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MEETING PAPER

XRAL STORAGE & TERMINALING CO.

A STATE OF THE ART LIGHT HYDROCARBON STORAGE FACILITY

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By

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ABOUT THE AUTHOR:

As a Professional Engineer, Marvin M. Miller specializes in project design, management, and operations services in the production, transportation, storage and processing of light hydrocarbons----- primarily LPG's and petrochemical feedstocks and intermediaries. His specialization includes providing design and economic analysis consultation on fractionation and pipeline projects for petroleum and petrochemical companies as well as technical consultation with various state and federal regulatory and enforcement agencies. He has been associated with salt dome underground storage and associated brine disposal projects for approximately thirty years and has been directly involved in the design, construction and operation of major light hydrocarbon storage facilities which presently represent over fourteen percent (14%) of the reported 1981 United States light hydrocarbon storage capacity.

Mr. Miller is President and Chief Executive Officer of Miller and Associates, Consulting Engineers, Inc., a professional engineering firm with principal offices in Houston, Texas, specializing in providing design, management, operation, and economic analysis services to the petroleum, petrochemical, and financial segments of the business community.

Mr. Miller recently directed the design and installation of the Xral Storage and Terminaling Company underground storage system at Mont Belvieu, Texas, and through his firm continues to serve as technical and management consultant to the project's owners. He is a registered professional Engineer and is a member of a select group of professional organizations. Among these are the American Chemical Society, (Senior Member), the National (U.S.) and Texas Societies of Professional Engineers, Gas Processors Association, American Petroleum Institute, Pipe Liners Club of Houston, Oil Men's Club of Houston, Houston Engineering and Professional Society, and Natural Gas Men of Houston. He is also an active member of the Texas State Bar Grievance Committee.

ABSTRACT

"XRAL-A STATE OF THE ART LIGHT HYDROCARBON STORAGE FACILITY"

by:

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In only seven short years, XRAL has been developed from a gleem-in-the-eye-plan for an unimproved pasture into the third largest storage facility on a salt dome which has the world's largest concentration of solution mined light hydrocarbon storage. Located on the Barbers Hill Dome approximately 32 miles east of Houston, XRAL's Mont Belvieu facility provides merchant long-term storage in fifteen caverns for diversified NGL's and high purity petrochemicals. This facility presently has a capacity in excess of 20 million barrels, is currently being expanded at an annual rate of 2-1/2 million barrels, and is presently capable of performing simultaneously fourteen independent product movements. Comprehensive preplanning of the pumping and manifold systems has permitted a four-fold expansion of the terminal with a minimum of piping changes and with little or no interruption of customer service. The cavern configurations have been customized to meet specific customer hydraulic-capacity requirements while retaining maximum utilization of the underground salt-mass. A sophisticated computer data acquisition and process control system provides constant monitioring of all piping systems, storage caverns, and custody measurement devices thus allowing safe and efficient operation of the facility with a minimum of personnel while retaining a maximum amount of both historical and real-time operational data. Initially designed to meet or exceed all then existing applicable design codes and regulations, the XRAL facility is finding it easy to comply with the current wave of increasingly restrictive new safety and environmental requirements.

XRAL STORAGE & TERMINALING COMPANY

A State of the Art Light Hydrocarbon Storage Facility

Xral Storage & Terminaling Company was formed in March, 1975, for the express purpose of establishing a merchant underground LPG storage facility in the Barbers Hill Salt Dome at Mont Belvieu, Texas. At that time six other companies operated underground storage facilities at Mont Belvieu----five of these facilities having been in operation since the 1950's. All of these existing storage facilities were proprietory and offered second party storage only when the space was not being utilized by the primary facility owner. Therefore, Xral's concept of "space for rent" provided a unique service to non-storage operators to obtain for varying periods of time storage space for their hydrocarbon products at the Barbers Hill Dome. In its position as the merchant warehouseman, Xral does not take title to the product stored inside its facilities; rather, it takes into its "care and custody" other companies' products and agrees to store and redeliver these products as directed by the "customer company" for a "specified" handling fee.

Although Xral Storage & Terminaling Company is chartered as a Texas corporation as a wholly owned subsidiary of Xcel Products Company of Houston, Texas, it has been in effect a joint venture since its inception. Xral derived its name by utilizing the "X" from Xcel Products Company and the "ral" from the Chaparral Division of Sante Fe Industries, the original project partner. Quite early in the project Chaparral was replaced by the English banking firm of Edward Bates & Sons who in turn were replaced in March, 1976, by UPG, Inc., a Delaware subsidiary of The Northern Companies with principal offices in Omaha, Nebraska.

The project has subsequently been managed to date under an "Agreement for Operation of Xral Storage Facility" dated June 9, 1976, amended on June 21, 1977.

Miller and Associates Consulting Engineers, Inc.'s, (MACE), chief executive officer served as the Xral project's general manager and chief operating officer from the project's inception until February of this year. In this capacity he personally directed the permitting, design, construction, staffing, and operation of the project. From time-to-time other employees of MACE served in various administrative and technical capacities in connection with the Xral project. MACE is currently contracted to serve as the project's technical consultants.

Xral's facilities are located on the Barbers Hill Salt Dome. This dome is situated entirely inside the corporate limits of the City of Mont Belvieu which is located in the southwestern part of Chambers County, Texas. The Xral property lies approximately 10 miles north of the city of Baytown, 55 miles west of the city of Beaumont, and approximately 32 miles east of the city of Houston. The location of this facility is shown on the first slide.

The proximity, or lack thereof, of a salt dome to facilities for the transportation of (a) its produced product (brine, sulfur, and/or salt), or (b) its stored materials (light hydrocarbons, petroleum liquids, and/or natural gas), significantly effects the dome's commercial potential. These transportation facilities can either be overland (i.e.: highway, rail), marine, and/or pipelines. The next three slides detail the accessibility of the Xral project property on the Barbers Hill Dome to these various transportation means.

Direct access to the Xral facility at Mont Belvieu is by a city maintained, two-lane, blacktopped road (Winfree Road). The project site lies approximately 2 miles north of Interstate Highway 10 and approximately 14 miles south of U.S. Highway 90. Both of these main transportation routes are accessible from the project site by Texas State Highway 146.

The Xral facilities at Mont Belvieu are dissected in a north/south direction by a spur line of the Southern Pacific Railroad. This spur line branches off of Southern Pacific's Houston/New Orleans main line approximately 15 miles north of the project at Dayton and terminates approximately 18 miles south of the project inside the City of Baytown, Texas. This spur line provides the primary rail service for the Baytown refining and petrochemical complexes and accordingly has been maintained in above average condition.

The Xral project is located approximately 14 miles north of the Houston Ship Channel. In addition, Cedar Bayou is navigable to barge traffic to within approximately five miles of the project site. Indicated by the blue arrows on the figure on this slide are these two waterways. The Trinity River located approximately 10 miles to the west of the Xral facility as shown on the extreme right section of this map is also navigable and provides a potential barge dock site.

Presently the Xral facility does not have any direct access to marine loading facilities. Originally the project was contemplated as a

receiving point for marine movements. Accordingly, three of the Xral wells (UGS-7, UGS-8, UGS-11) have cemented casing programs capable of handling well product movement rates in excess of 10,000 BPH. However, the required high capacity piping and pumping facilities to permit these ship-handling rates have not been installed.

At present all product movements in and out of the Xral facility at Mont Belvieu is via pipelines. Mont Belvieu is the terminus and transfer point for many of the major pipeline systems that serve the vast refinery and petrochemical complex of the gulf coast as well as distributing LPG's to the northeast and southeast consumption areas. The next slide indicates the location of the major United States LPG pipelines, terminals, and storage facilities. From this map the central location of the Xral project becomes apparent.

The next slide is a map showing the location of the major product pipelines in the south Texas area. This figure shows the almost ideal location of the Xral project at Mont Belvieu to these systems.

Mont Belviue is the terminus and transfer point for many of the major pipeline systems such as Texas Eastern, Arco, Exxon, Mobil, Warren, Chaparral, Dow, Union Carbide, Tenneco, Seminole, Enterprise, Shell, and Diamond Shamrock. The next slide entitled "Major LPG Pipelines - Mont Belvieu" illustrates the proximity of the Xral project to the pipeline networks serving the greater Houston metroplex.

The next two slides show the relationship of the Xral facility to the Mont Belvieu area pipeline grid.

The relationship of the Xral facilities to the other Mont Belvieu operators is shown on the next slide entitled "Industrial Ownership-Mont Belvieu". The Xral properties on this map are indicated in red. The long narrow rectangular property shown in the left central portion of this figure is the project's offsite brine pit area while the red, almost square, area in the center of the drawing is the plant storage site property. From this drawing it can be seen that the storage area property is entirely within the city limits of Mont Belvieu while the majority of the brine storage area lies outside the city limits. The Xral storage site property is abutted on the north by Continental Oil Company's storage facility and on the south by Exxon Pipeline Company's storage facility.

In designing the Xral storage site, consideration has been given to natural hazards which could effect the safety and operation of the storage facility. From a geologic hazard standpoint, the risk of damage to a cavern or to surface facilities at the Xral storage site resulting from differential ground displacement due to faulting is considered to be extremely remote. The Barbers Hill Salt Dome is in a state of equilibrium and upward salt movement of a magnitude great enough to cause new or renewed fault movement would be an unreasonable assumption.

Earthquake shocks generated by a local fault movement are considered to be extremely unlikely in the immediate vicinity of the Xral storage facility. The National Oceanic and Atmospheric Administration (NOAA) has classified the United States into four zones with different degrees of expected seismic risk. These subdivisions are based upon recorded history of past seismic activity. The entire region surrounding Barbers Hill Dome falls into a Zone 0 or a "no damage area" on NOAA's seismic risk map as shown in the next slide. This assumption has been verified by the historical earthquake record and the safety analysis report for the south Texas nuclear plant project located approximately 90 miles southwest of the Xral facility. In this safety analysis report, a thorough investigation has been made of all earthquakes dating back to 1699 which have occurred in a six hundred mile radius of the nuclear project site.

Damage from hurricanes can result from both wind and water. Dangerous and destructive tropical cyclones (hurricanes) can be expected across the Texas coast on the average of about once every three years. Although strong hurricane winds and tornadoes spawned during the course of the hurricane can cause great loss of life and property, the tide surge produced is normally the most destructive component on the Texas coast. A single severe hurricane can flood vast land areas. However, due to the Xral project facility being located at an average elevation of 48 feet above mean sea level and with the offsite pits at a average of 34 feet above mean sea level, flooding damage from hurricanes is not anticipated to be a significant factor at this facility. Due to the inherently mechancially stable nature of the project's piping systems, no significant direct wind induced damage is anticipated.

Injection of surplus brine by the various operators has for the past several years been into the caprock area of the dome. No evidence has been observed to date that this injection is of a magnitude to

produce hazardous effects at the Xral project site in the form of subsidence, differential ground displacement, or the generation of earthquake shocks due to reactivation of fault movement.

Elevation of the exposed ground surfaces overlying the Barbers Hill Salt Dome ranges 40 to 81 feet above sea level as shown on the next slide. It can be noted that the overlying surface topography closely approximates the subsurface salt mass elevations. On the Xral storage site properties elevations varying from 61 to 42 feet while elevations on the offsite brine pit property range from 41 feet at the CIWA canal to 21 feet at Cedar Bayou. Due to the rapid fall of the land lying east of the Southern Pacific Railroad, the Xral project's main terminal site affords excellent drainage; however, this same high degree of fall necessitates protection of these facilities from erosion induced damages. The terminal property west of the Southern Pacific Railroad tracks has very little natural drainage and consequently requires an ongoing effort to maintain artificial drainage facilities.

No subsidence monitoring program is available for the area directly overlying the Barbers Hill Salt Dome. Accordingly the degree of subsidence and its source (caprock, salt, or overburden) is poorly defined. The shape and configuration of the Xral subsurface caverns will be discussed later; however, it is considered highly improbable that surface subsidence will occur at the Xral terminal property site as a result of cavern roof and/or sidewall failures.

Presented on the next two slides are aerial photographs of the Xral terminal site. On each of these photographs the Xral terminal boundary has been overlayed.

The first of these photographs was obtained from aerial surveys flown on January 20, 1974. This photograph was taken approximately one year before the formation of Xral and shows the utilization of the terminal site at that time to be primarily unimproved pasturage. The most distinguishable features on this photograph inside the Xral boundaries are the railroad right of way with its adjacent pipeline corridors and a small oil production facility located in the southwestern portion of the property.

The second aerial photograph was obtained from an aerial survey flown on January 28, 1981, approximately five years after field construction of the Xral project had been initiated. This photograph

shows the location of the terminal's service roads, well pads, on site brine pit, Shell ethylene/propylene dehydration facilities, and initial office/control building. Comparison of this photograph with the plot plan of the facility shown on the next slide allows the further identification of the hydrocarbon pumping area, the fresh water booster pump and surge tank area, etc. Also shown on this photograph are the pipelines leaving the terminal facilities going to the (a) offsite fresh water pump station [center-left side of the photo], and (b) product pipelines leaving the terminal and going toward the Arco junction [right upper center of photograph].

The main electrical distribution to the Xral facility is by a 3,750 KVA substation with 12.5 KV overhead primary feeders. Secondary 4.160 KV service is supplied to the fresh water switch gear building (MCC-1) and to the hydrocarbon switch gear building (MCC-2). Distribution of the plant secondary 440 volt service is made by auxiliary circuit breakers and distribution panels located in both MCC-1 and MCC-2. The photograph on the next slide shows the incoming 3,750 KVA station with secondary overhead 4.160 KV distribution feeds.

The photograph on the next slide shows the overhead electrical distribution system located at the MCC-1 pole mounted 440-V transformers while the photograph shows the overhead feeds into MCC-2 and the associated pad mounted 440-V transformer system. In the foreground of this photograph is shown one of the two 150 ampere cathodic protection rectifiers with its associated deep well anode bed.

Shown on the next photograph are two 75 SCFM air compressors with coalescers, desicant and refrigerant dryers. Included in the plant air distribution system is 3,500 feet of two-inch and one-inch air headers with associated regulators and valving.

The Xral project product handling facilities consists of high pressure product injection pumps and associated suction and discharge manifolds, turbine and orifice meter measurement systems, product treating and dehydration facilities, pipeline distribution systems and associated instrumentation facilities. The majority of these facilities are located in the "process area" of the terminal and lie between the east/west coordinates of W2+00 and W3+00 and the plant north coordinates of N5+00 and N8+00.

The terminal's primary hydrocarbon pumping facility consists of three 600 hp, horizontal split case, multiple stage United centrifugal

transfer pumps. These pumps are shown in the next three photographs. The terminal's secondary product pumping requirements are handled by three 250 hp, vertical canned, Afton multistaged booster pumps. These pumps and their associated piping systems are shown on the next slide. The next four photographs show some details of the product pumping systems.

Incorporated in the terminal's product measuring system are four four-inch, ANSI 600#, turbine meter stations equipped for both volumetric and mass flow measurement; two 2-1/2-inch, ANSI 600#, turbine meter stations. In addition, the facility is equipped with three six-inch, ANSI 900#, mass flow orifice meter stations with Daniel senior fittings and associated densitometers. Associated with the six turbine meter stations is one ten-barrel, eight-inch, ANSI 600#, unidirectional, buried meter prover with its associated manifold piping. These systems can be seen on the next three (3) slides.

The Xral facility is equipped with a ANSI 600# (1,040 psig maximum working pressure), 2,000 BPH, regenerative National Tank Company skid mounted dehydrator with associated salt bath heater, forced draft coolers and interconnected pipe and control valves. This facility can be seen in the right-hand portion of the next photograph. The overhead pipe bridge carrying the regeneration gases to the dehydration/treating unit's salt-bath heater can be seen in the left center portion of this photograph.

The Xral terminal's brine handling facilities incorporates a 1.4 mmbbl offsite reservoir which is presently under construction, and a 10,000 barrel onsite reservoir with associated transfer pumping facilities, distribution pipelines, gas disengaging facilities with associated ignition equipment, and a onsite disposal well.

The next photograph shows the surface wellhead facilities associated with the disposal well SWD-1. This well is located at plant coordinates W2+00 and N2+50 and has a disposal capacity in excess of 6,000 BPH while operating with a vacuum at the surface.

The onsite 10,000 barrel brine reservoir is hyperlon lined and equipped with a 30" x 60' gas disengaging stack with LPG pilots. These facilities can be seen in the next photograph.

The Xral project is equipped with a supervisory and control system consisting of a central computer controlled operator station and remote telemetering units (RTUs) whose purpose is to gather field data, convert the data to a unique format, and transmit the data to the central station on command. The system as presently configured will monitor and control 10 cavern wells (and is immediately expandable to 12 wells), the brine and water systems, the main hydrocarbon pumps, meter stations Nos. 1 through 3, as well as monitoring and reporting on the safety and status condition of approximately 85% of the hydrocarbon piping, and 90%+ of the non-dedicated movements. Approximately one-half of the terminal's present product manifold valves are incorporated in the present phase of the computer program, with the large majority of those systems not presently scanned associated with the dedicated special purpose systems. As part of the initial construction program of the expansions to the terminal facility, the necessary instruments and controls to utilize the computer, as well as a significant percentage of the field wiring, has been installed on the remaining three storage caverns, the dedicated meter stations and their associated pumping systems.

The computer system provides the terminal operator with colored graphics allowing the visual indication of the status of all valves, pumps, and piping inside the terminal. In addition, visuals have been incorporated into the computer software program to provide ongoing product movement, authorization information (tender request status), remote turbine meter proving capability, individual cavern inventories, and the generation of product movement accounting tickets and daily operational status reports.

At the time of this paper, the Xral project operated fifteen storage wellheads. Each of these wellheads were equipped with associated automatic valving, pressure transmitters, associated brine/fresh-water/LPG measuring equipment. A slightly different wellhead configuration is utilized for leaching operations as opposed to product storage operations. The photograph on the next slide shows UGS-1 in the foreground configured for leaching services. In the right background is disposal well SWD-1. The next photograph is a typical Xral well configured for product storage. Note the interface detector lubricator with the associated cabling located on the top of the christmas tree. Each cavern is equipped with a bidirectional product measurement orifice tube, a unidirectional fresh water orifice tube, and a bidirectional brine orifice measurement tube.

Each of these tubes are equipped with the appropriate electronic transmitters, pressure sensors, and control valves as well as a RTU for Scada System interfacing. A typical well metering installation is shown on the next photograph.

The wellhead facilities are connected to the product manifold system by individual well flowlines. These lines are connected into the product manifold system by individual headers as shown on the next two photographs. Please note that each of these valves are equipped with specially designed position indicators. The second photograph shows the manifolding of the thermal relief valves to the terminal's closed flare system.

As of the time of this paper, fifteen (15) caverns, or storage well sites, had been drilled on the Xral terminal site for the purposes of either brine production or hydrocarbon storage. Four (4) of these well sites are located inside the boundaries of the fee property reserved by the UPG division of Northern Natural. As shown on the next slide, the remaining eleven (11) well sites are situated on the surrounding Xral fee property. All fifteen of these storage caverns, as well as one caprock disposal well, were permitted, drilled, and developed under the direct supervision of MACE's chief executive officer (assisted by other MACE personnel) acting in the capacity of Xral's general manager and chief operations officer.

As of February 1, 1982, the project's caverns had a total capacity of 19,843,000 barrels, of which 15,526,000 barrels were in assigned hydrocarbon product service with the remaining 4,317,000 barrels distributed between three (3) caverns which were being developed for additional capacity and to provide an operational brine source. The four (4) UPG caverns accounted for 6,478,000 barrels of the total capacity with three (3) caverns in product service with a combined storage capacity of 4,451,000 barrels.

As alluded to earlier in this paper, two different casing programs have been utilized in drilling and completing the Xral storage wells. One program, which has been utilized for twelve (12) caverns, utilizes a 13-3/8" O.D. lower cemented string into the salt mass and has a product handling capacity of approximately 100,000 barrels per day. The next slide is a diagrammatic representation of a completion utilizing this size program. As will be seen shortly, individual casing string setting depths will vary significantly depending upon the location of the well-bore in relation to the caprock and salt

structure. The second casing program shown on the next slide is typical of three well locations. This casing program, utilizing a 20" O.D. last cemented salt string, permits product movement rates up to 10,000 barrels per hour (240,000 barrels per day).

In order to accommodate storage customer hyraulic requirements, the project's cavern development leaching programs were specifically designed to provide three basic completed cavern shapes. These are illustrated by the next six slides. the "tear-drop" configuration is shown by the cross sections of Caverns UGS-1 and UGS-4; the "elongated cylinder" by Caverns UGS-6 and UGS-16; and the "truncated-cylinder" by Caverns UGS-5 and UGS-14.

Before we discuss cavern shapes further, lets first look at the project site's geology. Xral Storage & Terminaling Company's operations have been conducted to date on the Mont Belvieu Salt Dome on which is located the Barbers Hill oil field. This dome is located in the west-central portion of the Gulf Coast Geosyncline. This major regional feature forms a crescent roughly 750 miles long following the northern perimeter of the Gulf of Mexico subside and is filled with roughly 50,000 feet of sediments. One of the earliest units deposited in the paleogeosynclinal area is Louann salt of Jurassic age which reached a thickness of 3,000 to 5,000 feet. After this "mother salt" section was buried by sediments and underwent tectonic deformation, salt ridges and spines moved upward through the sediment. These salt bodies now form the salt domes of the Gulf Coast. The next slide is a structure contour map and cross section of the Barbers Hill, Lost Lake, and Moss Bluff domes which shows the comparison of the area's uplift in square miles of the three structures. The area of uplift at the Barbers Hill (Mont Belvieu) dome is approximately three times greater than that at the other domes; accordingly the amount of hydrocarbon accummulation at Barbers Hill is many times greater than that for the other domes.

The Barbers Hill salt structure pierces or uplifts strata ranging in age from Oligocene to Pleistocene and Recent. The general stratagraphic sequence reflects alternating marine transgressions represented by shales and transgressions represented by deltaic sands and muds. The general structure of the dome shows sediments upturned against the salt on all the flanks. The dips of the surrounding sediments increased toward the dome as shown in the figure, but there is no evidence that the strata are anywhere overturned. The next slide illustrates the relationship of the Xral property to the basic salt stalk as delineated by the 4,000 feet salt contour line.

Various cross sections have been developed utilizing subsurface information obtained during drilling operations conducted during oil exploration activities on the dome. These cross sections are shown on the next series of slides. As can be seen by the key map, section CC most closely illustrates a view looking into the northeast corner of the Xral property while section GG presents a view of the salt mass looking from the north to the south. Note that the initial geological work shows overhangs located in the north central, northeast, east, and south portions of the dome structure but postulates no overhangs in the western side of the dome on which the Xral facility is located. However, subsequent to the development of the majority of the Xral caverns, additional geological data became available through drilling activities of Exxon immediately south and adjacent to the Xral facility site. These drilling activities and subsequent seismographic work indicate a significant overhang on the southwest flank of the dome with perhaps a fold in the salt stalk appearing immediately south of the Xral site. This drilling activity and associated geophysical study resulted in a redefinition of the western edge of the dome. This revised geology has resulted in Exxon "abandoning" several undeveloped cavern sites on its fee property located directly south of Xral's property.

The information presented in this next and final series of slides has been developed from data obtained by downhole directional surveys conducted at the time of completion of well drilling activities and sonar caliper surveysobtained after partial or final cavern development. Where multiple sonar calipers are available on a particular cavern, the "latest" of these has been utilized in preparing the exhibits in this section unless a particular imtermediate survey showed a maximum diameter in excess of that indicated on a later survey.

The first slide in these series shows the apparent horizontal spacing of the fifteen existing storage caverns on the Xral terminal site. The surface location for UGS-13 is indicated in the upper left-hand portion of this figure for reference purposes only as at this time UGS-13 is an undrilled well site. The locations of each cavern surface wellhead is shown by the large circle with the included black quadrants. This information has been obtained from the project's "as-built" construction drawings as opposed to the locations as indicated on the individual well records. The location of the top of each storage cavern is indicated by a small open circle which was determined by utilizing the directional information combined with the

conducted at the time of completion of well drilling activities and sonar caliper surveys obtained after partial or final cavern development. Where multiple sonar calipers are available on a particular cavern, the "latest" of these has been utilized in preparing the exhibits in this section unless a particular imtermediate survey showed a maximum diameter in excess of that indicated on a later survey.

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Section A^1-A^1 illustrates the relative spacing in the plant north/south direction (magnetic northwest/southeast). From this figure it is apparent that the actual salt web thickness varies as a function of depth due to the "tear drop" configuration of the typical Xral well. The specially designed cavern configuration for UGS-5 is also apparent on this figure.

Vertical section B^1-B^1 indicates the adjacency of wells UGS-16, UGS-6, UGS-7, and UGS-8. Although the surface location of UGS-9 is indicated on this figure, it was not possible to delineate its cavern shape since this well was not sonared prior to being placed in product storage service. Vertical section C^1-C^1 similarly shows the subsurface configuration of caverns UGS-10, UGS-11, UGS-12, UGS-15, and UGS-14. (As previously reported, UGS-13 is an undeveloped well site location and is reported on this drawing for information purposes only.) It should be particularly noted that section C^1-C^1

is not a straight line through the Xral property. Accordingly the graphical information presented is to be utilized with the proper technical caution.

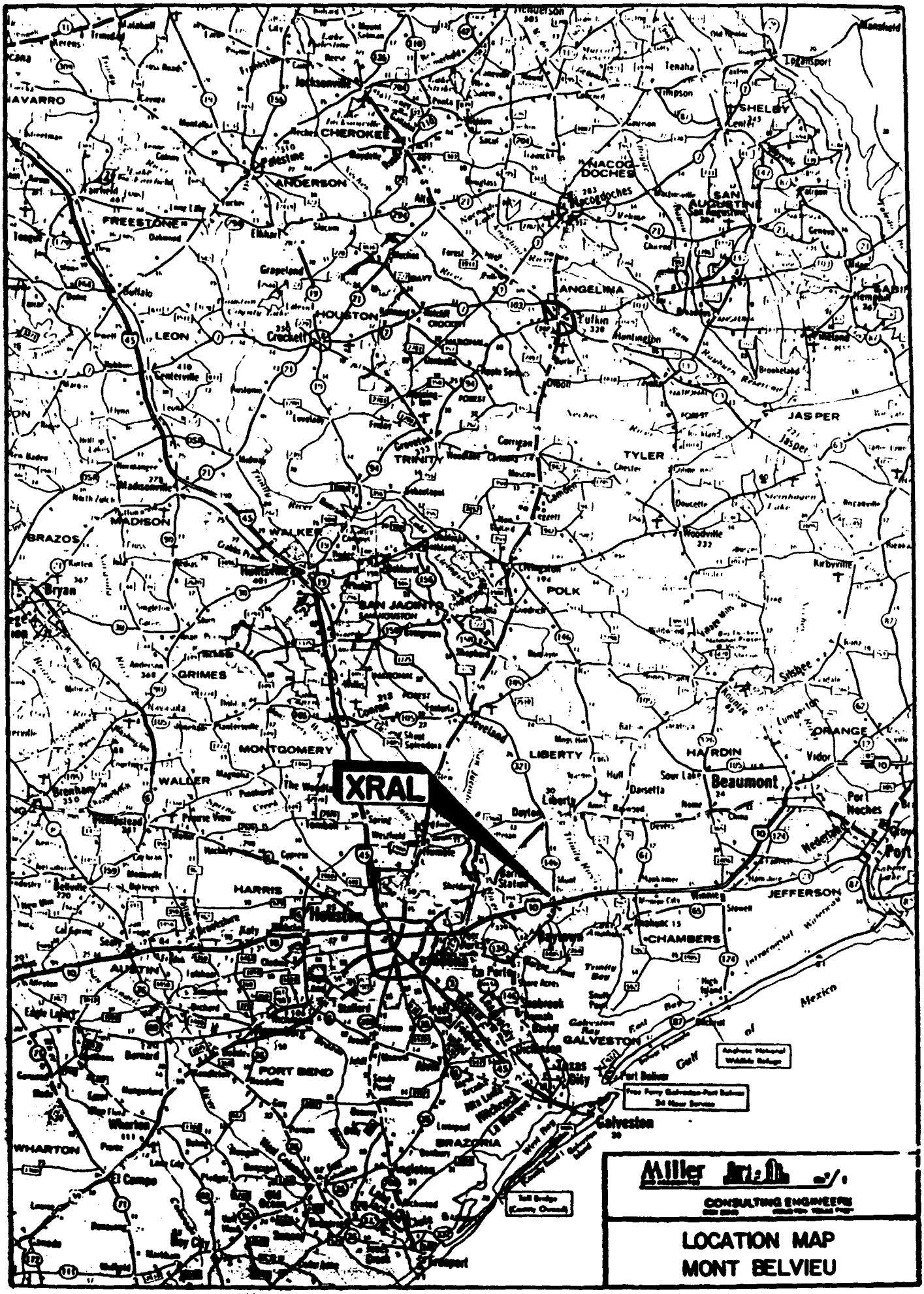
The three previous cross-sections have essentially been through drilling locations situated parallel to the edge of the dome structure, and thus each section has been following closely one of the subsurface contours. The next slide indexes three cross sections which cut more sharply toward the edge of the dome, thus beginning to illustrate how rapidly the caprock and salt mass falls off in elevation proceeding from plant-east to plant-west.

Section D-D^1 shows the sub-surface configurations of Caverns UGS-1, UGS-6, UGS-11, and UGS-12; while Section E-E^1 indicates the adjacency of caverns UGS-2, UGS-7, and UGS-12. Similiarly, section F-F^1 shows the relationship of caverns UGS-3, UGS-9, and UGS-14. Note now how the rapid dropoff of the caprock and top-of-the-salt stock is now becoming apparent.

The next slide indexes the last four cross-sections; each more increasingly defining the rapid dropoff of the dome structure. Section J-J^1 incorporates caverns UGS-1, UGS-7, UGS-15, and UGS-13. Section K-K^1 shows the relationship of caverns UGS-4, UGS-8, and UGS-12. Section G-G^1 cuts through UGS-5, UGS-9, and UGS-15, while caverns UGS-3, UGS-8 and UGS-15 are shown in section H-H^1.

From these foregoing sections, it can been seen that the drilling and development of the Xral storage caverns have presented a unique and challenging engineering and management assignment. We are proud of these facilities, both surface and subsurface, and look forward to continued association with this project as it moves from a development and construction period into a long-term operational and maintenance phase.

