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June 1998

Noninvasive Weight Determination of In-Place Ore Stockpiles at Six Defense Depots

by Keith J. Sjostrom, Donald E. Yule, Rodney L. Leist, Michael K. Sharp

WES

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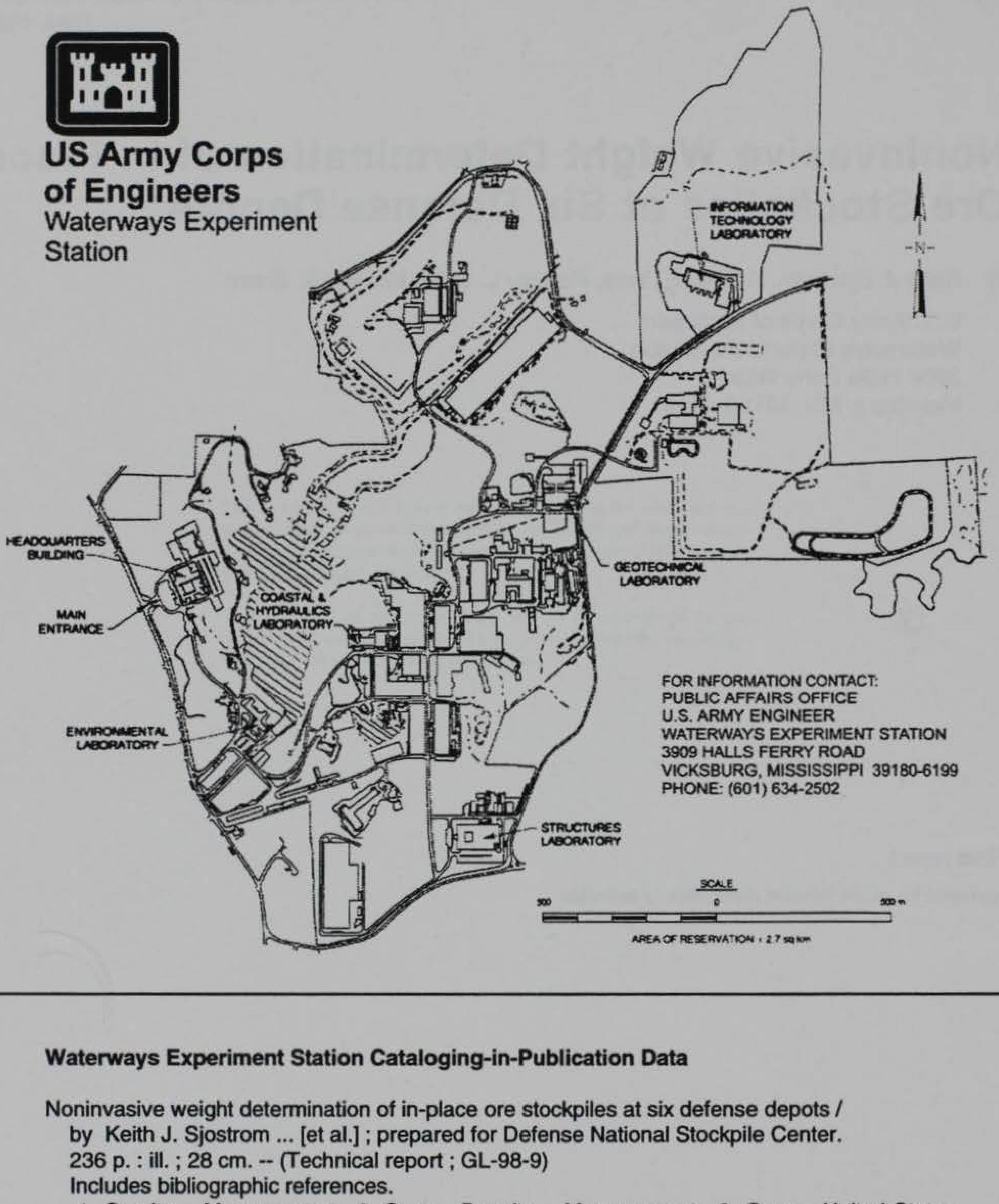

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Contents

Preface

The Defense National Stockpile Center (DNSC) maintains stockpiles of high-grade ores at various locations throughout the country and has a requirement to produce current weight estimates for selected piles as part of a national audit. A geophysical investigation to determine the material density and total weight of selected stockpiles of high-grade ores has been conducted by personnel of the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES). Analysis of microgravity measurements provide representative bulk density values of the high-grade ore. The weight of each ore stockpile is computed by multiplying the average density values and surveyed ore pile volume determinations. Microgravity measurements were collected over ore stockpiles at the following locations during the dates listed:

Hammond Depot, Indiana	29, 30 September 1997 and 1 October 1997
New Haven Depot, Indiana	1-10 October 1997
Warren Depot, Ohio	20-31 October 1997
Curtis Bay Depot, Maryland	9-25 November 1997
Point Pleasant Depot, West Virginia	1-6 December 1997
Anniston Army Depot, Alabama	10, 11 December 1997

The study was performed under sponsorship of the Defense National Stockpile Center of the Defense Logistics Agency, Ft. Belvoir, Virginia. The DNSC Project Coordinator was Mr. G. A. Vanegas.

The overall test program was conducted under the general supervision of Drs. W. F. Marcuson III, Director, GL, and A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division (EEGD), GL. Mr. Keith J. Sjostrom, EEGD, was the principal investigator. This report was prepared by Mr. Sjostrom under the supervision of Dr. M. E. Hynes, Chief, Earthquake Engineering and Geophysics Branch, EEGD, GL. Data acquisition and analysis were performed by Mr. Sjostrom and Messrs. Donald E. Yule, Rodney L. Leist, and Michael K. Sharp, EEGD, GL. Graphical presentation of the ore piles was provided by Mr. Grady A. Holley, Applied Research Associates, Vicksburg, Mississippi.

Acknowledgment is made to Messrs. Thomas E. Berry and Charles D. Hahn, Natural Resources Division, Environmental Laboratory, for surveying and determining the volume of each ore pile and providing the elevations of each gravity station for the ore piles studied at Hammond Depot and Anniston Army Depot. Gravity station elevations, ore pile contour plots, and volume determinations at the New Haven Depot and Warren Depot were provided by personnel of the U.S. Army Engineer District, Louisville, under the supervision of Mr. Boyd McClellan, Chief, Surveying and Mapping Section, Engineering Division. Elevation and volume data for the ore piles at the Point Pleasant Depot were provided by personnel of the U.S. Army Engineer District, Huntington, under the supervision of Messrs. Paul Dean and Michael Wetzel, Surveying and Mapping Section, Engineering Division. Pile volumes and topographic data for the ore stockpiles at the Curtis Bay Depot were provided by personnel of W. H. Gordon Associates, Inc., Chantilly, VA. W. H. Gordon Associates was operating under contract through the Engineering Division, U.S. Army Engineer District, Baltimore. The topographic surveys at each project area were performed during the same time frames as the microgravity work.

The authors would also like to acknowledge the cooperation and assistance provided by DNSC depot managers and personnel during the on-site microgravity and topographic investigations. These personnel are: Mr. John Olszewski, Hammond Depot; Mr. Fred Brooks, New Haven Depot; Messrs. John Pittano and Leon Morrison, Warren Depot; Mr. Joe Scholle, Curtis Bay Depot; Mr. Dave Taylor, Point Pleasant Depot; and Mr. Jim Buford and Ms. Debbie Underwood, Gadsden Depot (Anniston Army Depot).

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

Executive Summary

The Defense National Stockpile Center (DNSC) maintains stockpiles of high-grade strategic ores at various locations throughout the country. DNSC is required by the U.S. Inspector General to produce current weight estimates for 82 randomly selected ore stockpiles as part of an audit of the National Defense Stockpile Transaction Fund. The reliability of the weight estimates is important for assessing the current ore inventory within the Federal Government and for setting fair market values of the material when the ore stockpiles are sold to industry. The selected ore stockpiles for this study are located at the following sites: Hammond Depot, IN; New Haven Depot, IN; Warren Depot, OH; Curtis Bay Depot, MD; Point Pleasant Depot, WV; and Anniston Army Depot, AL. The pile material types are categorized as metallurgical fluorspar, beryl ore, metallurgical-grade manganese, high-carbon or low-carbon ferrochrome, and high-carbon ferromanganese.

Microgravity investigations to determine the average bulk material density for the selected stockpiles were conducted by personnel of the U.S. Army Engineer Waterways Experiment Station. Depending on the ore pile dimensions, two to four microgravity survey lines were conducted perpendicular to the length of the pile. For conically shaped piles, the survey consisted of two gravity lines which intersect at the pile apex. The measured gravity data were referenced to the base station datum for each profile by correcting for the effects due to latitude, elevation, earth tides, and instrument drift. In this manner, variations in the corrected gravity values are attributed solely to the ore pile material. The corrected gravity data sets are analyzed using Parasnis' method to compute a volume-averaged bulk density value for ore pile material. This method has the advantage of averaging the effect of density variations more accurately than can be done from surface or core samples. Ore pile volumes were computed from three-dimensional pile representations constructed from the measured elevation data.

The weight of stockpiled ore is calculated by multiplying the average bulk density value and computed pile volume. The percentage of difference between the computed weights and reported gross weights for each stockpile should be within ± 10 to ± 15 percent. Comparing the computed weights for each ore stockpile to the weights on record at DNSC, it is observed that 42 of the 82 piles surveyed are within or less than the expected percentage difference error range. The percent difference values for another 33 ore stockpiles range from ± 15 to ± 25 percent of which 12 piles have calculated weights between

± 15 to ± 18 percent of the reported value. Eight stockpiles have computed weights differing by greater than 25 percent of the reported values. Seventy-seven of the ore piles have calculated weights less than the weights on record.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02832	cubic meters
cubic yards	0.76455	cubic meters
feet	0.3048	meters
gal (measure of gravity)	1.0	centimeters per second squared
gal (measure of gravity)	0.01	meters per second squared
microGal	1.0×10^{-8}	meters per second squared
miles (U.S. statute)	1.6093	kilometers
pounds (mass)	0.45359	kilogram
pounds (force)	4.44822	Newtons
pounds per cubic foot	0.01602	grams per cubic centimeter
pounds per cubic foot	16.0184	kilograms per cubic meter
tons	907.1847	kilograms

1 Introduction

Background

The Defense National Stockpile Center (DNSC) of the Defense Logistics Agency (DLA), Ft. Belvoir, VA maintains stockpiles of high-grade ores at various defense depots throughout the country. While the initial or as-delivered weights of many of the piles of materials are known or have been estimated in previous years, the measures or estimates, many of which are 30 to 40 years old, may not be reliable. DNSC has a requirement from the U.S. Inspector General to produce current weight estimates for statistically selected piles as part of an Audit of National Defense Stockpile Transaction Fund FY 1997 Financial Statements. The reliability of the weight estimates are important for assessing the current ore inventory within the Federal government and for setting fair market values of the material when the ore stockpiles are sold to industry.

DNSC has requested assistance from the U.S. Army Engineer Waterways Experiment Station (WES) in determining the weight of 85 piles of heavy metal ores in the Defense National Stockpile at six locations: Hammond Depot, IN; New Haven Depot, IN; Warren Depot, OH; Curtis Bay Depot, MD; Point Pleasant Depot, WV; and Anniston Army Depot, AL (see Figure 1). The pile materials are all heavy metal ores consisting of either ferrochrome (high- and low-carbon content), high-carbon ferromanganese, metallurgical-grade manganese, metallurgical-grade fluorspar, or beryl ore. The size of the materials in the piles range from fines to boulder size.

Standard geotechnical methods for bulk density determination are not readily applied to the in-place pile materials because of the large range in size of the ore. Measuring the near-surface density values of the pile materials by a technique such as the ring density test will not give representative density values of the material near the base or center of the piles. Density determination methods which require displacing materials, i.e., material placed in known volume containers and weighed, are likely to produce values that are less than the actual material density.

A method for computing the weight of the in-place ore stockpiles and determining a truly representative bulk density for each pile is to measure the gravitational attraction of the piles. The gravitational attraction of an ore pile is the result of the integrated effect of the in-place bulk material density distributed over the volume of the pile. Analysis of the gravitational anomaly recorded over the pile results in an estimate of the representative bulk density of the ore material. The weight of a pile is computed by multiplying the average bulk density values with the measured pile volume. Gravitational determination of near-surface densities for use in gravity survey data reductions are done routinely in geophysics. However, determination of densities by gravity surveys is a non-standard technique for the present application.

Purpose and Scope

The objective of this investigation is to determine the in-place weight of 85 ore piles representative of the ore stockpiled under DNSC jurisdiction. The results will be used to check the current ore inventory as part of an audit of the National Defense Stockpile Transaction Fund, Fiscal Year 1997 Financial Statements. Pile volumes are determined using standard topographic surveying procedures. Material density values are derived through analysis of microgravity measurements performed over ore stockpiles. Pile weight is the product of the pile volume and material density.

Location of Test Sites

Eighty-five ore piles were originally selected by the Inspector General's Office to be audited. The pile designations, material types, dimensions, and originally reported gross weights, as provided by DNSC, are listed in Table 1. The statistically chosen ore stockpiles are located as follows. Three ore piles are located at the Hammond Depot in Hammond, IN. The material type for all three stockpiles is high-carbon ferrochrome. The survey includes 10 stockpiles of high-carbon ferrochrome and 10 piles of high-carbon ferromanganese stored at the New Haven Depot. The depot is located four miles east of New Haven, IN and seven miles east of Fort Wayne, IN. It is noted that DNSC records list one pile and one reported gross weight for Pile #23 (see Table 1). However, upon inspection of the site prior to the survey, two ferromanganese piles are labeled Pile #23 and investigators designated the stockpiles Piles #23A and #23B as shown in Figures B-23 and B-25, respectively. Twenty-four ore stockpiles are located at the Warren Depot south of Warren, OH. The ore stockpiles are categorized as follows: 11 piles of high-carbon ferromanganese, 10 stockpiles of high-carbon ferrochrome, two stockpiles of metallurgical fluorspar (grade A), and one pile of grade B fluorspar. The pile descriptions, dimensions, and reported weights are outlined in Table 1.

Twenty-six of the 85 original piles selected for this study are located at the Curtis Bay Depot in Glen Burnie, MD. The piles, as listed in Table 1, are comprised of high-carbon ferrochrome, high-carbon ferromanganese, and beryl ore. Two covered stockpiles of chemical-grade type A manganese were originally included in the study. These piles, Piles #131 and #139, were removed from the study when the depot manager was reluctant to allow anyone on the pile covers and it was noted the piles had not been disturbed since placement. In addition, three of the beryl ore piles, Piles #211 through #213, had been mechanically sorted according to material size at some time prior to the microgravity and topographic surveys. The sorted material was placed in separate piles but retained the original pile designations. For instance, the pile designation "Pile #211" encompasses five individual piles of material. In all, twelve sorted beryl ore piles exist, as shown in Appendix D.

Nine ore stockpiles were studied at the Point Pleasant Depot in Point Pleasant, WV. The inventory includes: one pile of high-carbon ferrochrome, five piles of low-carbon ferrochrome, and three stockpiles of high-carbon ferromanganese. Two of the low-carbon ferrochrome piles, Piles #54 and #55, were also covered and subsequently removed from the study for reasons similar to the covered manganese piles at Curtis Bay Depot, MD. The final pile of the study is located at the Anniston Army Depot west of Anniston, AL. The ore pile is denoted as Pile #1 and the material classified as metallurgical-grade manganese. At the conclusion of the field studies at each of the six sites, a total of 82 ore piles had been investigated as listed in Table 2.

2 Principles of Microgravity Surveying

The Microgravity Method

Gravimetry is one of the fundamental methods with which to map the distribution of the subsurface geology and determine the nature and magnitude of subsurface density anomalies. Near-surface density anomalies produce localized variations in the gravitational field near the surface of the earth. Systematic and precise measurements of the gravitational field allows the field to be mapped in detail on the surface of the earth. The measured gravity field is corrected for variations in the normal gravitation field of the earth and any large scale gravity effects relative to the survey area of interest. The resultant values, with respect to an arbitrary reference datum, are the gravity anomaly field. Analysis of the gravity anomaly field provides estimates of the density contrast between the anomalous feature and surrounding earth material. The depth to and geometry of the localized feature are also defined.

The normal gravitational field on the earth's surface is given by 9.80 m/s^2. Instead of using the units of m/s^2 for gravitational acceleration, geophysicists often employ the unit of Gal where 1 Gal = 10^{-2} m/s^2. Microgravimetry refers to high-resolution surveys of the gravitational field with gravimeters that have a measurement sensitivity and accuracy of approximately one microGal (1 μGal). The quantity of 1 μGal = 10^{-6} Gal = 10^{-8} m/s^2. Therefore, microgravimetry involves the measurement of gravity with a precision and accuracy of approximately 10^{-9} times that of the normal earth's gravitational field. The microgravity measurements recorded for this study were completed using a LaCoste and Romberg Model D Gravimeter as shown in Figure 2. The measurement characteristics of gravimeters used for microgravity surveys are discussed in detail in Butler (1980) and Torge (1989).

Microgravimetric surveys are of two types: (a) profile surveys, where gravity measurements are made along traverses generally perpendicular to the presumed strike of a linear-type structure, such as a fault, ridge, valley, buried river channel, or an elongated pile of material on the surface; and (b) areal surveys, where gravity measurements are made along a grid set up over the project area. Microgravity surveys are often conducted with measurement points separated by 5 to 30 ft to enhance the detectability and resolution of small and closely spaced subsurface features. Station locations and relative elevations must be accurately determined by a site leveling survey in which the station locations and elevations are measured to the nearest 0.1 and 0.01 ft, respectively. The field procedures used for the surveys are dictated by considerations of survey objectives and subsequent corrections which must be made to the measured data. The measurements in a microgravity survey are normally made relative to a local reference station, and there is usually no attempt to tie the values to an absolute gravity determination.

Analysis of the surface gravity anomaly, in many cases, allows the mass excess or deficiency associated with the density contrast to be determined (Butler 1980; Telford et al. 1990). When the values associated with the density contrast and the volume of the feature are known or can be measured, then the actual mass associated with the localized feature can be determined. For unique cases where a profile of gravity measurements crosses a topographic surface feature such as a hill, ridge, or ore pile and the surface feature being investigated is entirely above some reference datum, it is possible to determine the actual bulk density of the material comprising the structure directly from the gravity measurements (Nettleton 1940; Parasnis 1979; Telford et al. 1990; Sjostrom and Butler 1996). It is this last capability that is used to determine the bulk density and weight of an ore stockpile.

Field Procedures

Gravity values were collected along traverses established across the base, side slopes, and tops of each ore stockpile. The gravity survey lines were established and measured using microgravimetric procedures such as those outlined in Butler (1980). For elongated piles, the profile lines are oriented approximately perpendicular to the long axis or strike of the ore pile with two, three, or four profiles crossing each pile depending on the pile dimensions. An example is illustrated in the upper diagram of Figure 3. For more conical shaped piles, profile lines are oriented so as to intersect at the apex of the pile as shown in the lower diagram of Figure 3. Each survey line consists of 12 to 20 measurement stations with each station consisting of a leveled concrete pad like the one shown in Figure 4. The measurement stations are located so that at least three stations are positioned on either side of the pile on the non-ore base material to provide background gravity readings. The remaining stations are located on the side slopes and tops of the ore piles as shown in Figures 5 and 6, respectively. These are the measurement stations from which the gravity anomaly is determined and material densities derived. Typically, three to five measurement stations are located on each side slope depending on the height of the pile, with the remainder positioned on top of the pile. Horizontal spacing between stations varies from 5 to 20 ft depending on the number of gravity stations and overall width of the piles. Horizontal locations (x,y coordinates) and elevations (z coordinate) are established by electronic surveying instruments using standard topographic surveying procedures as shown in Figure 7. Horizontal positions are measured to an accuracy of 0.1 ft and elevations are determined to an accuracy of 0.01 ft using an arbitrary reference elevation. In addition to the position surveying performed for establishing the gravity survey lines, position and elevation measurements are also acquired for use in determining pile volumes.

Each gravity profile line has a base station located off the pile at the 'start' of the survey line as shown in Figure 8. All elevations and gravity measurements along the line are referenced to the base station elevation and base station gravity measurement. The gravity measurements along each profile line are typically determined in two measurement programs. Following the initial gravity readings at the base station, the first measurement program consists of approximately ten microgravity measurements as the survey proceeds towards and up the slope (see Figures 9 and 10) of the ore pile, stopping at a measurement station that is located near the crest of the stockpile; often the highest elevation along the profile and midpoint of the survey line. Once the reading at the top of the pile is collected, the gravity meter is returned back to the base station for additional readings to conclude the first program. The second measurement program for the profile line starts at the opposite end of the line from the base station and proceeds up the 'back' side of the ore pile. Gravity readings are collected until the crest or survey line midpoint is again reached. This station is the same stopping point as used for the first program. After recording the gravity meter reading at the pile crest, the survey again returns to the base station for the third and final set of base station readings. This two program procedure results in three sets of measurements at the base station and two readings at the central measurement point of the line.

The multiple base station measurements are used for earth tide and instrument drift corrections and data quality control. Since measurements at the base station are used as the reference data for the survey line and for correcting all other gravity measurements along the line, special care is exercised in acquiring data at the base station as discussed in Butler (1980). The two measurements at the midpoint of the survey line are used as an indicator of data quality control. Equipment performance and time constraints are also applied to each data acquisition program. If any type of equipment problem, such as jarring the instrument or low battery output, occurs during a program, the entire program is repeated. If the survey time exceeds 60 minutes for an individual program, the survey line is subdivided into additional programs. However, individual programs are typically completed in less than 45 minutes. Also, if the data quality and multiple readings are not within set limits (Butler 1980), the survey program may also have to be rerun.

Gravity Data Corrections

Corrections to microgravity data are required in order to compensate for normal gravity variations at the site over the time span required for the survey. Measured values are reduced in such a manner as to imply that all gravity data are collected along the same reference datum by implementing gravity corrections for the effects due to latitude, elevation, topography, earth tides, and instrument drift. After applying these corrections, variations in the corrected gravity values are assumed to be caused only by the ore stockpile being studied. The normal gravity variations and compensating corrections applied to microgravity data are discussed in brief below. More detailed explanations of gravity data corrections are found in Butler (1980), Telford et al. (1990), or Sjostrom and Butler (1996).

