grade.

Air Filtration: The basalt in the foundation slab is characterized by slightly weathered, dense, hard columnar basalt.

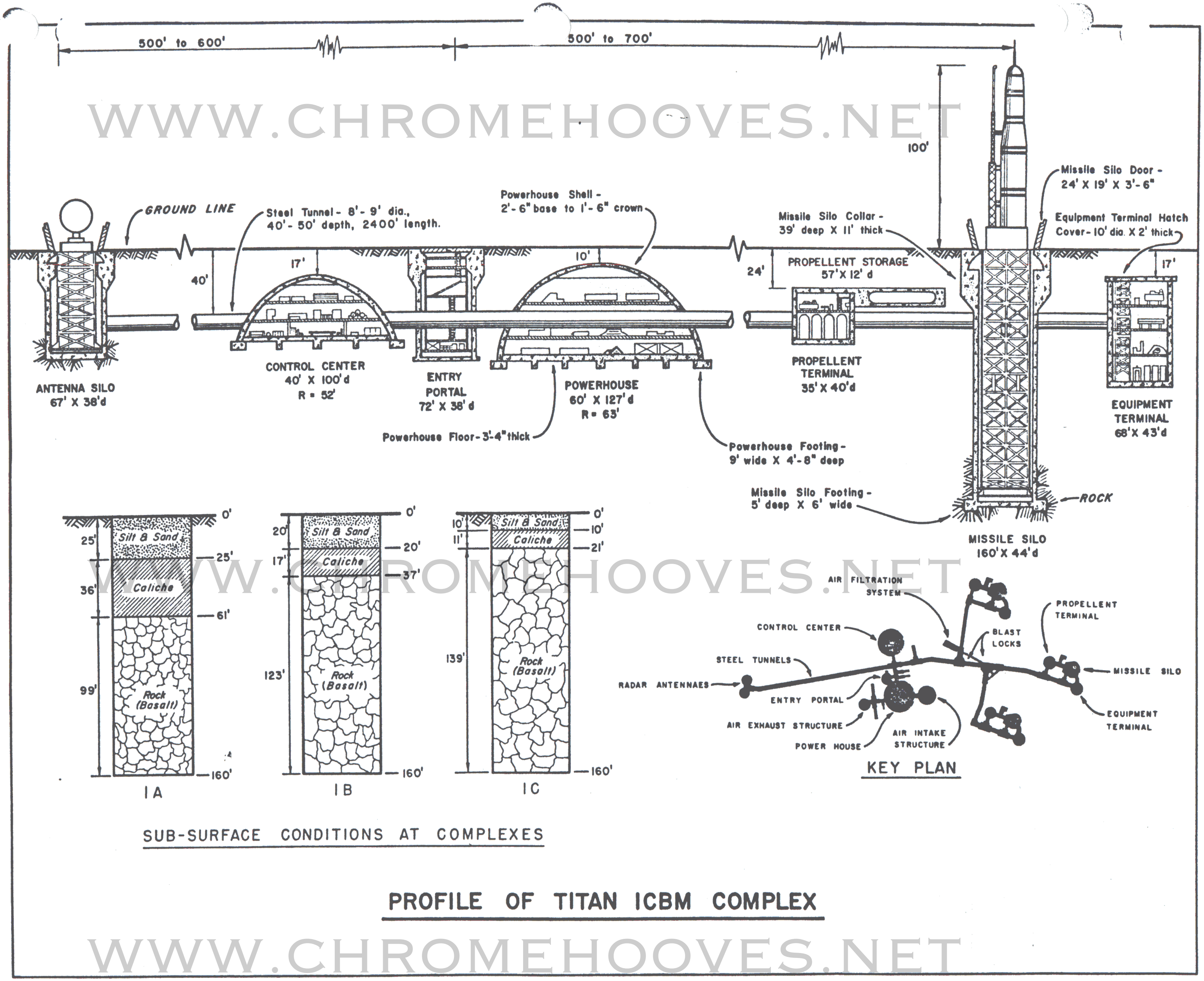

500' to 600'
500' to 700'
100'
GROUND LINE
Steel Tunnel - 8'- 9' dia., 40'- 50' depth, 2400' length.
Powerhouse Shell - 2'- 6" base to 1'- 6" crown
Missile Silo Collar - 39' deep X 11' thick
Missile Silo Door - 24' X 19' X 3'- 6"
Equipment Terminal Hatch Cover - 10' dia. X 2' thick
40'
17'
10'
24'
17'
PROPELLENT STORAGE 57' X 12' d
ANTENNA SILO 67' X 38'd
CONTROL CENTER 40' X 100'd R = 52'
ENTRY PORTAL 72' X 38' d
POWERHOUSE 60' X 127' d R = 63'
PROPELLENT TERMINAL 35' X 40'd
EQUIPMENT TERMINAL 68' X 43'd
Powerhouse Floor - 3'-4" thick
Powerhouse Footing - 9' wide X 4'-8" deep
Missile Silo Footing - 5' deep X 6' wide
ROCK
MISSILE SILO 160' X 44' d
Silt & Sand
Caliche
Rock (Basalt)
0'
25'
36'
61'
99'
160'
IA
20'
17'
37'
123'
IB
10'
11'
21'
139'
IC
SUB-SURFACE CONDITIONS AT COMPLEXES
AIR FILTRATION SYSTEM
CONTROL CENTER
BLAST LOCKS
PROPELLENT TERMINAL
STEEL TUNNELS
MISSILE SILO
RADAR ANTENNAES
ENTRY PORTAL
AIR EXHAUST STRUCTURE
POWER HOUSE
AIR INTAKE STRUCTURE
EQUIPMENT TERMINAL
KEY PLAN
PROFILE OF TITAN ICBM COMPLEX

Fig 13