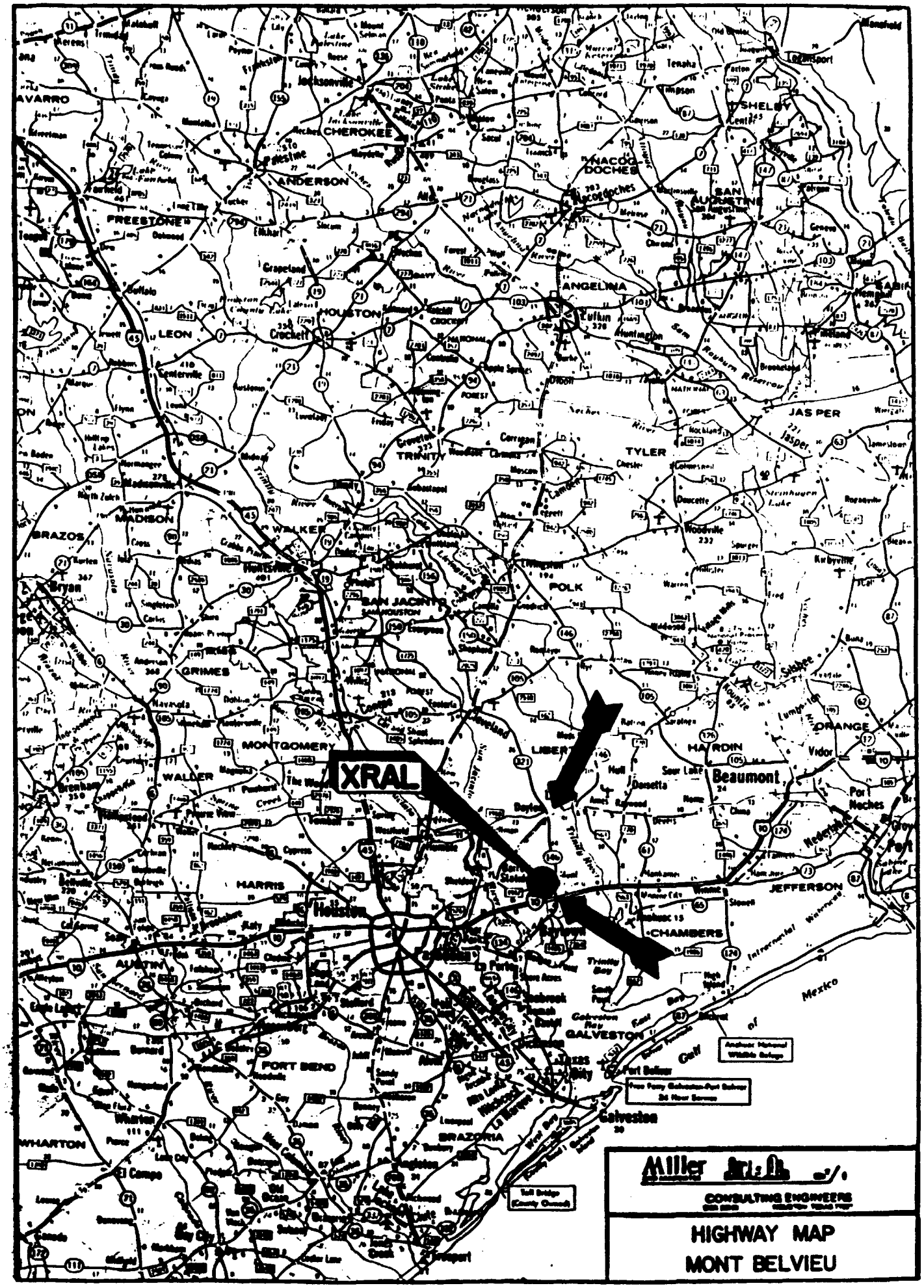
ILLUSTRATIONS



Miller

CONSULTING ENGINEERS

LOCATION MAP
MONT BELVIEU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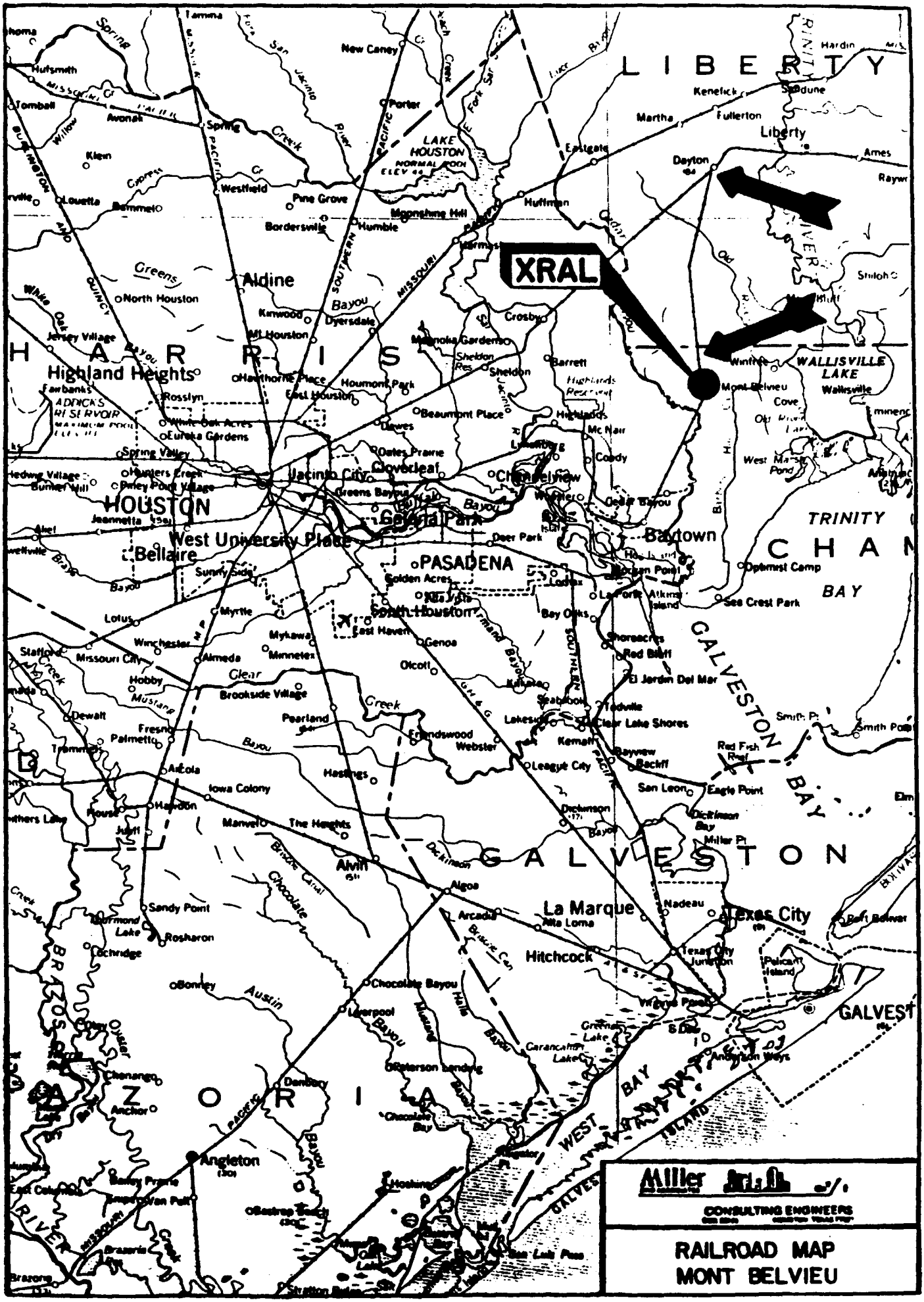
MONT BELVIEU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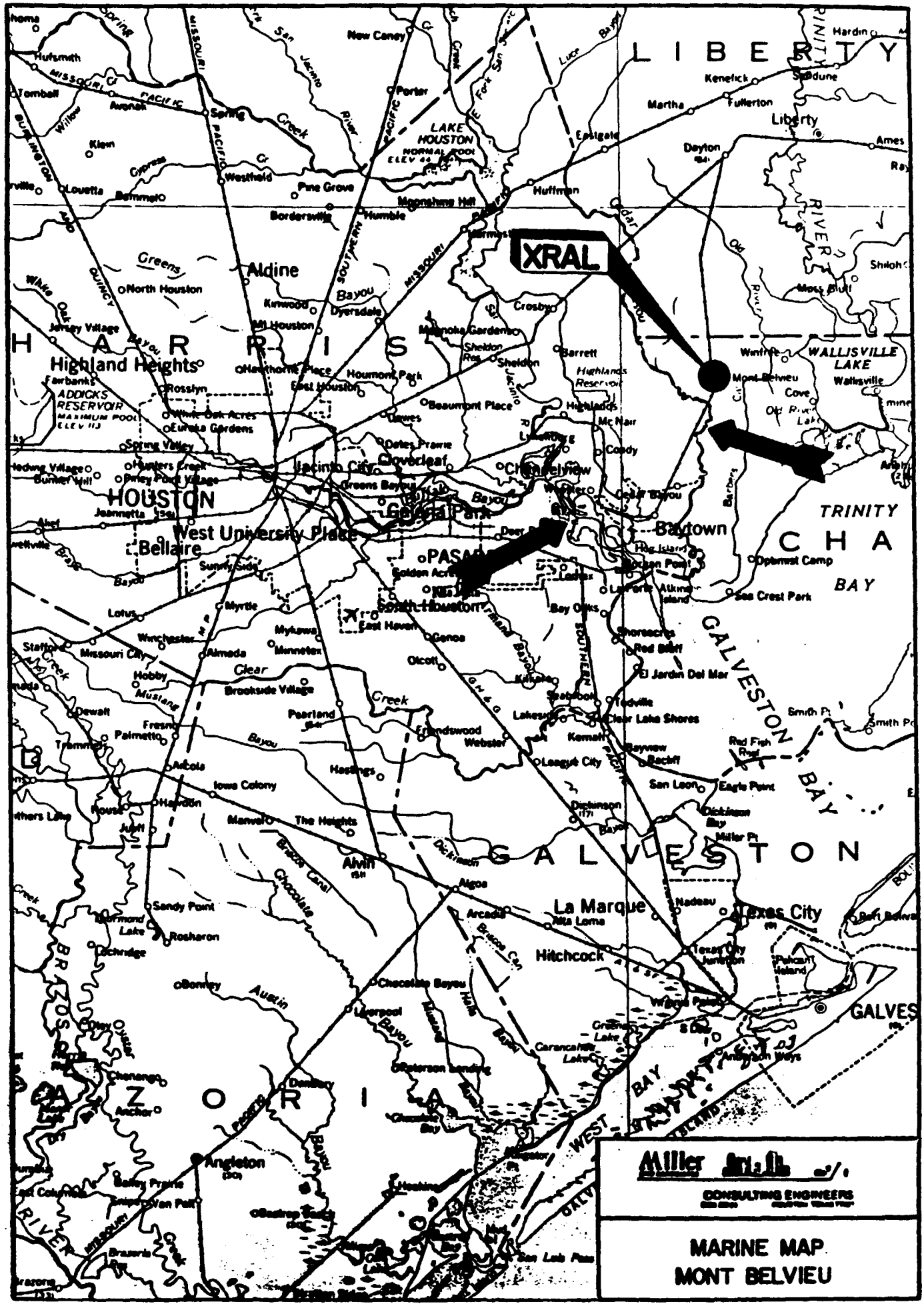
MONT BELVIEU


XRAL
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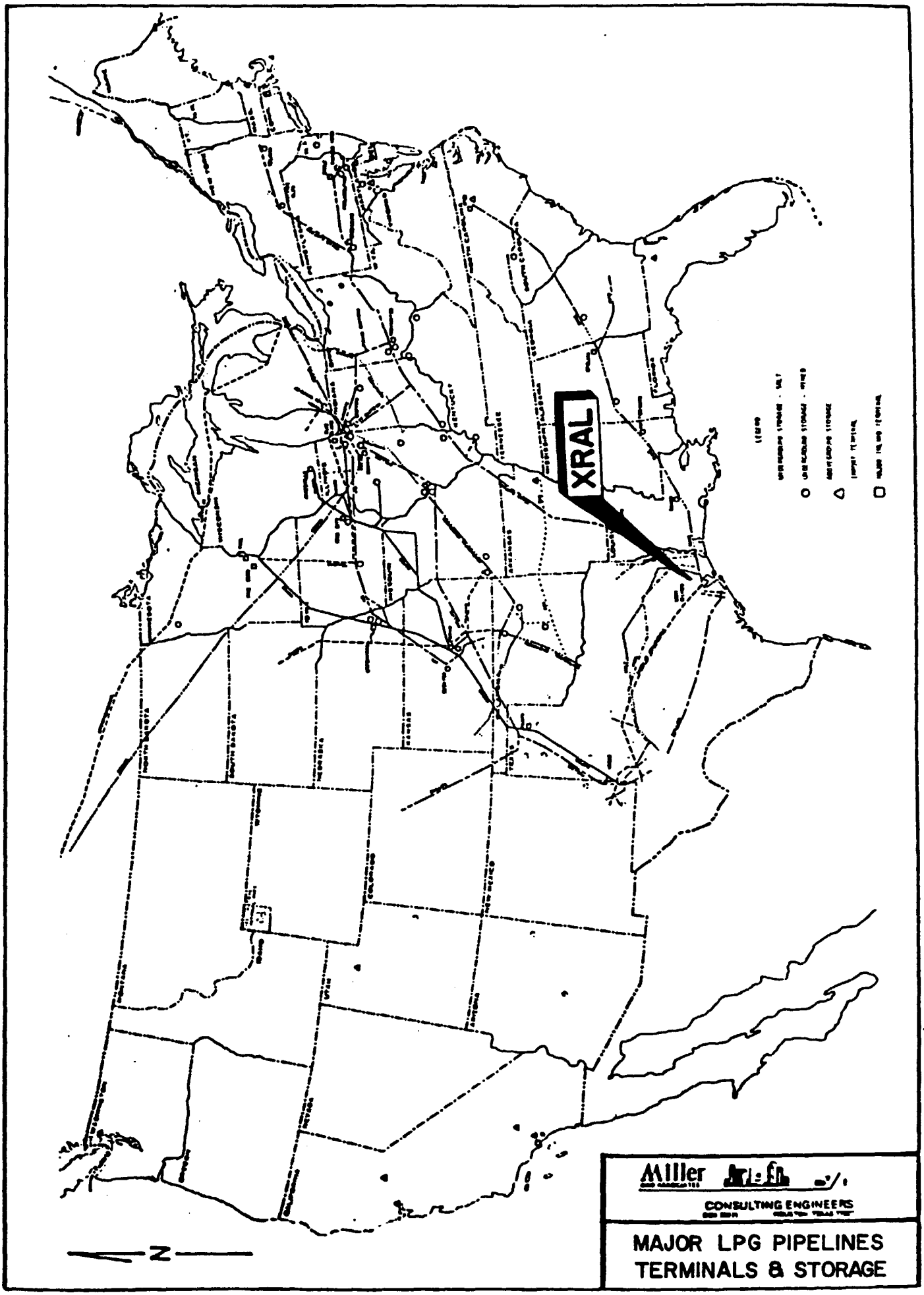
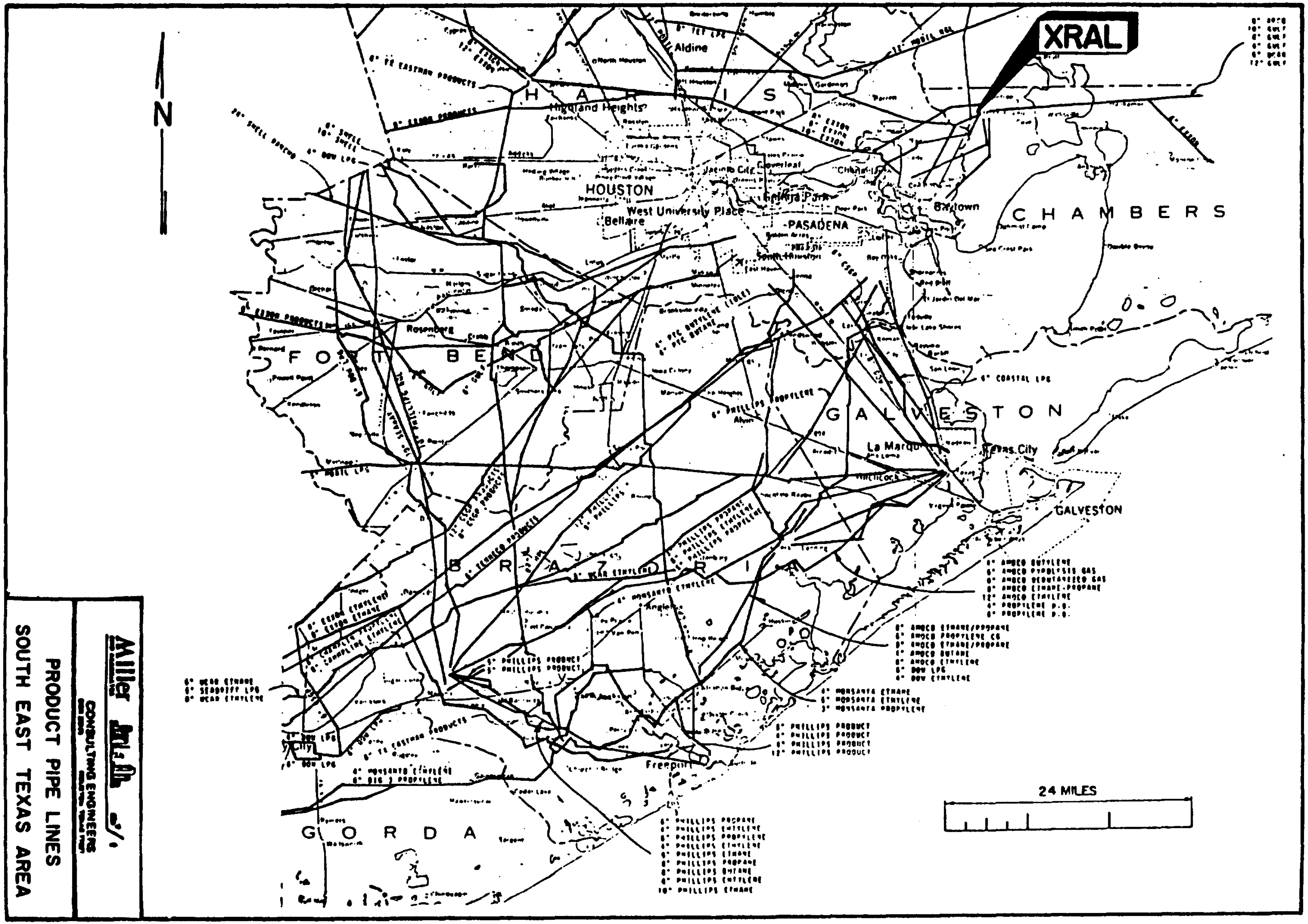
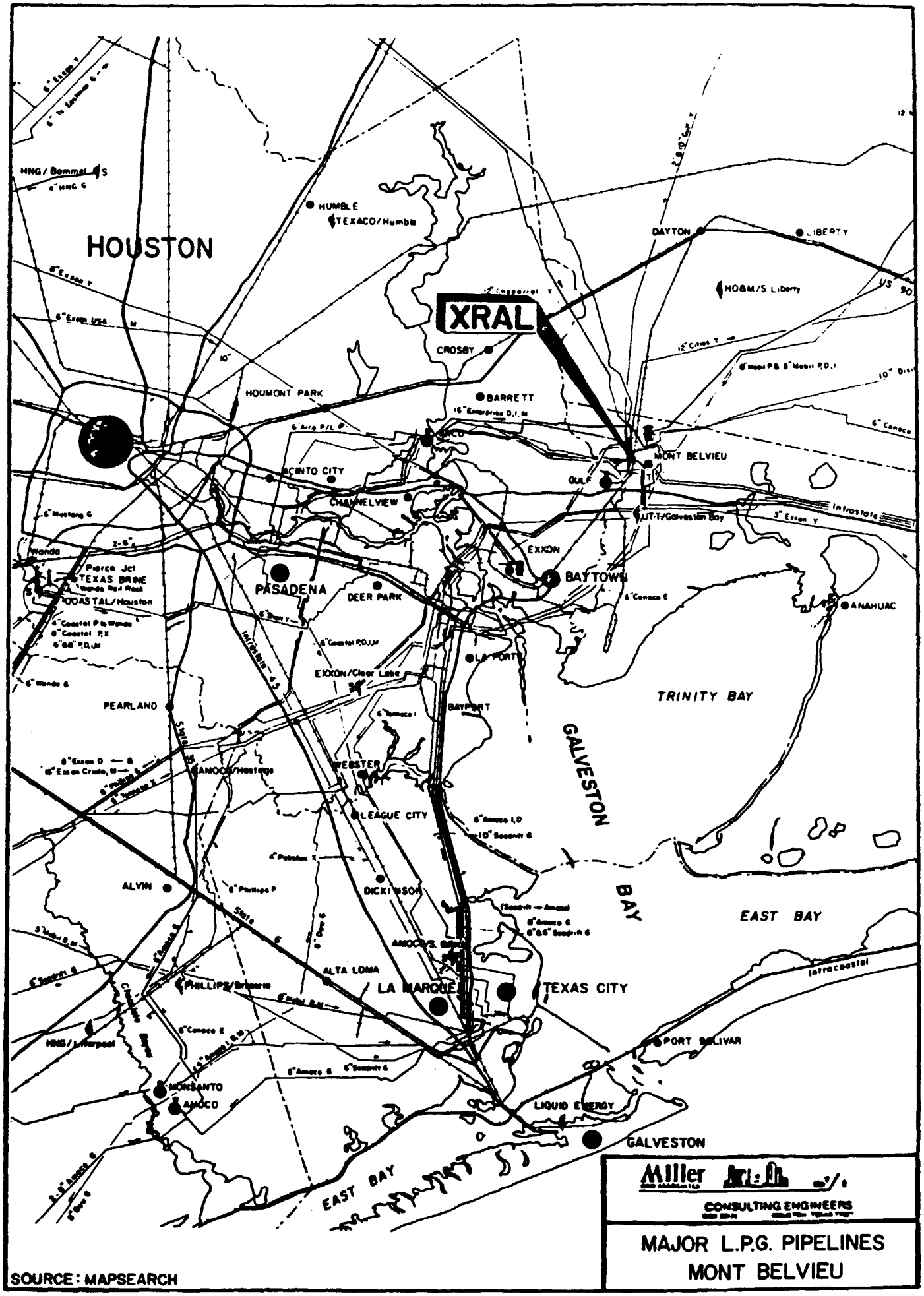
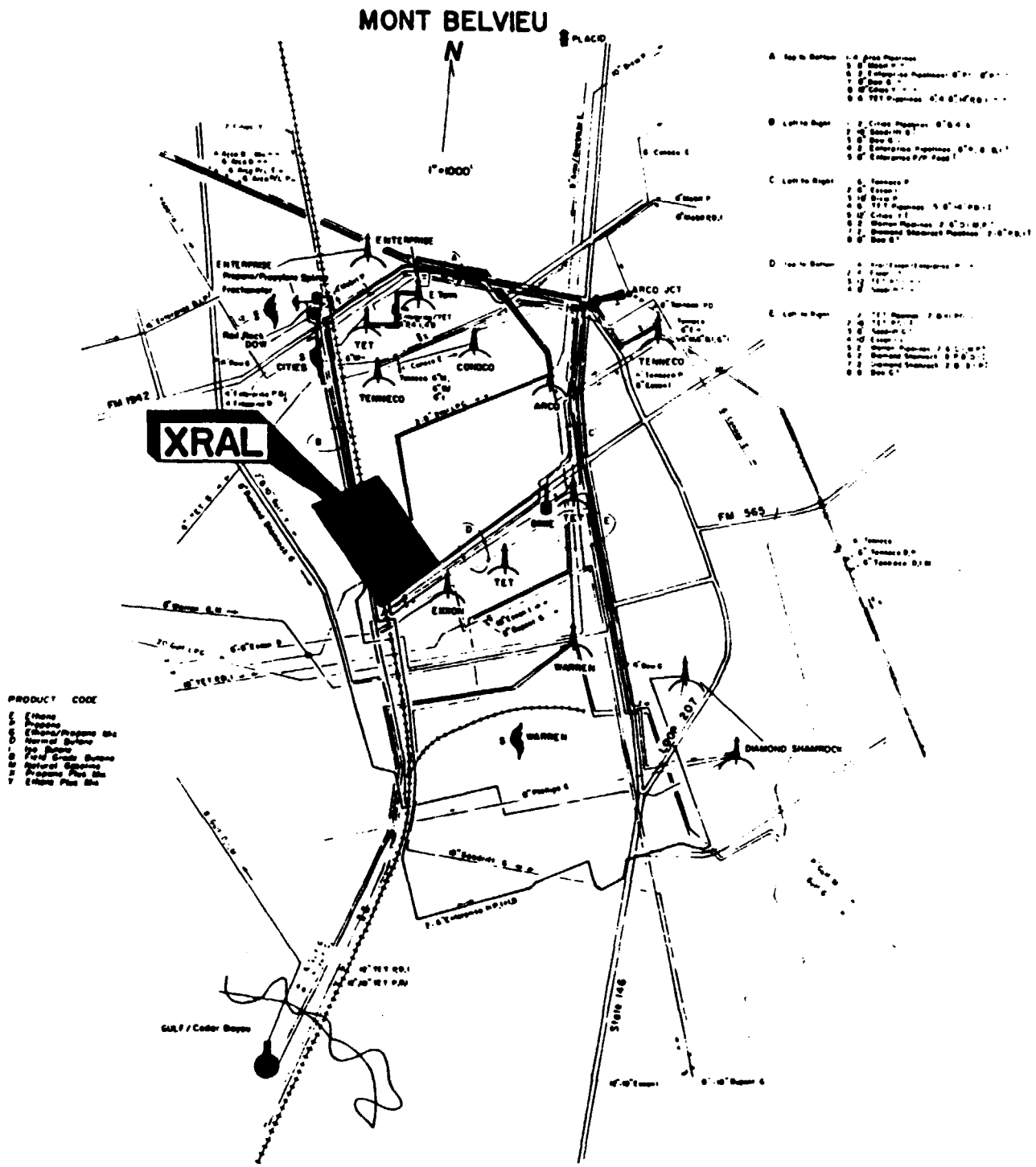
HARRIS
HOUSTON
GALVESTON
BRAZORIA
TRINITY
BAY
GALVESTON BAY
Miller
CONSULTING ENGINEERS
MARINE MAP
MONT BELVIEU


XRAL
Miller
CONSULTING ENGINEERS
MAJOR LPG PIPELINES
TERMINALS & STORAGE



PRODUCT PIPE LINES
SOUTH EAST TEXAS AREA
Miller
CONSULTING ENGINEERS
XRAL
N
24 MILES
HARRIS
CHAMBERS
FORT BEND
GALVESTON
BRAZORIA
GORDA
HOUSTON
Aldine
Highland Heights
West University Place
Bellaire
PASADENA
Baytown
Rosenberg
La Marque
Texas City
GALVESTON
Alvin
Angleton
Freeport

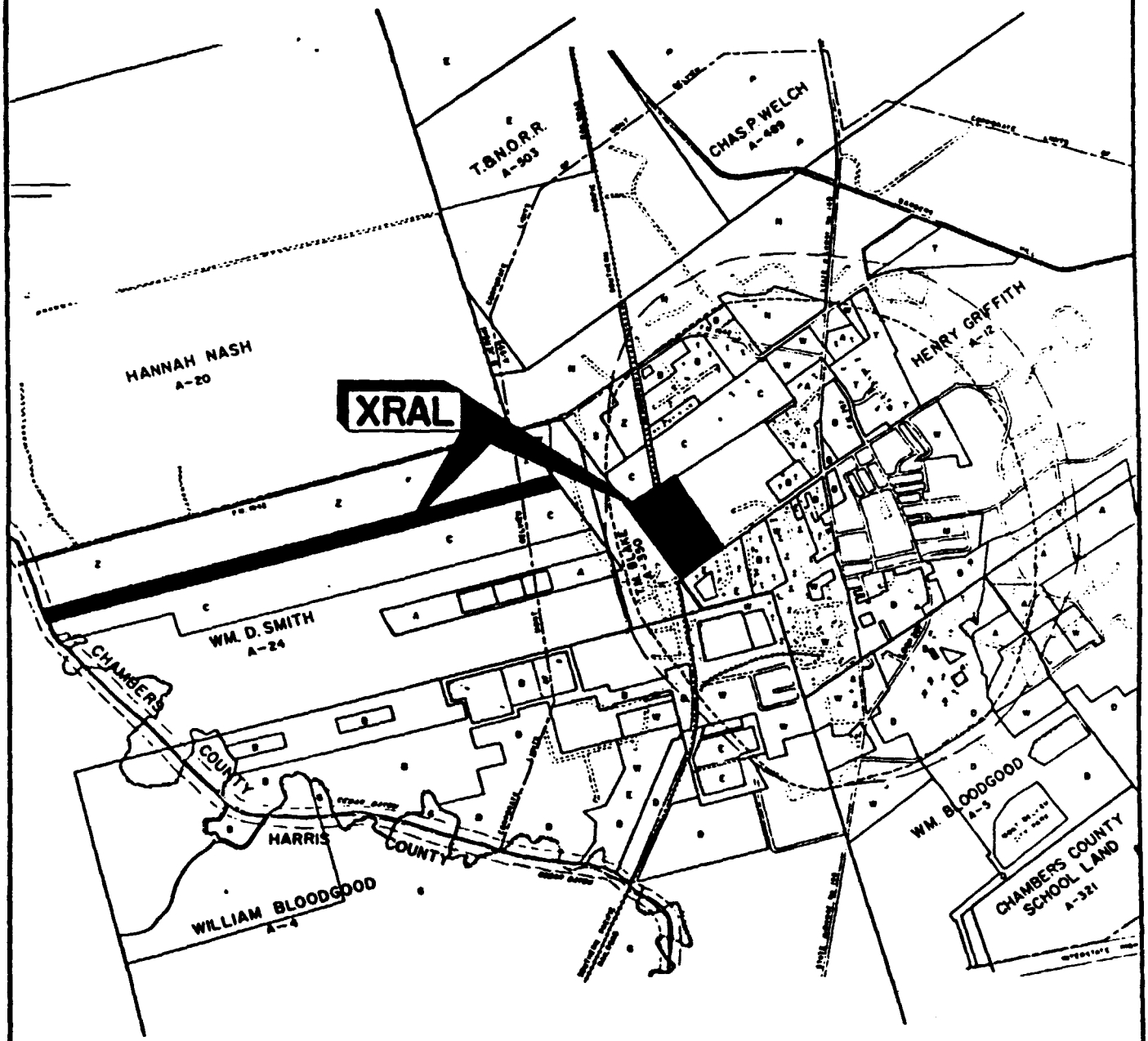

HOUSTON
XRAL
HUMBLE
TEXACO/Humble
CROSBY
HOUMONT PARK
BARRETT
DAYTON
LIBERTY
HOB M/S Liberty
US 90
MONT BELVIEU
GULF
ACINTO CITY
CHANNELVIEW
Intrastate
EXXON
BAYTOWN
PASADENA
DEER PARK
ANAHUAC
LA PORTE
EXXON/Clear Lake
TRINITY BAY
PEARLAND
BAYPORT
GALVESTON
WEBSTER
AMOCO/Hastings
LEAGUE CITY
ALVIN
DICKINSON
EAST BAY
ALTA LOMA
LA MARQUE
TEXAS CITY
PHILLIPS/Brazoria
HNG/Liverpool
PORT BOLIVAR
MONSANTO
AMOCO
LIQUID ENERGY
GALVESTON
EAST BAY
Intracoastal
Miller
CONSULTING ENGINEERS
MAJOR L.P.G. PIPELINES
MONT BELVIEU
SOURCE: MAPSEARCH