Corrections for time variations (drift). Gravity values over the survey area change with time because of earth tide effects and instrument drift. Earth tides, like ocean tides, are caused by the orientation of the sun and moon and are of sufficient amplitude to be detected by sensitive gravity meters. Instrument drift is caused by creep of the metal components in the meter due to thermal expansion or excessive movement. Over short time periods (less than 60 minutes), drift due to tidal and instrument fluctuation can be assumed to be linear over time. The usual procedure for correcting for drift is to reoccupy a base station frequently and assume that the gravity values at all stations in the survey area vary in the same manner as those between readings at the base station. Differences in gravity values at the base station are plotted with respect to time to produce a drift curve. The drift correction, denoted as Δg_{zD}, for each station is determined directly from the graph. Positive drift requires a negative correction and vice-versa.

Latitude correction. Both the rotation of the earth and its non-spherical shape produce a change in gravity values as a function of latitude. For microgravity surveys, it is usually sufficient to assign a reference latitude to the base station and use Equation 1 to compute latitude corrections for all other stations. The latitude correction, denoted as Δg_{zL}, is:

$$\Delta g_{zL} = \pm\left(0.2471 * \sin(2\phi)\ \frac{\mu Gal}{ft}\right) * \Delta s \tag{1}$$

where Δs is the north-south distance (in feet) between the measurement and base station and ϕ is the reference latitude of the base station. The correction term is added to the measured gravity value if the station is positioned south of the base station and subtracted if located north of the base station.

Free air correction. The free air correction, denoted as Δg_{zFA}, compensates for variations in gravitational attraction caused by the elevation difference between the gravity measurement station and reference datum. The correction is added to the measured gravity value if the station elevation is greater than the reference elevation because the gravitational attraction decreases with increasing elevation, and vice versa. The free air correction formula is:

$$\Delta g_{zFA} = \pm 94.041\ \frac{\mu Gal}{ft} * \Delta h \tag{2}$$

where Δh is the difference in elevation (in feet) between the measurement station and reference elevation of the base station.

Bouguer correction. The Bouguer correction compensates gravity values affected by differing masses of material beneath the measurement stations caused by elevation variations. The ore material between the reference elevation of the base station and the elevation of a measurement station is approximated by an infinite horizontal slab with density equal to that of the material beneath the station. The correction, denoted as Δg_{zB}, is calculated using the Bouguer slab formula:

$$\Delta g_{zB} = \pm\left(12.774 * \rho \ \frac{\mu Gal}{ft}\right) * \Delta h \tag{3}$$

where ρ is the material density (in g/cm^3) and Δh is the elevation difference (in feet) between the measurement point and base station. The quantity Δg_{zB} is subtracted from the measured gravity value if the station elevation is greater than the reference elevation, and vice versa.

When all of the preceding corrections have been applied to the observed gravity data, the result is the Bouguer gravity value, denoted as g_B. The Bouguer gravity value at a measurement station is given by

$$g_B = g_{obs} \pm \Delta g_{zL} \pm \Delta g_{zFA} \pm \Delta g_{zB} \pm \Delta g_{zD} \tag{4}$$

where g_{obs} is the observed gravity reading and the remaining terms are the gravity corrections discussed above. Subtracting the gravity readings recorded at the base station, denoted as g_{base}, from the Bouguer gravity values at each station using the equation

$$\Delta g_B = g_B - g_{base} \tag{5}$$

results in the Bouguer gravity anomaly. The Bouguer gravity anomaly is used in determining the density of the ore pile material whether through direct calculation or gravity modeling algorithms.

Determination of Bulk Material Density

In standard gravity surveying to determine geologic structure, the Bouguer corrections in the reduction of gravity data require a knowledge of the average densities of the near-surface rock and sediments. However, the premise of this application is to compute the material density values from the microgravity readings. Three methods were used to determine the density of the stockpiled ores. The first method, developed by Nettleton (1940), is an indirect, graphical technique to determine density. A plot of the observed gravity values, that have undergone the drift, latitude, and free air corrections, versus distance along the survey line is strongly correlated to the shape of the measured topography over the pile. By applying the Bouguer correction numerous times over a range of material density values, the resultant gravity anomaly curve found to have the least correlation with the topography curve, ideally a correlation factor of zero, is considered to have the most nearly correct bulk density value for the ore pile material. An example of this application, as reproduced from Telford (1990), is illustrated in Figure 11. This method has the advantage of averaging the effect of density variations more accurately than can be done from surface or core samples (Dobrin 1976). This method works best when the near-surface material is relatively homogeneous in nature.

The second method is an analytical approach developed by Parasnis (1979) and similar to Nettleton's graphical method. Expanding Equation 5 to include the observed gravity readings and all of the gravity correction terms, we obtain the equation

$$0 = [g_{obs} - g_{base} + (\pm\Delta g_{zD} \pm \Delta g_{zL} \pm \Delta g_{zFA}) \pm \Delta g_{zB}] - \Delta g_B \qquad (6)$$

Further expansion of the Bouguer slab correction term Δg_{zB} in Equation 6 and subsequent algebra solving for the material density parameter ρ, gives

$$\rho = \frac{[g_{obs} - g_{base} + (\pm\Delta g_{zD} \pm \Delta g_{zL} \pm \Delta g_{zFA})}{12.774 * \Delta h} - \frac{\Delta g_B}{12.774 * \Delta h} \qquad (7)$$

where ρ is defined in terms of g/cm^3. For a single, straight line gravity traverse over a survey area, Equation 7 resembles the formula for a straight line; i.e., y = mx - b. To solve for an average bulk density value, Parasnis considers the Bouguer gravity anomaly, defined in Equation 5, to be a random error with a mean value equal to zero (Telford et al. 1990). Therefore, plotting the values in the numerator versus the values in the denominator of the first term and drawing the best fit straight line through the data points and through the origin, the absolute value of the slope will be the material density ρ. Obviously, as Telford et al. (1990) states, all the points will not lie on this line unless the subsurface is uniform and the Bouguer anomaly Δg_B is everywhere zero. Therefore, the best fit straight line through the data is found using least squares analysis. An example of Parasnis' method is presented in Figure 12.

The third method used to assist in the determination of the bulk material density of an ore stockpile is a two-and-a-half dimensional gravity modeling routine developed by Cady (1980). The computer algorithm uses as input the Bouguer gravity anomaly values calculated using Equation 5 for microgravity data collected perpendicular to the strike of a two dimensional (2-D) cross-sectional shape of finite length. An elongated ore pile is an excellent example of such a feature. The topographic survey data along the gravity survey line are used to construct a detailed 2-D cross-section of the ore pile. Theoretical gravity values are calculated for the feature by inputting various estimates of the material density into the gravity modeling algorithm. The best density estimate is that value which provides the lowest least squares error between the observed and calculated gravity data. This method is much more cumbersome and time consuming than the first two methods, however, the advantage of this method is that it allows investigation of possible ore material settlement below the ground surface. This program was used primarily for piles at the New Haven Depot where the stockpiles are situated on soil and material settlement below grade is expected.

Parasnis' method was used almost exclusively for the analysis of the microgravity data. Nettleton's method was used in conjunction with Parasnis' method in instances where the gravity data sets contained erratic or spurious values or the survey lines intersected at the apex of the pile. However, no matter which analysis procedure is used and depending on the number of gravity survey lines performed over each ore pile, two, three, or four spatially distributed, volume-averaged bulk density values are determined during the investigation of a specific ore pile. These density values are averaged to determine a single in-place density value for the ore pile material.

3 Data Analysis and Results

Determination of Ore Pile Volume

Topographic surveys to compute the volumes of the ore stockpiles were completed using standard land surveying methods. Topographic field data were acquired using a Topcon GTS-3C total station system with accompanying data collector, theodolite, and laser rangefinder at the New Haven, Warren, and Curtis Bay Depots. At the Hammond Depot, Point Pleasant Depot, and Anniston Army Depot, all topographic data were collected using Trimble 4000 series Global Positioning System (GPS) receivers configured for real-time kinematic (RTK) survey operation. This method works by using radio communication to triangulate between the satellite network, an on-site positioning base station, and roving GPS receivers to process the positioning and elevation data at the location of the receivers in real-time. Horizontal data at each site were referenced to either an arbitrary coordinate system of the survey crew's discretion or to the local North American Datum Zone (in feet) or Universal Transverse Mercator System (in meters). The vertical data are referenced to an arbitrary elevation datum or to the National Geodetic Vertical Datum of 1929. It should be noted that only the relative positions and elevations between the data points are required for data processing. All positioning and elevation data are expressed in units of feet except for those data sets at the Hammond Depot and Anniston Army Depot where they are in units of meters.

The limits of the topographic survey program are determined by the location of the gravity measurement stations on and off the ore pile. This program includes surveying each ore pile from toe to toe while taking into account all ridges, depressions, and other significant characteristics on the pile surface. The base of each stockpile is determined by a planar surface passing through the elevation points along the toe of the pile. *It should be noted that any ore material below this planar surface caused by material settlement underneath the pile is not included in the land survey pile volume determination.*

The acquired positioning and elevation data are displayed in two-dimensional (2-D) contour plots to illustrate the elevation of distinct features or characteristics unique to each pile. The contour plots for each pile at the six project areas are illustrated in Appendices A through F. The contour interval for all ore pile elevation plots is one foot with the exception of those at the Hammond Depot and Anniston Army Depot where the contour interval is 0.2 m.

Volumes were computed from the topographic survey data using three-dimensional (3-D) surface models of each ore pile generated by graphics packages such as Softdesk 8 Civil Survey software, ArcInfo, or Microstation InRoads. These software packages incorporate several methods such as the triangle, grid, end-area, and triangulated irregular network (TIN), to compute the volume of material between the pile surface model and planar base. As an example using the TIN method, the elevation points on the surface models are triangulated using a set mesh size to form a series of columnar grids. Volume estimates for each triangulated grid section are computed between the 3-D surface model and planar base of a pile. Grid volumes are accumulated over the entire pile to provide a total reported volume. Volumes for each pile are expressed in units of cubic yards (yd^3). Registered land surveyors leading the ore pile volume determination portion of this effort at each site established a volume determination accuracy of ± 5 percent. The volume accuracy clearly depends on the following factors: (1) number of data points used to characterize the pile, (2) definition of irregularities in the ore pile geometry, and (3) accurate determination of the base and outside edge of the pile. It should also be remembered that any portion of the ore material below grade (i.e., below the surrounding ground surface level) caused by material settlement or an irregular placement surface cannot be accounted for in the land survey volume calculation.

At some of the project areas such as New Haven Depot, stockpiles of ore material were originally placed on prepared surfaces comprised of soil or gravel as opposed to asphalt or concrete. At these pile locations, settlement of the ore material below the current ground surface is expected. Likewise, specific piles of ore, such as Pile #153 at Curtis Bay Depot, may have been deposited on unprepared, irregular surfaces. In any case, position and elevation measurements along the toe of a pile will be unable to account for any ore material that settles below the current grade of the ground surface or the undulations in the placement surface. In an attempt to model material settlement below grade, simple 3-D geometric models were used based on site characteristics, pile geometry, and reported gross weight. The depth of material settlement below grade is estimated by incorporating the reported ore pile weight and soil parameters describing soil types and conditions, compaction factors, and specific gravity. For larger, elongated ore piles, a 2.5-D forward modeling program was used to estimate the depths of material settlement below the current ground surface. The estimated volume of material below the current ground surface is added to the above-ground volume determined from the topographic data to yield the total pile volume. Measured volumes for all piles are listed in Table 2 and printed on each of the elevation contour plots in Appendices A through F.

Calculation of Material Density

Depending on the long axis dimension of each ore pile, two to four gravity surveys are performed to determine the average bulk density of the stockpiled ore. The observed gravity data acquired along each profile are analyzed using

Equation 7 and applying Parasnis' method to compute a density value over an individual survey line. Nettleton's method, an indirect, graphical technique to determine density, and a 2.5-D forward modeling computer algorithm were also used when necessary to verify results. The bulk density values are averaged to determine a single in-place density value for the ore material. Since microgravity measurements were performed only over randomly selected piles rather than each, individual pile, the average density values for piles of similar ore material are further averaged to obtain a single, representative density value that may be applied to those piles in which no gravimetric surveys were performed.

Based on published examples (Parasnis 1979; Dobrin 1976; Telford et al. 1990), the ore material density determination accuracy is estimated at ± 0.2 g/cm^3 (12.4 lb/ft^3). For example, if the computed bulk material density value is 2.5 g/cm^3, this accuracy estimate translates to approximately ± 8 percent of the true value. For more dense ore pile materials, the computed density values become more accurate.

Calculation of Ore Pile Weight

Following determination of representative material density values from the microgravimetric measurements, the total weight of the ore pile material is calculated by multiplying the material density and total volume estimates of each respective ore pile. The computed weight of the ore stockpiles are determined using the equation

$$Weight = (\rho) * \left(62.428 \frac{lb}{ft^3}\right) * \left(27 \frac{ft^3}{yd^3}\right) * (V) \tag{8}$$

where ρ is the computed density of the ore material (in g/cm^3) and V is the calculated volume of the ore pile (in yd^3) above the ground surface. The total weight is given in units of pounds (lb). Based on the accuracy of the ore material density calculation and pile volume determination, the computed weight of an ore stockpile should be accurate to within ± 10 to ± 15 percent depending on the actual density of the ore material. Outside factors such as settlement of the ore material below the ground surface, irregular pile geometries, poor definition of the pile base, or poor quality gravity data will increase the error range.

The difference between the originally reported weight of each pile of ore, provided by DNSC, and the calculated weight is given in terms of percent using the equation

$$Difference = \left(\frac{Calculated - Reported}{Reported}\right) * 100\, percent \tag{9}$$

where 'Calculated' and 'Reported' are the respective pile weights in units of pounds (lb). In the discussion of the results, negative percent differences represent calculated pile weights that are less than the reported gross weights.

Results

The measured volumes, average calculated weights, and percent difference values between the computed weight estimates and original ore pile weights for each pile at the six DNSC sites are listed in Table 2. Negative percent differences indicate that the computed ore pile weight values are less than those values reported by DNSC. A discussion of the results for the ore piles within each material category at the six sites are provided below.

Hammond Depot, Indiana

Ferrochrome, High-Carbon. Three piles of high-carbon ferrochrome are located at the Hammond Depot with pile dimensions and reported gross weights listed in Table 1. Photographs and elevation contour plots of each ferrochrome pile are presented in Figures A-1 through A-6. The larger piles, Piles #7 and #11, are situated on reinforced concrete pads whereas Pile #1, the third pile, is located on a weathered asphalt surface. The measured pile volumes are indicated on the elevation plots and listed in Table 2.

Microgravity data were gathered over each ferrochrome stockpile. Three gravity profiles were performed over Pile #7 as shown in Figure A-4 whereas Pile #1 was traversed by two survey lines. Only one gravity survey was performed over Pile #11. The computed material density values are 3.033, 3.989, and 3.999 g/cm^3 for Piles #1, #7, and #11, respectively. The calculated weight for each pile and the percent difference between the calculated weights and reported gross weights at the time of placement are outlined in Table 2. The difference values for Piles #1, #7, and #11 are -13.75, -3.29, and -9.16 percent, respectively, and indicate the computed weights are less than the reported weights but within the expected experimental errors for this procedure.

New Haven Depot, Indiana

Twenty-one stockpiles of ore were studied at the New Haven Depot. The stockpiled materials consist of ten piles of high-carbon ferrochrome and eleven stockpiles of high-carbon ferromanganese. It is noted that two stockpiles of ferromanganese at the site are designated Pile #23 where only one was indicated in the information provided by DNSC. The topographic survey crew labeled the stockpiles Piles #23A and #23B as indicated in Figures B-23 and B-25, respectively. The pile descriptions, dimensions, and reported weights for all 21 piles are listed in Table 1. Elevation contour plots and photographs illustrating each ore pile are presented in Figures B-1 through B-42 in Appendix B. The results for each group of ore stockpiles are described below.

Ferrochrome, High-Carbon. The dimensions and reported gross weights of the ten ferrochrome stockpiles are presented in Table 1. Photographs and elevation contour plots of each pile are presented in Figures B-1 through B-20.

Each pile is situated on a gravel or crushed rock base and material settlement below the original elevation of the placement surface is evident. The pile volumes computed from the topographic survey program only account for the amount of ore material above the current ground surface. Since the ore material is situated on a gravel or crushed rock base, the ore material compacts the soil underneath the pile such that ore material settles below the grade of the original ground surface. The material existing at elevations less than the current elevation of the ground surface is therefore, not accounted for by the topographic survey. Numerical algorithms based on simple 3-D geometric models incorporating the local soil conditions, pile geometry, and reported gross weight were used to provide estimates of the volumes of ore material below grade for each pile. The estimated volume of material below grade is added to the pile volumes computed from the topographic surveys. Pile volumes are listed in Table 2 and indicated on the elevation contour plot for each respective pile.

Microgravity measurements were performed over four of the ten piles at the site. The piles surveyed are Piles #4, #11, #56, and #68. Two gravity transects were performed over each pile with the survey lines intersecting at the apex of the pile. The total number of gravity measurement points along each line varied from 15 to 17 stations with five of the stations along each line placed off of the pile on non-ore material. Computed material density values derived using the gravity data analysis procedures range from 2.539 to 2.887 g/cm^3 with an average material density of 2.730 g/cm^3. The pile weight is calculated by multiplying the pile volume and computed bulk material density for each respective pile (see Equation 8). For ore piles that were not investigated directly with the microgravity method, the average material density value is used in the weight determination. The calculated weights of the ten piles of ferrochrome ore are presented in Table 2. The difference values between the average calculated weight in relation to the weight on record (see Table 2) for all but one pile range from -18.01 to -27.30 percent. Only the calculated weight for Pile #67 is within the expected error bounds. The higher than expected difference values are likely caused by inaccurate estimation of the pile volumes.

Ferromanganese, High-Carbon. Eleven stockpiles of high-carbon ferromanganese at the site were investigated. The dimensions and reported gross weights of each pile are listed in Table 1 and photographs and elevation contour plots of the piles are presented in Figures B-21 through B-42. Each pile is situated on natural soil or gravel and ore material settlement below the current ground surface is likely. The pile volumes listed in Table 2 for the stockpiles of ferromanganese incorporate the above-ground ore volume determined from the topographic surveys and estimates of the amount of ore material which has settled below grade.

Microgravity surveys were performed over four of the 11 ore piles with three of the four piles randomly selected prior to the site investigation. Some modification to the original pile selection had to be done due to the orientation and location of the piles. The ore stockpiles surveyed during the investigation are Piles #28, #31, #32, and #37. Two gravity surveys were performed over each stockpile with 8 to 12 gravity stations placed on the ore material depending on the dimensions of the pile. Analysis of the corrected gravity data from the four piles provided computed material density values ranging from 2.929 to 3.341 g/cm^3. The average computed bulk density value is 3.166 g/cm^3.

The computed ore pile weights are listed in Table 2. The percent difference between the calculated weight and reported gross weight for each pile (see Table 2) indicate that each of the calculated weights are less than the weights on record. Difference values range from -6.77 percent for Pile #20 to -23.73 percent for Pile #31. Four of the 11 stockpiles had percent difference values within the expected error bound as indicated in Table 3. Difference values greater than 15 percent are likely caused by poor definition of the pile boundaries and underestimation of the pile volumes because of settlement of the earth and pad material underneath the ferromanganese stockpiles. A good example of the difficulty defining the pile boundary is presented in Figure 13 which depicts the area between Piles #31 and #32. The difference values between the calculated weights for Piles #23A and #23B and the reported gross weight of 3,151,400 lb for "Pile #23" are -16.09 and -8.42 percent, respectively. Adding the computed weights for Piles #23A and #23B and comparing to the documented weight, the difference is +76.12 percent. *Author's note: It is thought that Pile #23A is the actual "Pile #23" by reviewing the ore pile placement and labeling sequence at the site. Pile #23B is situated between Pile #32 and Pile #34 and may be mislabeled. However, the depot manager stated that Pile #33 was removed from the site a number of years ago.*

Warren Depot, Ohio

Twenty-four stockpiles of ore were studied at the Warren Depot. The stockpiled ores consist of: 10 piles of high-carbon ferrochrome, three piles of metallurgical-grade fluorspar, and 11 stockpiles of high-carbon ferromanganese. The pile descriptions, dimensions, and reported weights on record at DNSC are listed in Table 1. Elevation contour plots and photographs illustrating each ore pile are presented in Appendix C. The results for each group of ore stockpiles are described below.

Ferromanganese, High-Carbon. Ferromanganese is stockpiled in 11 piles at the depot with each pile situated on an asphalt surface overlying crushed rock or gravel. The dimensions and reported gross weights of the piles are given in Table 1. Elevation contour plots and computed pile volumes derived from the topographic survey are presented in Figures C-1 to C-20. Each elevation contour plot is preceded with a photograph of the ore pile.

Microgravity surveys were performed only over Piles #27, #34, #36, and #38. Three microgravity profiles were performed over Piles #34 and #36 (see Figures C-10 and C-12) and two profiles over Piles #27 and #38 as shown in

Figures C-6 and C-14. Each survey line consisted of 11 to 14 gravity stations with 7 to 9 stations positioned on the ore material. The computed material density values for the piles surveyed ranged from 3.292 to 3.551 g/cm^3. The overall average material density value is 3.452 g/cm^3. The average material density value is used to calculate the pile weight of the seven remaining ferro-manganese piles. The calculated pile weights and percent difference values between the computed and reported weights are listed in Table 2. The percent differences for each pile are within the expected error bounds for this technique with the exception of Pile #41 which has a difference value of -15.44 percent. The computed weights for each pile are less than the weights on record.

Fluorspar, Metallurgical-Grade. Material classified as metallurgical fluorspar (Grade A) is stored in two stockpiles, designated as Piles #3 and #3A, at the Warren Depot. The other fluorspar pile is categorized as metallurgical fluorspar (Grade B) and designated as Pile #4. Each of the three piles were originally placed on a prepared soil/gravel surface. The dimensions and reported gross weights, as provided by DNSC, are indicated in Table 1. Photographs and elevation contour plots of the three stockpiles are presented in Figures C-21 through C-26. Pile volumes derived from the elevation data are noted on each of the contour plots and listed in Table 2.

A total of seven microgravity surveys were performed over the three fluorspar stockpiles. Survey lines consisted of nine gravity measurement stations situated on the ore material and five stations located on the surrounding non-ore, earth material. The average bulk material density value computed from the gravity data for Piles #3 and #3A is 1.755 g/cm^3. The average density value for the material composing Pile #4 is 1.501 g/cm^3. The computed pile weights for the three stockpiles are presented in Table 2. Table 2 also lists the percent difference values between the calculated weights and the reported gross weights. The percent difference values are -10.87, -17.38, and -7.73 for Piles #3, #3A, and #4, respectively with each calculated weight value underestimating the originally reported weight.