Miller and Associates
CONSULTING ENGINEERS

PIPELINE DETAIL MAP
MONT BELVIEU

SOURCE: MAPSEARCH

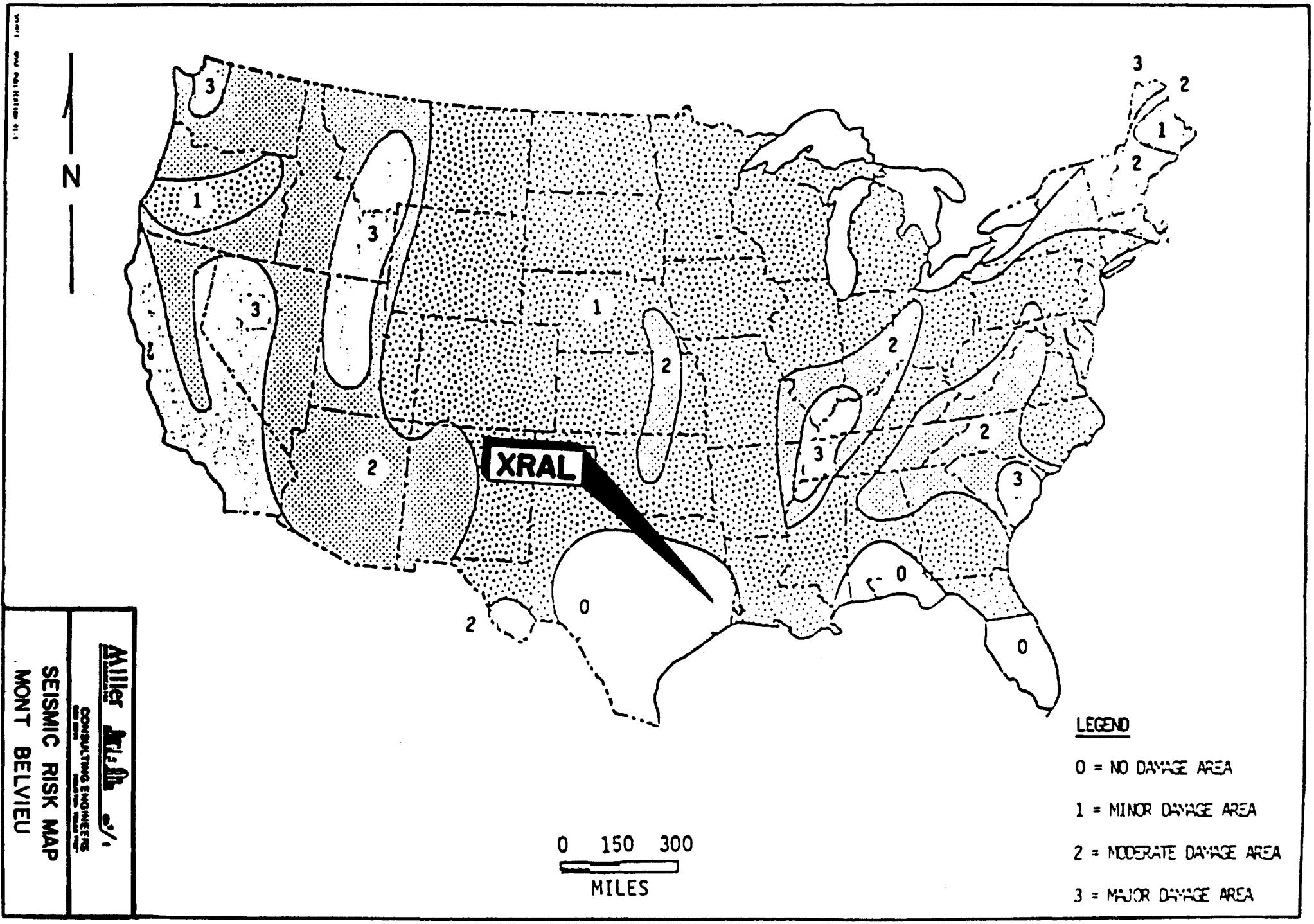


LEGEND

Miller

CONSULTING ENGINEERS

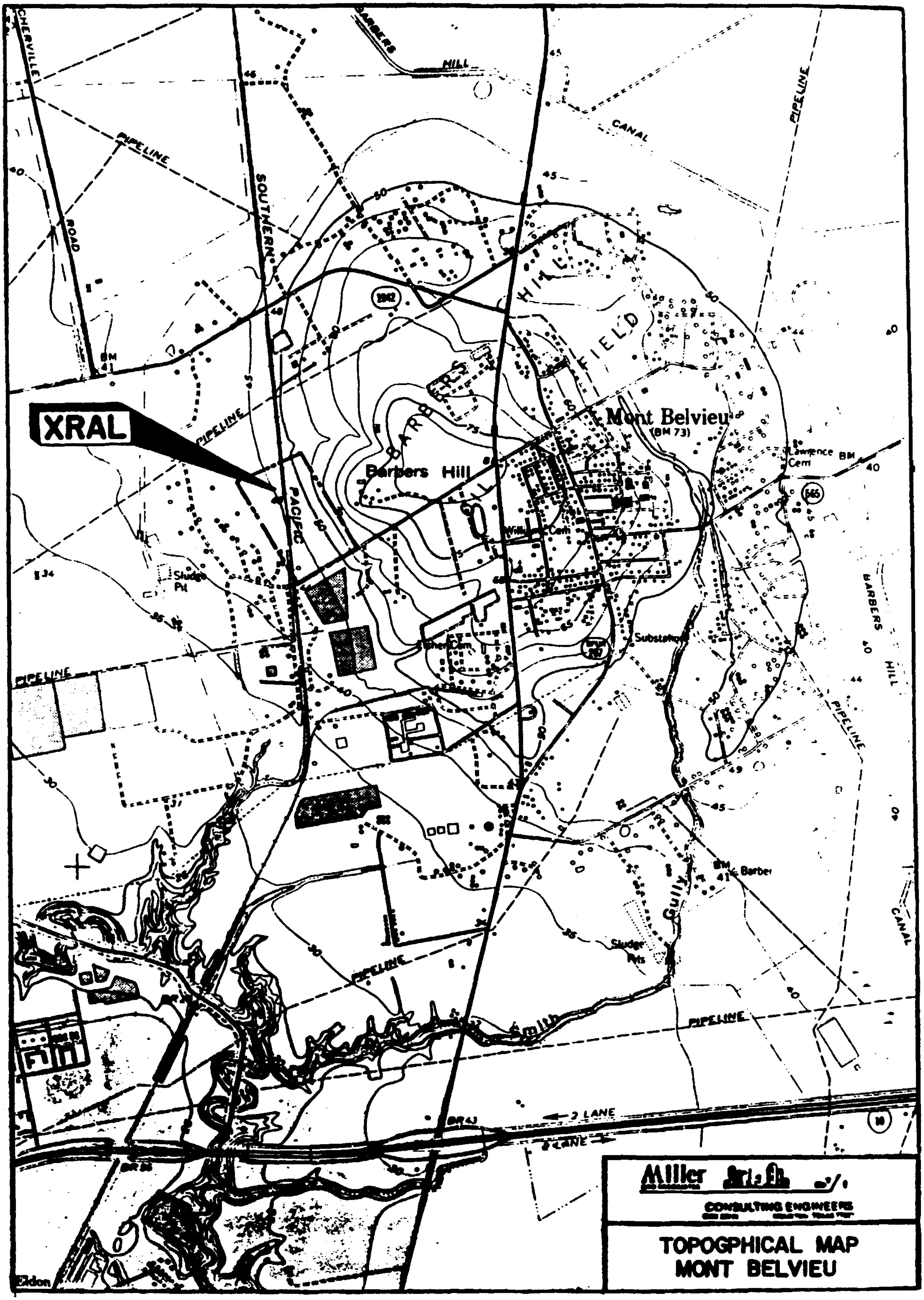
INDUSTRIAL OWNERSHIP
MONT BELVIEU

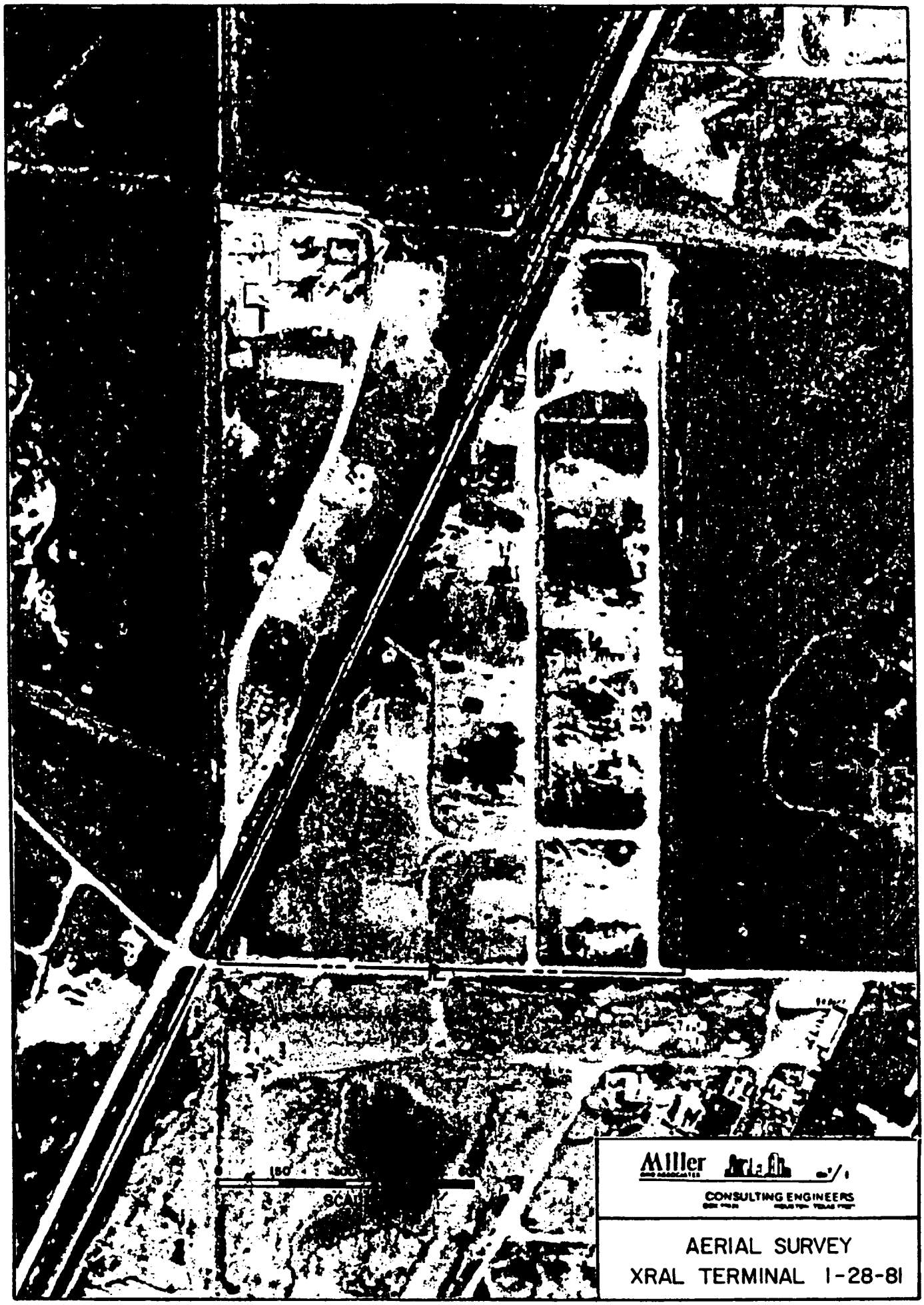


Miller Mitchell &
CONSULTING ENGINEERS

SEISMIC RISK MAP

MONT BELVIEU


XRAL
Mont Belvieu
(BM 73)
Barbers Hill
BARBERS HILL FIELD
SOUTHERN PACIFIC
PIPELINE
CANAL
ROAD
Lawrence Cem
Sludge Pit
Sludge Pits
Substation
Gully
Smith
Barber
2 LANE
Eldon
Miller
CONSULTING ENGINEERS
TOPOGPHICAL MAP
MONT BELVIEU



Miller and Associates

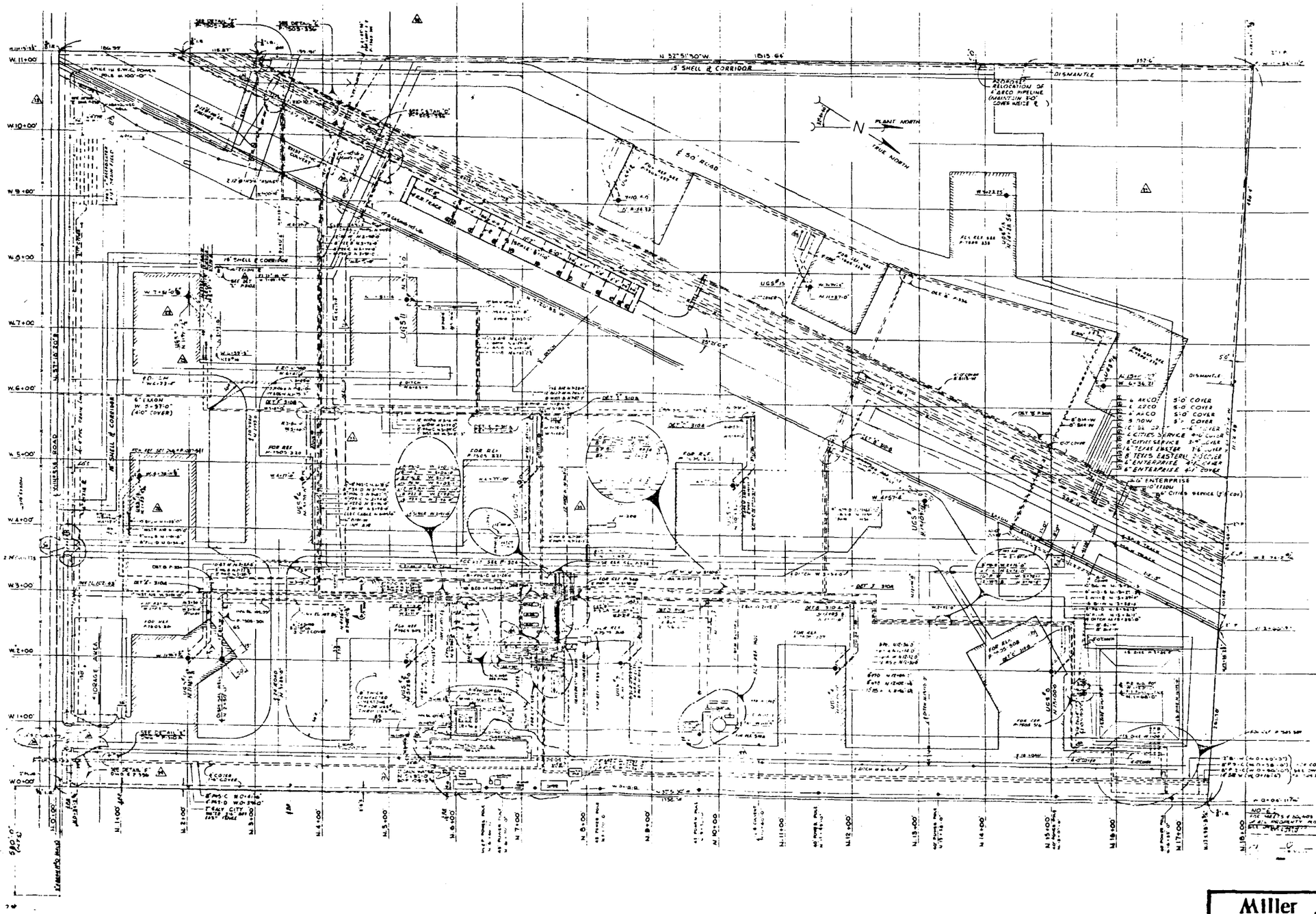
CONSULTING ENGINEERS

AERIAL SURVEY

XRAL TERMINAL 1-28-81

Miller
CONSULTING ENGINEERS

AERIAL SURVEY
XRAL TERMINAL 1-20-74



Miller and Associates

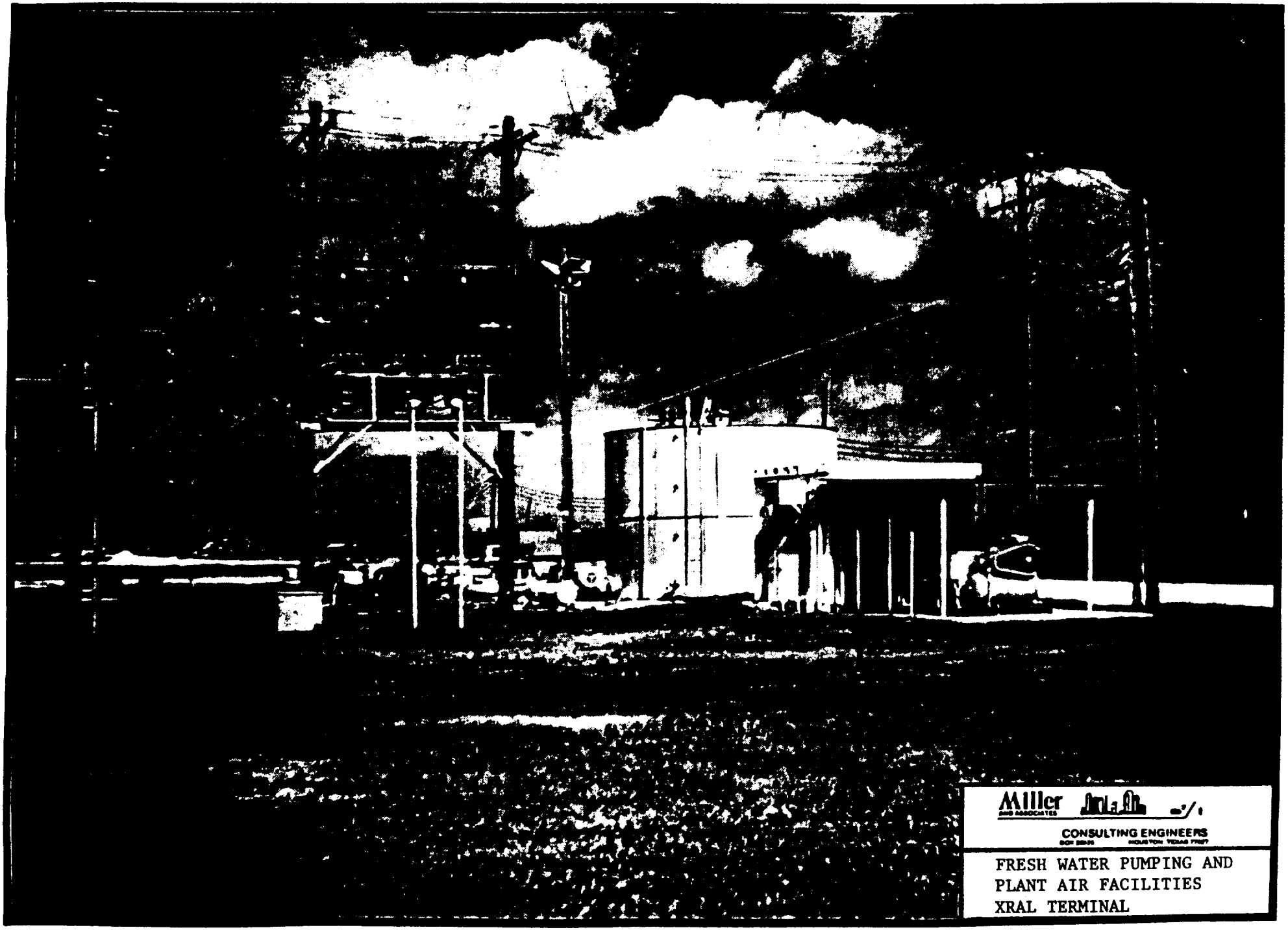
CONSULTING ENGINEERS

PLOT PLAN
XRAL TERMINAL

Miller and Associates

CONSULTING ENGINEERS

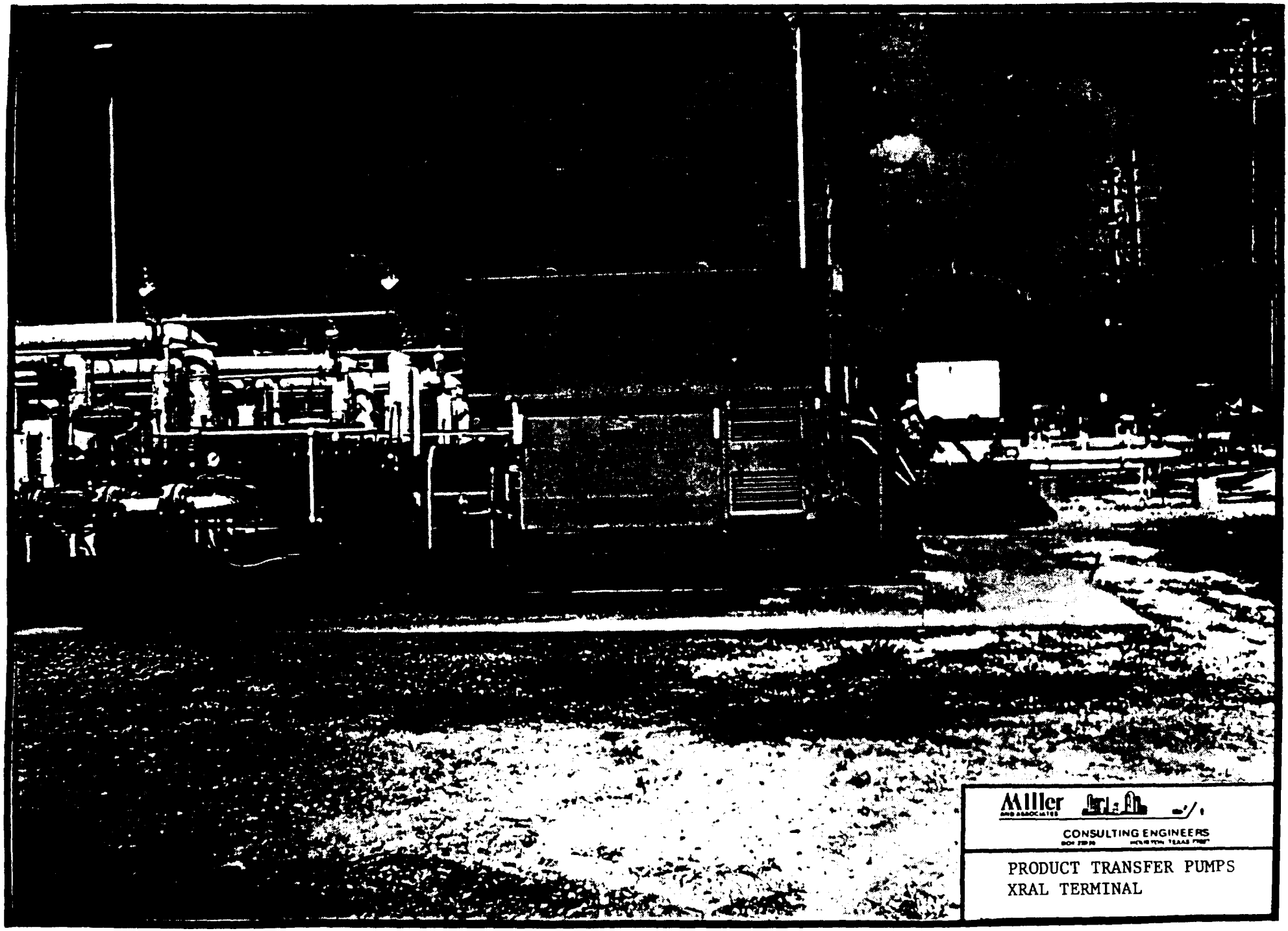
PRIMARY ELECTRICAL SERVICE
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

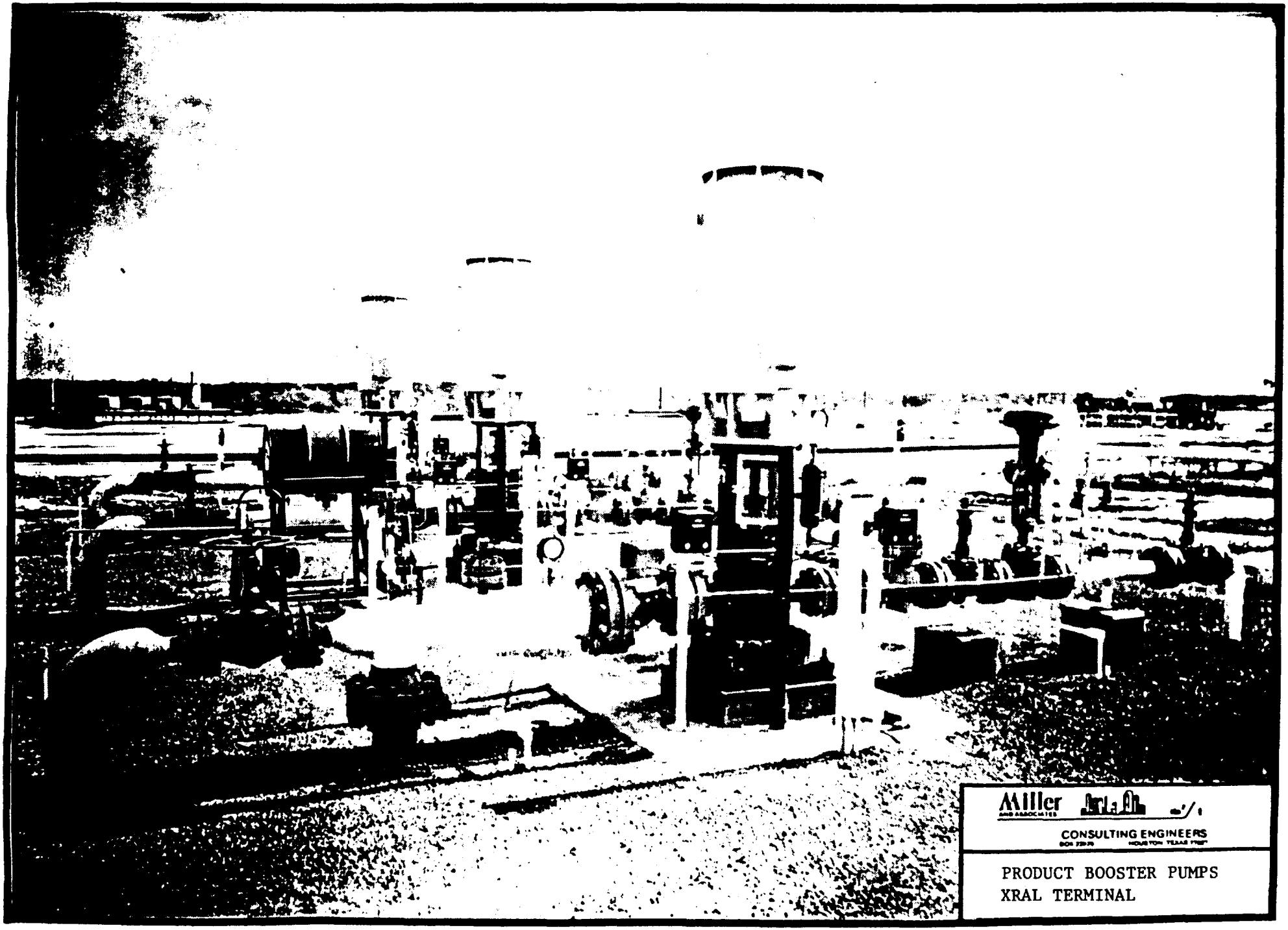
FRESH WATER PUMPING AND
PLANT AIR FACILITIES
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

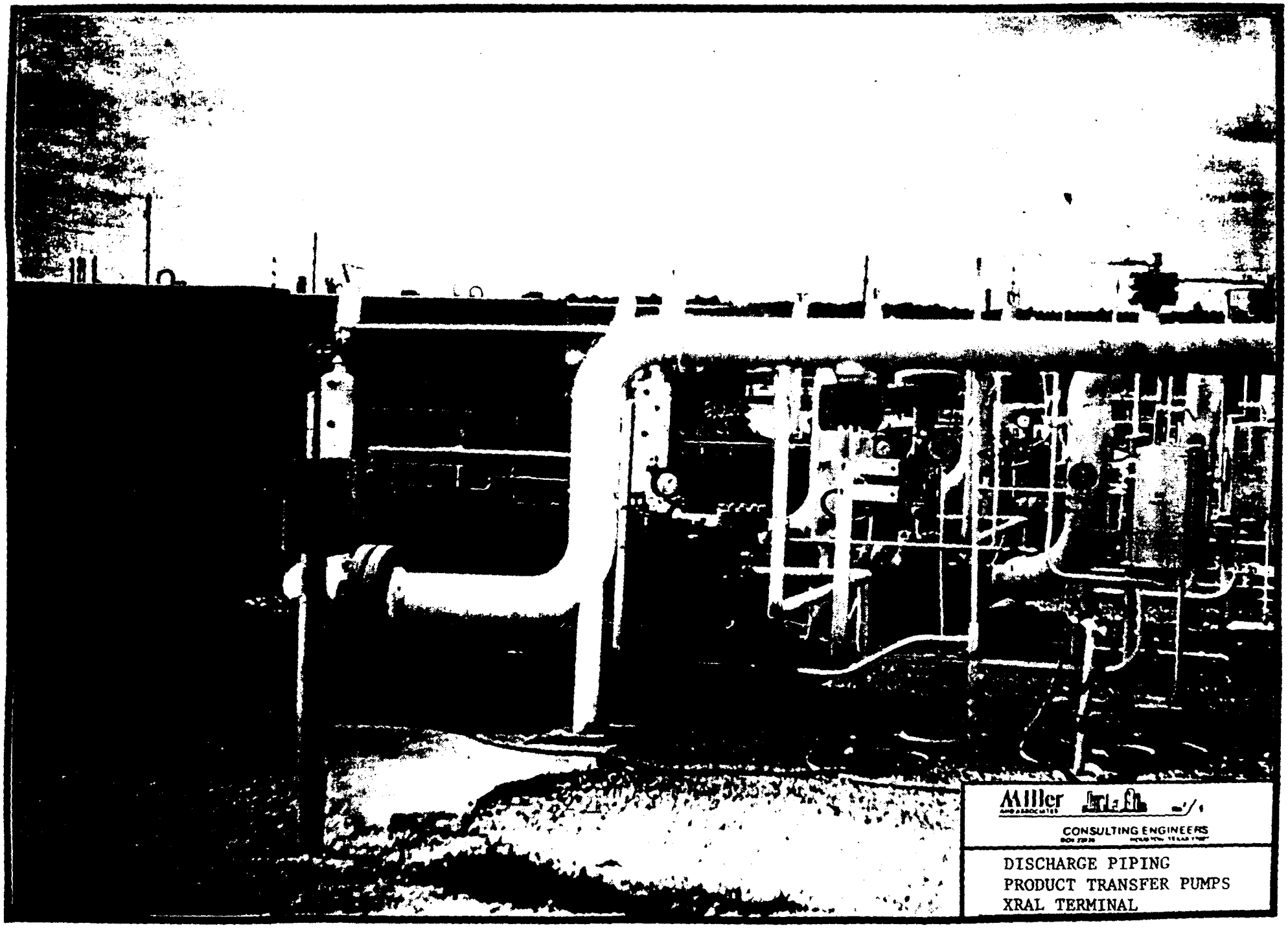
PRODUCT TRANSFER PUMPS
XRAL TERMINAL

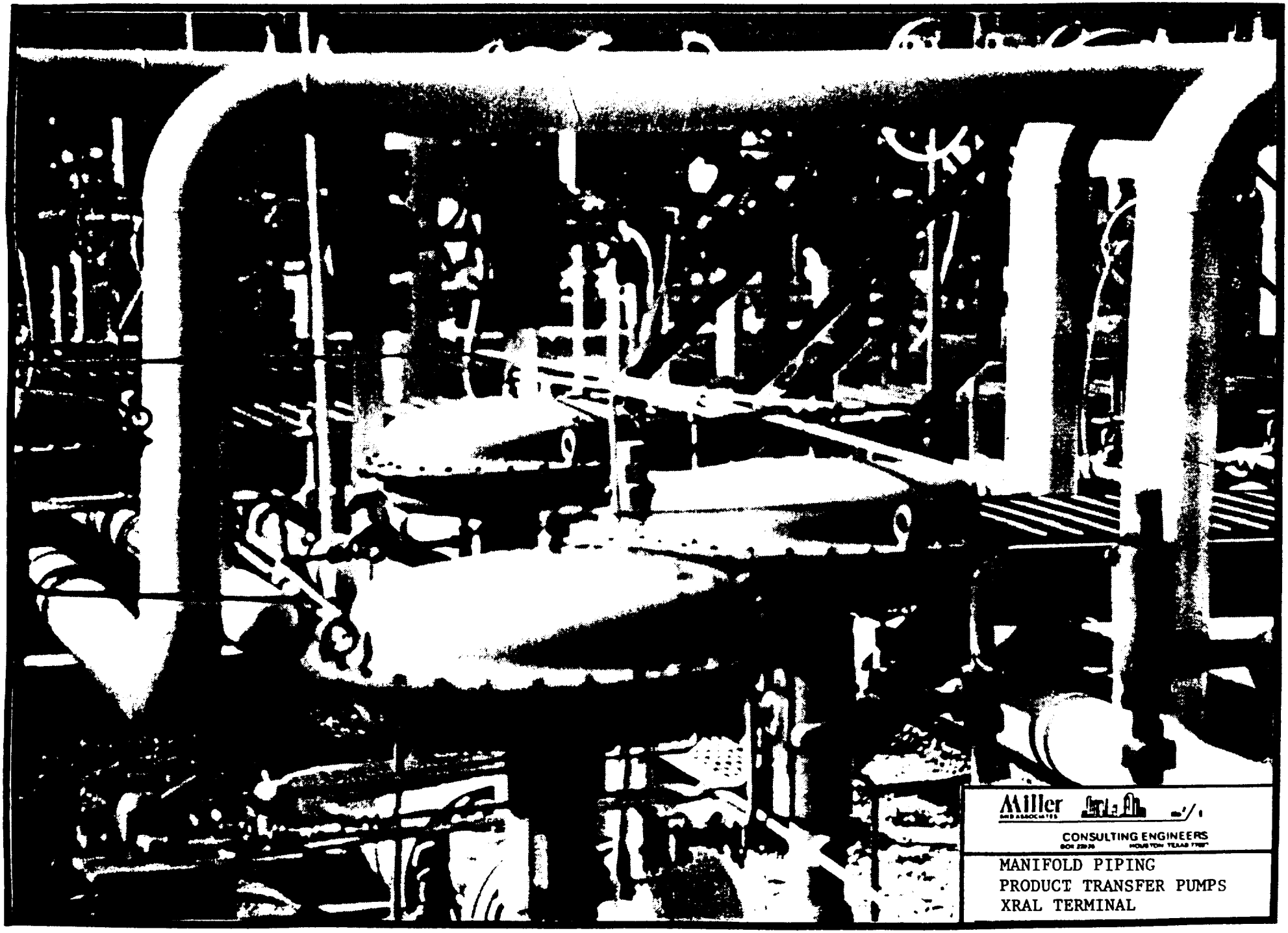


Miller and Associates

CONSULTING ENGINEERS

PRODUCT BOOSTER PUMPS
XRAL TERMINAL

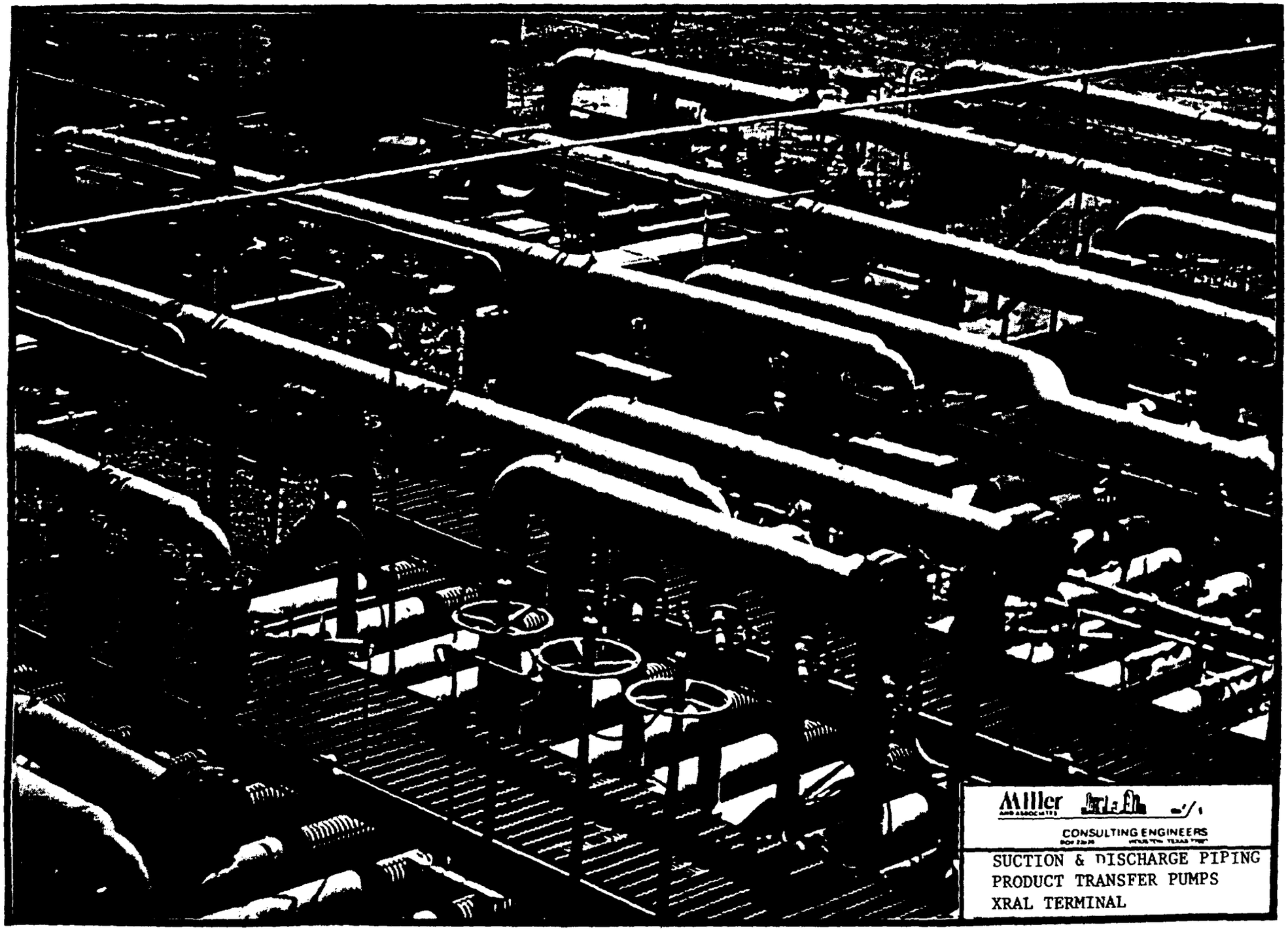

Miller
CONSULTING ENGINEERS
DISCHARGE PIPING
PRODUCT TRANSFER PUMPS
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

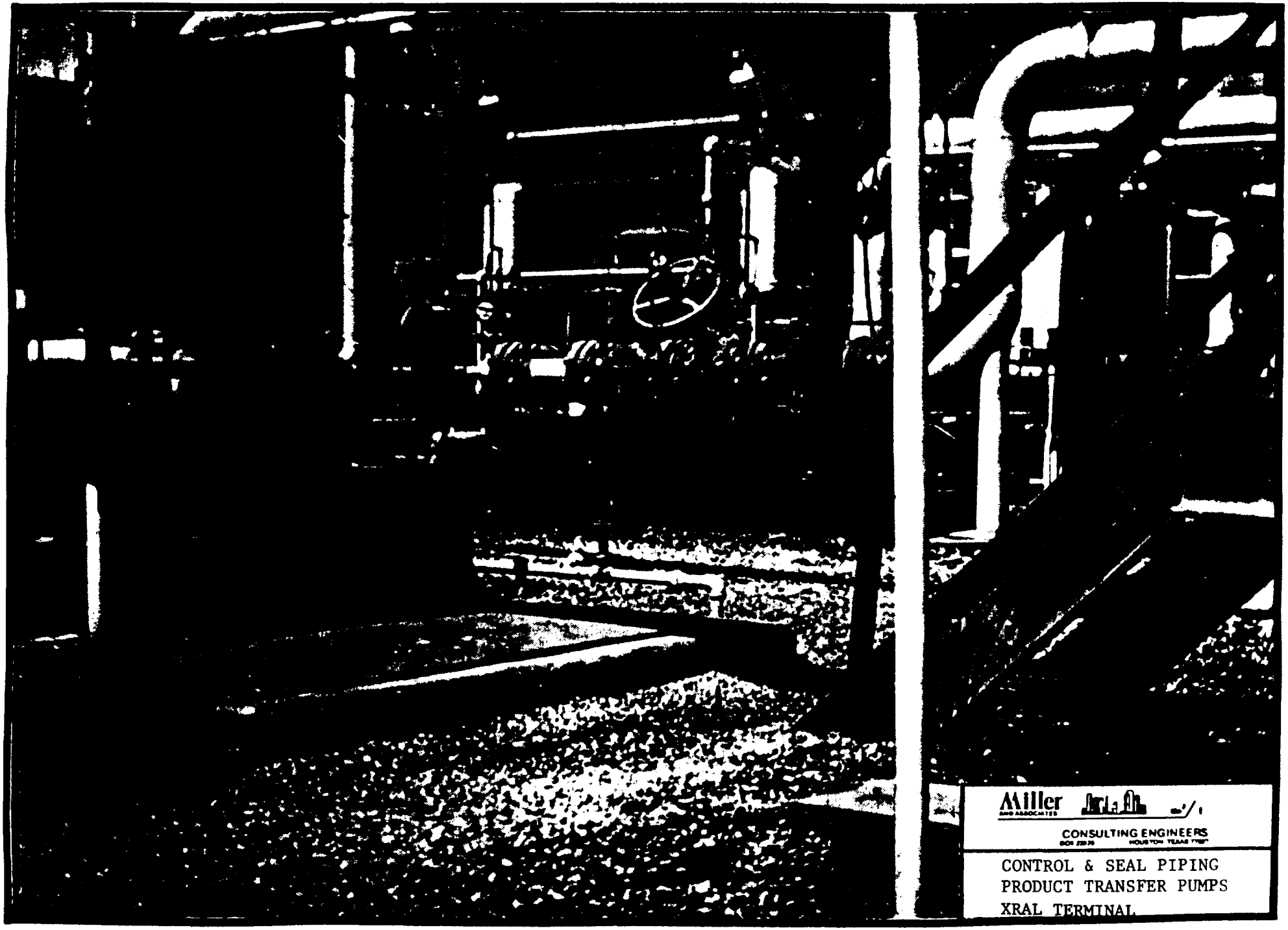
MANIFOLD PIPING
PRODUCT TRANSFER PUMPS
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

SUCTION & DISCHARGE PIPING
PRODUCT TRANSFER PUMPS
XRAL TERMINAL



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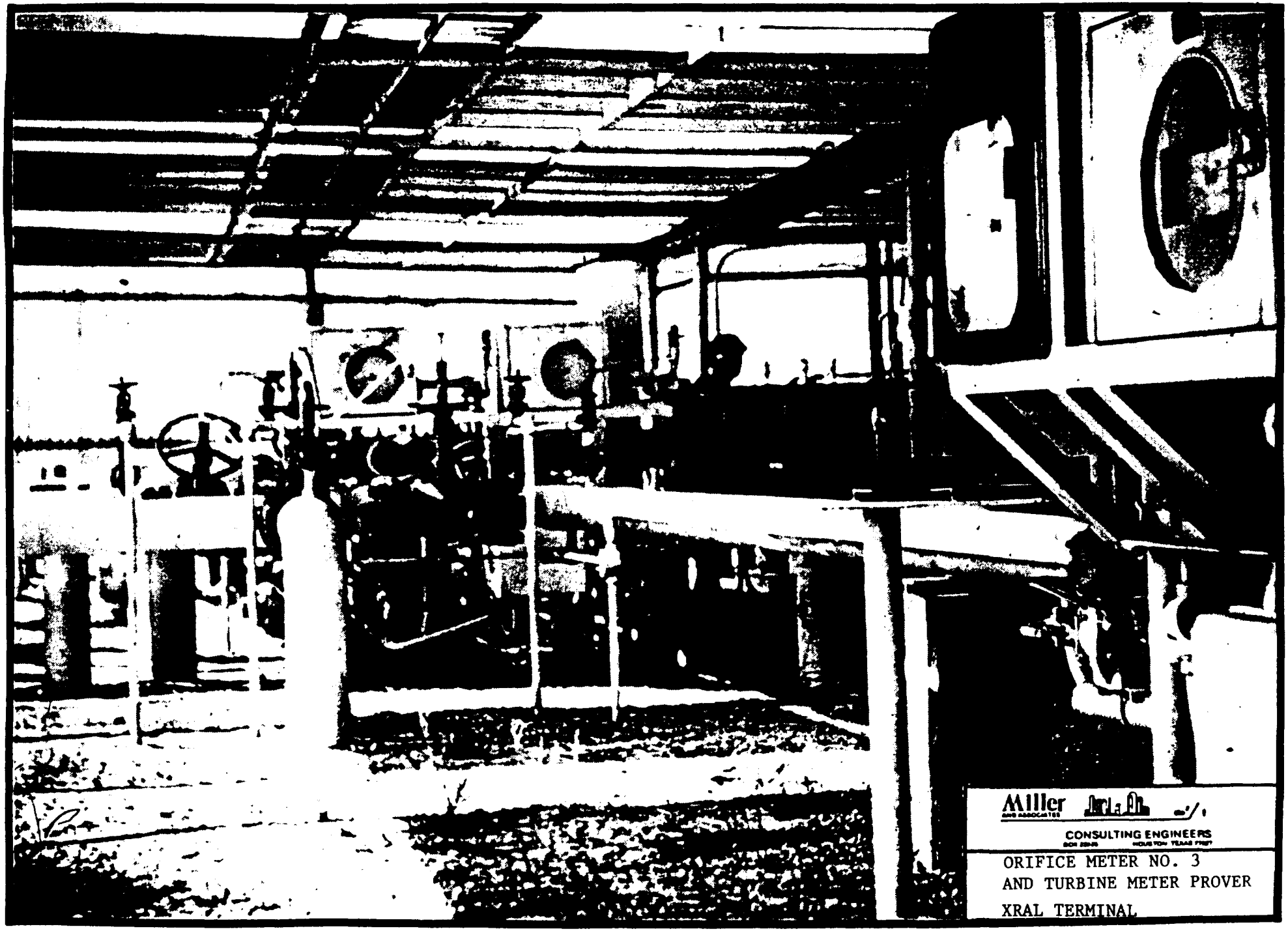
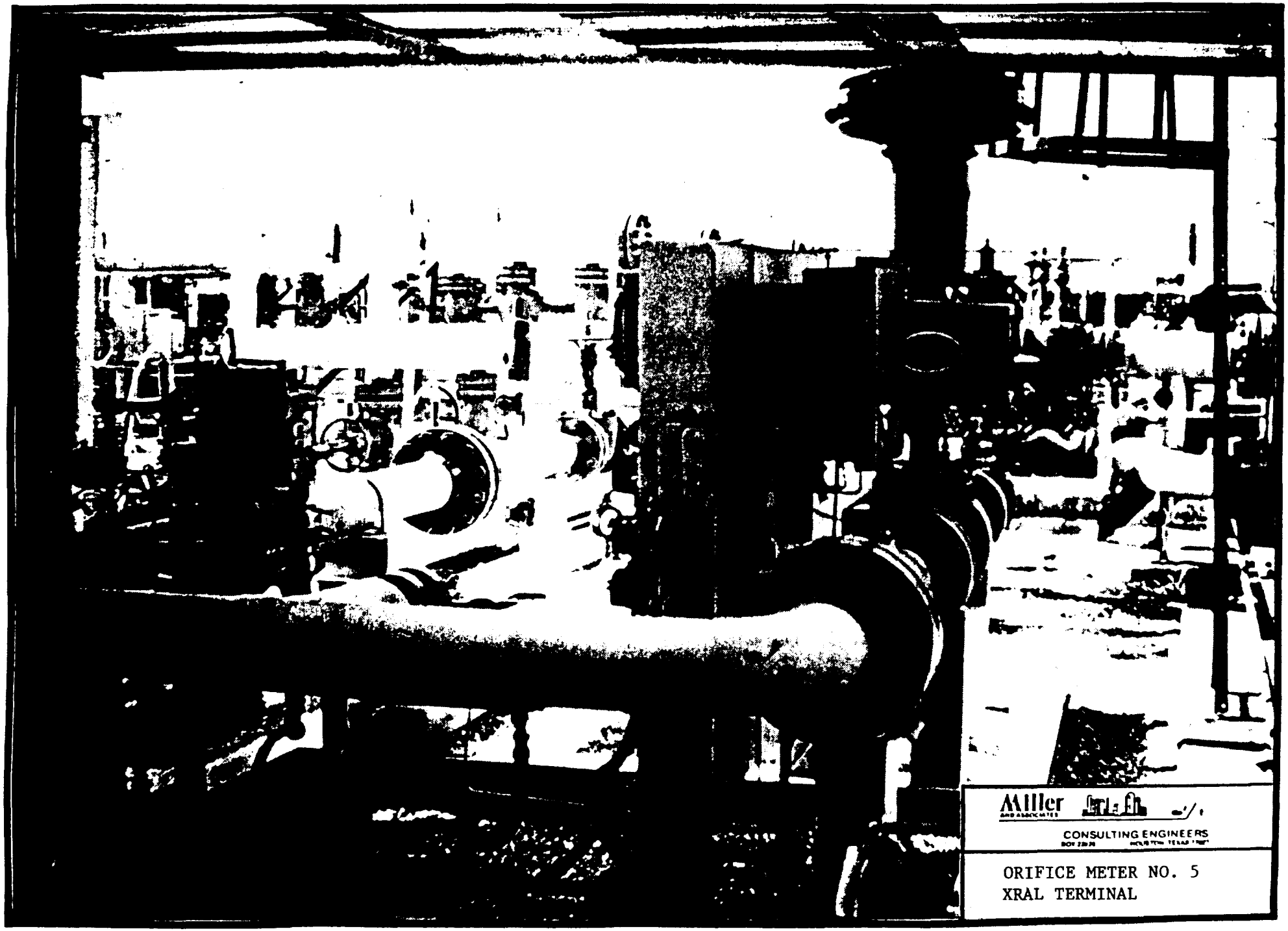
CONTROL & SEAL PIPING
PRODUCT TRANSFER PUMPS
XRAL TERMINAL


Miller
CONSULTING ENGINEERS
TURBINE METERS
XRAL TERMINAL

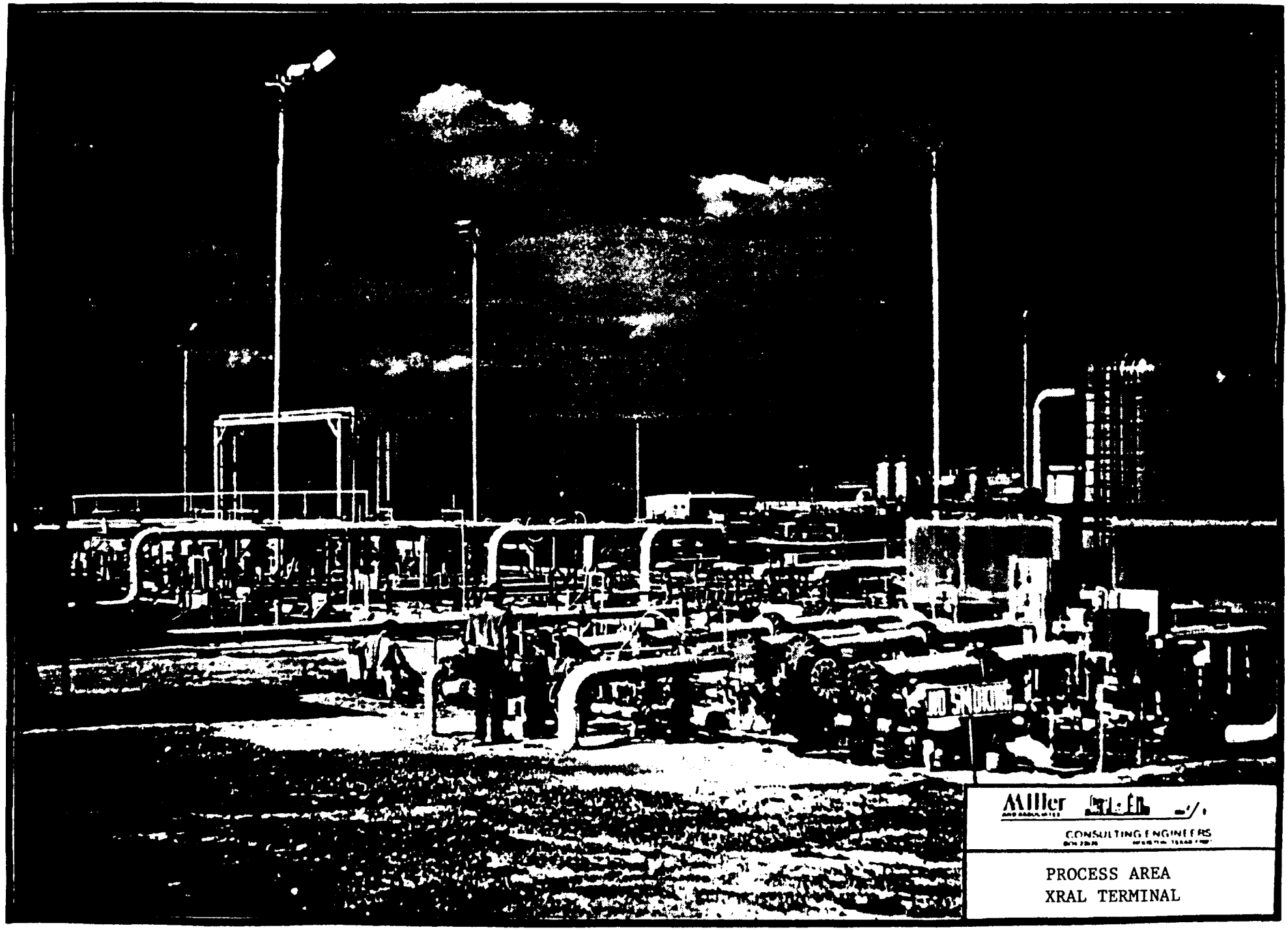

Miller
CONSULTING ENGINEERS
ORIFICE METER NO. 3
AND TURBINE METER PROVER
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

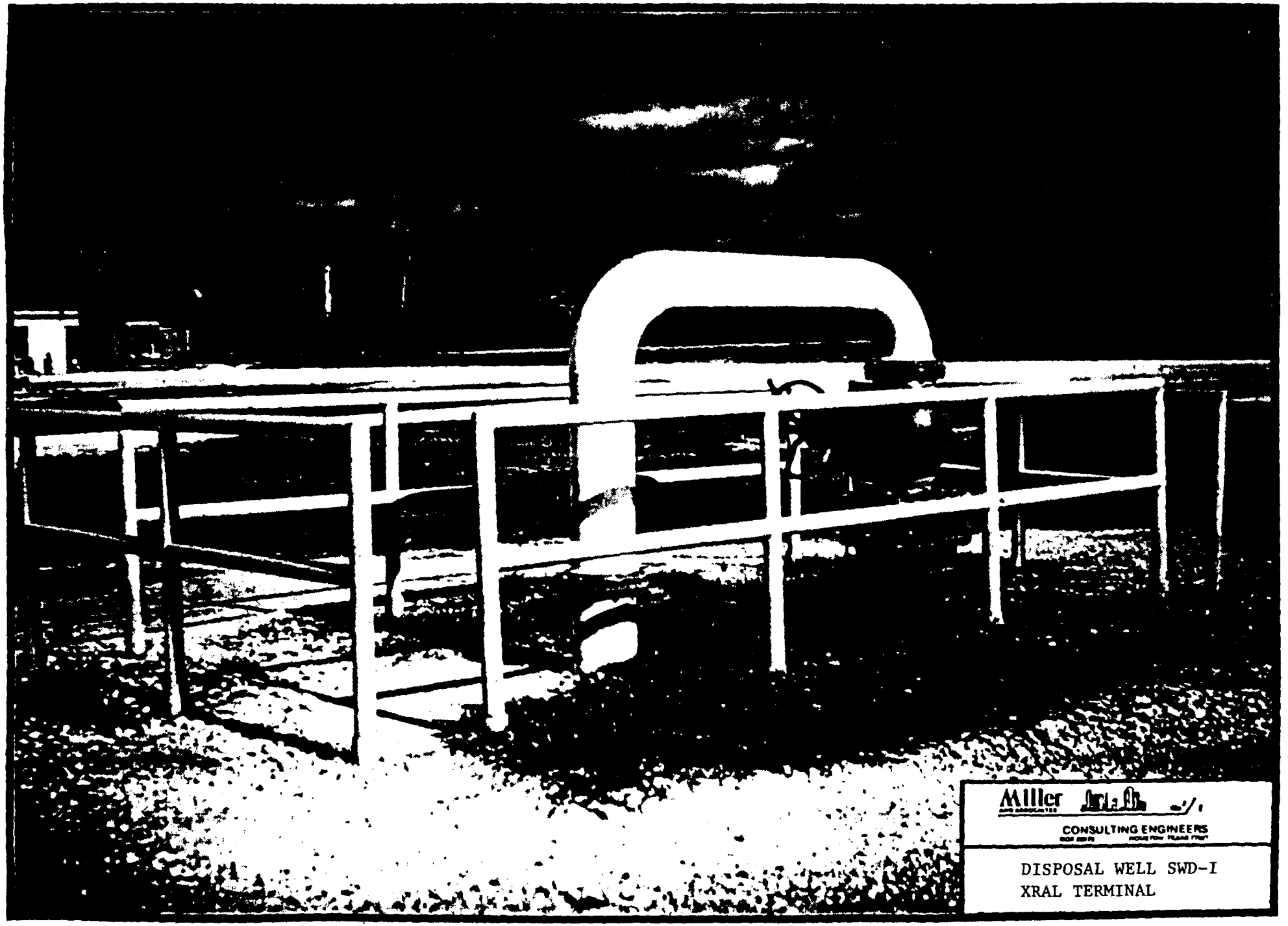
ORIFICE METER NO. 5
XRAL TERMINAL



Miller

CONSULTING ENGINEERS

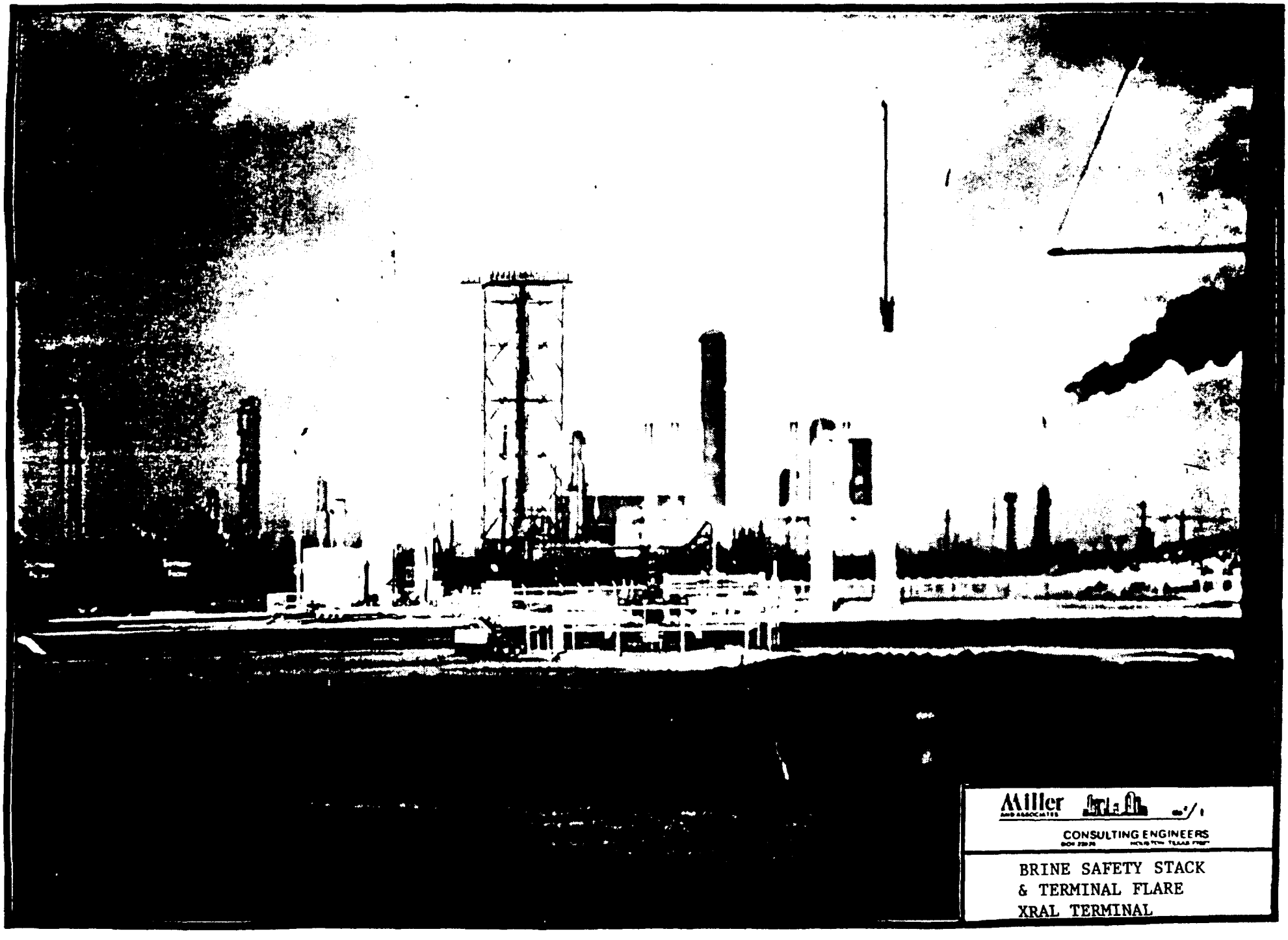
PROCESS AREA
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