Ferrochrome, High-Carbon. The FY97 audit included 10 piles of high-carbon ferrochrome at the Warren Depot. The pile dimensions and original gross weights on record at DNSC are outlined in Table 1. An elevation contour plot and corresponding photograph, with the exception of Piles #16 and #22, of each ferrochrome stockpile are presented in Figures C-27 through C-36 in Appendix C. Each ferrochrome pile is composed primarily of cobble size material and situated on an asphalt surface. The measured volumes of each ore pile are listed in Table 2 and noted on the elevation contour plots. Microgravity surveys were performed over four of the ten stockpiles. Two gravity profiles each were conducted over Piles #3, #6, #9, and #19 with 9 to 13 gravity measurements acquired on the ore material along each survey depending on the pile dimensions. The average bulk density value resulting from the analysis of the microgravity data is 3.047 g/cm^3. The calculated weights for each ferrochrome stockpile are listed in Table 2 along with the percent difference values between the computed weights and the weights on record. For all but two of the piles, the percent difference values range from -19.35 to -26.88 percent and indicate that the computed weights are less than originally reported weight values. The 'less than reported weight' values are likely a result of poor definition of the pile boundaries and factors such as the close proximity of other ferrochrome piles and the conical shape of the piles affecting the measured gravity values. The difficulties in accurately determining the boundary or toe of each pile and the tight grouping of the piles are evident in Figure 14 which illustrates the area of the depot occupied by Piles #6 through #12. The difference values for Piles #11 and #19 are -4.21 and -9.92 percent, respectively and are within the expected error bounds for this technique.

Curtis Bay Depot, Maryland

Twenty-six stockpiles of ore were studied at the Curtis Bay Depot and are categorically grouped into three material types: beryl ore, high-carbon ferrochrome, or high-carbon ferromanganese. The pile descriptions, dimensions, and originally reported weights are listed in Table 1. Elevation contour plots and photographs illustrating each ore pile are presented in Figures D-1 through D-58 in Appendix D. The results for each group of ore stockpiles are described below. Two covered piles composed of metallurgical-grade manganese were originally slated to be studied. However, reluctance of the depot manager in allowing anyone to climb on the pile covers and subsequently finding that the covers had not been disturbed since the material was originally placed at the site, the piles were removed from the microgravity investigation by the DLA Inspector General's Office.

Beryl Ore. Beryl ore is stockpiled in eight designated piles at two locations on the depot. The first location consists of Pile #159 and Piles #207 through #210 as shown in Figures D-1 and D-3. Elevation contour plots and measured pile volumes are presented in Figures D-2 and D-4 through D-7. These five piles are situated on reinforced concrete and each pile is encompassed by a 2 to 3 ft high wall constructed of old railroad ties. Seven microgravity survey lines were performed over three of the five ore piles and each survey line has seven gravity stations positioned on the ore material. The computed material density values range from 1.579 to 1.792 g/cm^3 with an average value of 1.649 g/cm^3. The computed weights for each of the five piles are listed in Table 2. The differences between the computed weights in relation to the weight on record (see Table 2) range from +0.16 to -6.89 percent; well within the expected error bounds for this technique.

The second cluster of beryl ore piles is located towards the southeastern corner of the depot and consists of Piles #211 through #213. The material in each of these piles has been mechanically sorted according to size and, therefore, three to five smaller piles may be under the umbrella of a specific pile designation. The individual piles are poorly marked and accurate records or maps detailing each pile were unavailable. Based on what little information was available, it was determined that Pile #211 consists of five ore piles as shown in Figures D-8 through D-12 whereas Piles #212 and #213 are comprised of three piles each (see Figures D-14 through D-16 and D-19 through D-21, respectively). Another pile within this cluster contains the fine-grained material that resulted from the sorting process of Piles #212 and #213. This pile, shown in Figure D-18, has no official pile designation but was labeled Pile #212/#213 by the survey crew. Elevation contour plots and measured pile volumes from the topographic survey for each pile are noted in Appendix D. The measured pile volumes listed in Table 2 reflect the cumulative total of all individual piles under a given pile designation. All piles within this second cluster are situated on an asphalt surface.

A total of six microgravity survey lines were performed over a random sampling of the piles within this second cluster. The computed bulk density values ranged from 1.437 to 1.700 g/cm^3 with an overall average density value of 1.542 g/cm^3. The total calculated weights for each pile designation, see Table 2, are found by multiplying the cumulative volume estimates for each pile designation and average density value. The difference values for Piles #211, #212, and #213 are +319.59, -2.15, and -23.76 percent, respectively. The weights of the individual piles under each pile designation were not computed. No further discussion of the results from the second cluster of beryl ore piles will be provided because of the limited pile information and uncertainties in the actual pile designations.

Ferrochrome, High-Carbon. Ten stockpiles of high-carbon ferrochrome were studied at the Curtis Bay Depot during the investigation. The pile dimensions and reported gross weights provided by DNSC are reproduced in Table 1. Photographs and elevation contour plots of each ferrochrome pile are presented in Figures D-23 through D-42. Measured pile volumes are noted on the respective elevation contour plots and also listed in Table 2.

The ferrochrome stockpiles are located at two separate areas on the depot. The first set consists of Piles #118, #120, and #125. These piles are positioned on weathered asphalt pads and ground settlement beneath each pile is evident. Microgravity surveys were performed over Piles #118 and #120 and the resultant bulk density values were 2.792 and 2.706 g/cm^3, respectively. The average density value is 2.749 g/cm^3 and used in the weight calculation for Pile #125. The calculated weights and percent difference values between the calculated weights and weights on record are presented in Table 2. The percent difference values range from -10.00 to -17.34 percent and indicate that the calculated weights are less than the reported gross weights.

The remaining seven ferrochrome piles are located on a reinforced concrete surface and, therefore, no significant settlement of the material beneath the pile is expected. However, the concrete is highly fractured in the vicinity of Pile #203 and a pool of water surrounds the pile which may indicate that the material may have settled below the original placement surface. A wooden barrier constructed of railroad crossties encompasses each of the piles. Gravity surveys were performed over two of these piles, namely Piles #108 and #121, with 9 to 12 gravity measurements on each line acquired on the ore material. The computed bulk density values range from 2.852 to 3.253 g/cm^3. The average density value is 3.113 g/cm^3 and used in the weight calculations for Piles #110 through #112, #114, and #203. The calculated weights for these seven piles are listed in Table 2. Percent difference values between the computed and reported weights, see Table 2, range from -7.83 to -22.80 percent with the exception of Pile #110 which has a difference value of -39.40 percent. Possible explanations for the higher than expected difference value for Pile #110 may include poor definition of the pile geometry, material has been removed from the pile at some time prior to the survey, or the documented weight on record is in error. Of the remaining piles, four of the six computed pile weights are within 15 percent of the weight on record.

Ferromanganese, High-Carbon. Photographs and elevation contour plots of the eight piles of high-carbon ferromanganese studied at the depot are presented in Figures D-43 through D-58 in Appendix D. The dimensions and reported gross weights for these piles, as provided by DNSC, are outlined in Table 1. Each ferromanganese pile, with the exception of Pile #153, is situated on a reinforced concrete surface and surrounded by a barrier constructed of railroad crossties. Material settlement below the original placement surface has likely occurred for all but two of the ferromanganese stockpiles based on cracks visible in the concrete surface at the toe of each pile and ponded water at the base. Pile #153, the largest of the eight piles, is located approximately 750 ft northwest of the other stockpiles. This pile was originally placed on a base comprised of gravel and crushed rock and significant compaction and settlement of the ground beneath the pile is detected. Pile #153 was also being removed from the site during this study. The computed pile volumes for the stockpiles of ferromanganese are listed in Table 2 and indicated on the elevation contour plot of each ore pile.

Microgravity surveys were performed over three of the eight ferromanganese ore piles with the three piles randomly selected prior to the site investigation. The ore stockpiles surveyed during the investigation include Piles #24, #27, and #154. Three gravity survey lines were performed over Piles #24 and #27 (see Figures D-46 and D-52, respectively) with 11 to 14 gravity stations along each line placed on the ore material. Two microgravity profiles were performed over Pile #154 as shown in Figure D-58. Analysis of the corrected gravity data from the eight survey lines provided computed material density values ranging from 3.340 to 3.642 g/cm^3. The average computed bulk density value is 3.497 g/cm^3. The computed pile weights are listed in Table 2. The percent difference values reflecting the difference between the calculated weight and reported gross weight for each pile are also presented in Table 2. Each of the calculated weights, with the exception of Pile #24, are less than the weights on record with percent differences ranging from -7.50 to -49.46 percent. Five stockpiles, Piles #18, #25, #27, #99, and #154, have difference values within the expected experimental errors of this procedure. Pile #26 has the highest difference value of this group at -49.46 percent. However, it was noted during the field investigation that some material may have been removed from the southwestern end of the pile since original placement of the ferromanganese. If this is the case, the computed weight is likely more representative of the current weight than the percent difference value implies. Pile #24 had a difference of +129.70 percent and it is possible that the weight on record at DNSC is in error. The weight on record for Pile #24 is 15,651,840 lb and is far less than the weights provided for Piles #25 through #27 which are of comparable size.

Pile #153 was being removed during the microgravity and topographic surveys. The originally reported pile weight (see Table 1) prior to any material removal was 249,162,520 lb. Topographic surveys to determine the volume of the remaining part of the pile were completed on 14 November 1997. Up until that day, a total of 21,218,120 lb of ferromanganese had been removed from the ends of the pile and trucked to a loading facility. Therefore, the reported weight of the pile at the time of the volume measurement was 227,944,400 lb. The estimated volume of the remaining pile material is 32,172.4 yd^3. The computed weight, using an average material density value of 3.497 g/cm^3, is 189,636,651.35 lb. The difference between the computed weight and adjusted weight on record is -16.81 percent.

Point Pleasant Depot, West Virginia

Nine stockpiles of ore were originally slated to be studied at the Point Pleasant Depot. The stockpiled ores consist of: one pile of high-carbon ferrochrome, five piles of low-carbon ferrochrome, and three stockpiles of high-carbon ferromanganese. The pile descriptions, dimensions, and reported weights as provided by the DNSC are listed in Table 1. Photographs illustrating each ore pile are presented in Appendix E. It is noted that two of the low-carbon ferrochrome piles, Piles #54 and #55, are covered as shown in Figure E-3. Finding that the covers had not been disturbed since the material was originally placed at the site and restrictions by the depot manager on climbing on the covers, the piles were removed from the investigation by the DLA Inspector General's Office. The results for each group of ore stockpiles are described below.

Ferrochrome, High-Carbon. Pile #62, as shown in Figure E-1, is described by DNSC as high-carbon ferrochrome having a reported weight of 279,054,660 lb. The ore material is primarily cobble size and situated on a reinforced concrete surface. An elevation contour plot generated from the topographic surveys is illustrated in Figure E-2 and the computed volume is 44,558.37 yd^3. Two gravity surveys were performed over the pile as shown in Figure E-2 with 14 of the 19 gravity measurements along each line collected directly over the ore material. The average computed bulk density value determined from the corrected gravity data is 3.486 g/cm^3 which translates to a calculated weight of 261,818,218.87 lb as indicated in Table 2. The computed weight of the ferrochrome differs from the reported gross weight by -6.18 percent.

Ferrochrome, Low-Carbon. Material classified as low-carbon ferrochrome is stored in five stockpiles at the Point Pleasant Depot. The piles investigated for this study are designated as Piles #57, #62A, and #63 and the dimensions and reported gross weights are listed in Table 1. Photographs and elevation contour plots of the three stockpiles are presented in Figures E-3 through E-8. The ferrochrome material composing Piles #62A and #63 is situated on reinforced concrete surfaces and surrounded by a two foot wall constructed of railroad crossties. Pile volumes are noted on each of the respective contour plots in Appendix E and listed in Table 2.

A total of five microgravity surveys were performed over Piles #62A and #63 with survey lines typically consisting of 13 to 16 measurement stations. Computed density values derived from the gravity data sets yield an overall average bulk density value of 3.459 g/cm^3. The computed pile weights for each pile are presented in Table 2. The difference values between the calculated and reported gross weights for Piles #62A and #63 are -20.30 and -17.17 percent, respectively. Each calculated weight value underestimates the originally reported weight and the difference values fall outside of the expected experimental error range.

The low-carbon ferrochrome material composing Pile #57, as well as Piles #54 and #55, have the unique characteristic of being hand stacked. Piles #54 and #55 are also covered to protect the material from the elements as shown in Figure E-3. The material along the edge of Pile #57 is stacked on a concrete surface but it is unknown whether the concrete is continuous across the entire base of the pile. The estimated volume of this pile is 1,024.75 yd^3. Stacking the material by hand increases the bulk material density because the void ratio between the chunks of ore has been reduced as compared to the random dumping of material as found with Piles #62A and #63. Changes in the bulk density of a material versus the compaction parameters for material particles of this size are limited but an increase in the bulk density of 25 percent is not unexpected (Das 1985). Using the material density value of 3.459 g/cm^3 as determined over Piles #62A and #63, an increase of 25 percent yields a density value of approximately 4.324 g/cm^3. The computed weight found by multiplying the adjusted density estimate and pile volume is shown in Table 2 and underestimates the reported gross weight by 15.36 percent.

Ferromanganese, High-Carbon. High-carbon ferromanganese is stockpiled in three piles designated Piles #59, #60, and #61 as illustrated in the photographs presented in Figures E-9, E-11, and E-13, respectively. The dimensions and reported gross weights of the three piles are given in Table 1. Elevation contour plots and computed pile volumes derived from the topographic survey follow each pile photograph. The pile volumes are also tabulated in Table 2. The material composing Piles #59 and #60 is situated on a weathered asphalt and concrete surface. The material composing Pile #61 rests on a relatively new concrete pad but it is unknown whether or not the concrete is reinforced. Each pile is surrounded by a short wall constructed of railroad crossties.

Microgravity surveys were performed only over Piles #60 and #61. Two microgravity profiles were performed over Pile #60 with each survey line consisting of seven measurement stations positioned on the ore material. Four gravity profiles crossed Pile #61 and 13 measurement stations along each line were directly over ore material. Five gravity measurement stations for each of the six profile lines were located off the ore pile. The average computed material density values for these survey lines ranged from 3.374 to 3.628 g/cm^3. The overall average material density is 3.495 g/cm^3 and this value is used to determine the weight for Pile #59. The calculated weights of each stockpile and percent difference values between the computed and reported weights are presented in Table 2. The difference values are -13.16, -14.80, and -17.46 percent for Piles #59, #60, and #61, respectively.

Anniston Army Depot, Alabama

Manganese, Metallurgical-Grade. Pile #1, as shown in Figure F-1 of Appendix F, is composed of fine to cobble size material classified as metallurgical-grade manganese. A contour map of the ore pile, constructed from the measured elevation data, is presented in Figure F-2. Pile #1 has an estimated volume of 14,000 yd^3. The pile is situated on either natural soil, gravel, or crushed rock. Three microgravity surveys were performed over the pile (see Figure F-2) with each survey line consisting of 18 to 21 measurement stations; 13 to 16 of which are positioned on the ore pile material. Analysis of the corrected gravity data provided an average material density value of 2.610 g/cm^3. The calculated weight of Pile #1 is 61,590,216.24 lb. The reported gross weight on record at DNSC is 59,984,420 lb which is approximately 2.68 percent less than the average calculated weight determined from this technique.

Summary of Results

Comparing the calculated weights for each ore stockpile at the six sites to the reported weights provided by DNSC, percent difference values are calculated and grouped into specific difference ranges. The distribution of piles within each range are given in Table 3. It is shown that the computed weights of 42 of the 82 piles studied are less than or within the expected percent difference error range of ± 10 to ± 15 percent. The percent difference values for another 33 ore stockpiles are outside the expected error range with values ranging from ± 15 to ± 25 percent. The computed weights of the remaining seven piles have differences greater than 25 percent of the reported values. Differences between the computed pile weights and reported weights may be caused by any of the following factors:

a. Poor definition of the intricate pile geometries and edges.

b. Inaccurate elevations or models too simplistic to accurately define the pile base.

c. Inhomogeneities within the ore pile material which create highly variable density estimates.

d. Settlement of the ore material below the originally prepared ground surface.

e. Possible removal of ore material at some piles.

f. Unrepresentative density values computed from suspect gravity data sets.

It is also possible that the weights on record for some piles may be inaccurate as was the case for at least two ore piles at the Sierra Army Depot, CA (Sjostrom and Butler 1996).

Looking more closely at the distribution of ore piles versus the percent difference error ranges presented in Table 3, it is shown that the computed weights for piles investigated at both the Hammond Depot, IN and Anniston Army Depot, AL are less than or within the expected percent difference range of the reported gross weights for each pile. All piles surveyed at the Hammond Depot, New Haven Depot, Warren Depot, and Point Pleasant Depot had calculated weights less than the weights on record at DNSC. A total of five piles had calculated weights greater than the weight on record but three of the five are within four percent of the documented values.

All of the ferrochrome and ferromanganese piles at the New Haven Depot are situated on natural soil, gravel, or crushed rock and, therefore, settlement of the ore material below the original placement surface was expected. Any material below the current ground surface at the time of the investigation cannot be accounted for with the topographic field procedures. Simplified computer models were used during data interpretation and analysis to attempt to model the material settlement. After attempting to account for settlement, the majority of the ore stockpiles studied, 16 of 21 piles, still had computed weights that underestimated the reported gross weights by a range of -16.09 to -27.03 percent. Poor definition of some of the pile boundaries and bases also added errors in the weight calculations. However, five of the sixteen ore piles did have percent difference values that were below or within the expected error bounds of the testing procedure. During this study, ferromanganese Piles #23A and #23B were treated as individual piles each with a reported weight of 3,151,400 lb. The difference between the calculated weights for Piles #23A and #23B and reported gross weight are -16.09 and -8.42 percent, respectively. Combining the two piles, the total calculated weight is 5,550,184.17 lb and exceeds the documented weight by over 76 percent.

Following the field study at the Warren Depot, it was found that the calculated weights of 14 of the 24 ore piles are within 15 percent of the documented weights. The 14 stockpiles within this difference range include 10 of 11 high-carbon ferromanganese piles and 2 of 3 metallurgical fluorspar piles. The remaining ten piles, eight of which are composed of high-carbon ferrochrome (see Table 2), have percent difference values ranging from -15.44 and -26.88 percent with the eight greatest difference values belonging to the ferrochrome piles. One reason for the higher than expected errors for the ferrochrome piles is likely due to poor definition of the pile boundaries.

Sixteen of the 26 ore stockpiles studied at the Curtis Bay Depot have computed weight estimates within ±10 to ±15 percent of the reported weights. An additional six piles have percent difference values within the -15 to -25 percent range whereas the remaining four piles have difference values in excess of ±25 percent. The four piles with percent difference values greater than ±25 percent are listed as follows along with a probable explanation for the higher than expected error values:

a. Pile #211: Excess pile mass resulting from some of the unmarked, sorted beryl ore piles being designated as 'Pile #211' when this may not be correct.

b. Pile #110: Erroneous calculated volume due to poor geometric definition of the pile or weight on record in error.

c. Pile #24: Weight on record likely in error.

d. Pile #26: Ore material may have been removed from pile at some time prior to the study.

Each of the unsorted beryl ore piles have percent difference values less than the expected error range. The three sorted beryl ore piles, on the other hand, had difference values which varied from -23.76 to +319.59 percent and this wide range in values are likely caused by errors in pile documentation and uncertainties in determining which sorted piles belong in the appropriate pile designation. Pile #153, the largest high-carbon ferromanganese pile at the site, was being removed during the study and had a computed weight of 189,636,651.35 lb as of 14 November 1997. The difference between the computed weight and adjusted weight on record (i.e., the originally reported weight less the quantity of ore removed prior to the survey) is -16.81 percent.

All of the seven ore stockpiles investigated at the Point Pleasant Depot have computed pile weights that are within 20.30 percent of the documented weight. Three of the six ore stockpiles, ferromanganese Piles #59 and #60 and high-carbon ferrochrome Pile #62, have difference values less than or within the expected error bounds for this technique. The calculated weight of Pile #57, in which the low-carbon ferrochrome material was stacked by hand, has a difference value of -15.36 percent from the reported weight.

It is also of interest to note how the average bulk density values of the ore stockpiles compare to those of similar composition at different sites and to those from previous investigations. A compilation of the material density information is outlined in Table 4. The average density values of the 22 total high-carbon ferromanganese ore piles surveyed at the Warren, Curtis Bay, and Point Pleasant Depots ranged from 3.292 to 3.642 g/cm^3. This range of values compares well to the bulk material densities computed for ferromanganese piles at the Seneca Army Depot, NY and Belle Mead Depot, NJ (Sjostrom 1997) and Hammond Depot, IN (Sjostrom and Butler 1996). The computed densities for the 11 ferromanganese stockpiles at the New Haven Depot are less than the above stated range and this may be attributed to the fact that these piles are all conically shaped and situated on natural soil or gravel such that ore material settlement below the elevation of the original placement surface has taken place. A total of 34 piles of high-carbon ferrochrome were surveyed at five of the six sites (see Tables 1 and 4). The average bulk density values for this material have a wide range with values varying from 2.539 to 3.999 g/cm^3. Once again, the computed density values for the ten piles at New Haven Depot are located at the lower end of the stated range as shown in Table 4. The range of high-carbon ferrochrome density values, with exception to the 10 piles at New Haven Depot, are in line with computed material densities for similar material surveyed at the Seneca Army Depot, NY, Large, PA, Belle Mead Depot, NJ, and Stockton Depot, CA (Sjostrom 1997) and at an industrial site in Charleston, SC (Sjostrom and Berry 1996). The three ore stockpiles of low-carbon ferrochrome surveyed at the Point Pleasant Depot were found to have bulk material densities ranging from 2.964 to 3.470 g/cm^3. These values compare well to bulk density values determined for ore piles at the Belle Mead and Somerville Depots, NJ (Sjostrom 1997) but less than a computed value of

3.843 g/cm^3 for a pile of low-carbon ferrochrome surveyed in 1995 at the Ravenna Army Ammunition Plant, OH (Sjostrom and Butler 1996) as shown in Table 4. The bulk density value of the metallurgical-grade manganese at the Anniston Army Depot is 2.610 g/cm^3 and is greater than the computed density values for manganese piles located at the Sierra Army Depot, CA and Ravenna Army Ammunition Plant, OH (Sjostrom and Butler 1996) as outlined in Table 4.

4 Conclusions

The Defense National Stockpile Center (DNSC) of the Defense Logistics Agency maintains stockpiles of high-grade ores at various defense depots and storage facilities throughout the country. DNSC has a requirement to produce current weight estimates for 85 statistically selected ore piles as part of a national audit. The selected ore stockpiles for this study are located at the following sites: Hammond Depot, IN; New Haven Depot, IN; Warren Depot, OH; Curtis Bay Depot, MD; Point Pleasant Depot, WV; and Anniston Army Depot, AL. The pile material types are categorized as metallurgical fluorspar, beryl ore, metallurgical-grade manganese, high-carbon or low-carbon ferro-chrome, and high-carbon ferromanganese. During the investigation, four stockpiles were removed from the study because the pile material was covered and the covers had not been disturbed since original placement of the ore. One pile was added to the study when it was discovered that two piles of ferroman-ganese, both designated Pile #23, exist at the New Haven Depot. Therefore, a total of 82 ore piles were studied during this investigation.

Microgravity measurements were performed over the ore to provide aver-age bulk density values of the in-place material. Depending on the ore pile length, two to four gravity survey lines were conducted perpendicular to the strike of the pile. For piles which are conically shaped, two gravity profiles were performed with each line intersecting at the apex of the pile. The mea-sured gravity data are referenced to the base station datum for each profile by correcting for the effects due to latitude, elevation, topography, earth tides, and instrument drift. In this manner, variations in the corrected gravity values are assumed to be due solely to the ore pile material. The corrected gravity data sets are analyzed using Parasnis' method to compute a volume-averaged bulk density value for ore pile material. This method has the advantage of averag-ing the effect of density variations more accurately than can be done from sur-face or core samples. The pile density determination accuracy is estimated to be approximately ± 0.2 g/cm^3 (12.5 lb/ft^3) which translates to approximately ± 8 percent of the true value. Ore pile volumes were computed from three-dimensional pile representations constructed from the measured elevation data and estimated to be within five percent of the actual value if no material settle-ment below the plane of the ground surface has occurred.

The weight of stockpiled ore is calculated by multiplying the average bulk density value and computed pile volume. The percent difference between the computed weights and the reported gross weights for each stockpile should be within ±10 to ±15 percent. Comparing the computed weights for each ore stockpile to the weights on record at DNSC, it is observed that 42 of the 82 piles surveyed are below or within the expected percent difference error range. The percent difference values for another 33 ore stockpiles range from ±15 to ±25 percent of which 12 piles have calculated weights between ±15 to ±18 percent of the reported value. Eight stockpiles have computed weights differing by greater than 25 percent of the reported values. All of the ore piles, with the exception of five, have calculated weights that are less than the weights on record.

The computed weights of the ore piles surveyed at the Hammond Depot and Anniston Army Depot have percent difference values which are within the expected error range of the test procedure. On the other hand, the highest difference values were determined at the New Haven Depot where the computed weights of 16 of the 21 stockpiles, all underestimating the reported gross weight, have percent difference values greater than 15 percent. The higher than expected difference values are likely caused by settlement of some of the ore material below the elevation of the current ground surface. Any material below the ground surface cannot be accounted for with the topographic surveying procedures. Each of the piles at the New Haven Depot are situated on a natural earth, gravel, or crushed rock surface as opposed to an asphalt or concrete pad. Poor definition of some pile boundaries and bases also added errors in the weight calculations. Poor definition of the pile base was the contributing factor to the larger than expected errors for the computed weights of eight of the ten high-carbon ferrochrome piles at the Warren Depot. However, of the 24 ore piles studied at the Warren Depot, the calculated weights of 14 of the stockpiles are within 15 percent of the documented weights.

Sixteen of the 26 ore piles studied at the Curtis Bay Depot have computed weights which are within 15 percent of the reported gross weights. An additional six stockpiles have difference values between the calculated and reported weight in the range of -15 to -25 percent. One of these piles is Pile #153 which was being removed from the site at the time of the survey. Three piles have differences in excess of 40 percent and the differences can be attributed to: reported weight likely in error (Pile #24), possibility of material being removed from the pile at some time prior to the survey (Pile #26), and ore pile material mislabeled following sorting processes (Pile #211). At the Point Pleasant Depot, WV, all seven stockpiles in the audit have computed pile weights less than the reported weights. In addition, the percent difference values for three of the piles are below or within the expected error range of the technique.

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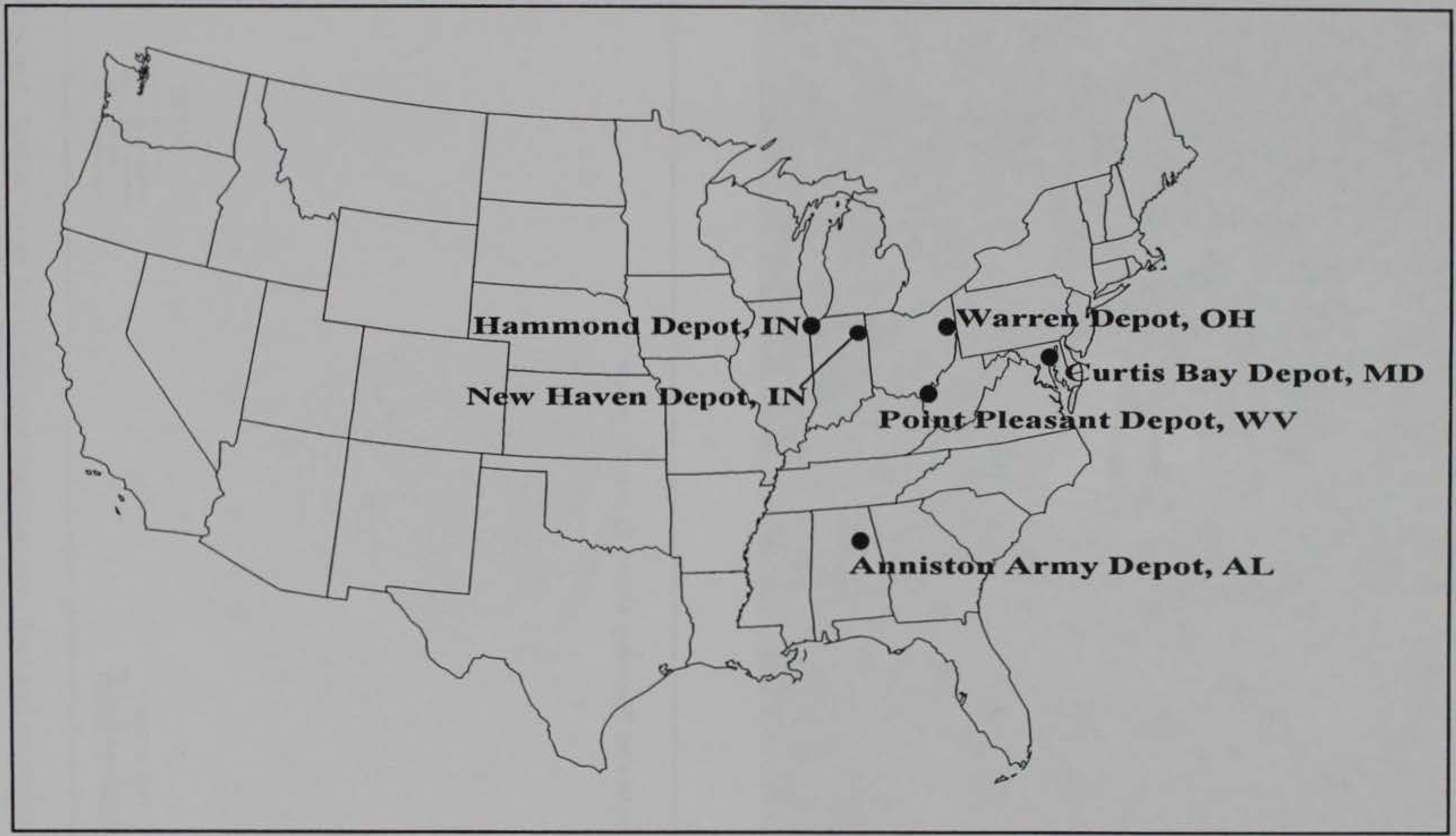


Figure 1. Location of project areas

Figure 2. LaCoste and Romberg Model D gravity meter

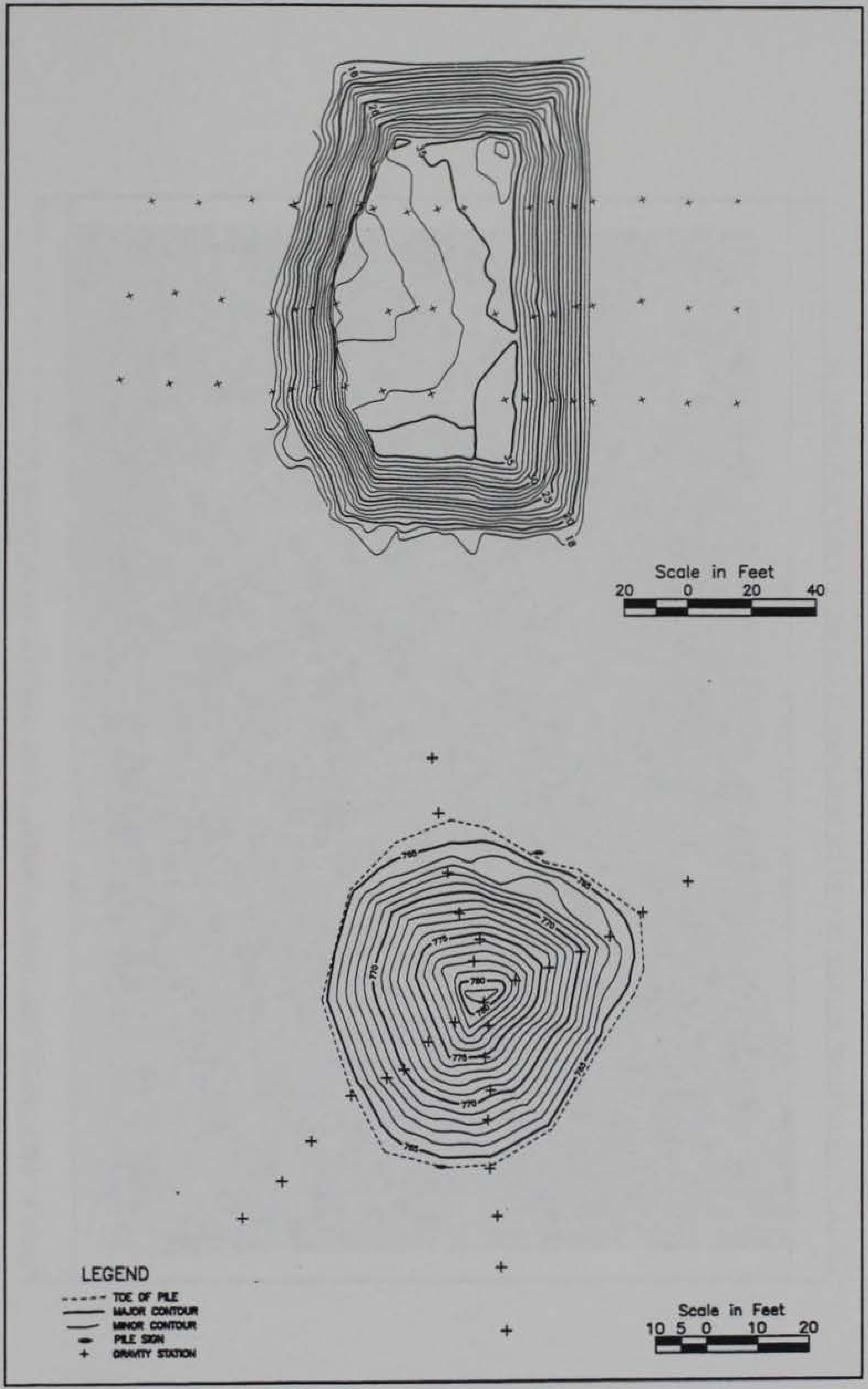


Figure 3. Typical survey line layout over elongated piles (top) and conical shaped piles (bottom)

Figure 4. Microgravity measurement station on Pile #56, New Haven Depot, IN

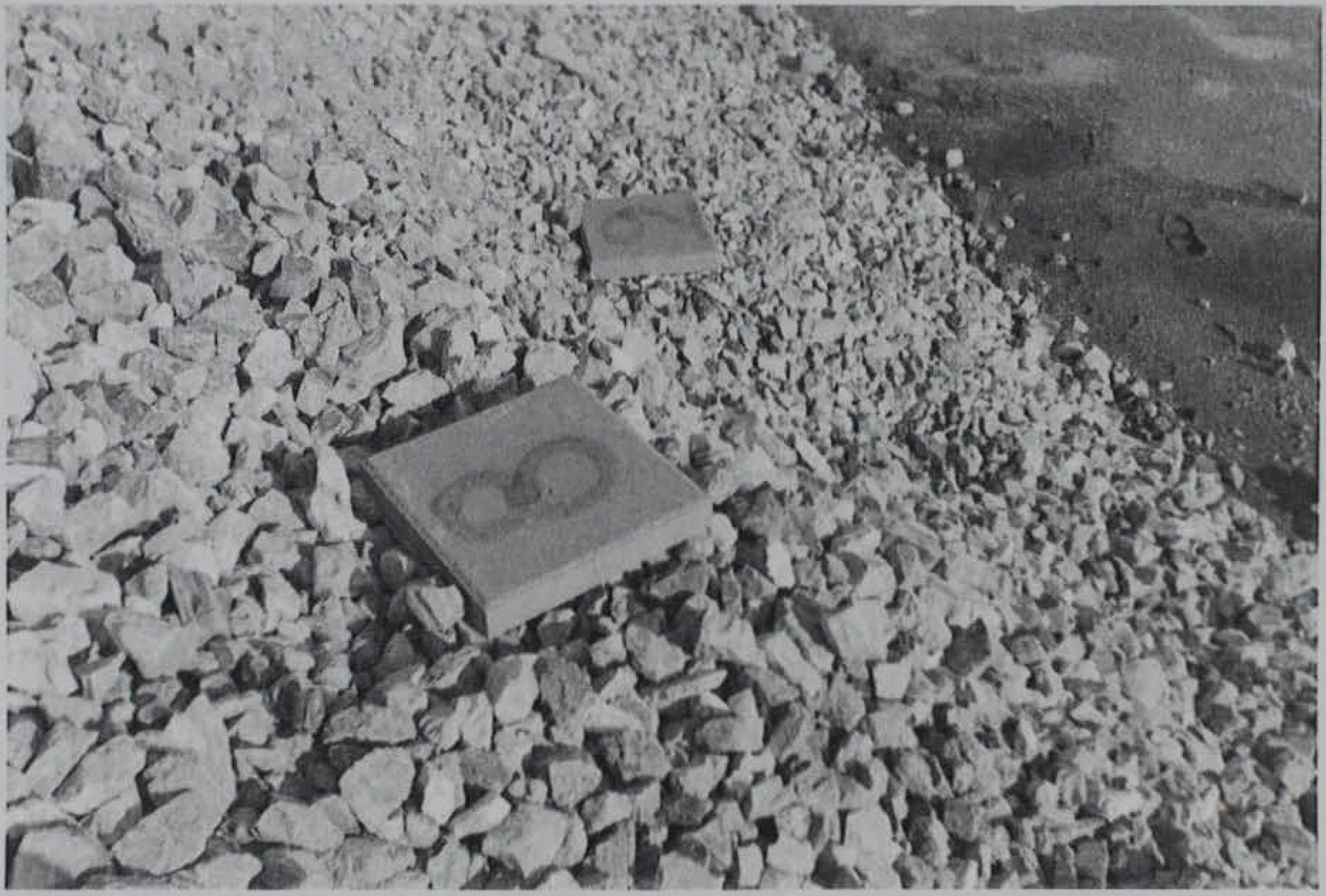


Figure 5. Microgravity stations located on side slope of Pile #212, Curtis Bay Depot, MD