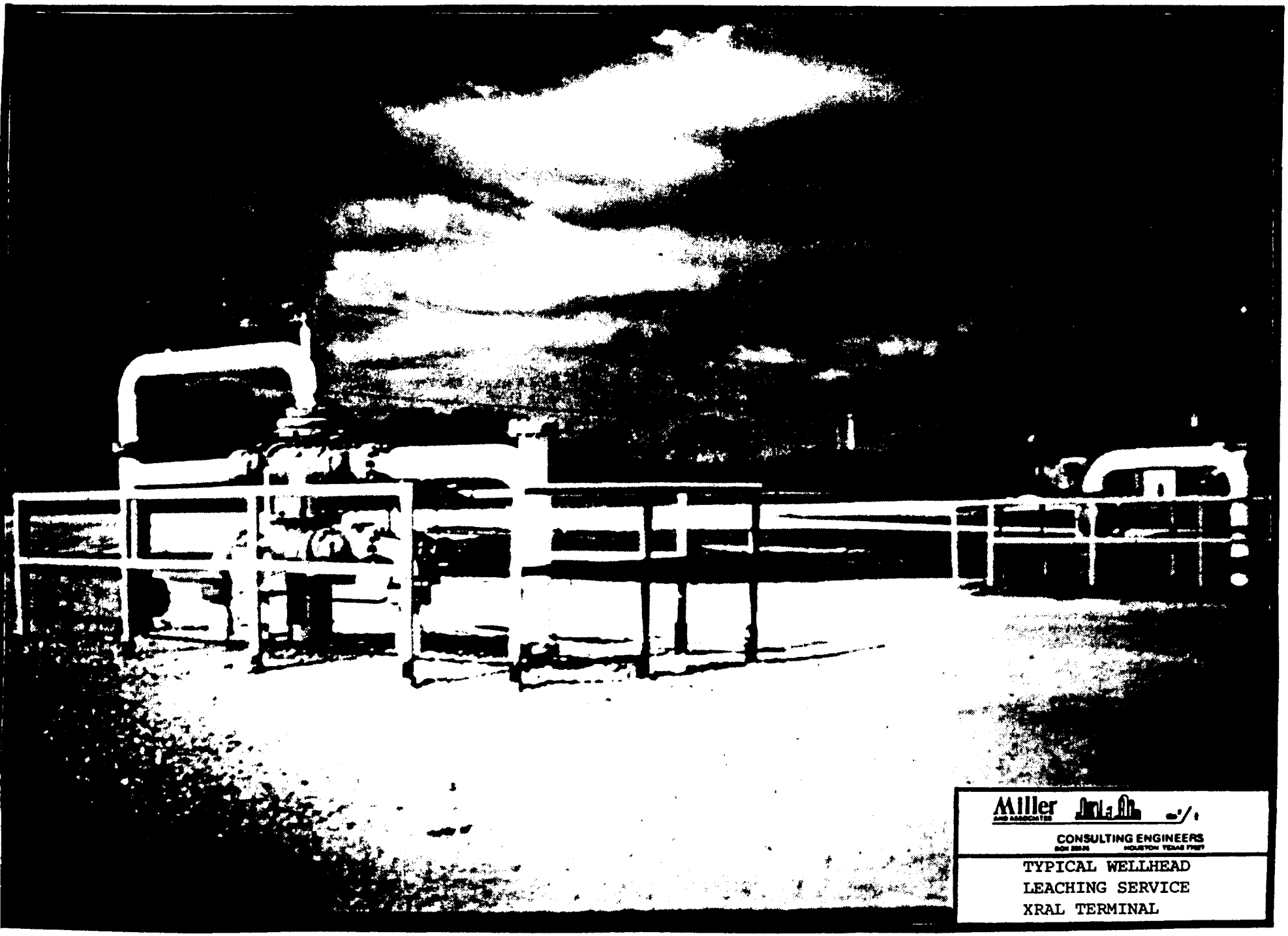
DISPOSAL WELL SWD-I
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

BRINE SAFETY STACK
& TERMINAL FLARE
XRAL TERMINAL

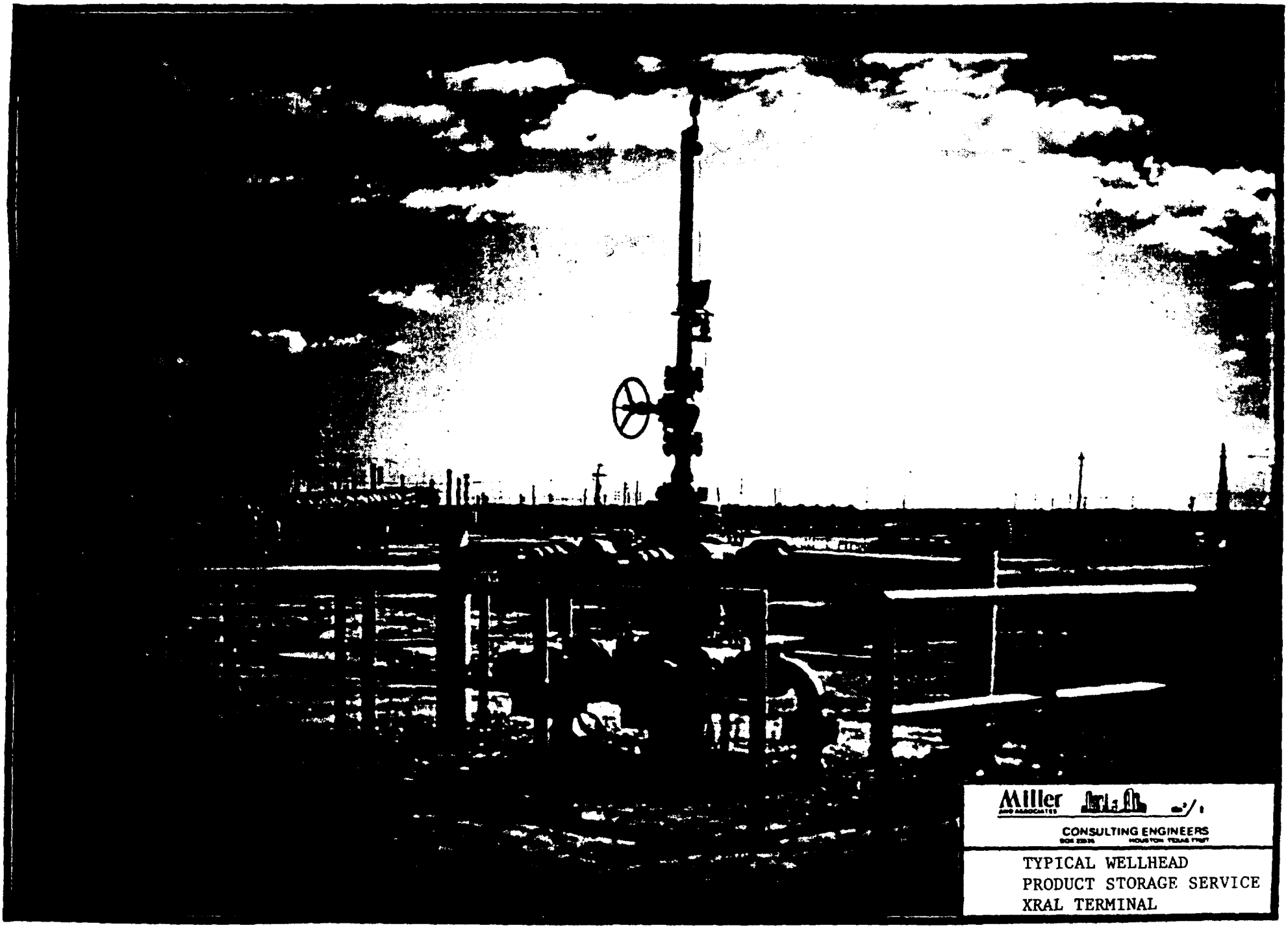


Miller and Associates

CONSULTING ENGINEERS

P.O. BOX 22525 HOUSTON, TEXAS 77027

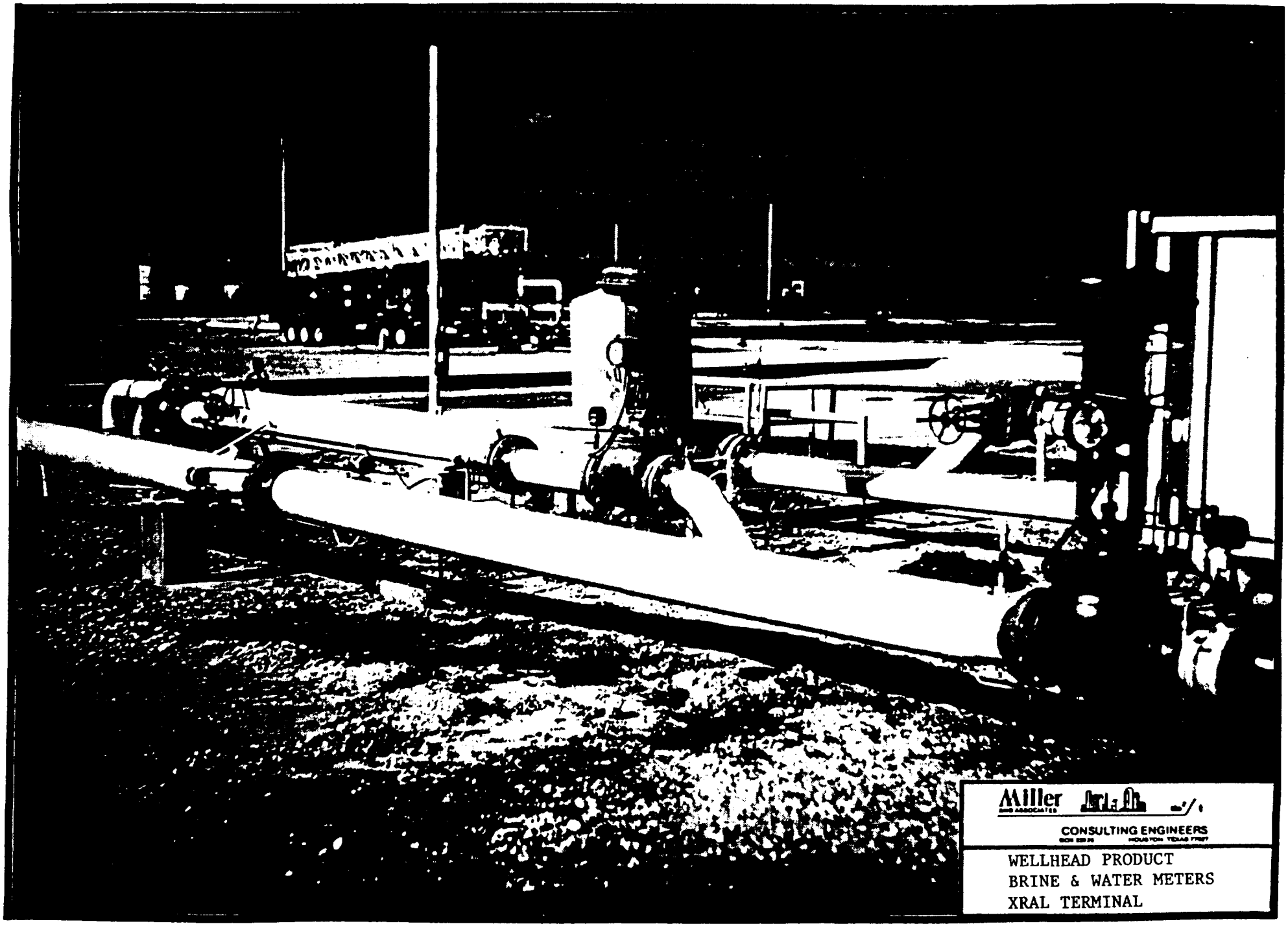
TYPICAL WELLHEAD
LEACHING SERVICE
XRAL TERMINAL

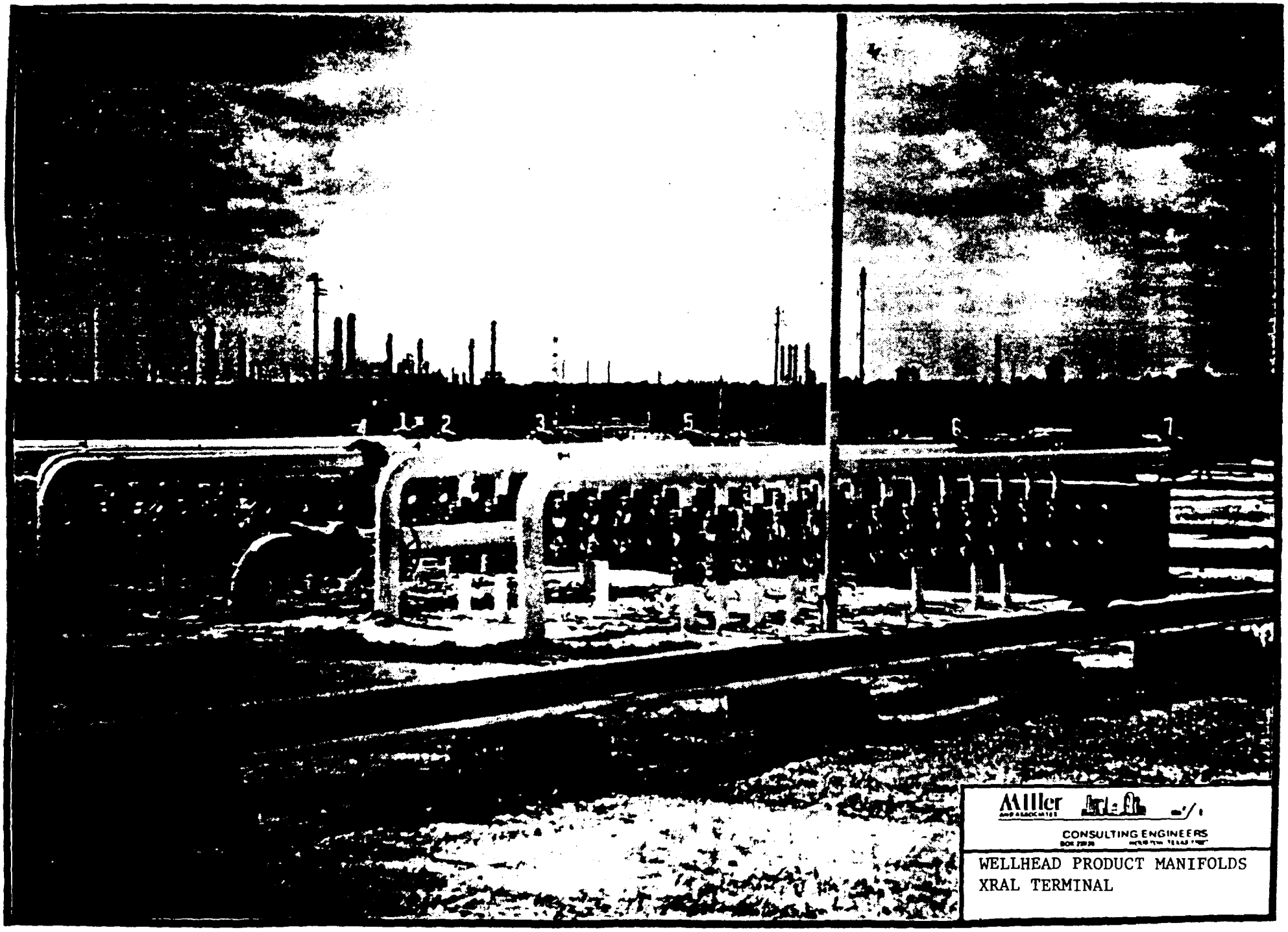


Miller and Associates

CONSULTING ENGINEERS

TYPICAL WELLHEAD
PRODUCT STORAGE SERVICE
XRAL TERMINAL

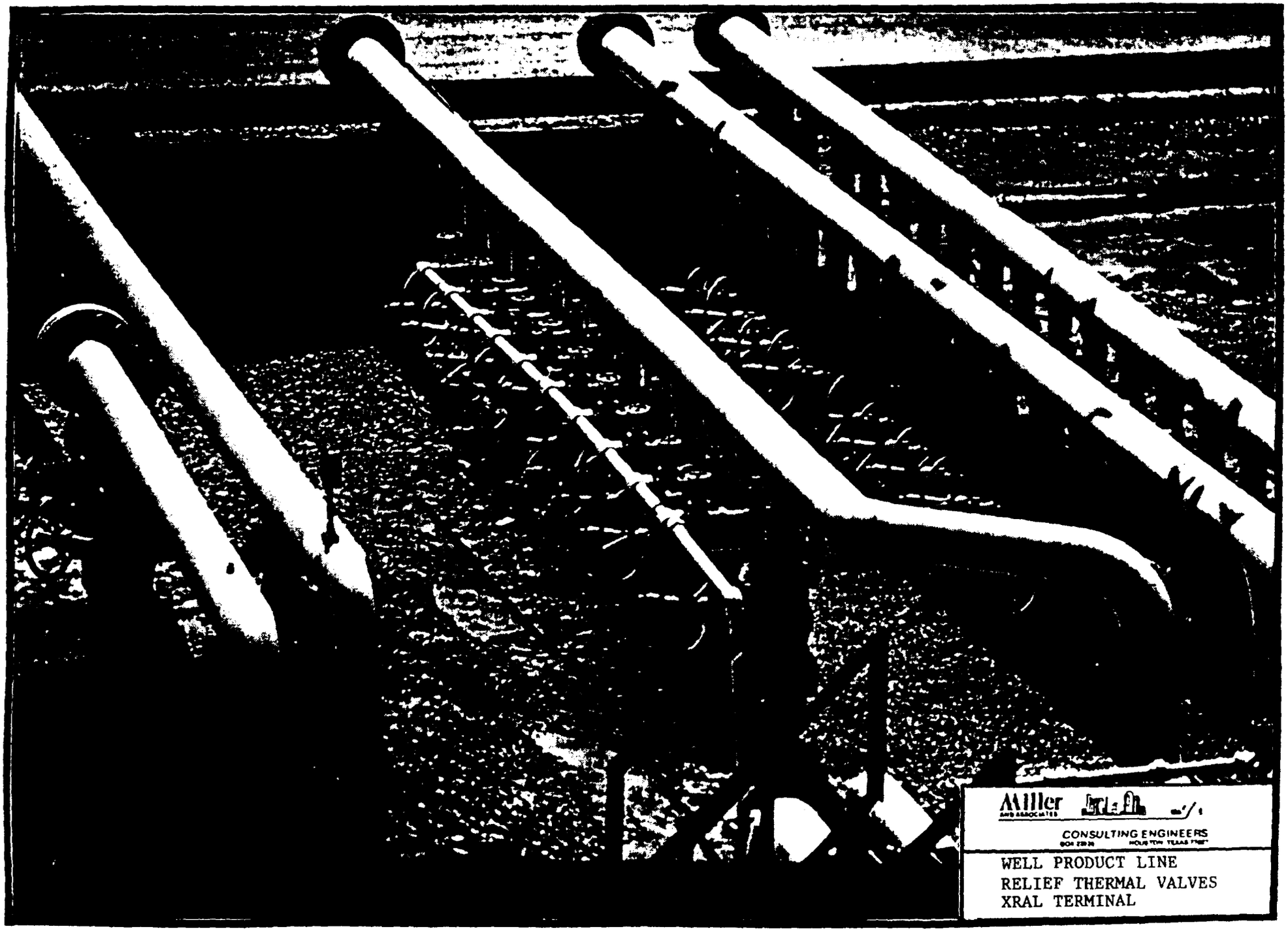

Miller
CONSULTING ENGINEERS
WELLHEAD PRODUCT
BRINE & WATER METERS
XRAL TERMINAL



Miller and Associates

CONSULTING ENGINEERS

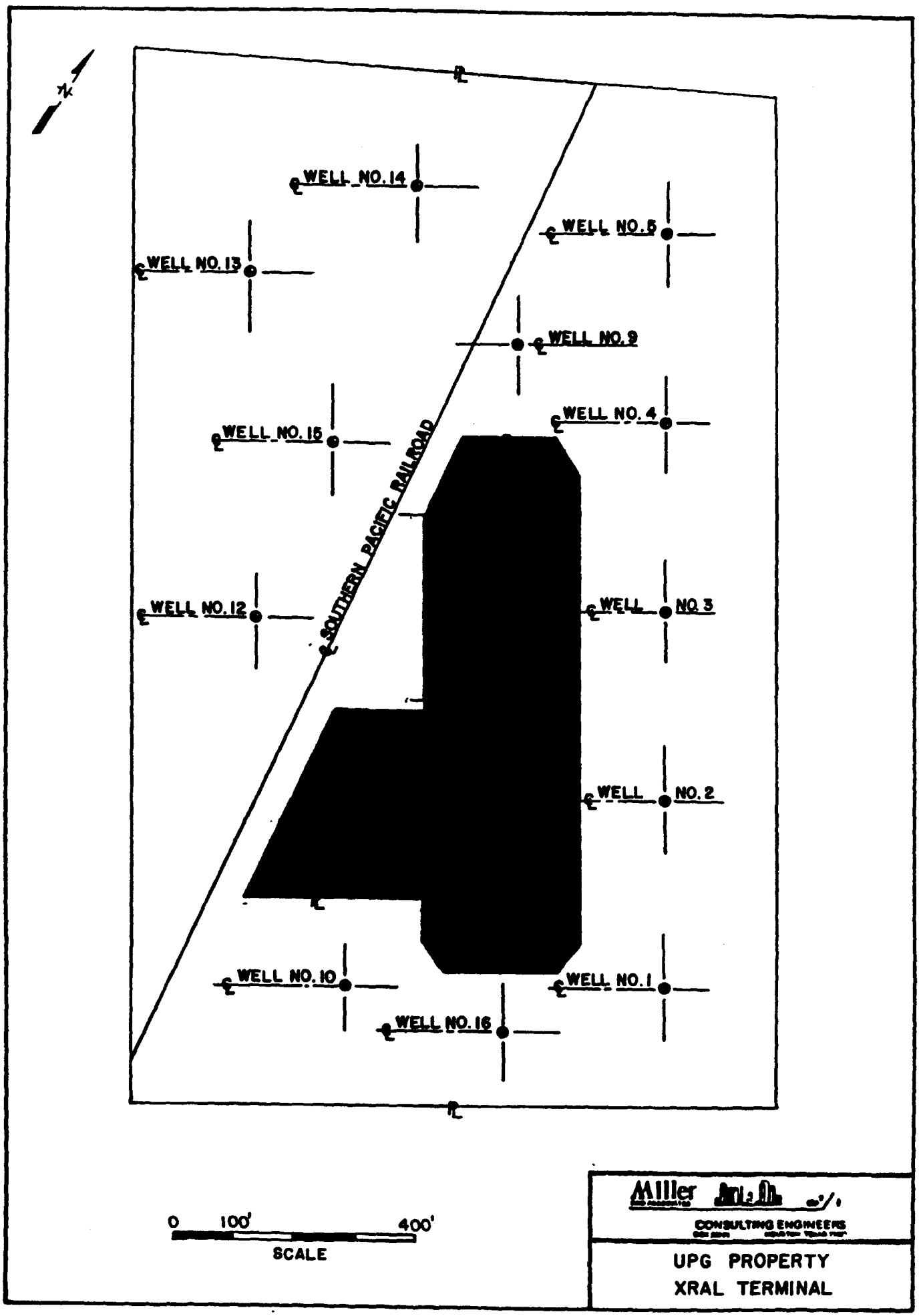
WELLHEAD PRODUCT MANIFOLDS
XRAL TERMINAL