Figure 6. Microgravity stations positioned on top of ferromanganese pile

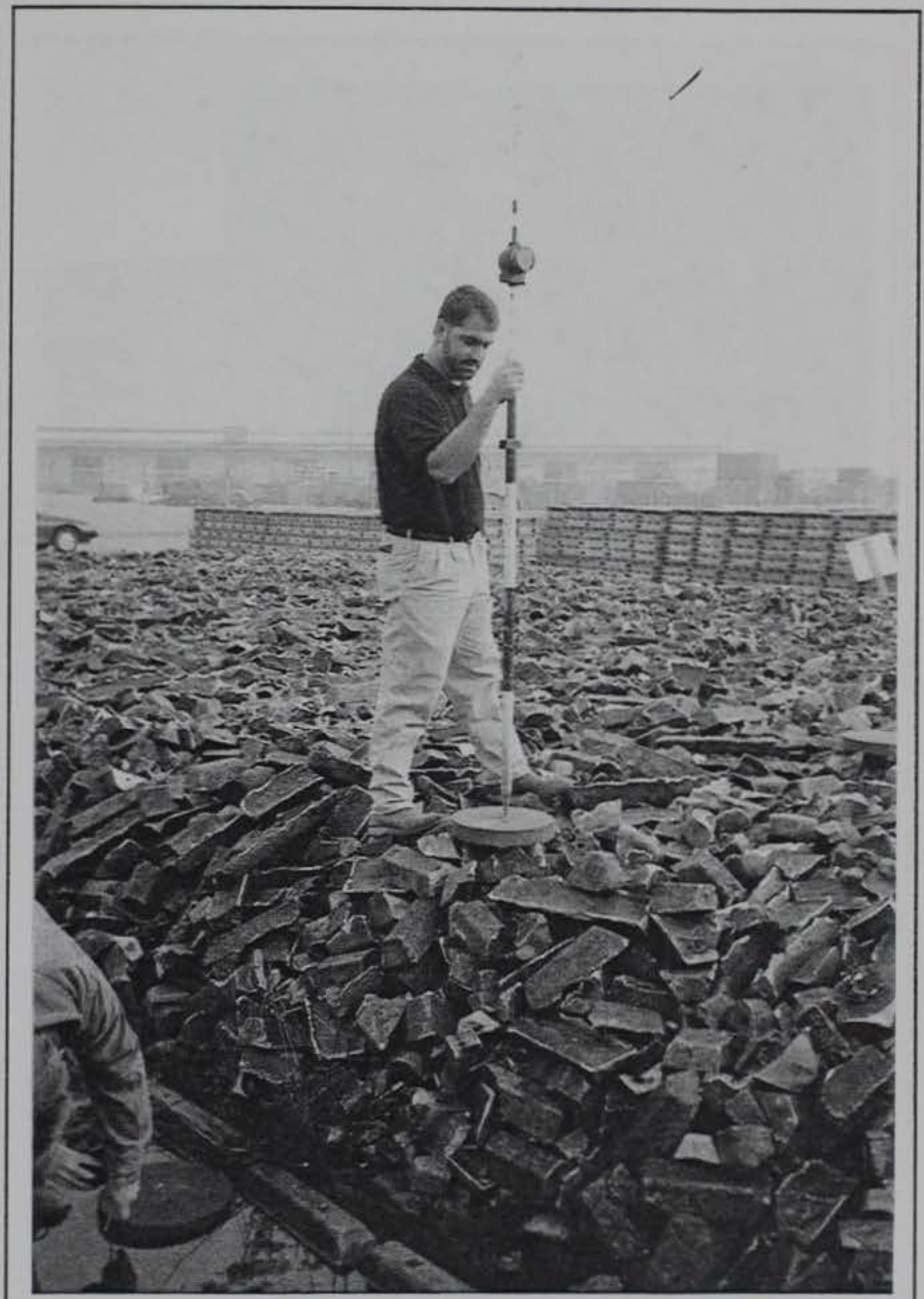


Figure 7. Elevation measurement at microgravity station

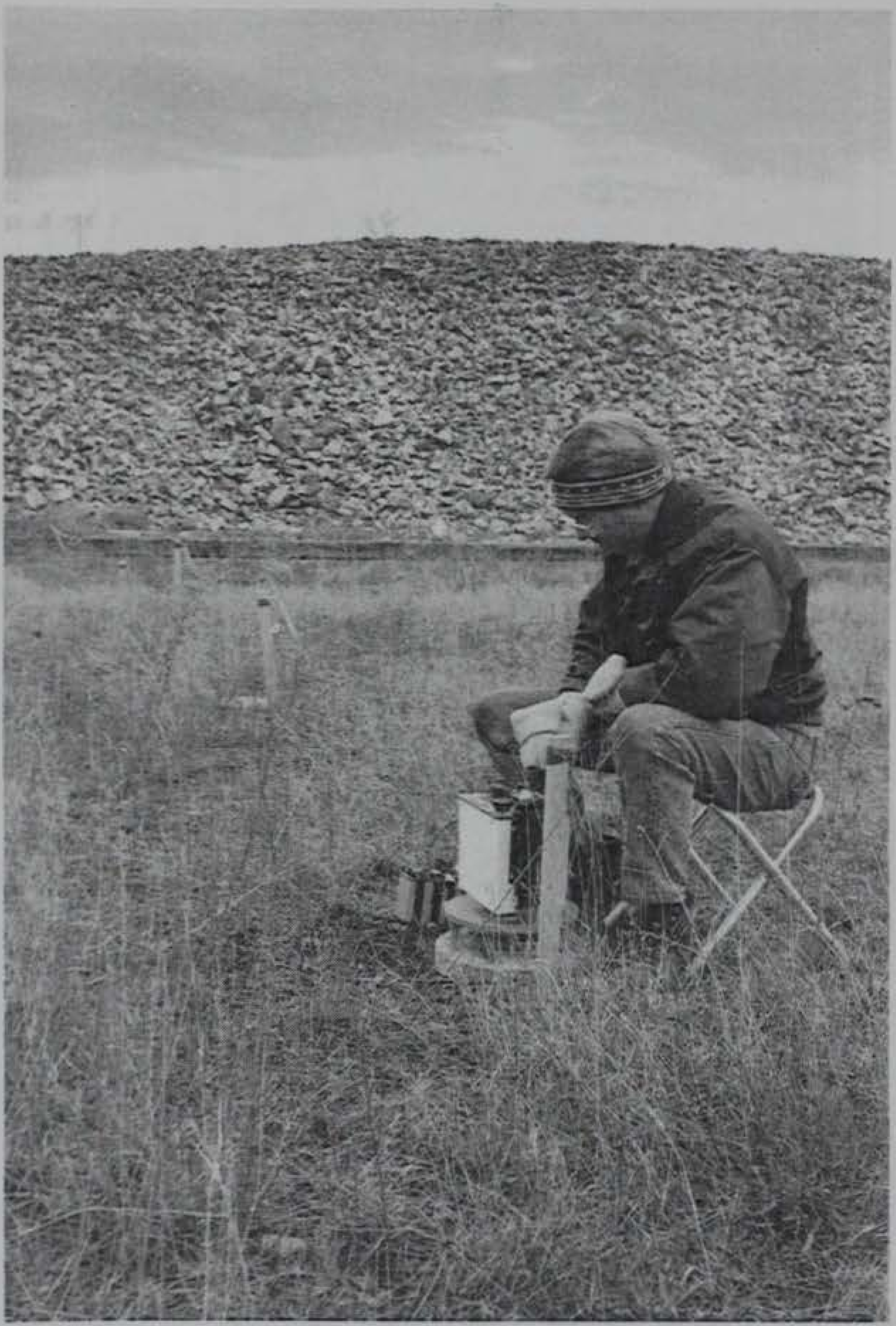


Figure 8. Microgravity measurement at base station

Figure 9. Microgravity measurement on side slope of pile

Figure 10. Microgravity measurement near the crest of an ore pile

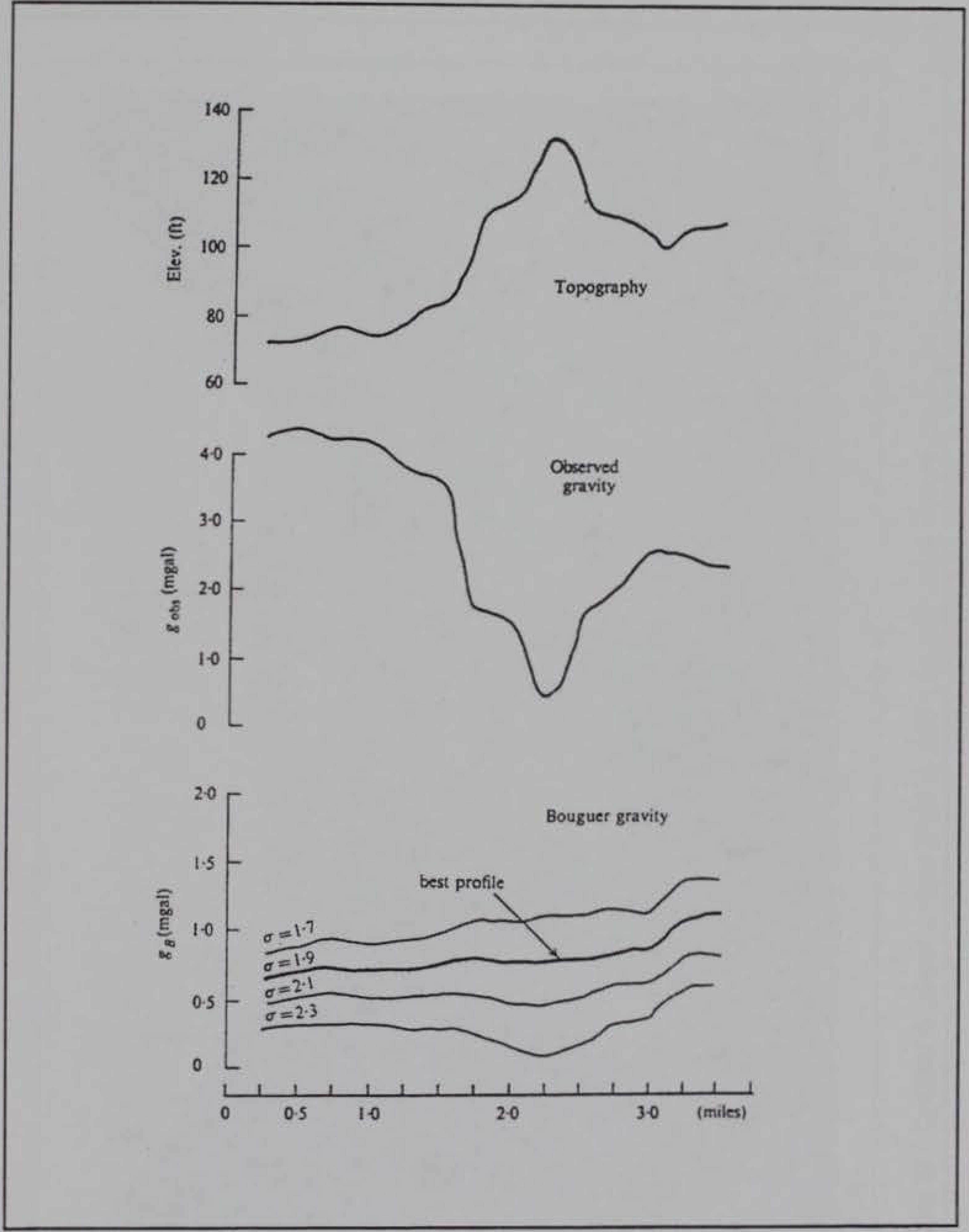


Figure 11. Application of Nettleton's method for estimating material density (Telford et al. 1990)

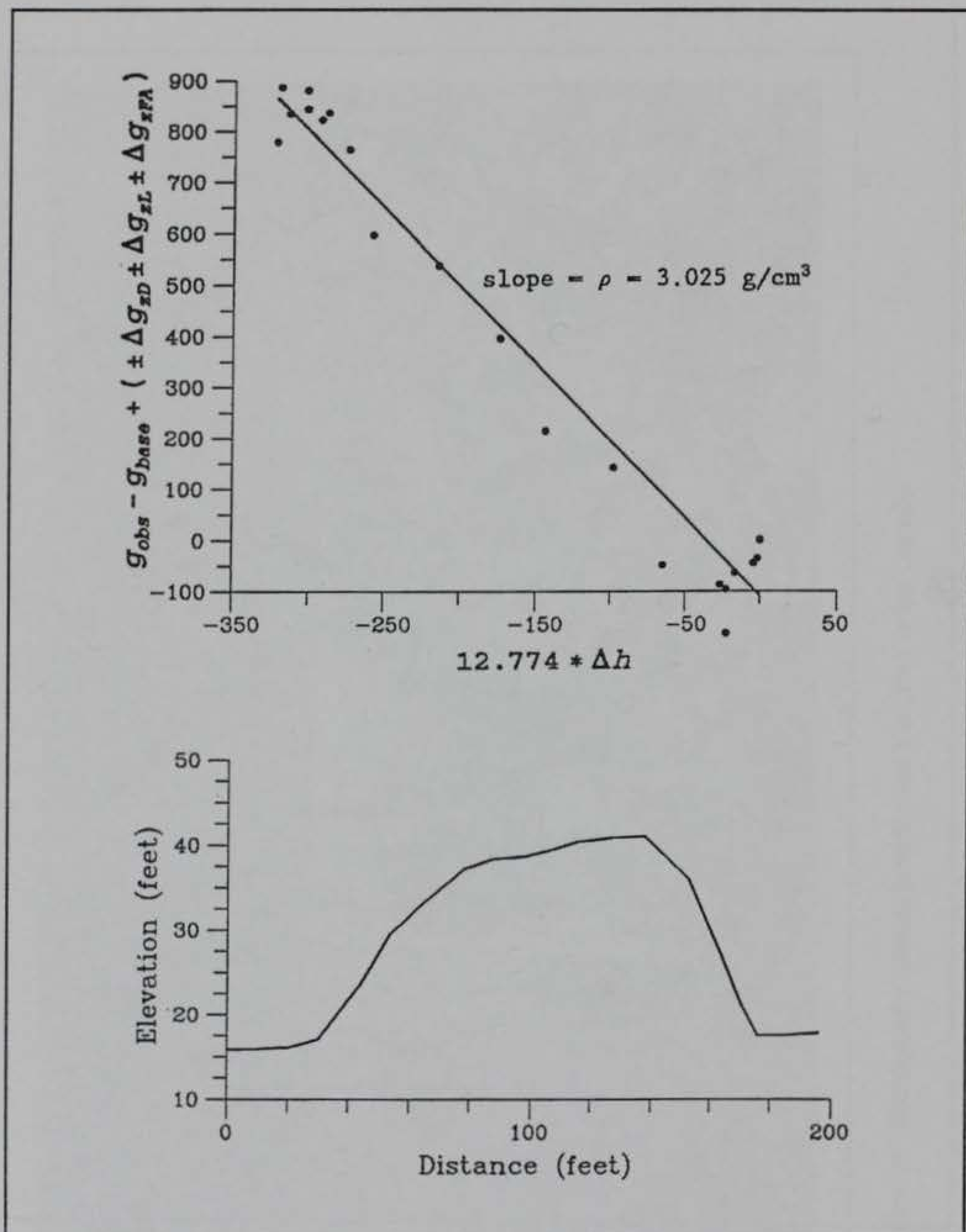


Figure 12. Application of Parasnis' method for computing material density

Figure 13. Contact between edges of Piles #31 and #32, New Haven Depot, IN

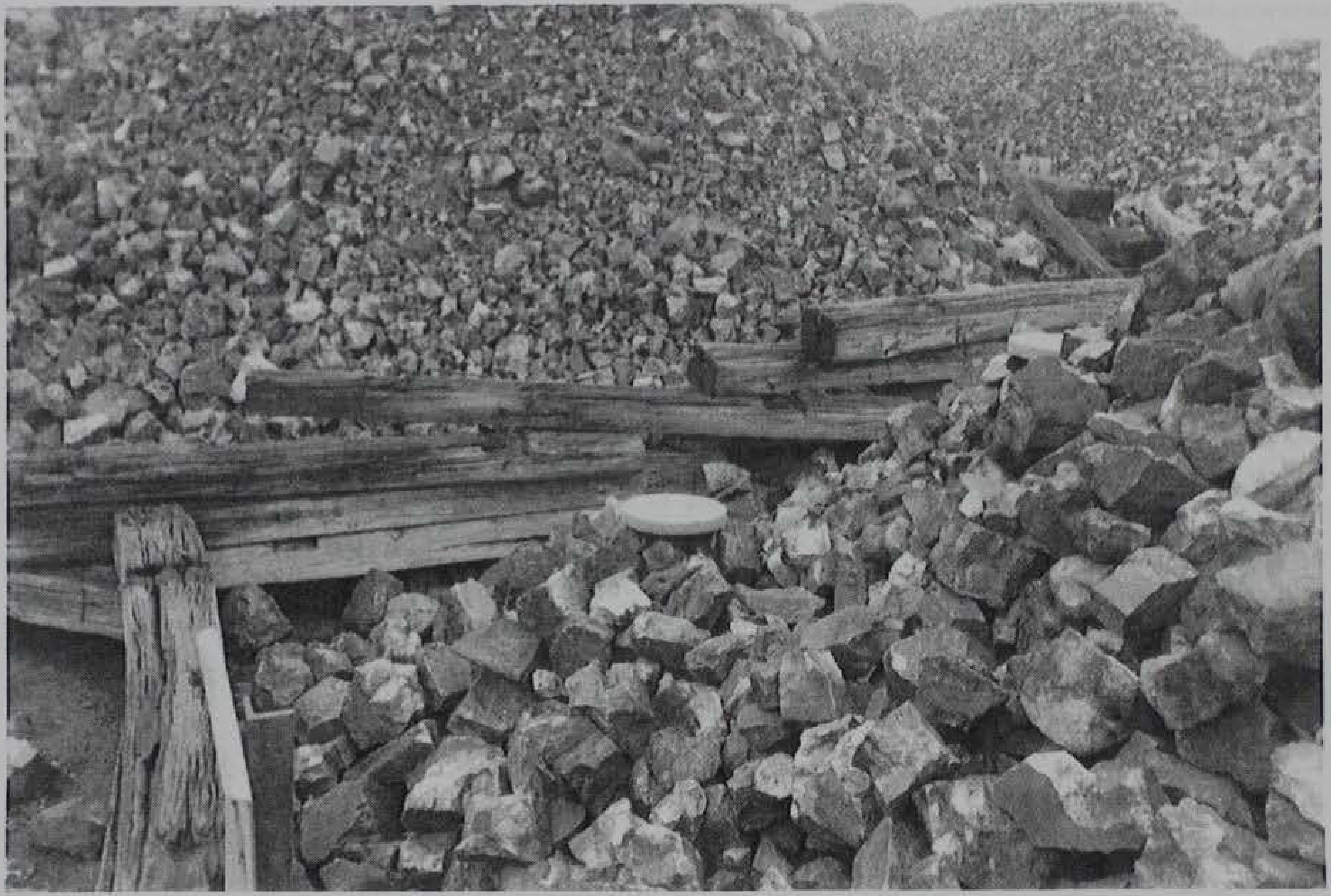


Figure 14. An example of the difficulties in determining pile boundaries, Warren Depot, OH

Table 1
Reported Descriptions of Ore Stockpiles

Pile No.	Length, ft	Width, ft	Height, ft	Foundation Type	Reported Gross Weight, lbs	Material Description	Material Type (abbrev.)
Hammond Depot, IN							
1	100	70	20	Asphalt	10,198,850	Ferrochrome, High-Carbon	FC,HC
7	225	150	17	Concrete	91,515,040	Ferrochrome, High-Carbon	FC,HC
11	226	150	18	Concrete	103,484,060	Ferrochrome, High-Carbon	FC,HC
New Haven Depot, IN							
4	82	72	21	Gravel/Crushed Rock	12,675,580	Ferrochrome, High-Carbon	FC,HC
11	68	56	18	Gravel/Crushed Rock	7,704,805	Ferrochrome, High-Carbon	FC,HC
13	448	32	8	Gravel/Crushed Rock	1,143,500	Ferrochrome, High-Carbon	FC,HC
56	80	60	14	Gravel/Crushed Rock	9,268,375	Ferrochrome, High-Carbon	FC,HC
57	70	46	14	Gravel/Crushed Rock	5,859,020	Ferrochrome, High-Carbon	FC,HC
58	70	50	14	Gravel/Crushed Rock	7,913,733	Ferrochrome, High-Carbon	FC,HC
61	70	64	14	Gravel/Crushed Rock	7,880,200	Ferrochrome, High-Carbon	FC,HC
67	18	18	6	Gravel/Crushed Rock	293,250	Ferrochrome, High-Carbon	FC,HC
68	90	74	20	Gravel/Crushed Rock	13,451,625	Ferrochrome, High-Carbon	FC,HC
71	66	56	18	Gravel/Crushed Rock	7,563,860	Ferrochrome, High-Carbon	FC,HC
20	36	21	7	Soil/Gravel	667,410	Ferromanganese, High-Carbon	FM,HC
23A[1]	50	40	12	Soil/Gravel	3,151,400	Ferromanganese, High-Carbon	FM,HC
23B[1]	50	40	12	Soil/Gravel	3,151,400	Ferromanganese, High-Carbon	FM,HC
28	75	50	10	Soil/Gravel	5,324,800	Ferromanganese, High-Carbon	FM,HC
31	80	60	13	Soil/Gravel	8,405,160	Ferromanganese, High-Carbon	FM,HC
32	65	42	13	Soil/Gravel	4,849,000	Ferromanganese, High-Carbon	FM,HC
34	60	30	8	Soil/Gravel	2,204,040	Ferromanganese, High-Carbon	FM,HC
37	55	80	12	Soil/Gravel	8,429,080	Ferromanganese, High-Carbon	FM,HC
38	50	24	9	Soil/Gravel	2,134,000	Ferromanganese, High-Carbon	FM,HC
39	30	30	8	Soil/Gravel	1,127,320	Ferromanganese, High-Carbon	FM,HC
45	30	24	9	Soil/Gravel	650,460	Ferromanganese, High-Carbon	FM,HC
Warren Depot, OH							
25	60	50	20	Asphalt	4,485,750	Ferromanganese, High-Carbon	FM,HC
26	57	36	15	Asphalt	2,177,450	Ferromanganese, High-Carbon	FM,HC
27	168	48	22	Asphalt	17,104,960	Ferromanganese, High-Carbon	FM,HC
28	408	53	27	Asphalt	53,193,380	Ferromanganese, High-Carbon	FM,HC
34	270	70	20	Asphalt	48,662,000	Ferromanganese, High-Carbon	FM,HC
36	265	70	20	Asphalt	50,098,553	Ferromanganese, High-Carbon	FM,HC
38	200	55	20	Asphalt	38,485,820	Ferromanganese, High-Carbon	FM,HC
39	35	24	8	Asphalt	921,340	Ferromanganese, High-Carbon	FM,HC
40	35	24	8	Asphalt	963,660	Ferromanganese, High-Carbon	FM,HC

(Sheet 1 of 3)

Table 1 (Continued)							
Pile No.	Length, ft	Width, ft	Height, ft	Foundation Type	Reported Gross Weight, lbs	Material Description	Material Type (abbrev.)
Warren Depot, OH (Continued)							
41	35	24	8	Asphalt	1,015,320	Ferromanganese, High-Carbon	FM,HC
42	10	55	20	Asphalt	26,734,410	Ferromanganese, High-Carbon	FM,HC
3	790	50/125	15/25	Soil/Gravel	69,600,000	Metallurgical Fluorspar, Grade A	F,MGA
3A	90	40	12/15	Soil/Gravel	4,461,080	Metallurgical Fluorspar, Grade A	F,MGA
4	311	60	12/15	Soil/Gravel	24,738,240	Metallurgical Fluorspar, Grade B	F,MGB
3	30	326	-	Asphalt	20,286,460	Ferrochrome, High-Carbon	FC,HC
6	115	-	9	Asphalt	999,450	Ferrochrome, High-Carbon	FC,HC
8	90	-	8	Asphalt	440,780	Ferrochrome, High-Carbon	FC,HC
9	104	-	12	Asphalt	932,050	Ferrochrome, High-Carbon	FC,HC
10	93	-	9	Asphalt	617,200	Ferrochrome, High-Carbon	FC,HC
11	93	-	9	Asphalt	554,100	Ferrochrome, High-Carbon	FC,HC
12	120	-	12	Asphalt	1,663,460	Ferrochrome, High-Carbon	FC,HC
16	270	-	12	Asphalt	5,583,200	Ferrochrome, High-Carbon	FC,HC
19	180	-	15	Asphalt	3,231,280	Ferrochrome, High-Carbon	FC,HC
22	105	-	10	Asphalt	557,120	Ferrochrome, High-Carbon	FC,HC
Curtis Bay Depot, MD							
159	120	110	15	Concrete	3,441,973	Beryl Ore	BO
207	50	38	15	Concrete	937,220	Beryl Ore	BO
208	88	31	15	Concrete	1,465,320	Beryl Ore	BO
209	51	39	15	Concrete	911,920	Beryl Ore	BO
210	60	30	12	Concrete	764,360	Beryl Ore	BO
211[2]	80	67	20	Asphalt	609,280	Beryl Ore (sorted)	BO(s)
212[2]	74	56	25	Asphalt	3,086,080	Beryl Ore (sorted)	BO(s)
213[2]	40	22	10	Asphalt	295,720	Beryl Ore (sorted)	BO(s)
108	80	125	20	Concrete	19,970,700	Ferrochrome, High-Carbon	FC,HC
110	50	95	10	Concrete	4,307,668	Ferrochrome, High-Carbon	FC,HC
111	63	120	20	Concrete	17,696,460	Ferrochrome, High-Carbon	FC,HC
112	46	120	20	Concrete	11,511,980	Ferrochrome, High-Carbon	FC,HC
114	57	107	21	Concrete	13,477,380	Ferrochrome, High-Carbon	FC,HC
118	60	112	21	Asphalt	10,490,860	Ferrochrome, High-Carbon	FC,HC
120	45	60	16	Asphalt	2,810,360	Ferrochrome, High-Carbon	FC,HC
121	55	77	18	Concrete	6,969,460	Ferrochrome, High-Carbon	FC,HC
125	55	67	18	Asphalt	4,981,160	Ferrochrome, High-Carbon	FC,HC
203	45	110	21	Concrete	6,454,040	Ferrochrome, High-Carbon	FC,HC
131[3]	408	186	30	Unknown	136,830,700	Manganese, Chemical-Grade Type A	M,CGA
(Sheet 2 of 3)							

Table 1 (Concluded)

Pile No.	Length, ft	Width, ft	Height, ft	Foundation Type	Reported Gross Weight, lbs	Material Description	Material Type (abbrev.)
Curtis Bay Depot, MD (Continued)							
139[3]	213	144	30	Unknown	57,208,900	Manganese, Chemical-Grade Type A	M,CGA
18	80	9	6	Concrete	1,793,440	Ferromanganese, High-Carbon	FM,HC
24	220	77	20	Concrete	15,651,840	Ferromanganese, High-Carbon	FM,HC
25	240	55	30	Concrete	72,392,040	Ferromanganese, High-Carbon	FM,HC
26	465	76	20	Concrete	90,454,040	Ferromanganese, High-Carbon	FM,HC
27	190	80	30	Concrete	44,067,100	Ferromanganese, High-Carbon	FM,HC
99	47	33	12	Concrete	2,290,420	Ferromanganese, High-Carbon	FM,HC
153[4]	47	96	12	Soil/Gravel	249,162,520[5] 227,944,400[6]	Ferromanganese, High-Carbon	FM,HC
154	75	66	20	Concrete	12,033,700	Ferromanganese, High-Carbon	FM,HC
Point Pleasant Depot, WV							
62	250	205	75	Concrete	279,054,660	Ferrochrome, High-Carbon	FC,HC
54[7]	384	54	20	Asphalt/Concrete	51,612,534	Ferrochrome, Low-Carbon	FC,LC
55[7]	105	55	18	Asphalt/Concrete	7,981,400	Ferrochrome, Low-Carbon	FC,LC
57	86	54	18	Asphalt/Concrete	8,824,075	Ferrochrome, Low-Carbon	FC,LC
62A	507	30	20	Concrete	34,154,246	Ferrochrome, Low-Carbon	FC,LC
63	582	30	24	Concrete	45,990,703	Ferrochrome, Low-Carbon	FC,LC
59	274	43	19	Asphalt/Concrete	27,086,900	Ferromanganese, High-Carbon	FM,HC
60	118	32	20	Asphalt/Concrete	9,206,680	Ferromanganese, High-Carbon	FM,HC
61	817	128	35	Concrete	588,360,546	Ferromanganese, High-Carbon	FM,HC
Anniston Army Depot, AL							
1	686	190	15	Soil / Gravel	59,984,420	Manganese, Metallurgical-Grade	M,MG

(Sheet 3 of 3)

[1] Two piles designated 'Pile #23' were found at New Haven Depot.
[2] The ore material in Piles #211, #212, and #213 has been sorted according to size and is now stored in several piles; all with the same pile designation.
[3] Piles #131 and #139 (covered) were removed from the study by the DLA Inspector General's Office in November 1997.
[4] Pile #153 was being removed during the field study.
[5] Originally reported weight.
[6] Reported weight as of 14 November 1997 when volume determination was made.
[7] Piles #54 and #55 (covered) were removed from the study by the DLA Inspector General's Office in December 1997.

Table 2
Comparison of Reported and Computed Ore Pile Weights

Pile No.	Material Type (abbrev.)	Measured Volume, yd^3	Reported Gross Weight, lbs	Average Calculated Weight, lbs	Percent Difference
Hammond Depot, IN					
1	FC,HC	1,720.20	10,198,850	8,796,720	-13.75
7	FC,HC	13,163.32	91,515,040	88,505,989	-3.29
11	FC,HC	13,946.94	103,484,060	94,009,885	-9.16
New Haven Depot, IN					
4	FC,HC	2,038.60	12,675,580	9,380,756	-25.99
11	FC,HC	1,322.40	7,704,805	6,053,908	-21.43
13	FC,HC	196.56	1,143,500	904,484	-20.90
56	FC,HC	1,497.10	9,268,375	7,118,641	-23.19
57	FC,HC	1,001.20	5,859,020	4,607,090	-21.37
58	FC,HC	1,329.15	7,913,733	6,116,174	-22.71
61	FC,HC	1,404.13	7,880,200	6,461,200	-18.01
67	FC,HC	59.40	293,250	273,333	-6.79
68	FC,HC	2,186.00	13,451,625	9,778,996	-27.30
71	FC,HC	1,288.40	7,563,860	5,928,660	-21.62
20	FM,HC	116.60	667,410	622,232	-6.77
23A[1]	FM,HC	495.50	3,151,400	2,644,221	-16.09
23B[1]	FM,HC	540.80	3,151,400	2,885,963	-8.42
28	FM,HC	886.30	5,324,800	4,834,287	-9.21
31	FM,HC	1,201.30	8,405,160	6,410,702	-23.73
32	FM,HC	700.60	4,849,000	3,738,731	-22.90
34	FM,HC	331.50	2,204,040	1,769,040	-19.74
37	FM,HC	1,307.00	8,429,080	6,974,767	-17.25
38	FM,HC	313.10	2,134,000	1,670,849	-21.70
39	FM,HC	163.00	1,127,320	869,845	-22.84
45	FM,HC	109.20	650,460	582,743	-10.41
Warren Depot, OH					
25	FM,HC	667.19	4,485,750	3,882,071	-13.46
26	FM,HC	326.20	2,177,450	1,898,008	-12.83
27	FM,HC	2,603.15	17,104,960	15,146,531	-11.45
28	FM,HC	7,808.56	53,193,380	45,434,413	-14.59
34	FM,HC	7,342.99	48,663,320	43,096,787	-11.44
36	FM,HC	7,597.91	50,098,553	43,824,537	-12.52
38	FM,HC	5,991.36	38,485,820	34,860,964	-9.42
39	FM,HC	137.41	921,340	799,526	-13.22
40	FM,HC	140.93	963,660	820,007	-14.91

(Sheet 1 of 3)

Table 2 (Continued)

Pile No.	Material Type (abbrev.)	Measured Volume, yd^3	Reported Gross Weight, lbs	Average Calculated Weight, lbs	Percent Difference
Warren Depot, OH (Continued)					
41	FM,HC	147.56	1,015,320	858,584	-15.44
42	FM,HC	4,096.11	26,734,410	23,833,377	-10.85
3	F,MGA	20,970.53	69,600,000	62,033,990	-10.87
3A	F,MGA	1,246.00	4,461,080	3,685,856	-17.38
4	F,MGB	9,022.43	24,738,240	22,826,924	-7.73
3	FC,HC	2,893.14	20,286,460	14,834,464	-26.88
6	FC,HC	151.40	999,450	777,574	-22.20
8	FC,HC	65.56	440,780	336,709	-23.61
9	FC,HC	142.81	932,050	734,660	-21.18
10	FC,HC	94.16	617,200	483,595	-21.65
11	FC,HC	103.35	554,100	530,794	-4.21
12	FC,HC	243.80	1,663,460	1,252,130	-24.73
16	FC,HC	876.71	5,583,200	4,502,685	-19.35
19	FC,HC	566.77	3,231,280	2,910,868	-9.92
22	FC,HC	86.64	557,120	444,973	-20.13
Curtis Bay Depot, MD					
159	BO	1,204.10	3,441,973	3,204,704	-6.89
207	BO	321.80	937,220	972,002	+3.71
208	BO	484.90	1,465,320	1,464,648	-0.05
209	BO	328.60	911,920	913,338	+0.16
210	BO	260.40	764,360	723,777	-5.31
211[2]	BO(s)	983.60	609,280	2,556,502	+319.59
212[2]	BO(s)	1,161.79	3,086,080	3,019,640	-2.15
213[2]	BO(s)	81.11	295,720	225,444	-23.76
108	FC,HC	3,297.70	19,970,700	18,031,638	-9.71
110	FC,HC	497.50	4,307,668	2,610,450	-39.40
111	FC,HC	3,108.55	17,696,460	16,310,984	-7.83
112	FC,HC	1,923.14	11,511,980	10,090,977	-12.34
114	FC,HC	2,178.96	13,477,380	11,433,299	-15.17
118	FC,HC	2,006.25	10,490,860	9,441,558	-10.00
120	FC,HC	493.63	2,810,360	2,323,059	-17.34
121	FC,HC	1,232.93	6,969,460	5,926,948	-14.96
125	FC,HC	896.00	4,981,160	4,216,641	-15.35
203	FC,HC	964.28	6,454,040	5,059,708	-21.60
18	FM,HC	261.41	1,793,440	1,540,852	-14.08
24	FM,HC	5,856.60	15,651,840	35,952,467	+129.70

(Sheet 2 of 3)

Table 2 (Concluded)

Pile No.	Material Type (abbrev.)	Measured Volume, yd^3	Reported Gross Weight, lbs	Average Calculated Weight, lbs	Percent Difference
Curtis Bay Depot, MD (Continued)					
25	FM,HC	11,339.88	72,392,040	66,841,668	-7.67
26	FM,HC	7,755.80	90,454,040	45,715,705	-49.46
27	FM,HC	7,058.60	44,067,100	40,761,402	-7.50
99	FM,HC	344.70	2,290,420	2,031,796	-11.29
153[3]	FM,HC	32,172.40	249,162,520[4] 227,944,400[5]	189,636,651	-16.81
154	FM,HC	1,880.62	12,033,700	10,853,704	-9.81
Point Pleasant Depot, WV					
62	FC,HC	44,558.37	279,054,660	261,818,219	-6.18
57	FC,LC	1,024.75	8,824,075	7,468,731	-15.36
62A	FC,LC	4,668.99	34,154,246	27,221,791	-20.30
63	FC,LC	6,534.12	45,990,703	38,096,129	-17.17
59	FM,HC	3,992.73	27,086,900	23,521,245	-13.16
60	FM,HC	1,370.78	9,206,680	7,844,237	-14.80
61	FM,HC	80,167.51	588,360,546	485,645,818	-17.46
Anniston Army Depot, AL					
1	M,MG	14,000.00	59,984,420	61,590,216	+2.68
					(Sheet 3 of 3)

[1] Two piles designated 'Pile #23' were found at New Haven Depot.
[2] The ore material in Piles #211, #212, and #213 has been sorted according to size and is now stored in several piles; all with the same pile designation.
[3] Pile #153 was being removed during the field study.
[4] Originally reported weight.
[5] Reported weight as of 14 November 1997 when volume determination was made.

Table 3
Distribution of Stockpiles Versus Percent Difference Ranges

	Percent Difference Range	Number of Ore Stockpiles							Expected Error Range Description
		Hammond Depot, IN	New Haven Depot, IN	Warren Depot, OH	Curtis Bay Depot, MD	Point Pleasant Depot, WV	Anniston Army Depot, AL	Total	
Calculated Weight **Greater Than** Reported Weight	> +40%	-	-	-	2	-	-	2	Well Outside
	+25% to +40%	-	-	-	-	-	-	-	
	+15% to +25%	-	-	-	-	-	-	-	Outside
	+10% to +15%	-	-	-	-	-	-	-	Within
	0% to +10%	-	-	-	2	-	1	3	Below
Calculated Weight **Less Than** Reported Weight	0% to -10%	2	4	4	10	1	-	21	
	-10% to -15%	1	1	10	4	2	-	18	Within
	-15% to -25%	-	14	9	6[1]	4	-	33	Outside
	-25% to -40%	-	2	1	1	-	-	4	Well Outside
	< -40%	-	-	-	1	-	-	1	
Total		3	21	24	26	7	1	82	

[1] Pile #153 at Curtis Bay Depot, MD was being removed during the gravity investigation.

Table 4
Comparison of Computed Material Density Values

Material Type	Computed Density, g/cm^3	Number of Piles	Location (Year)
High-Carbon Ferromanganese	2.929 - 3.341	11[1]	New Haven Depot, IN (1997)
	3.292 - 3.551	11	Warren Depot, OH (1997)
	3.340 - 3.642	8	Curtis Bay Depot, MD (1997)
	3.374 - 3.628	3	Point Pleasant Depot, WV (1997)
	3.388 - 3.449	13	Seneca Army Depot, NY (1996)
	3.589 - 3.677	3	Belle Mead Depot, NJ (1996)
	3.903	1	Hammond Depot, IN (1995)
High-Carbon Ferrochrome	3.033 - 3.999	3	Hammond Depot, IN (1997)
	2.539 - 2.887	10[1]	New Haven Depot, IN (1997)
	2.732 - 3.161	10	Warren Depot, OH (1997)
	2.852 - 3.253	10	Curtis Bay Depot, MD (1997)
	3.486	1	Point Pleasant Depot, WV (1997)
	2.991 - 3.178	9	Seneca Army Depot, NY (1996)
	3.386 - 3.794	8	Unmanned Site, Large, PA (1996)
	3.211	1	Belle Mead Depot, NJ (1996)
	3.518	1	Stockton Depot, CA (1996)
	3.085 - 3.775	3	Industrial Site, Charleston, SC (1996)
Low-Carbon Ferrochrome	2.964 - 3.470	3	Point Pleasant Depot, WV (1997)
	3.033 - 3.211	8	Belle Mead Depot, NJ (1996)
	3.182 - 3.258	2	Somerville Depot, NJ (1996)
	3.843	1	Ravenna Army Ammunition Plant, OH (1995)
Metallurgical-Grade Manganese	2.610	1[1]	Anniston Army Depot, AL (1997)
	1.910 - 2.100	2[1]	Sierra Army Depot, CA (1995)
	1.800	1[1]	Ravenna Army Ammunition Plant, OH (1995)

[1] Pile material placed on natural soil, gravel, or crushed rock rather than an asphalt or concrete surface.

Appendix A
Ore Pile Elevation Contour Plots and Photographs, Hammond Depot, Indiana

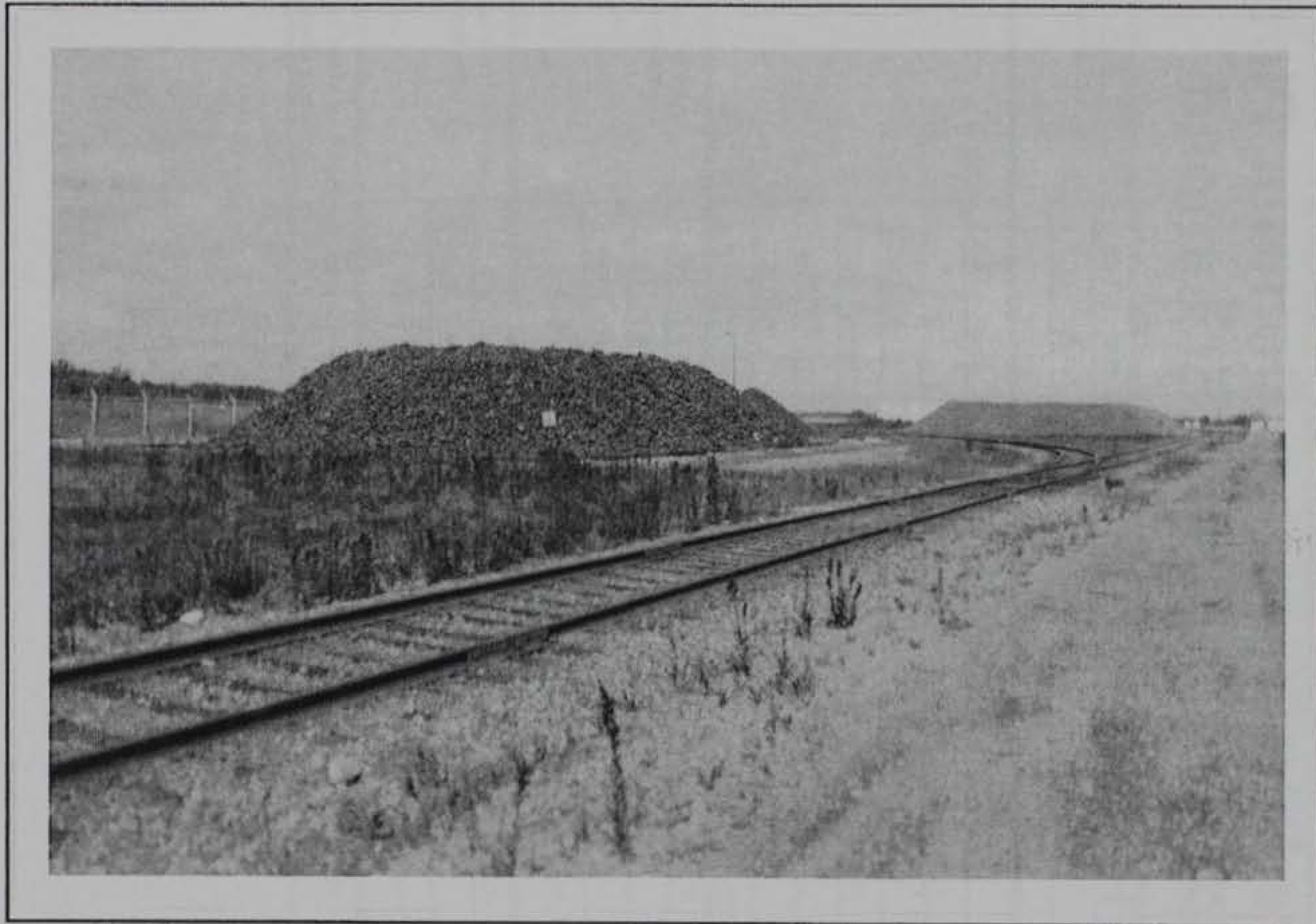


Figure A-1. Pile #1, Hammond Depot, IN. Pile #7 is visible in the background (right)