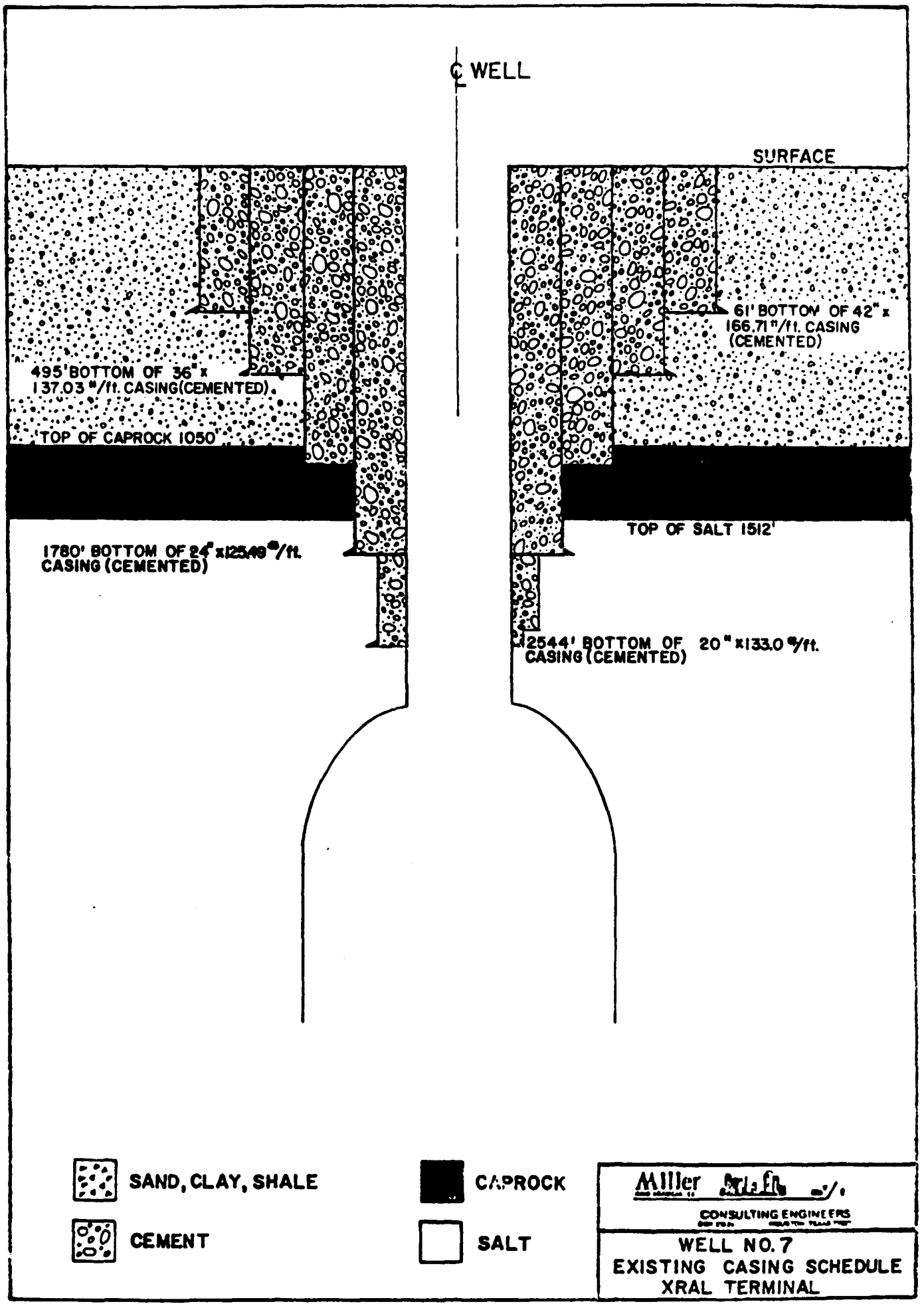


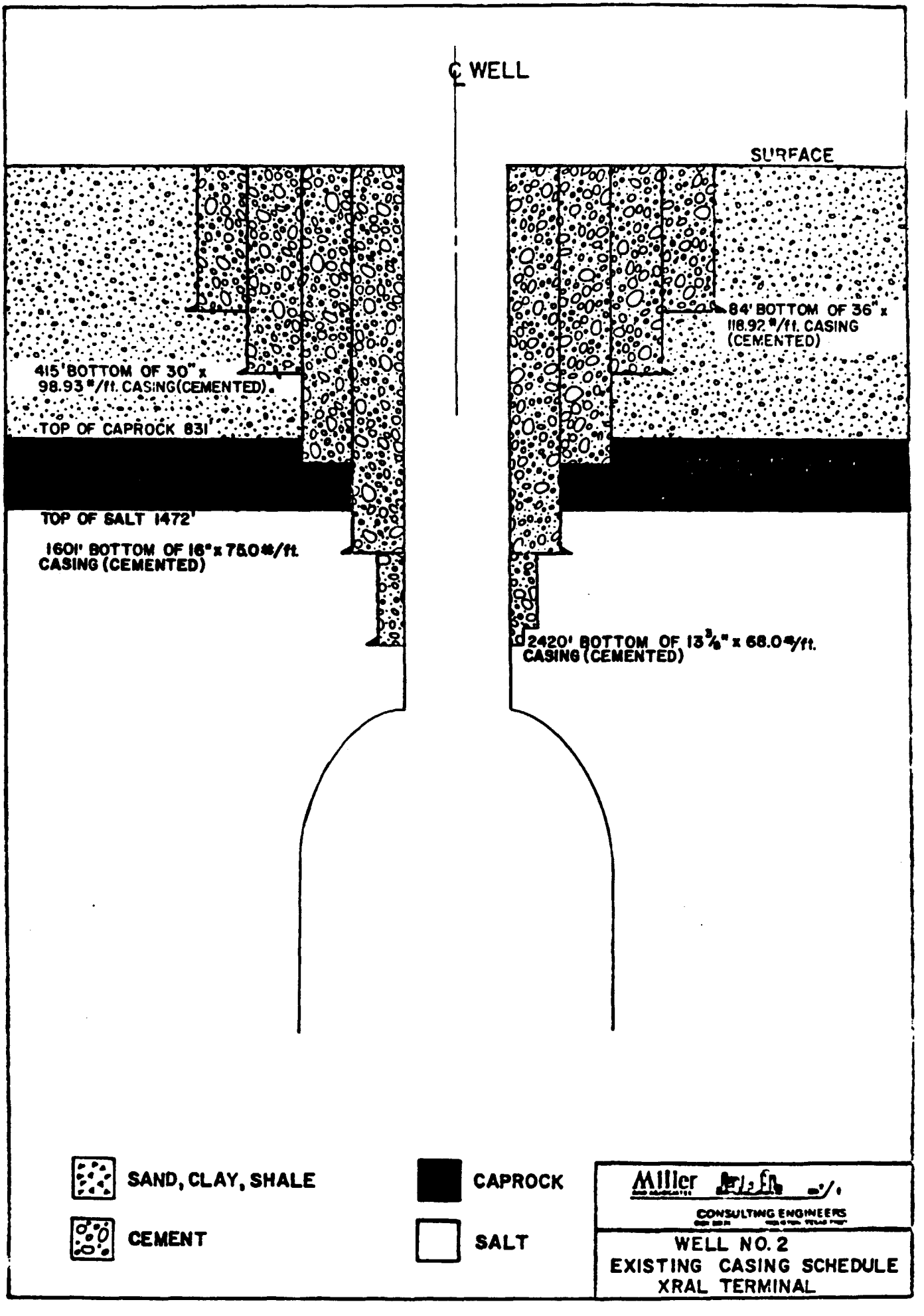
Miller and Associates

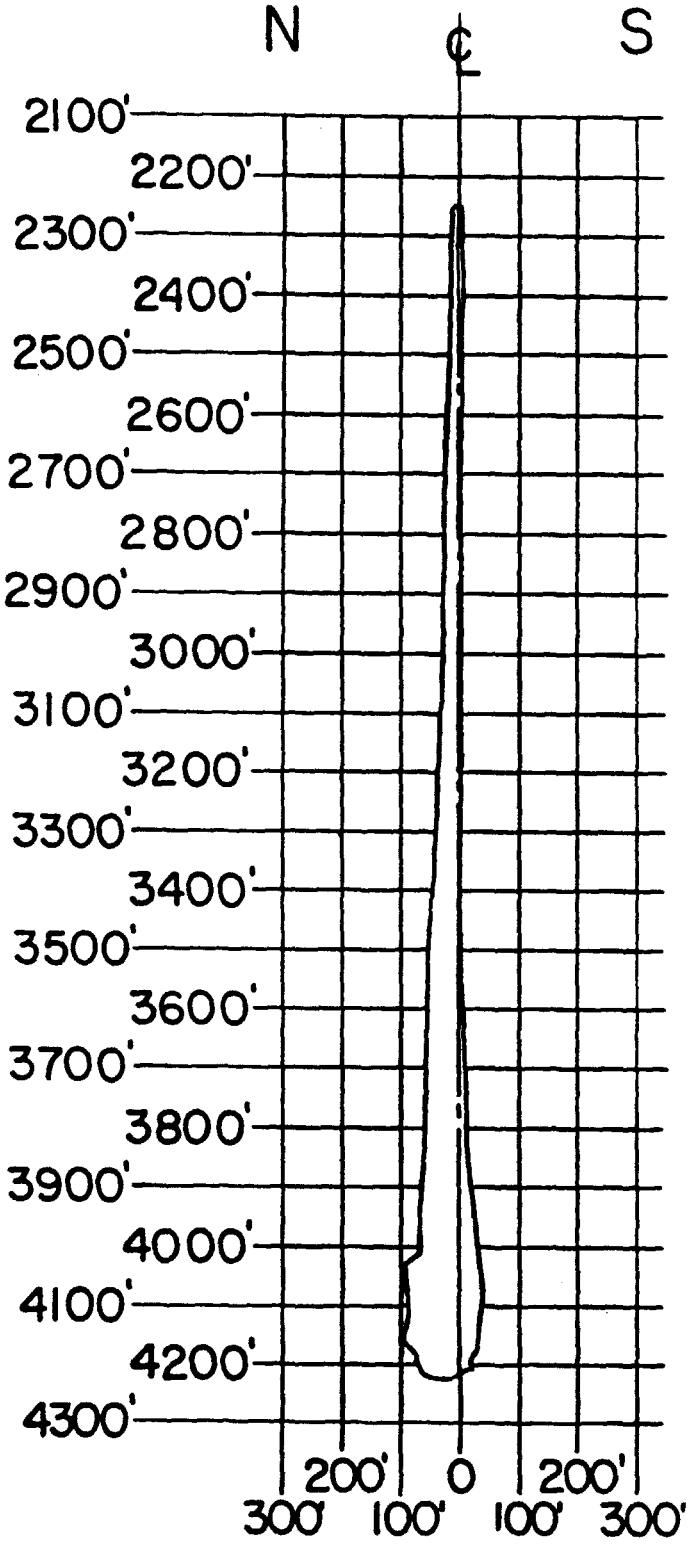
CONSULTING ENGINEERS

WELL PRODUCT LINE
RELIEF THERMAL VALVES
XRAL TERMINAL


N
℄ WELL NO. 14
℄ WELL NO. 5
℄ WELL NO. 13
℄ WELL NO. 9
℄ WELL NO. 15
℄ WELL NO. 4
℄ SOUTHERN PACIFIC RAILROAD
℄ WELL NO. 12
℄ WELL NO. 3
℄ WELL NO. 2
℄ WELL NO. 10
℄ WELL NO. 1
℄ WELL NO. 16
0 100' 400'
SCALE
Miller
CONSULTING ENGINEERS
UPG PROPERTY
XRAL TERMINAL


℄ WELL
SURFACE
61' BOTTOM OF 42" x 166.71 #/ft. CASING (CEMENTED)
495' BOTTOM OF 36" x 137.03 #/ft. CASING (CEMENTED).
TOP OF CAPROCK 1050'
TOP OF SALT 1512'
1780' BOTTOM OF 24" x 125.49 #/ft. CASING (CEMENTED)
2544' BOTTOM OF 20" x 133.0 #/ft. CASING (CEMENTED)
SAND, CLAY, SHALE
CEMENT
CAPROCK
SALT
Miller
CONSULTING ENGINEERS
WELL NO. 7
EXISTING CASING SCHEDULE
XRAL TERMINAL


℄ WELL
SURFACE
84' BOTTOM OF 36" x 118.92 #/ft. CASING (CEMENTED)
415' BOTTOM OF 30" x 98.93 #/ft. CASING (CEMENTED)
TOP OF CAPROCK 831'
TOP OF SALT 1472'
1601' BOTTOM OF 16" x 75.0 #/ft. CASING (CEMENTED)
2420' BOTTOM OF 13 3/8" x 68.0 #/ft. CASING (CEMENTED)
SAND, CLAY, SHALE
CEMENT
CAPROCK
SALT
Miller
CONSULTING ENGINEERS
WELL NO. 2
EXISTING CASING SCHEDULE
XRAL TERMINAL

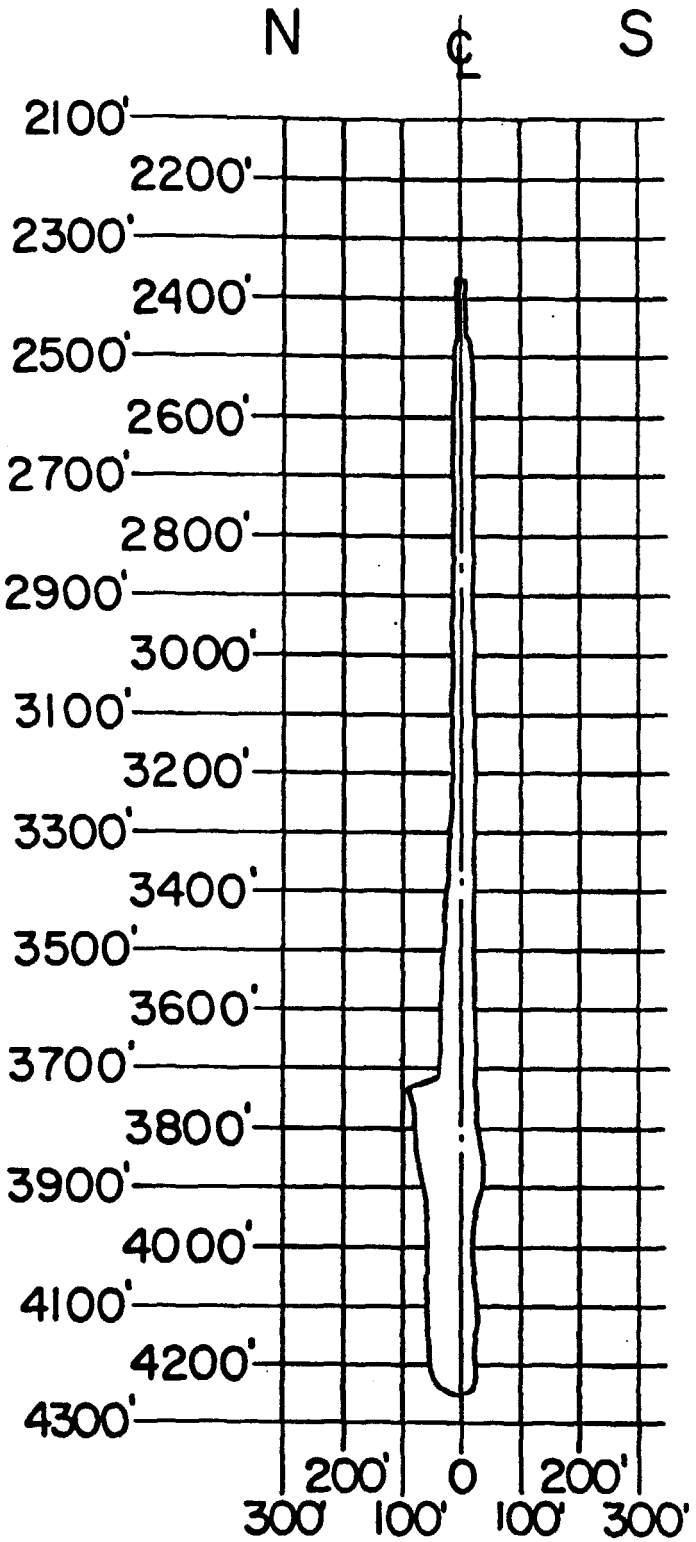


Miller Engineers

CONSULTING ENGINEERS

XRAL UGS NO.1
VERTICAL CROSS SECTION

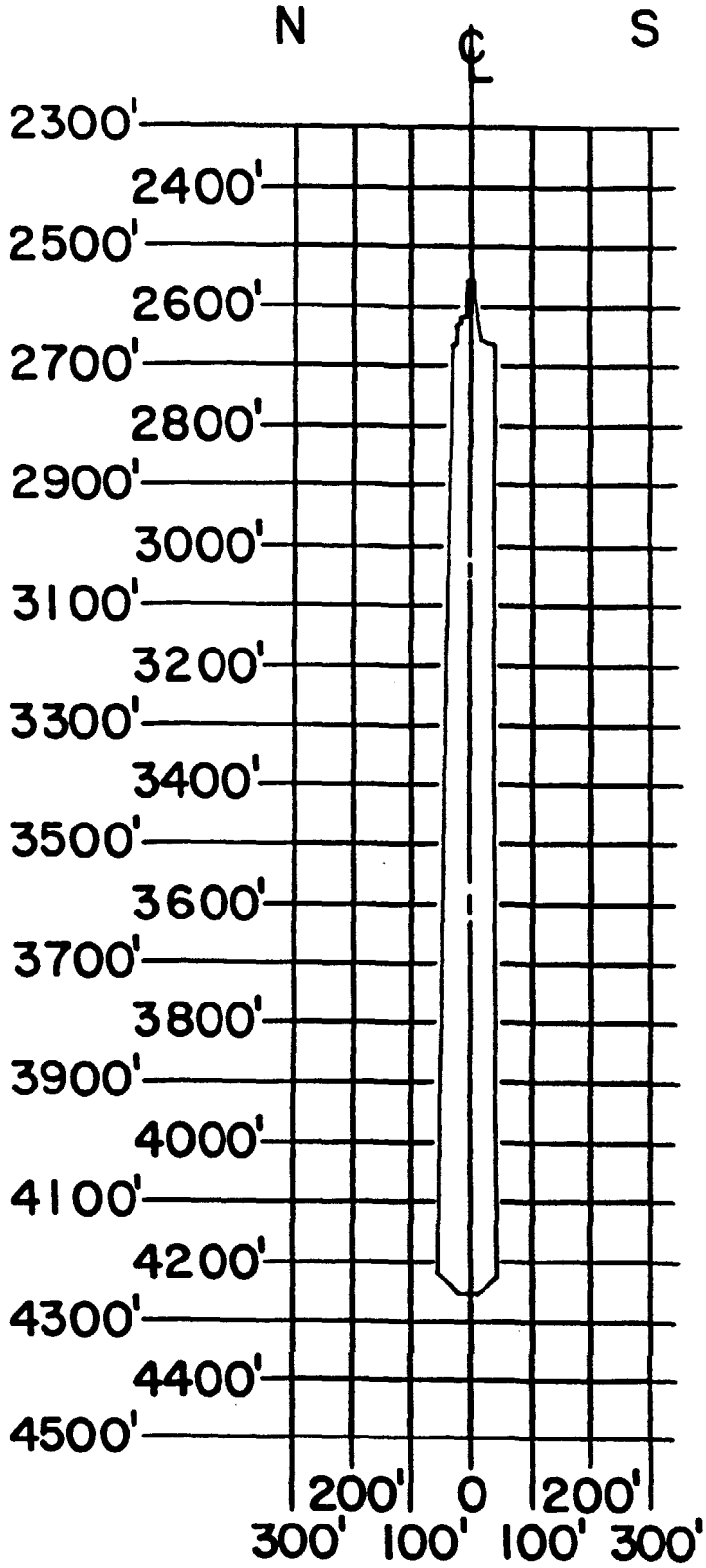
SOURCE: SONAR CALIPER SURVEY-APRIL 22, 1981



SOURCE: SONAR CALIPER SURVEY - JULY 8, 1977

Miller & Lents, Ltd.
CONSULTING ENGINEERS

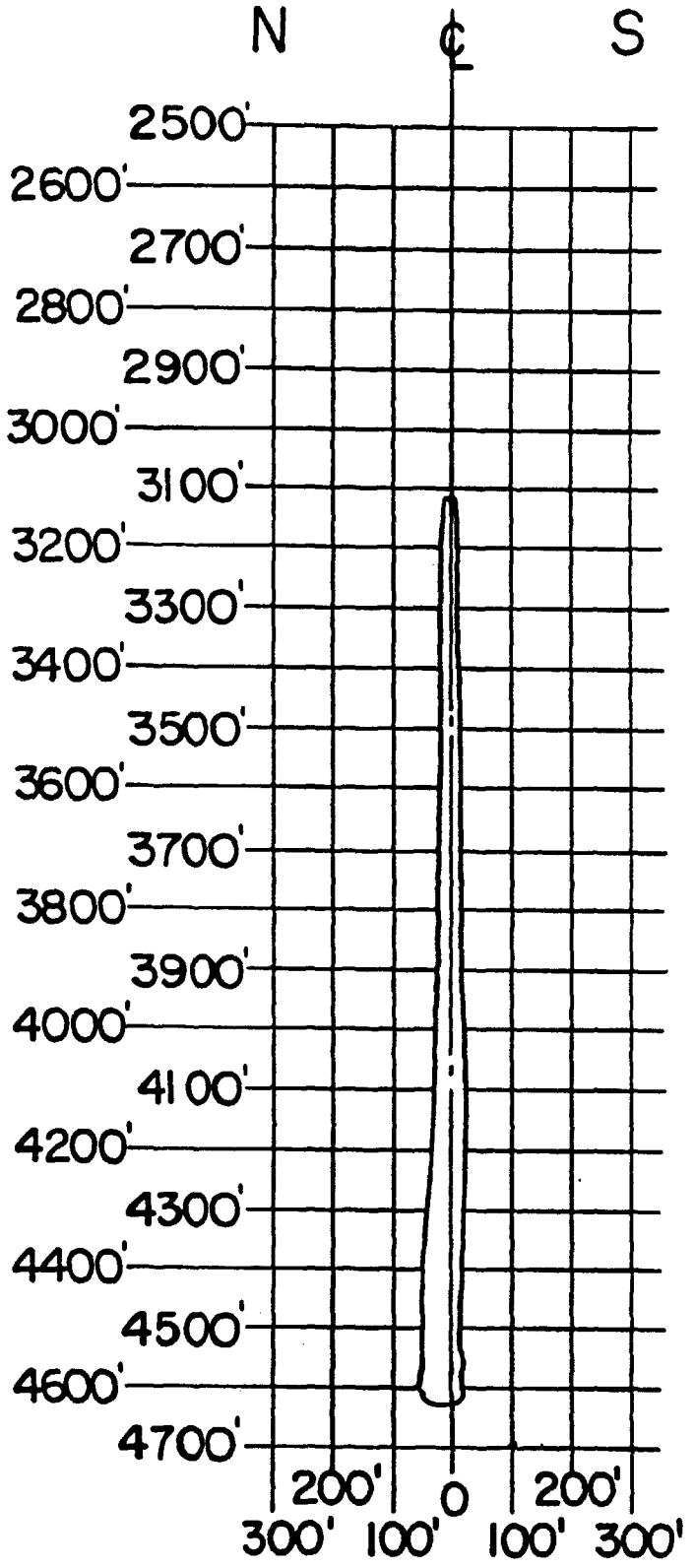
XRAL UGS NO. 4
VERTICAL CROSS SECTION



Miller and Lents, Ltd.
CONSULTING ENGINEERS

XRAL UGS NO. 6
VERTICAL CROSS SECTION

SOURCE: SONAR CALIPER SURVEY- APRIL 26, 1982

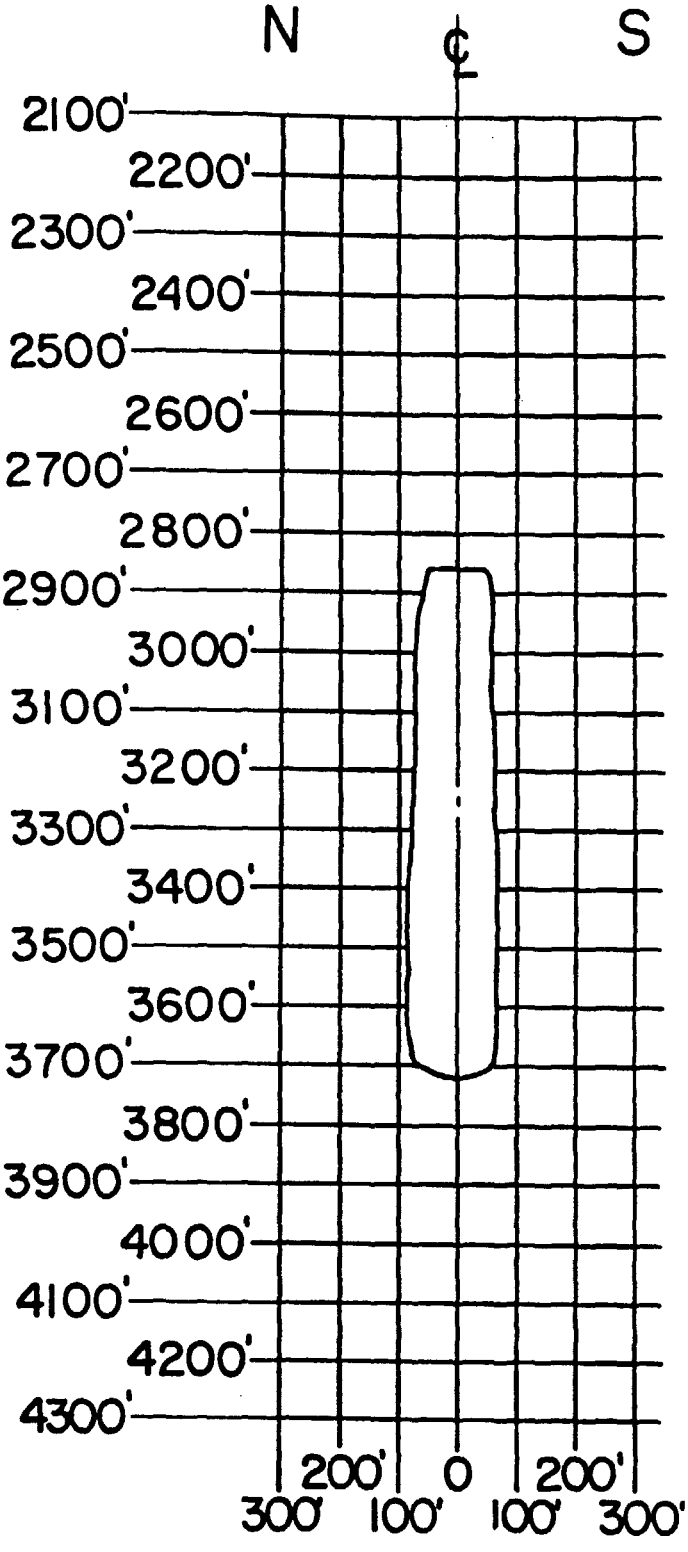


Miller and Associates

CONSULTING ENGINEERS

XRAL UGS NO.16
VERTICAL CROSS SECTION

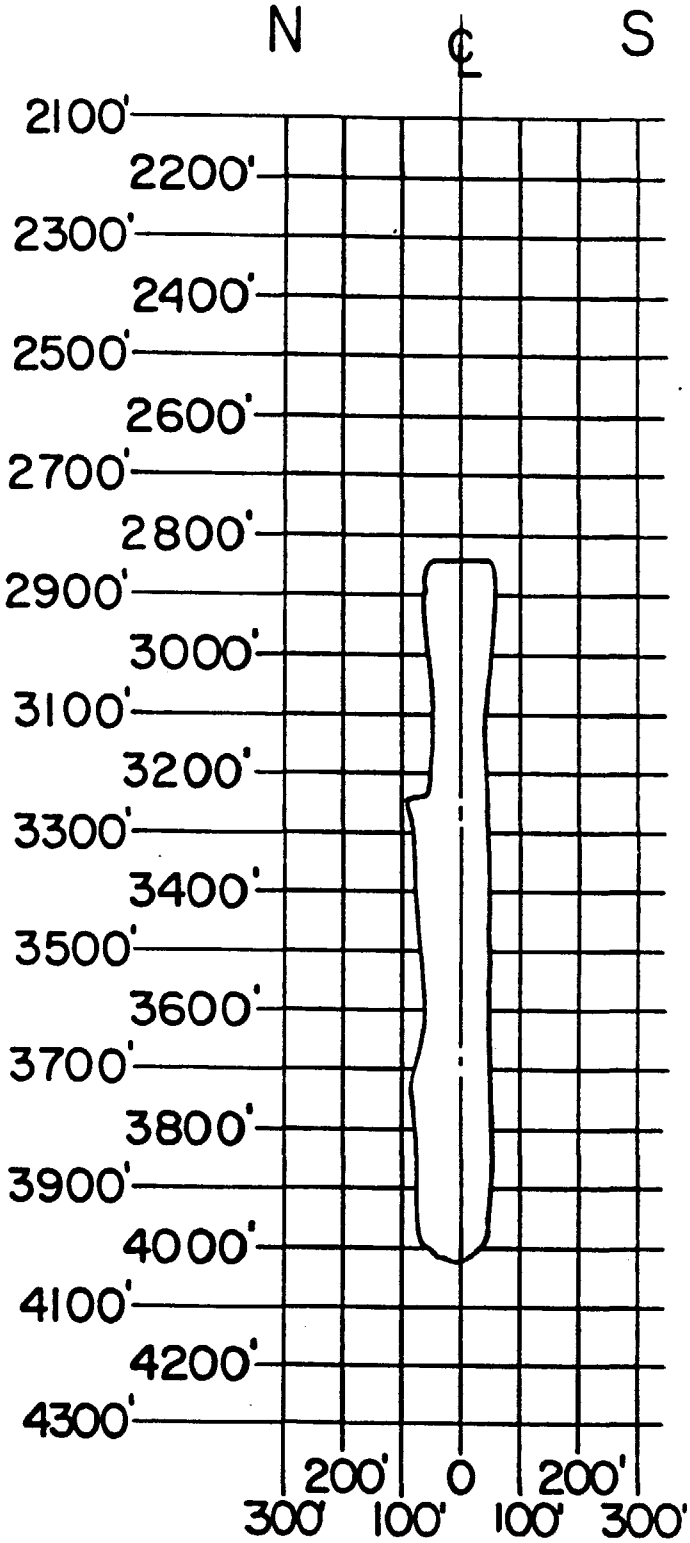
SOURCE: SONAR CALIPER SURVEY - MARCH 16, 1981



Miller Braun & Co.
CONSULTING ENGINEERS

XRAL UGS NO.5
VERTICAL CROSS SECTION

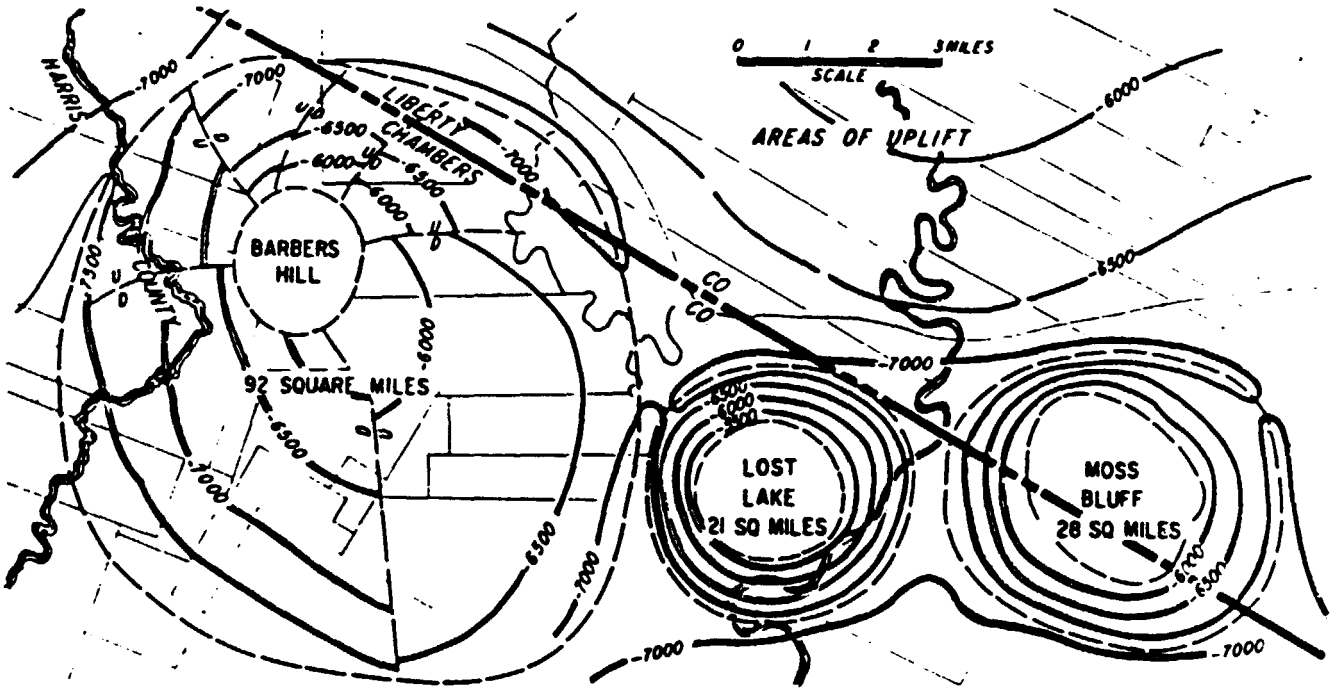
SOURCE: SONAR CALIPER SURVEY - JUNE 1, 1979

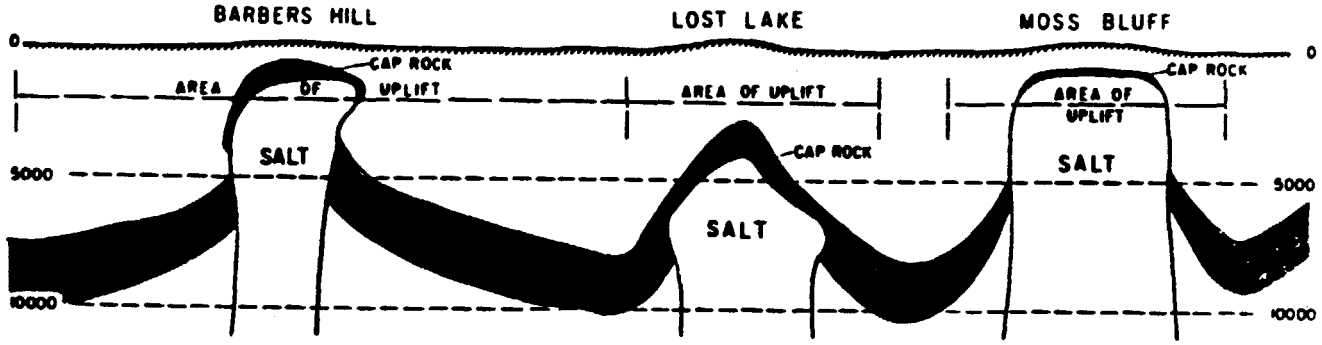


Miller and Lents, Ltd.
CONSULTING ENGINEERS

XRAL UGS NO.14
VERTICAL CROSS SECTION

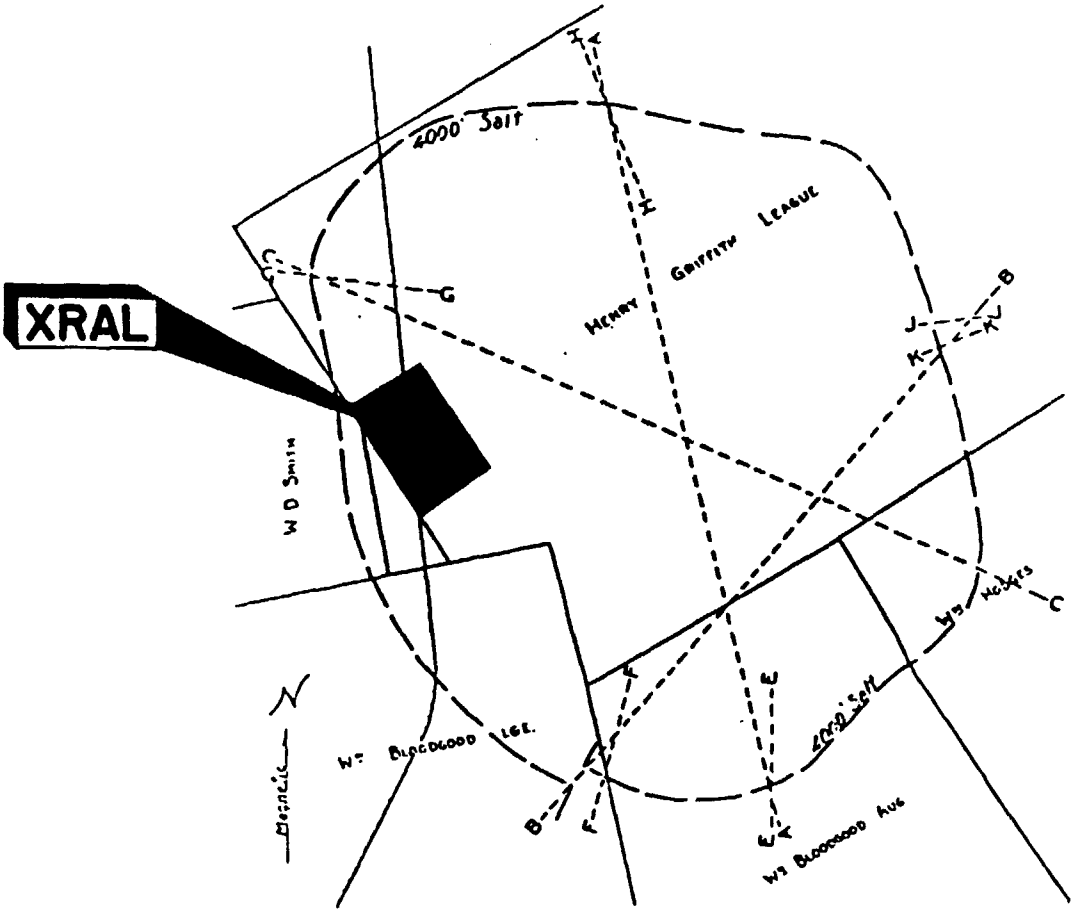
SOURCE SONAR CALIPER SURVEY-DEC.8,1979





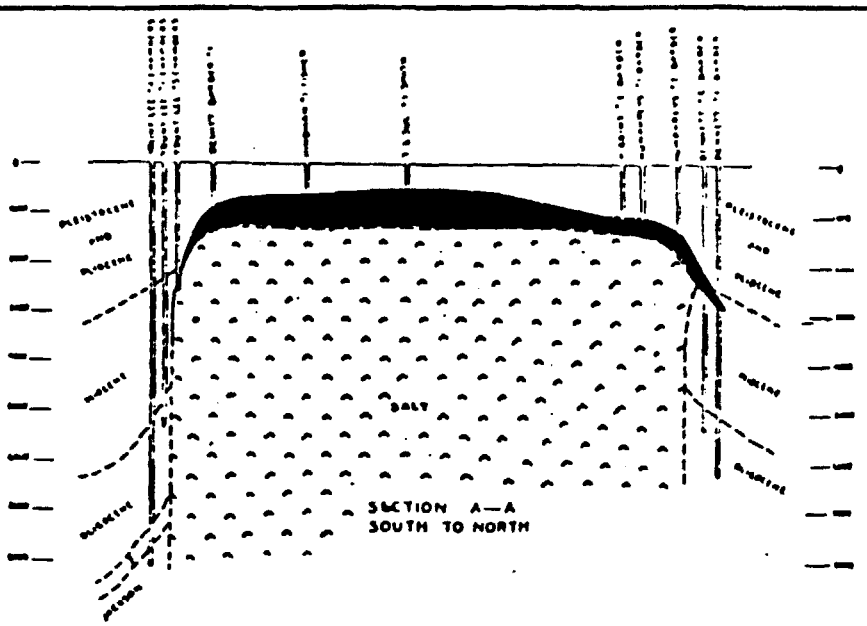
Miller and Associates
CONSULTING ENGINEERS