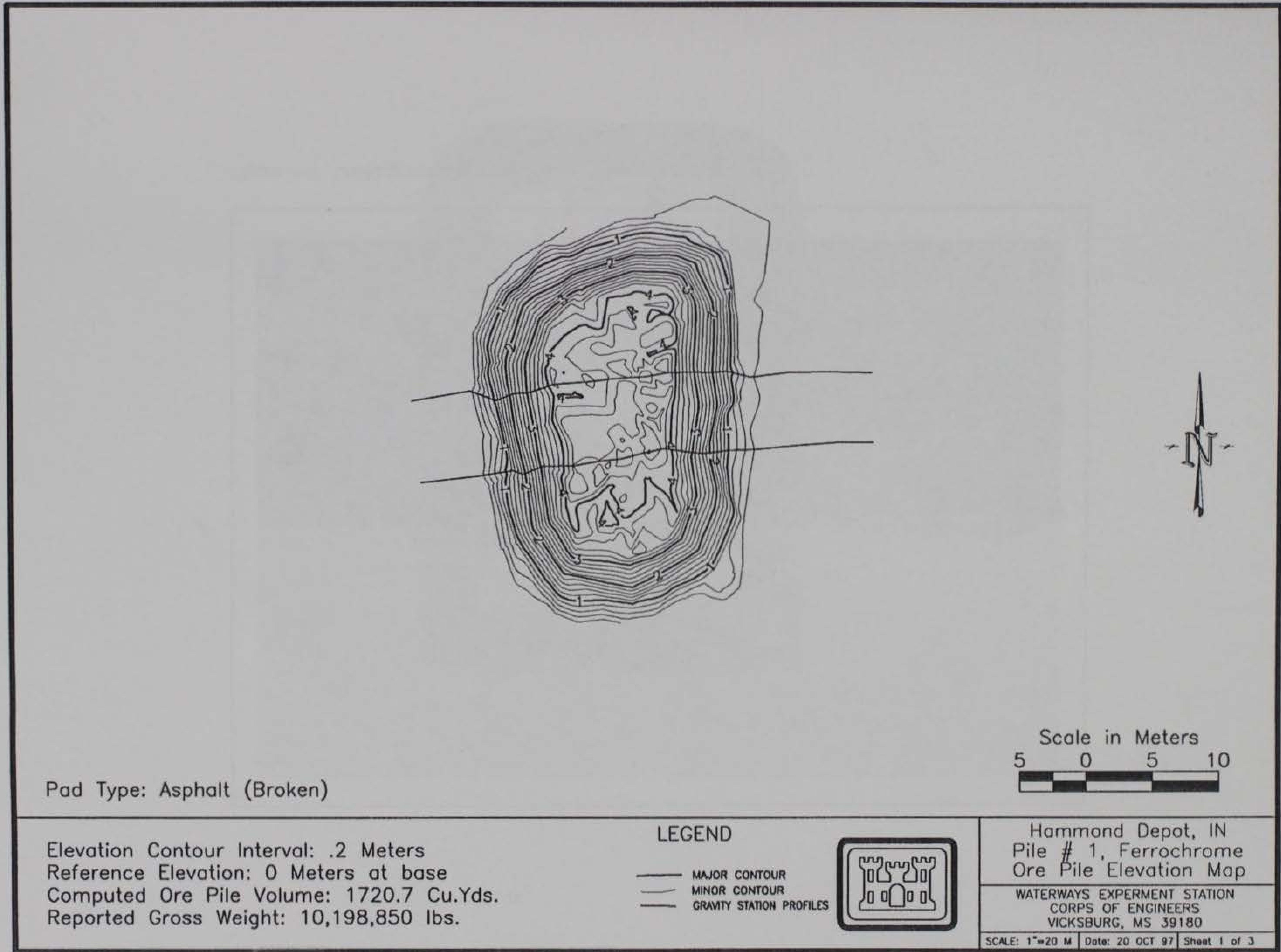


Figure A-2. Elevation contour plot of Pile #1, Hammond Depot, IN

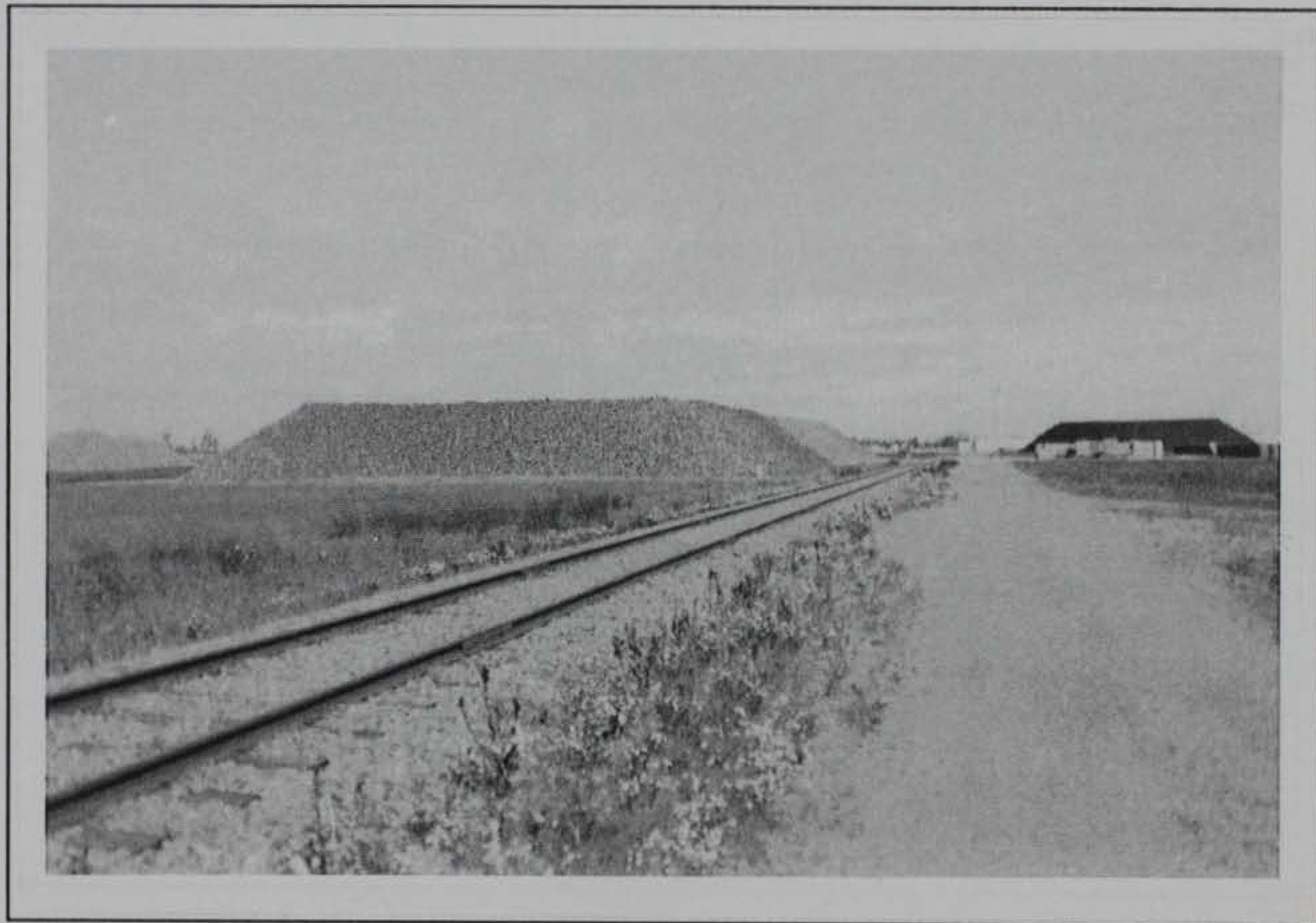


Figure A-3. Looking north towards Pile #7, Hammond Depot, IN

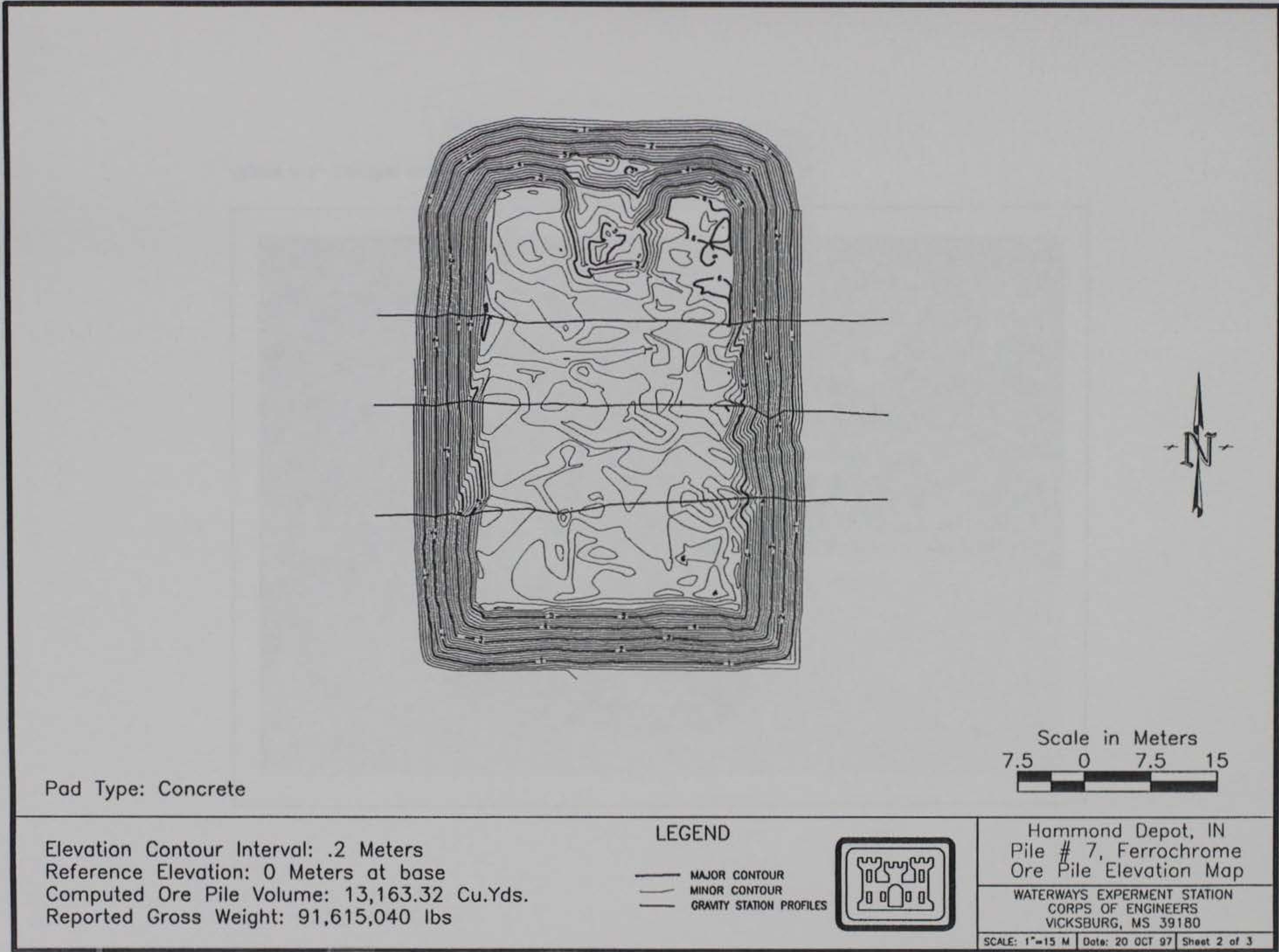


Figure A-4. Elevation contour plot of Pile #7, Hammond Depot, IN

Figure A-5. Looking northeast towards Pile #11, Hammond Depot, IN

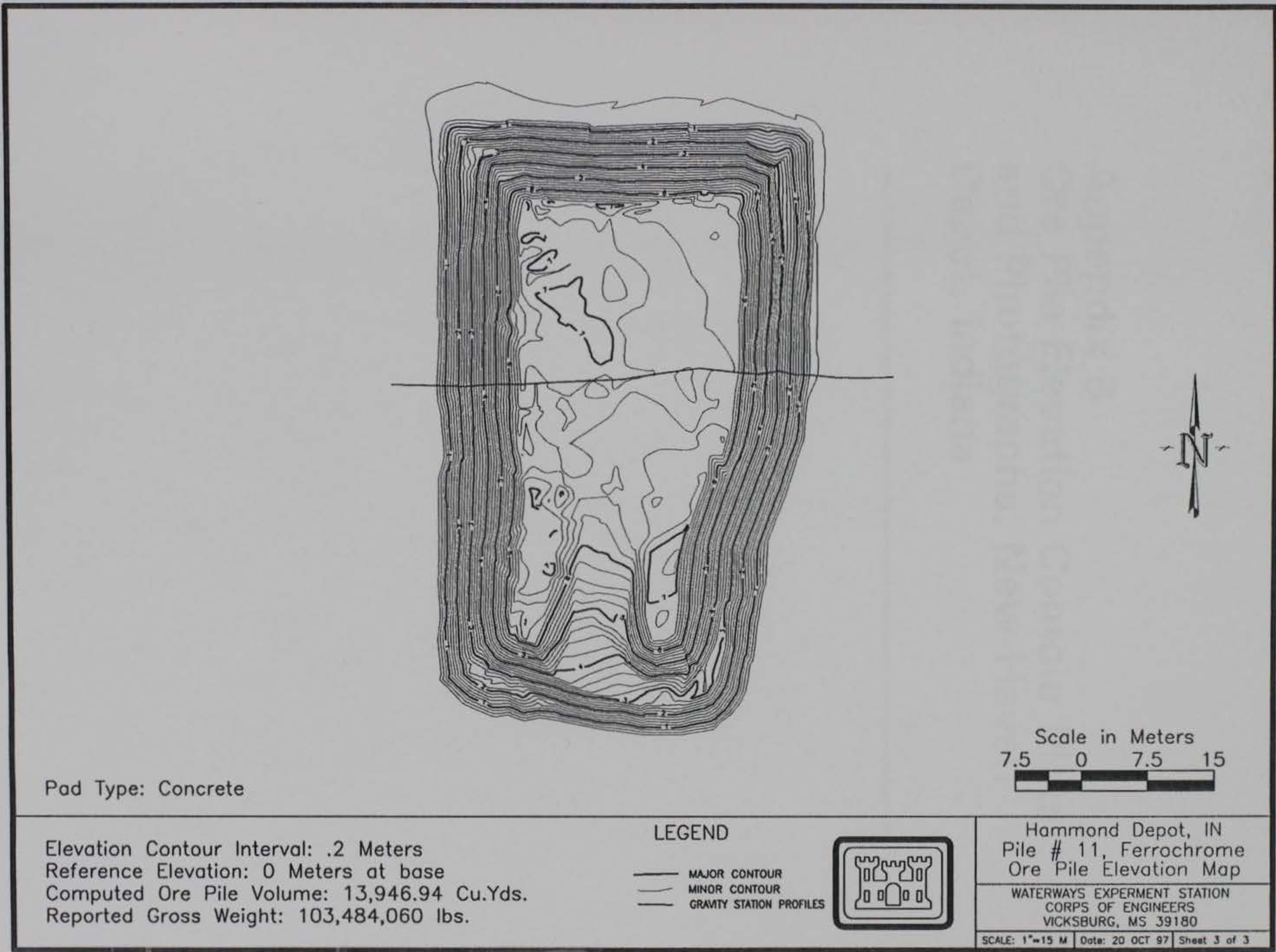


Figure A-6. Elevation contour plot of Pile #11, Hammond Depot, IN

Appendix B
Ore Pile Elevation Contour Plots and Photographs, New Haven Depot, Indiana

Figure B-1. Pile #4, New Haven Depot, IN

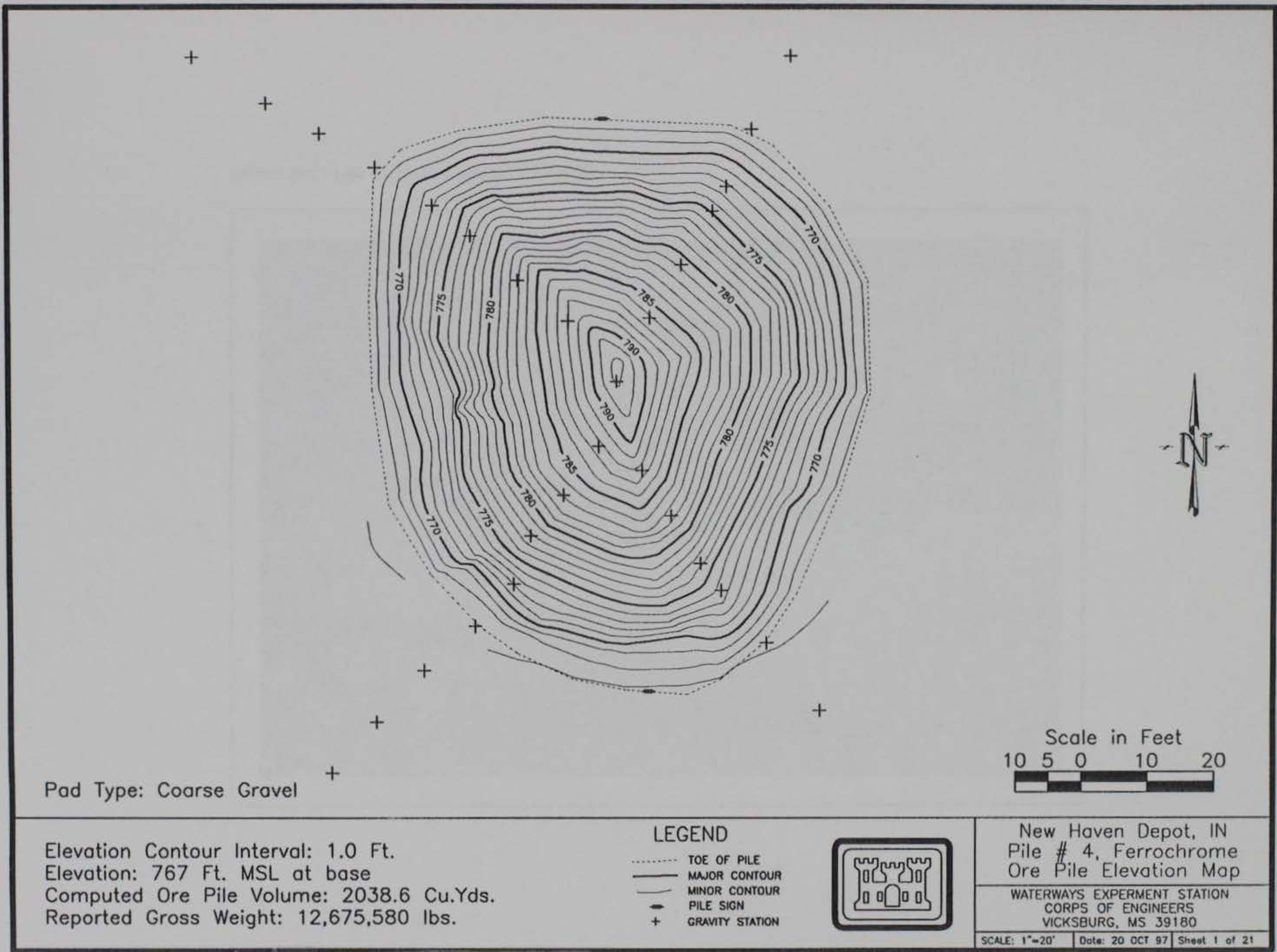


Figure B-2. Elevation contour plot of Pile #4, New Haven Depot, IN

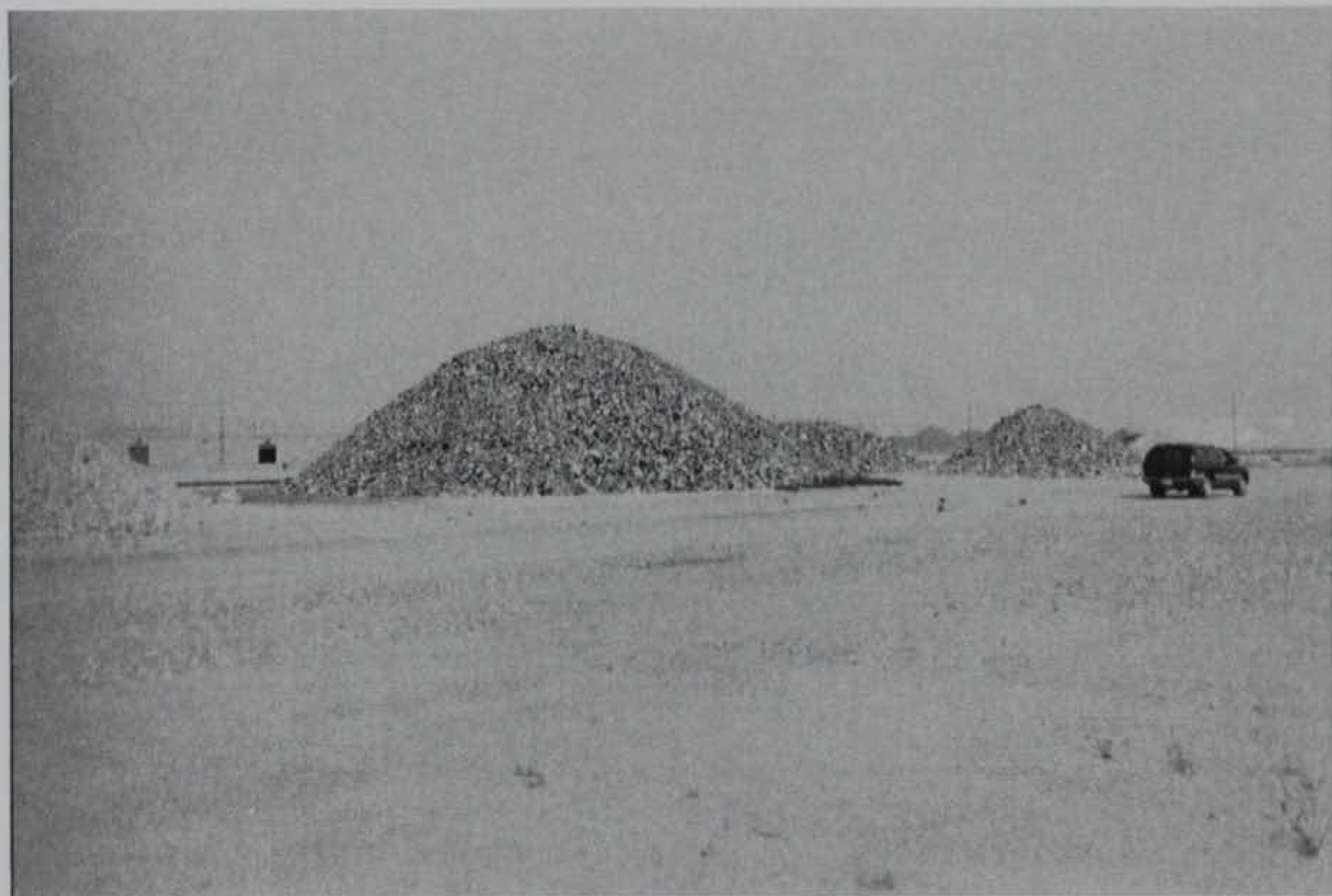


Figure B-3. Pile #11, New Haven Depot, IN

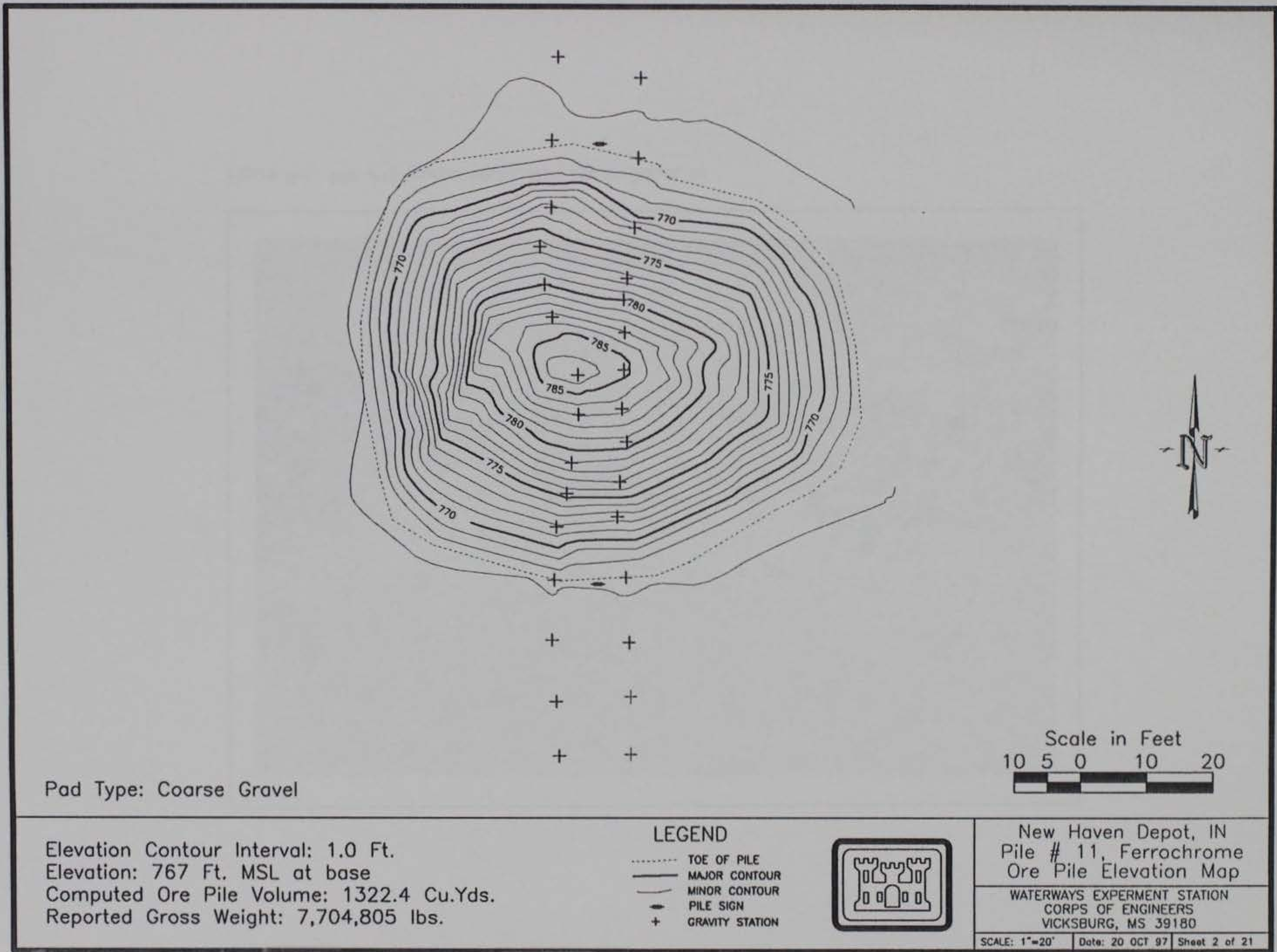


Figure B-4. Elevation contour plot of Pile #11, New Haven Depot, IN

Figure B-5. Pile #13 (center back), New Haven Depot, IN

Pad Type: Coarse Gravel

Elevation Contour Interval: 1.0 Ft.
Elevation: 767 Ft. MSL at base
Computed Ore Pile Volume: 196.56 Cu.Yds.
Reported Gross Weight: 1,143,500 lbs.

LEGEND
TOE OF PILE
MAJOR CONTOUR
MINOR CONTOUR
PILE SIGN
+ GRAVITY STATION

New Haven Depot, IN
Pile # 13, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 20 OCT 97 | Sheet 3 of 21