STRUCTURE & CONTOUR
CHAMBERS & LIBERTY
COUNTY DOMES

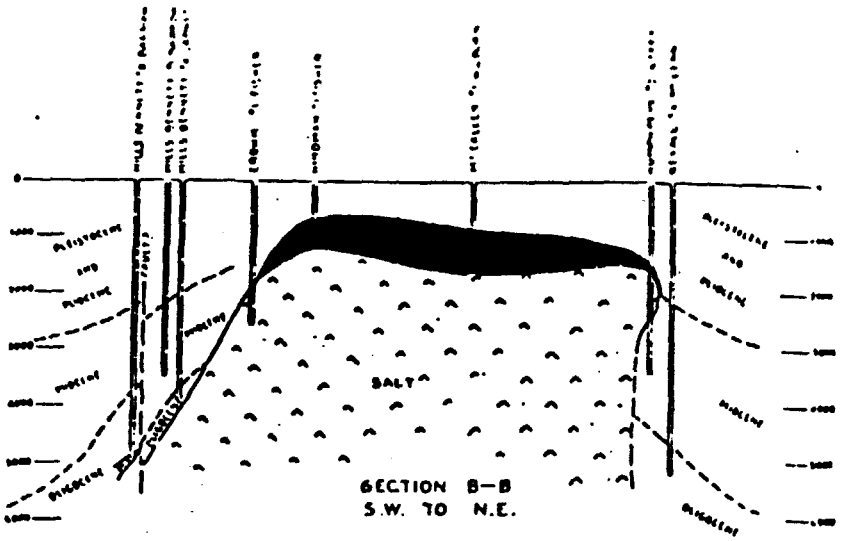


Miller and LaFleur, Inc.
CONSULTING ENGINEERS

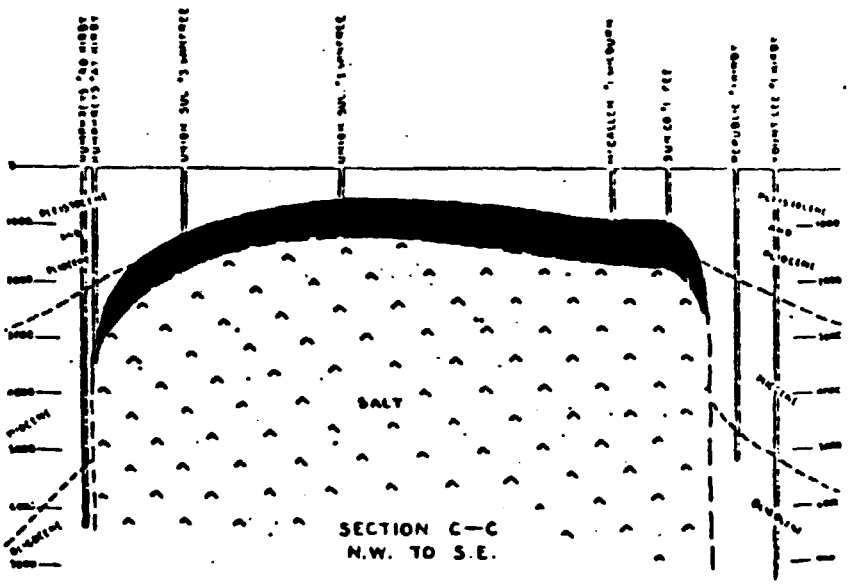
KEYMAP CROSS SECTION
MONT BELVIEU



SECTION A—A
SOUTH TO NORTH



SECTION B—B
S.W. TO N.E.

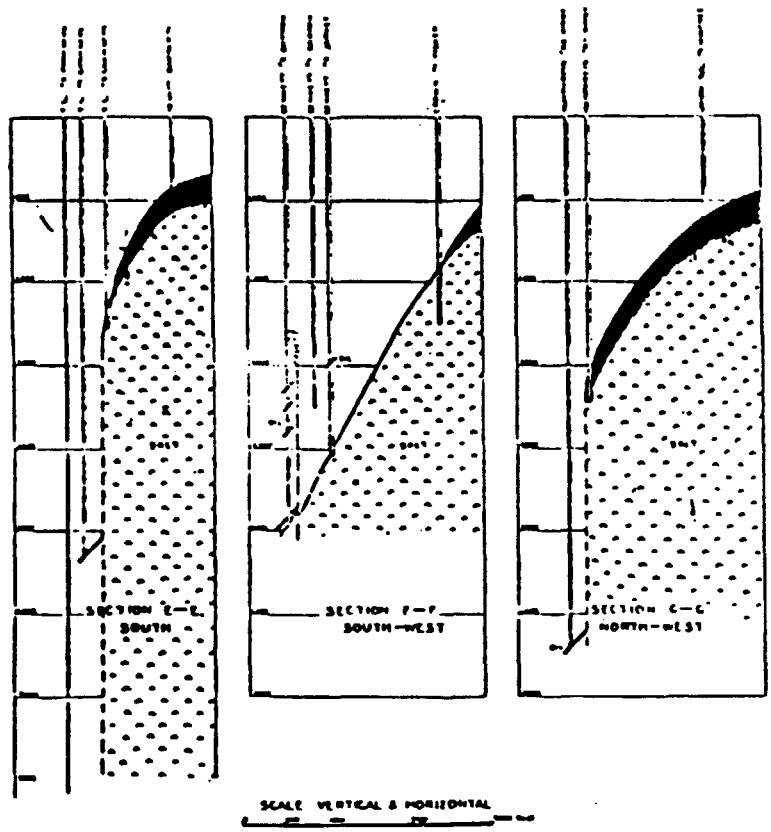


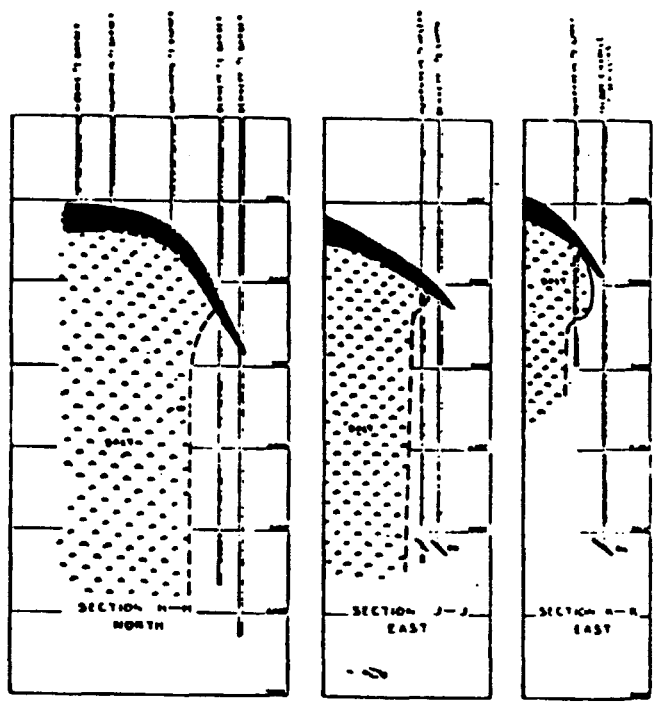
SECTION C—C
N.W. TO S.E.

Miller and Associates

CONSULTING ENGINEERS

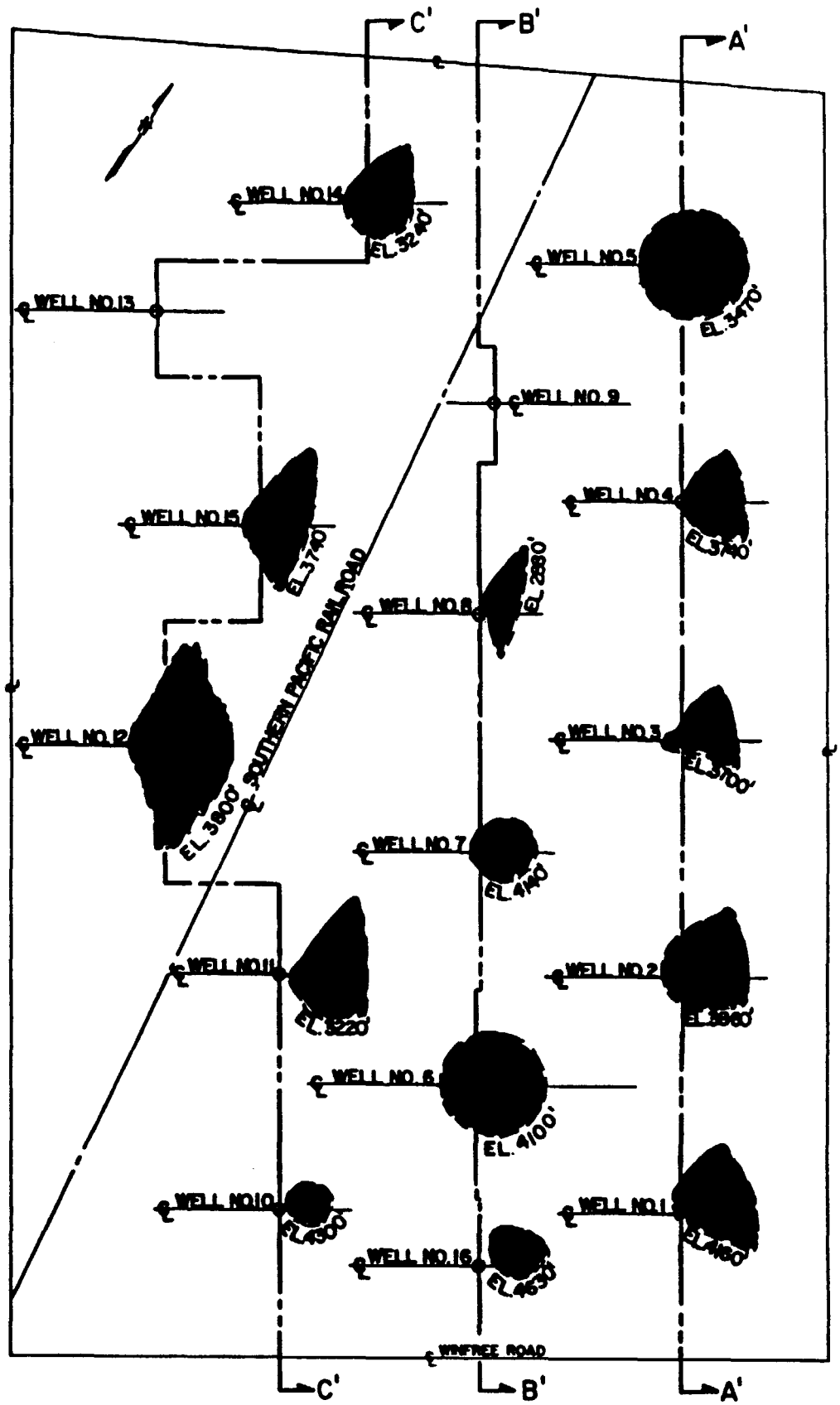
CROSS SECTIONS
A-A, B-B, C-C
MONT BELVIEU





Miller Braithwaite
CONSULTING ENGINEERS

CROSS SECTIONS
E-E, F-F, G-G, H-H, J-J, K-K
MONT BELVIEU



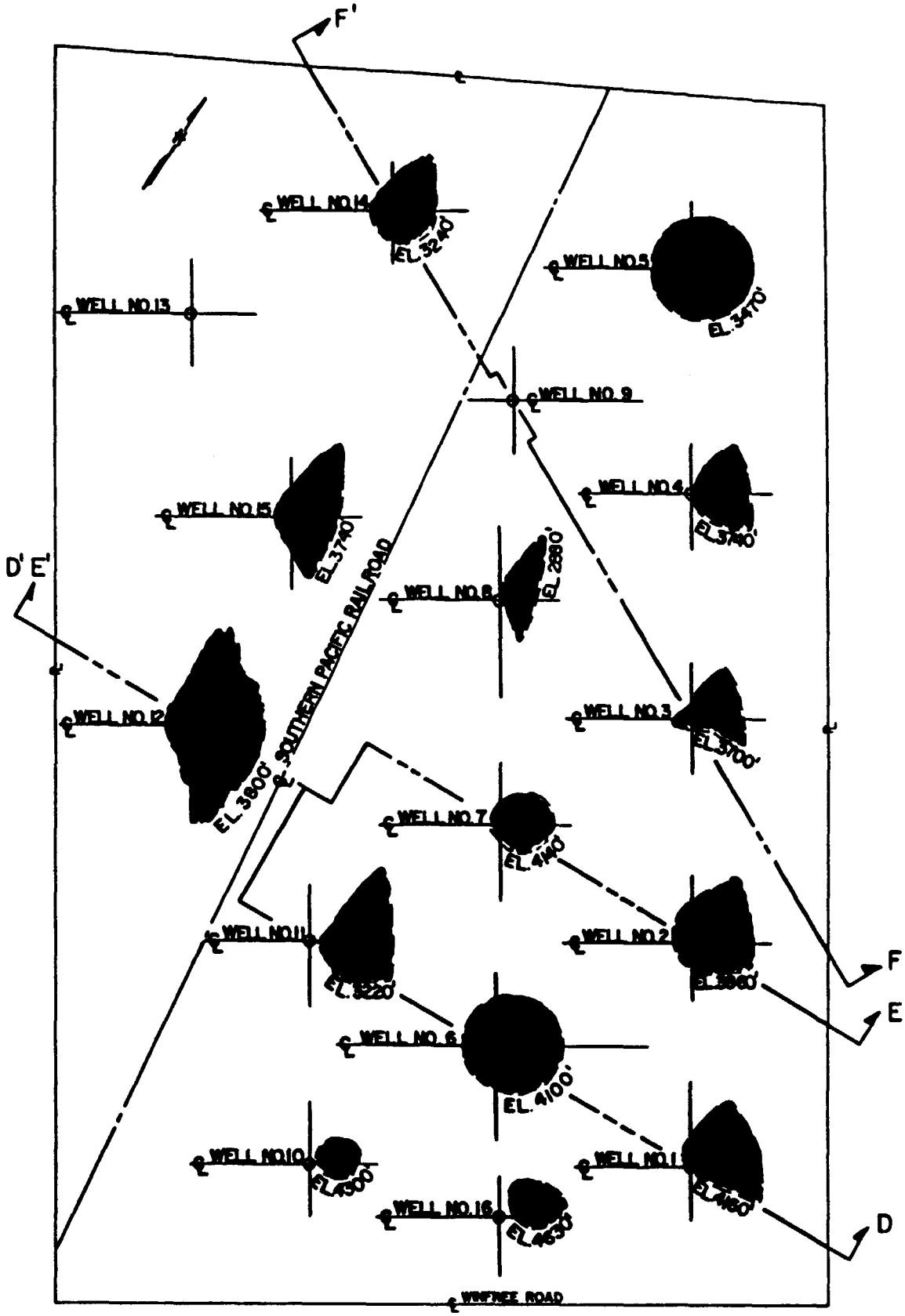
0 100' 400'

SCALE

Miller

CONSULTING ENGINEERS

APPARENT HORIZONTAL SPACING
XRAL CAVERNS



0 100' 400'

SCALE

Miller and Associates

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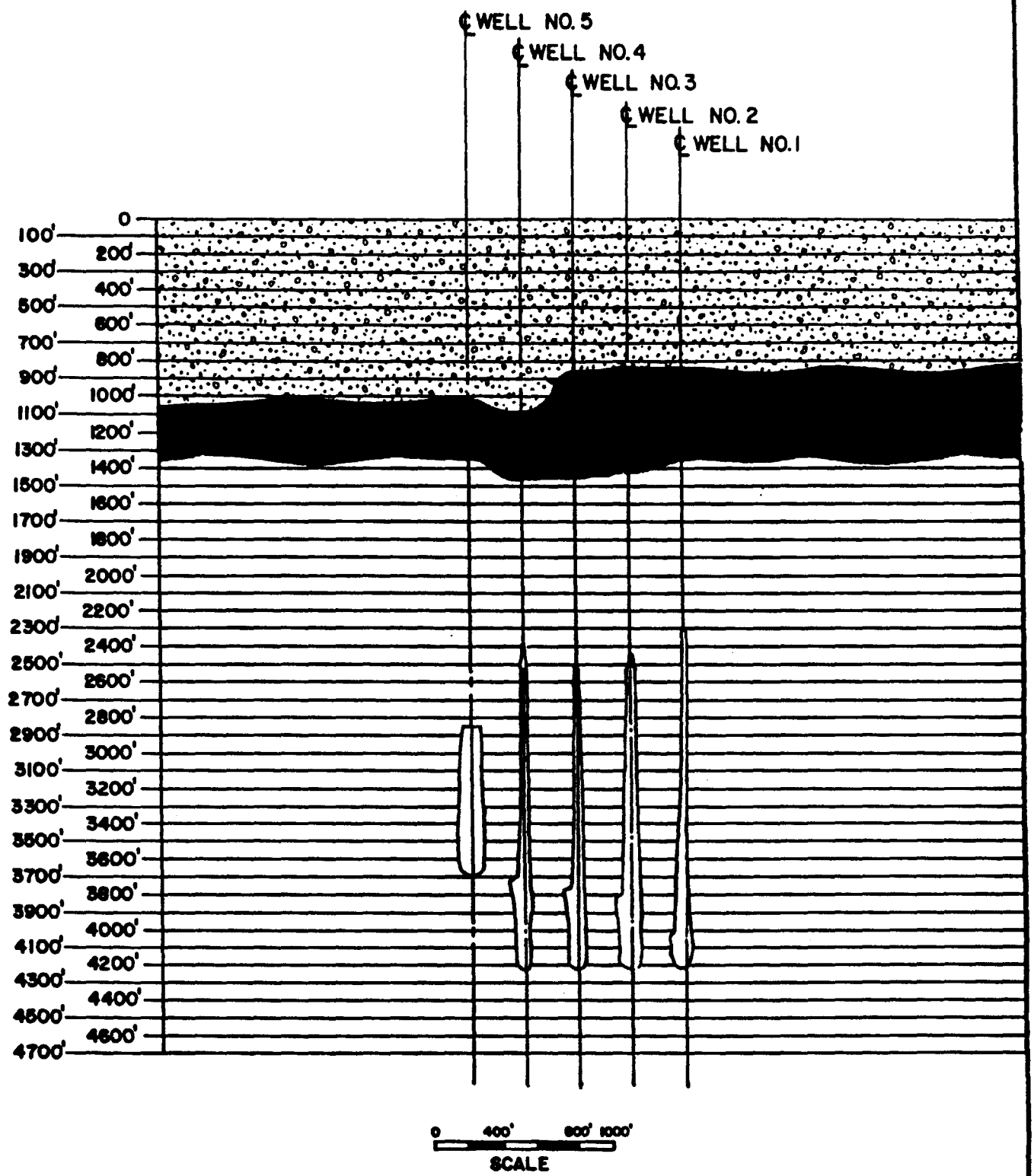
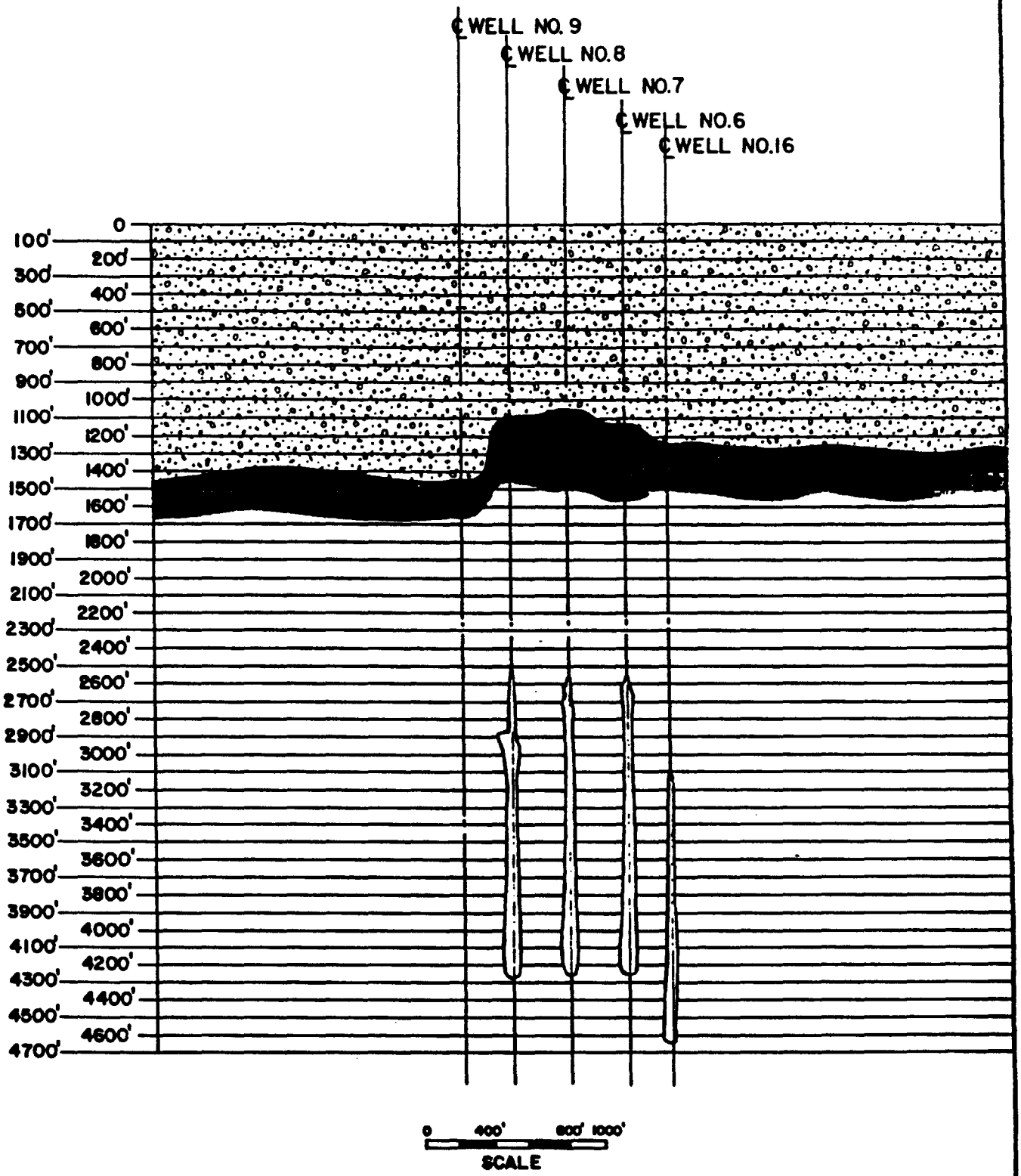
APPARENT HORIZONTAL SPACING
XRAL CAVERNS


℄ WELL NO. 5
℄ WELL NO. 4
℄ WELL NO. 3
℄ WELL NO. 2
℄ WELL NO. 1
0
100'
200'
300'
400'
500'
600'
700'
800'
900'
1000'
1100'
1200'
1300'
1400'
1500'
1600'
1700'
1800'
1900'
2000'
2100'
2200'
2300'
2400'
2500'
2600'
2700'
2800'
2900'
3000'
3100'
3200'
3300'
3400'
3500'
3600'
3700'
3800'
3900'
4000'
4100'
4200'
4300'
4400'
4500'
4600'
4700'
0 400' 800' 1000'
SCALE
SAND, CLAY, SHALE
SALT
CAPROCK
Miller
CONSULTING ENGINEERS
VERTICAL SECTION A'-A'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

CAPROCK

Miller

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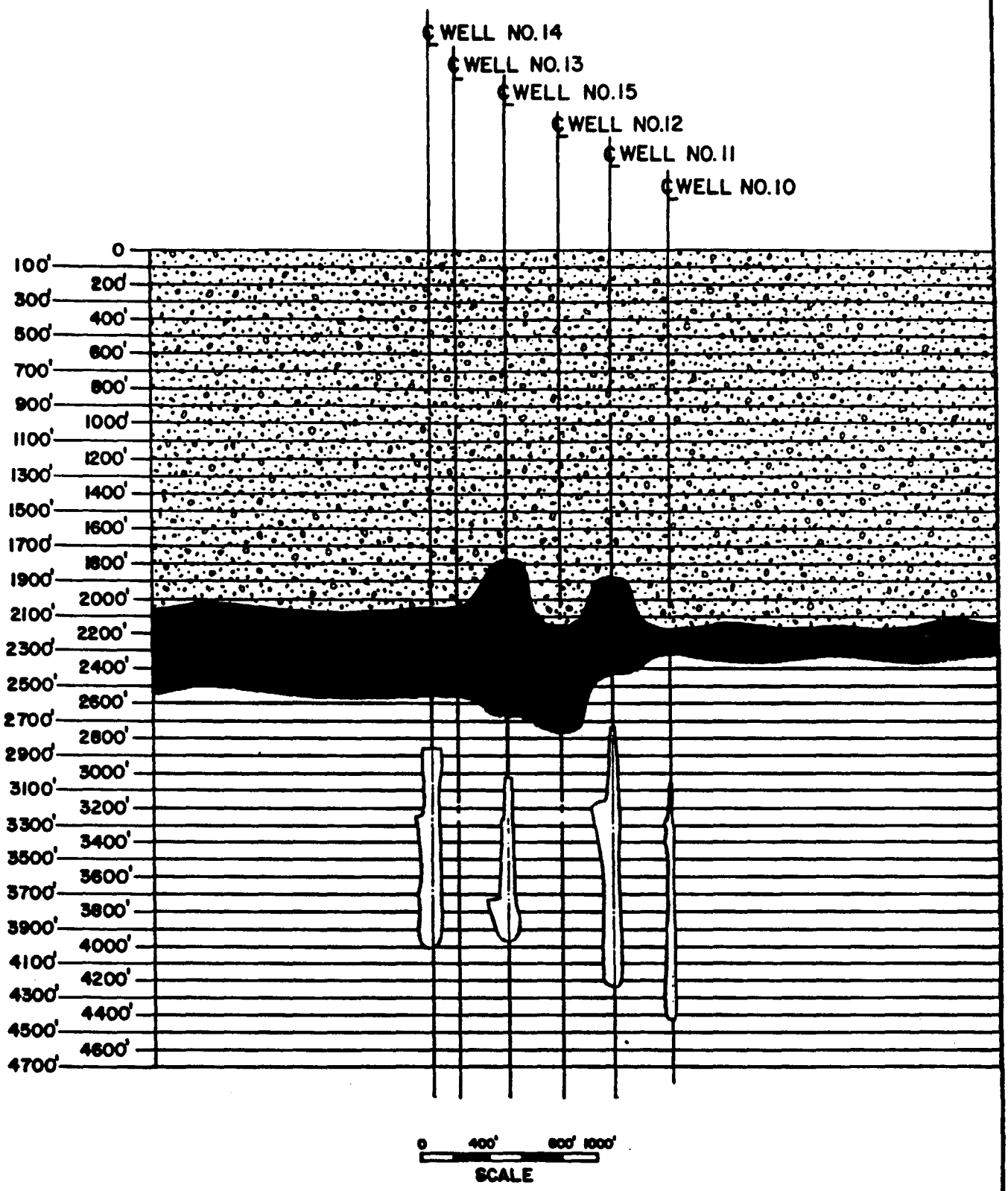
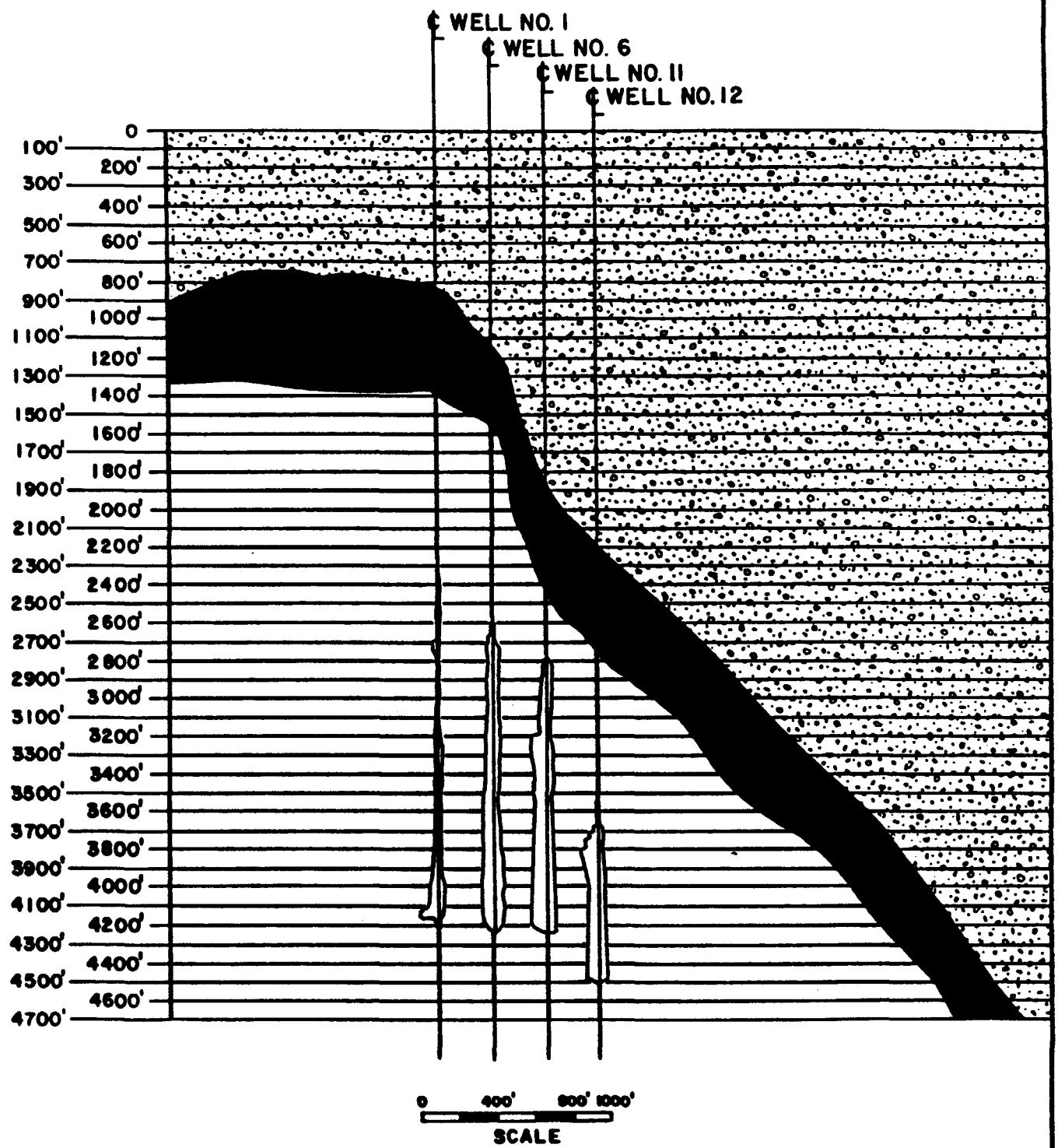
VERTICAL SECTION B'-B'
XRAL CAVERNS


℄ WELL NO. 14
℄ WELL NO. 13
℄ WELL NO. 15
℄ WELL NO. 12
℄ WELL NO. 11
℄ WELL NO. 10
0
100'
200'
300'
400'
500'
600'
700'
800'
900'
1000'
1100'
1200'
1300'
1400'
1500'
1600'
1700'
1800'
1900'
2000'
2100'
2200'
2300'
2400'
2500'
2600'
2700'
2800'
2900'
3000'
3100'
3200'
3300'
3400'
3500'
3600'
3700'
3800'
3900'
4000'
4100'
4200'
4300'
4400'
4500'
4600'
4700'
0
400'
800'
1000'
SCALE
SAND, CLAY, SHALE
SALT
CAPROCK
Miller
CONSULTING ENGINEERS
VERTICAL SECTION C'-C'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

CAPROCK

Miller

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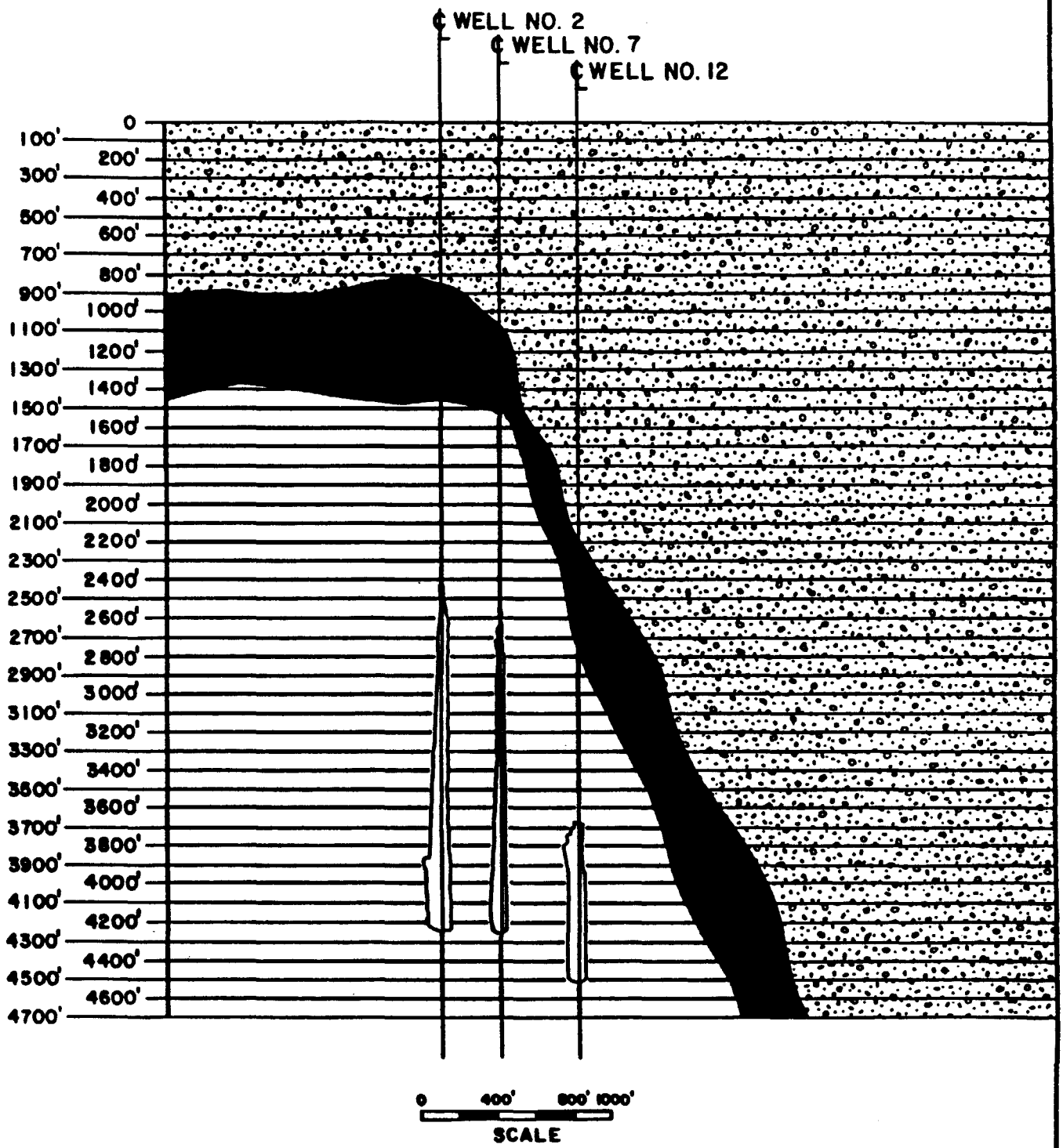
VERTICAL SECTION D-D'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

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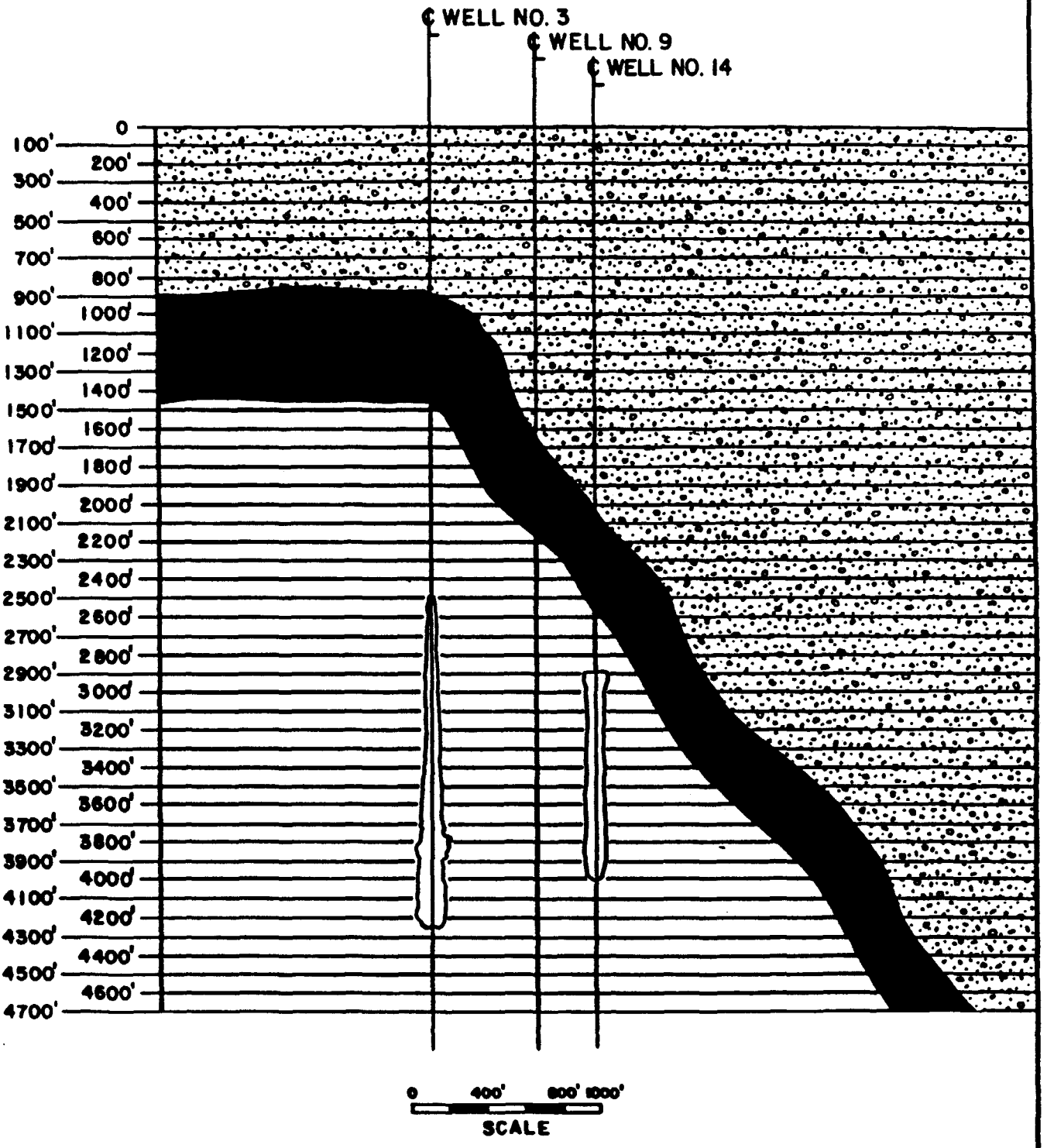
VERTICAL SECTION E-E'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

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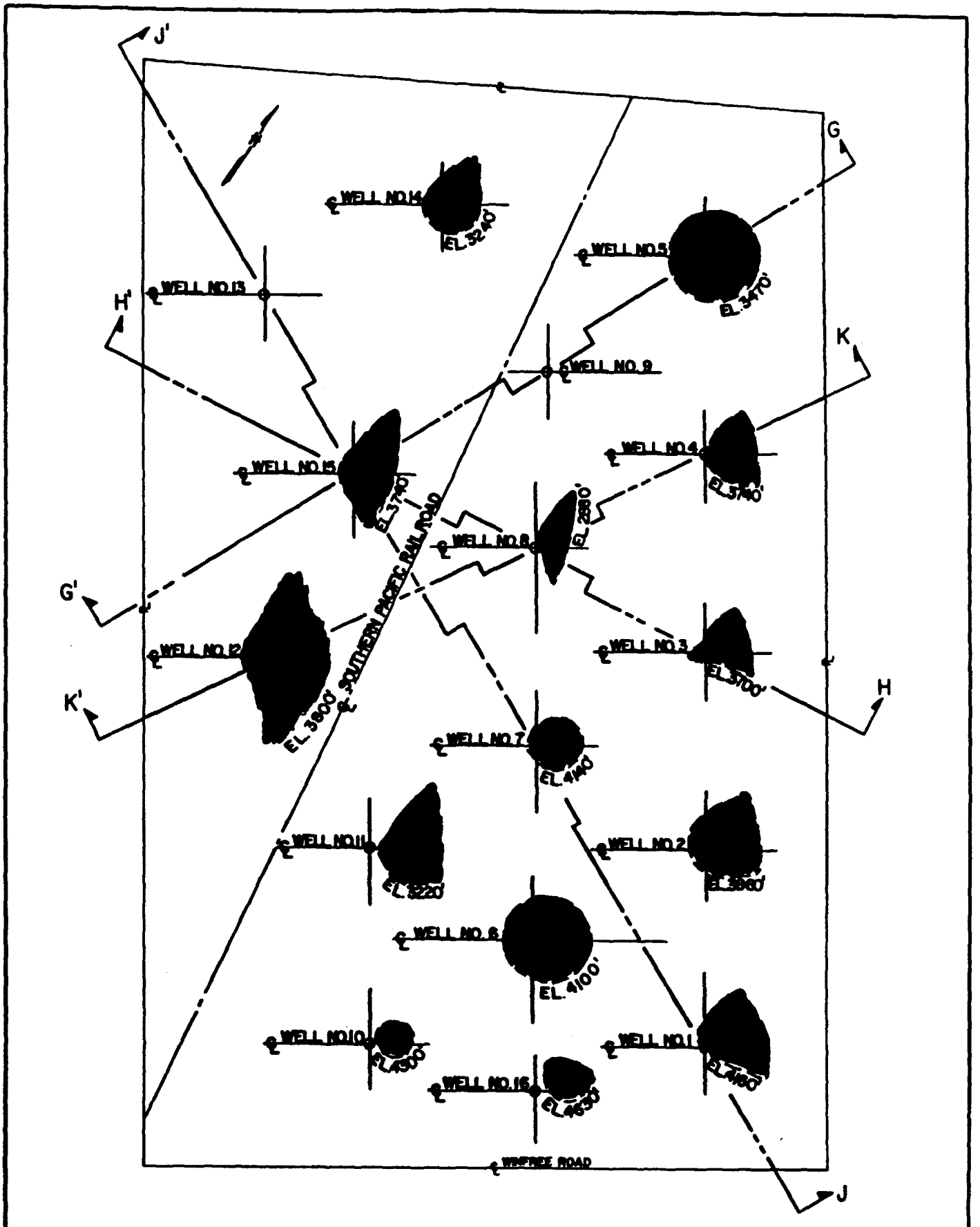
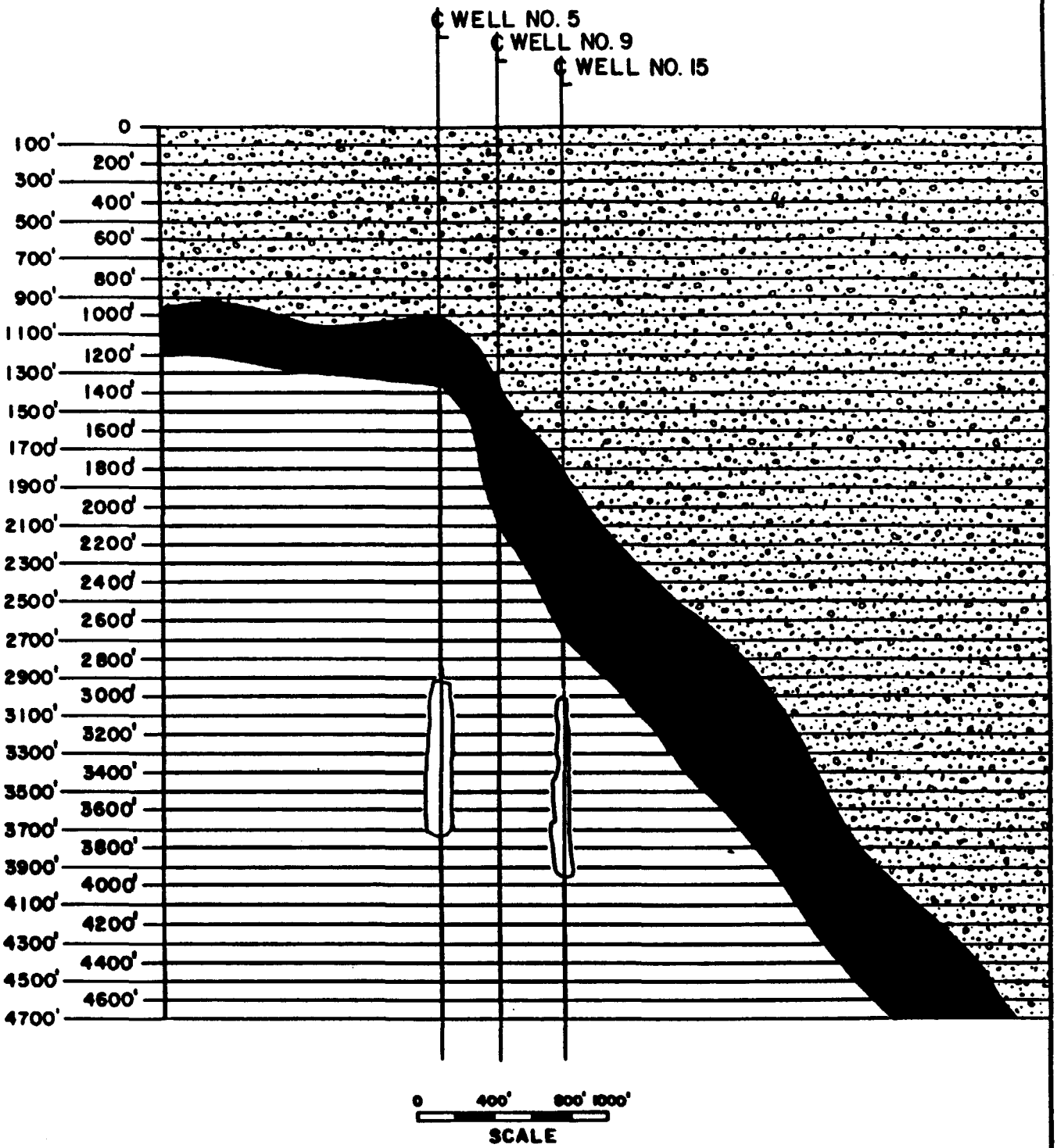
VERTICAL SECTION F-F'
XRAL CAVERNS


J'
G
H'
K
G'
K'
H
J
WELL NO.14
EL.3240'
WELL NO.5
EL.3470'
WELL NO.13
WELL NO.9
WELL NO.15
EL.3740'
WELL NO.4
EL.3740'
WELL NO.8
EL.2880'
SOUTHERN PACIFIC RAILROAD
WELL NO.12
EL.3900'
WELL NO.3
EL.3700'
WELL NO.7
EL.4140'
WELL NO.11
EL.3220'
WELL NO.2
EL.3960'
WELL NO.6
EL.4100'
WELL NO.10
EL.4300'
WELL NO.16
EL.4630'
WELL NO.1
EL.4460'
WINFREE ROAD
0
100'
400'
SCALE
Miller and Associates
CONSULTING ENGINEERS
APPARENT HORIZONTAL SPACING
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

CAPROCK

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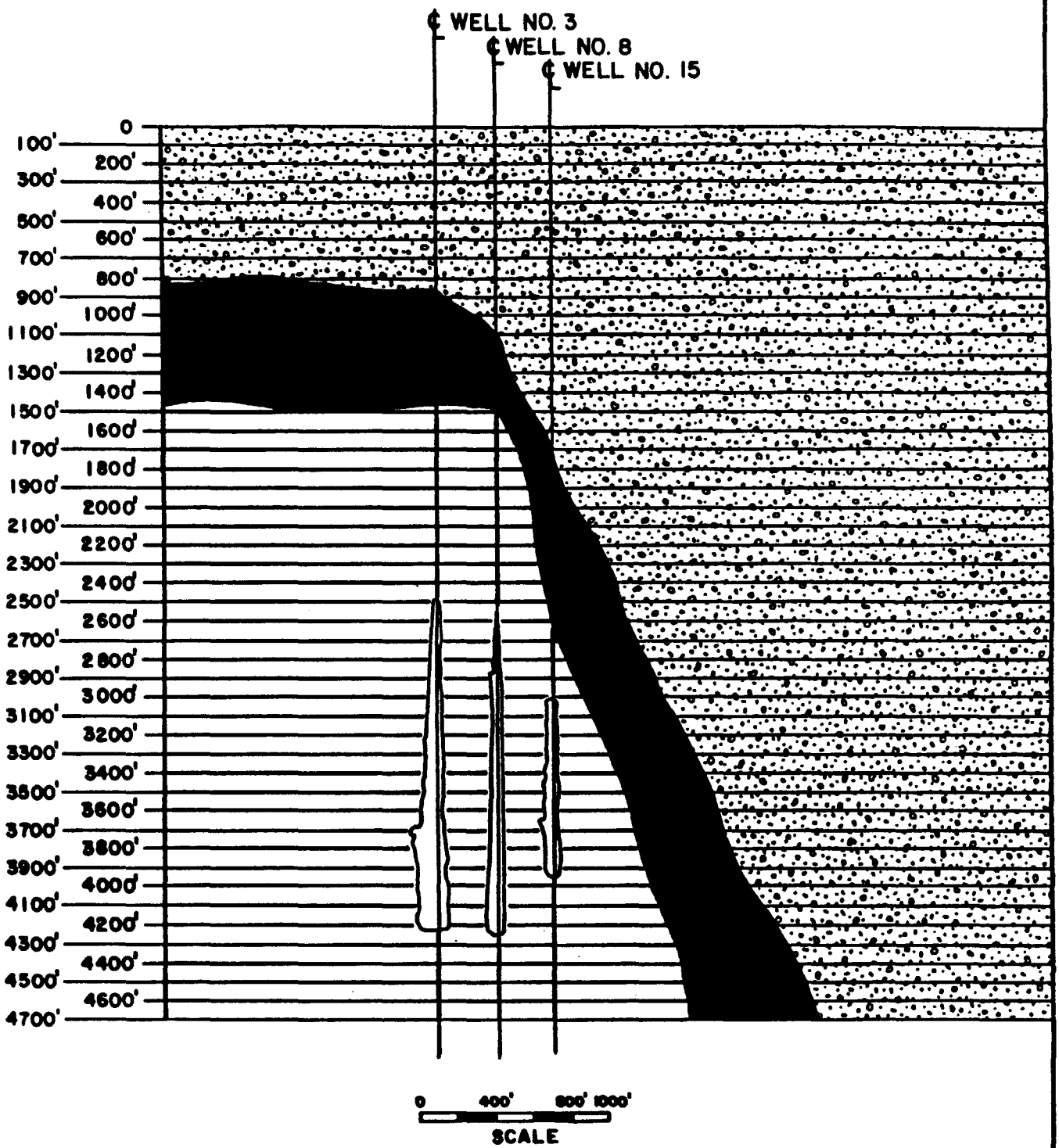
VERTICAL SECTION G-G'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

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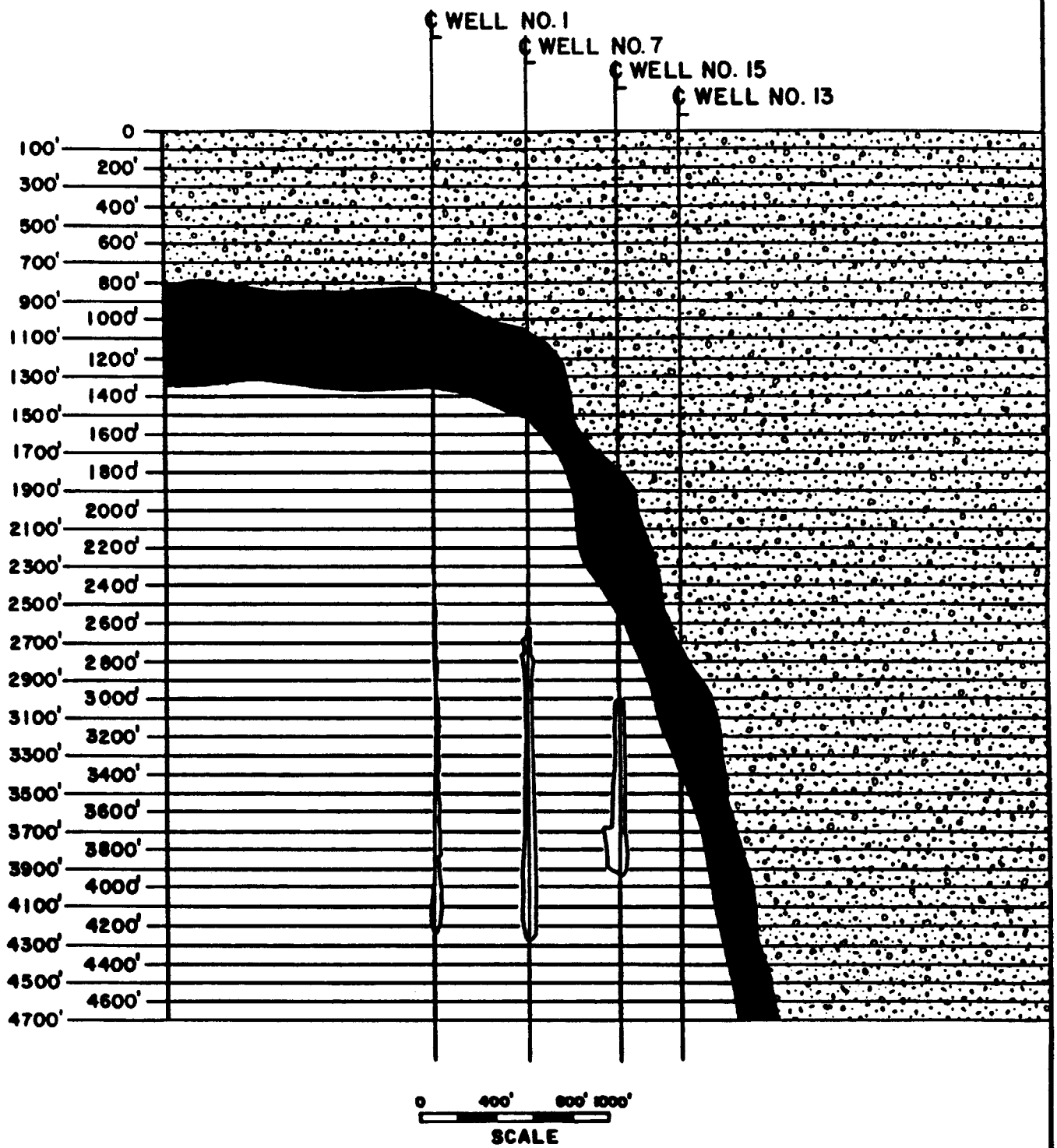
VERTICAL SECTION H-H'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

CAPROCK

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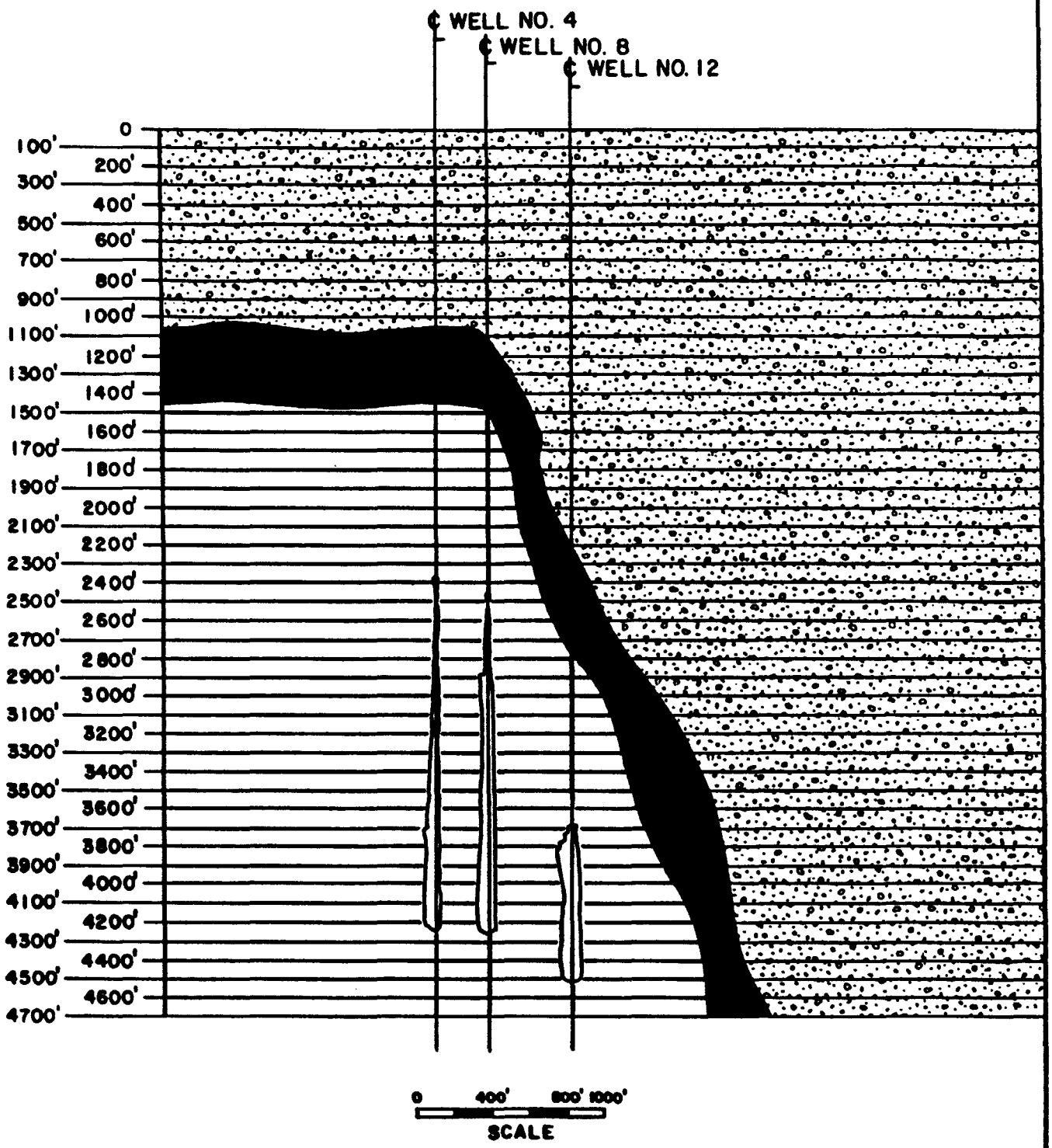
VERTICAL SECTION J-J'
XRAL CAVERNS



SAND, CLAY, SHALE

SALT

CAPROCK

Miller

CONSULTING ENGINEERS

VERTICAL SECTION K-K'
XRAL CAVERNS