Figure B-6. Elevation contour plot of Pile #13, New Haven Depot, IN

Figure B-7. Pile #56, New Haven Depot, IN

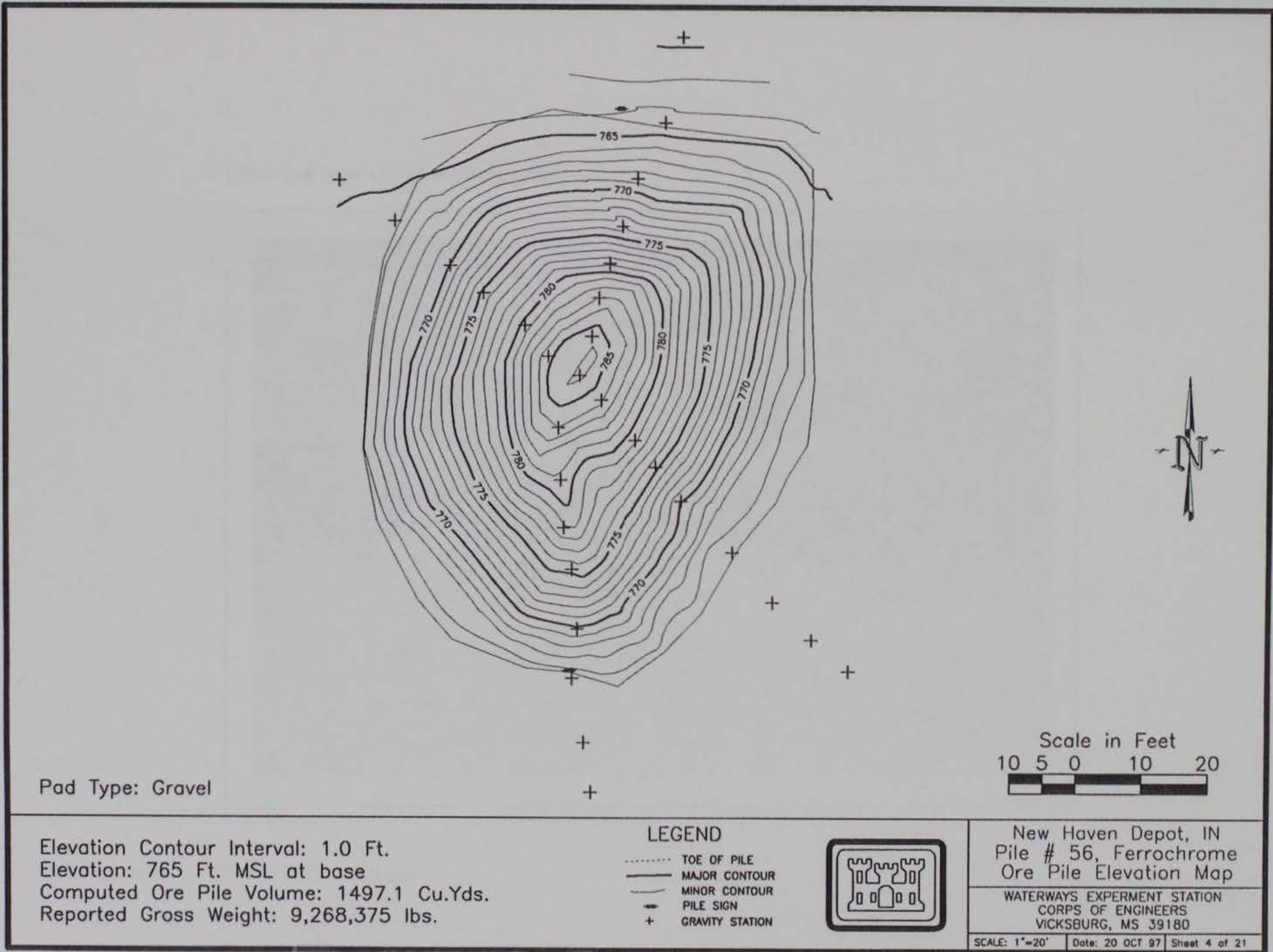


Figure B-8. Elevation contour plot of Pile #56, New Haven Depot, IN

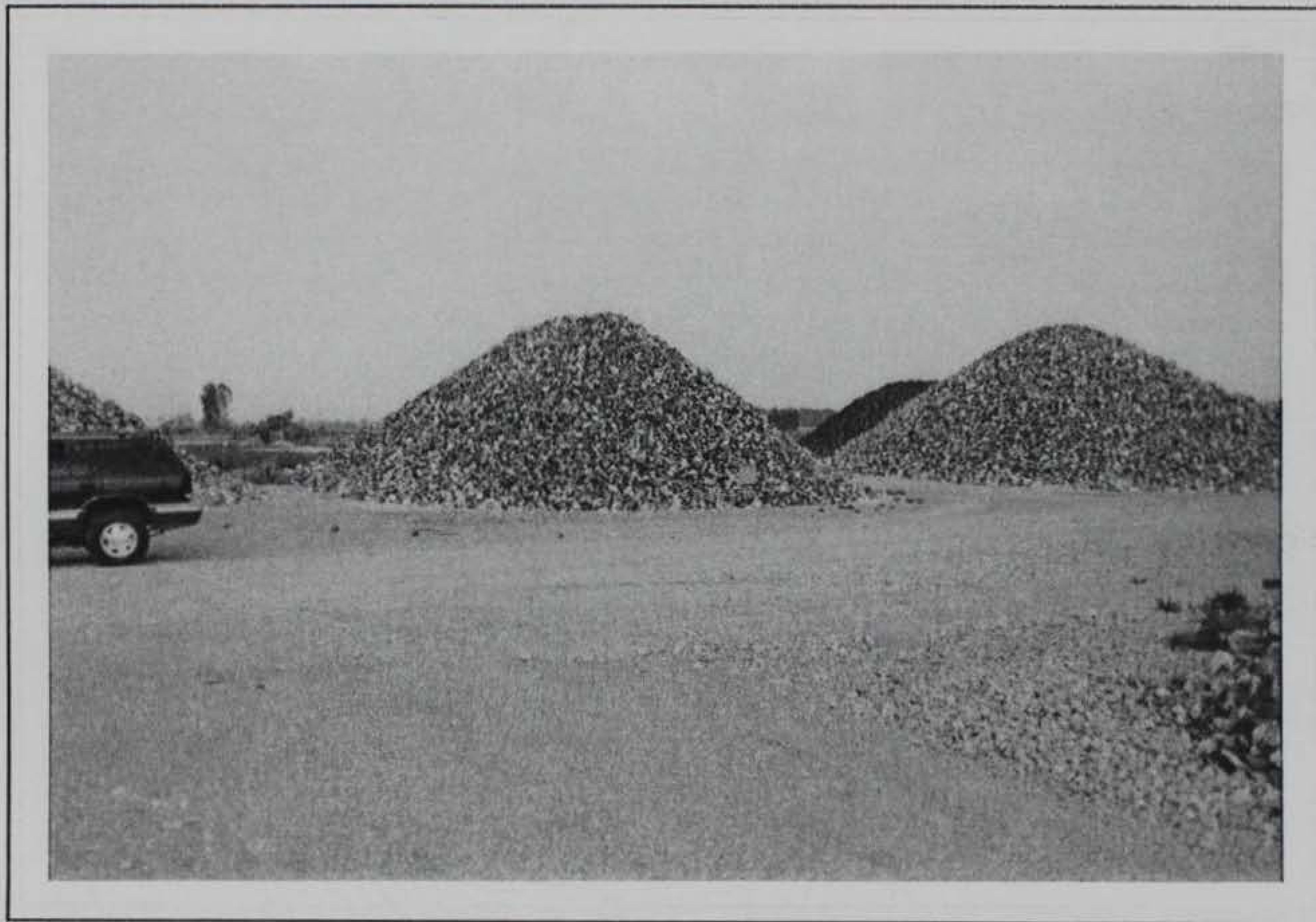


Figure B-9. Pile #57, New Haven Depot, IN

Figure B-10. Elevation contour plot of Pile #57, New Haven Depot, IN

Figure B-11. Pile #58, New Haven Depot, IN

Pad Type: Gravel

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 765 Ft. MSL at base
Computed Ore Pile Volume: 1329.15 Cu.Yds.
Reported Gross Weight: 7,913,733 lbs.

LEGEND
- TOE OF PILE
- MAJOR CONTOUR
- MINOR CONTOUR
- PILE SIGN
- GRAVITY STATION

New Haven Depot, IN
Pile # 58, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 20 OCT 97 | Sheet 6 of 21

Figure B-12. Elevation contour plot of Pile #58, New Haven Depot, IN

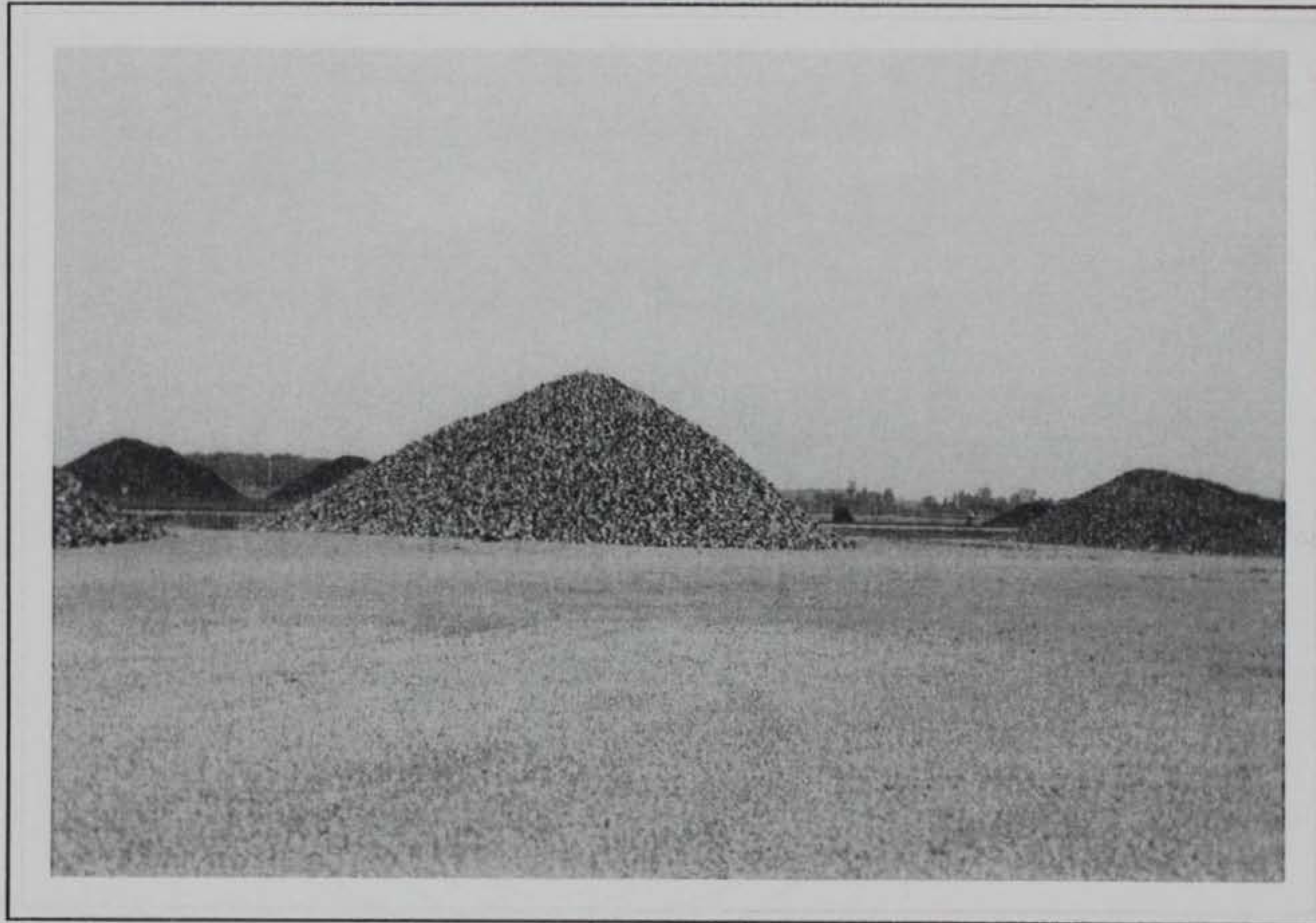


Figure B-13. Pile #61, New Haven Depot, IN

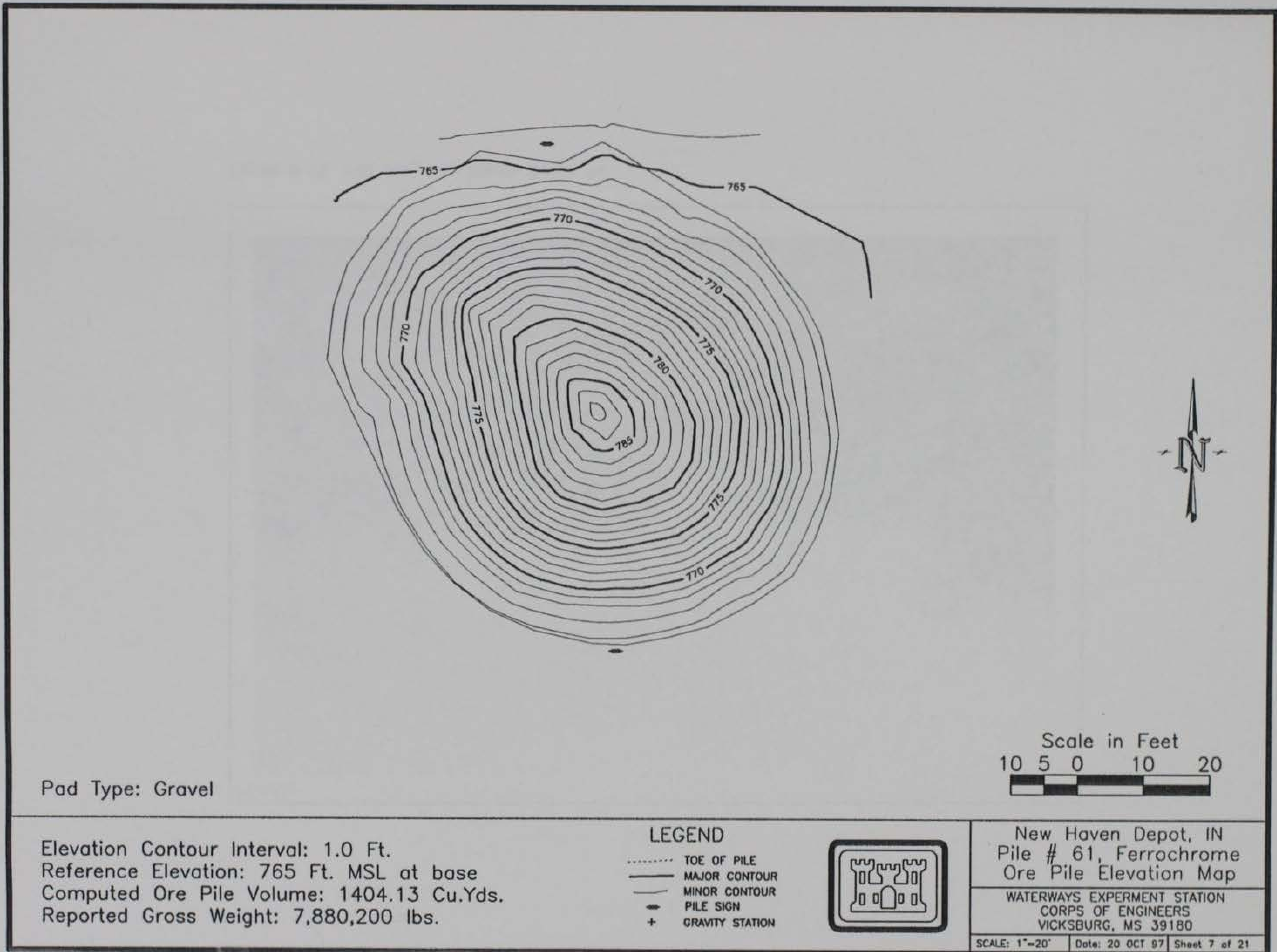
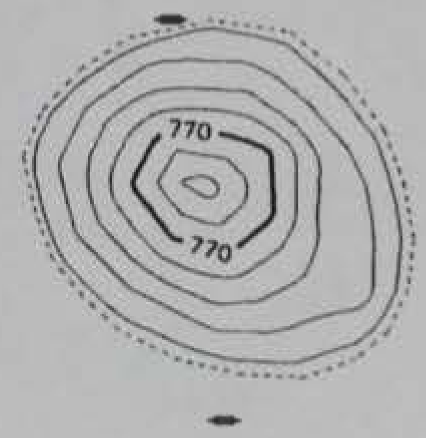


Figure B-14. Elevation contour plot of Pile #61, New Haven Depot, IN

Figure B-15. Pile #67, New Haven Depot, IN



Scale in Feet

10 5 0 10 20

Pad Type: Coarse Gravel

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 765 Ft. MSL at base
Computed Ore Pile Volume: 59.4 Cu.Yds.
Reported Gross Weight: 293,250 lbs.

LEGEND

- TOE OF PILE
- MAJOR CONTOUR
- MINOR CONTOUR
- PILE SIGN
- GRAVITY STATION

New Haven Depot, IN
Pile # 67, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'	Date: 20 OCT 97	Sheet 8 of 21

Figure B-16. Elevation contour plot of Pile #67, New Haven Depot, IN

Figure B-17. Pile #68 (center left), New Haven Depot, IN. The smaller pile to the right is Pile #67

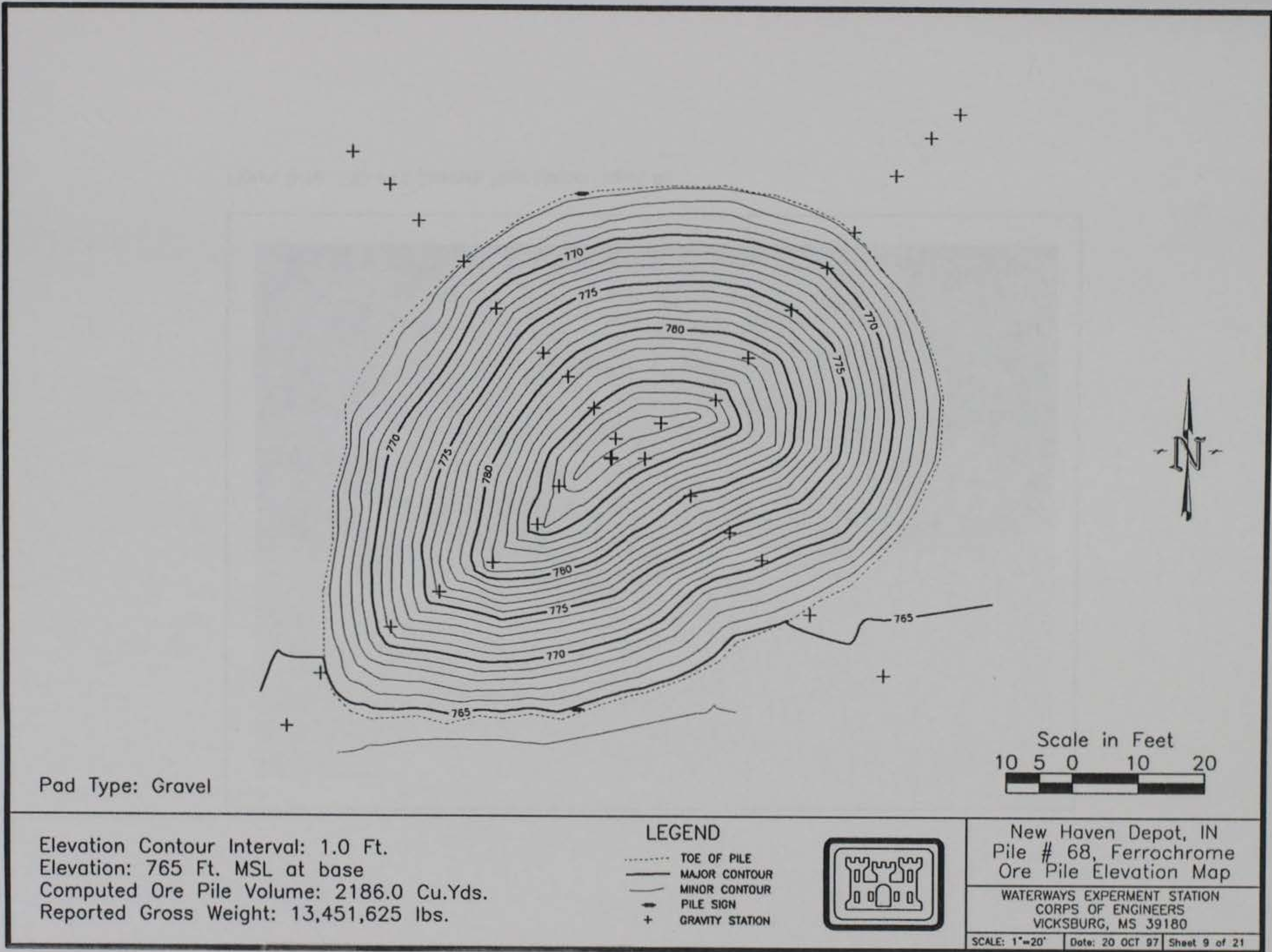


Figure B-18. Elevation contour plot of Pile #68, New Haven Depot, IN

Figure B-19. Pile #71 (center), New Haven Depot, IN

Scale in Feet

10 5 0 10 20

Pad Type: Gravel

Elevation Contour Interval: 1.0 Ft.
Elevation: 765 Ft. MSL at base
Computed Ore Pile Volume: 1288.4 Cu.Yds.
Reported Gross Weight: 7,563,860 lbs.

LEGEND

- TOE OF PILE
- MAJOR CONTOUR
- MINOR CONTOUR
- PILE SIGN
- + GRAVITY STATION

New Haven Depot, IN
Pile # 71, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'	Date: 20 OCT 97	Sheet 10 of 21

Figure B-20. Elevation contour plot of Pile #71, New Haven Depot, IN

Figure B-21. Pile #20, New Haven Depot, IN

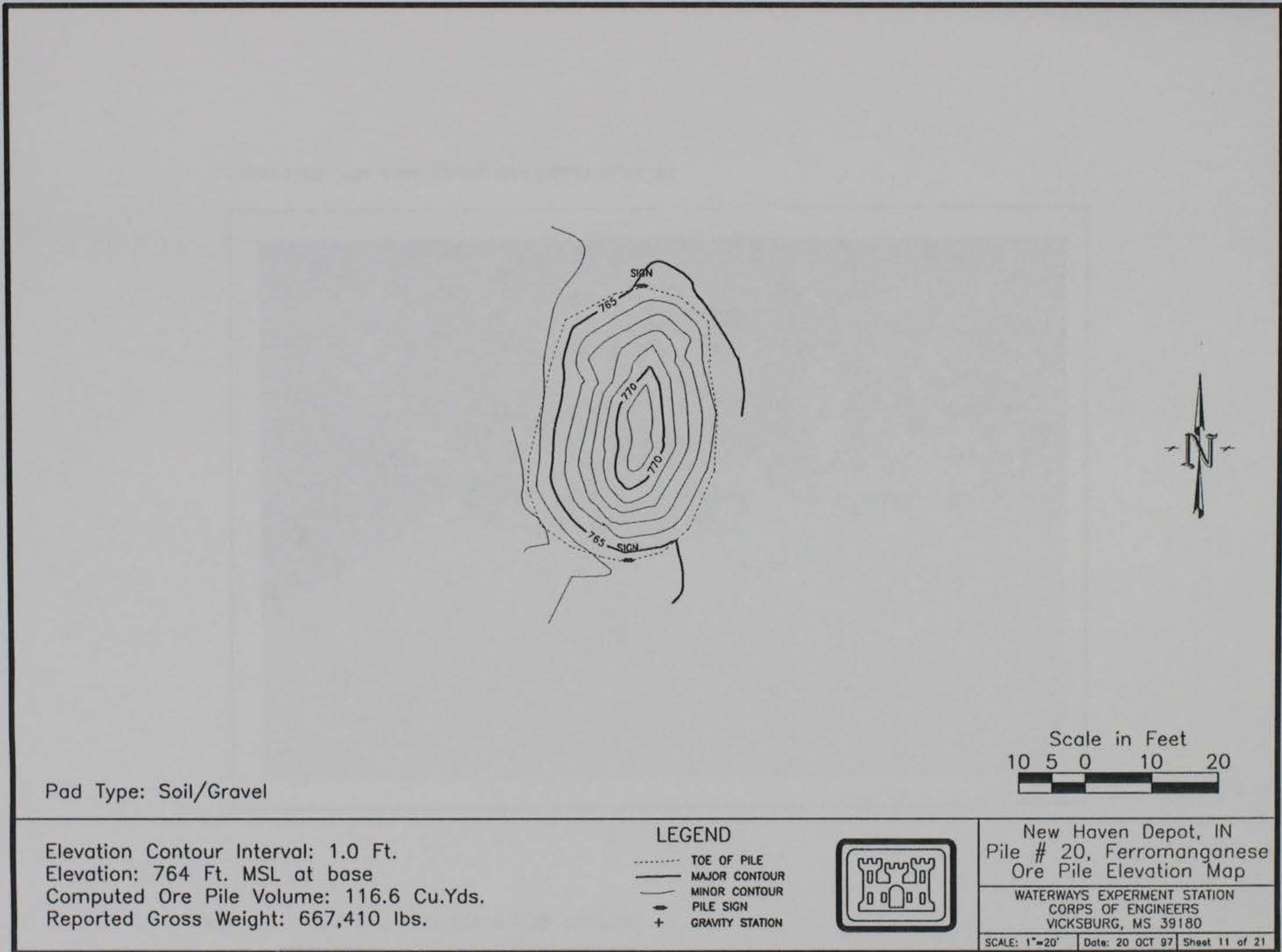
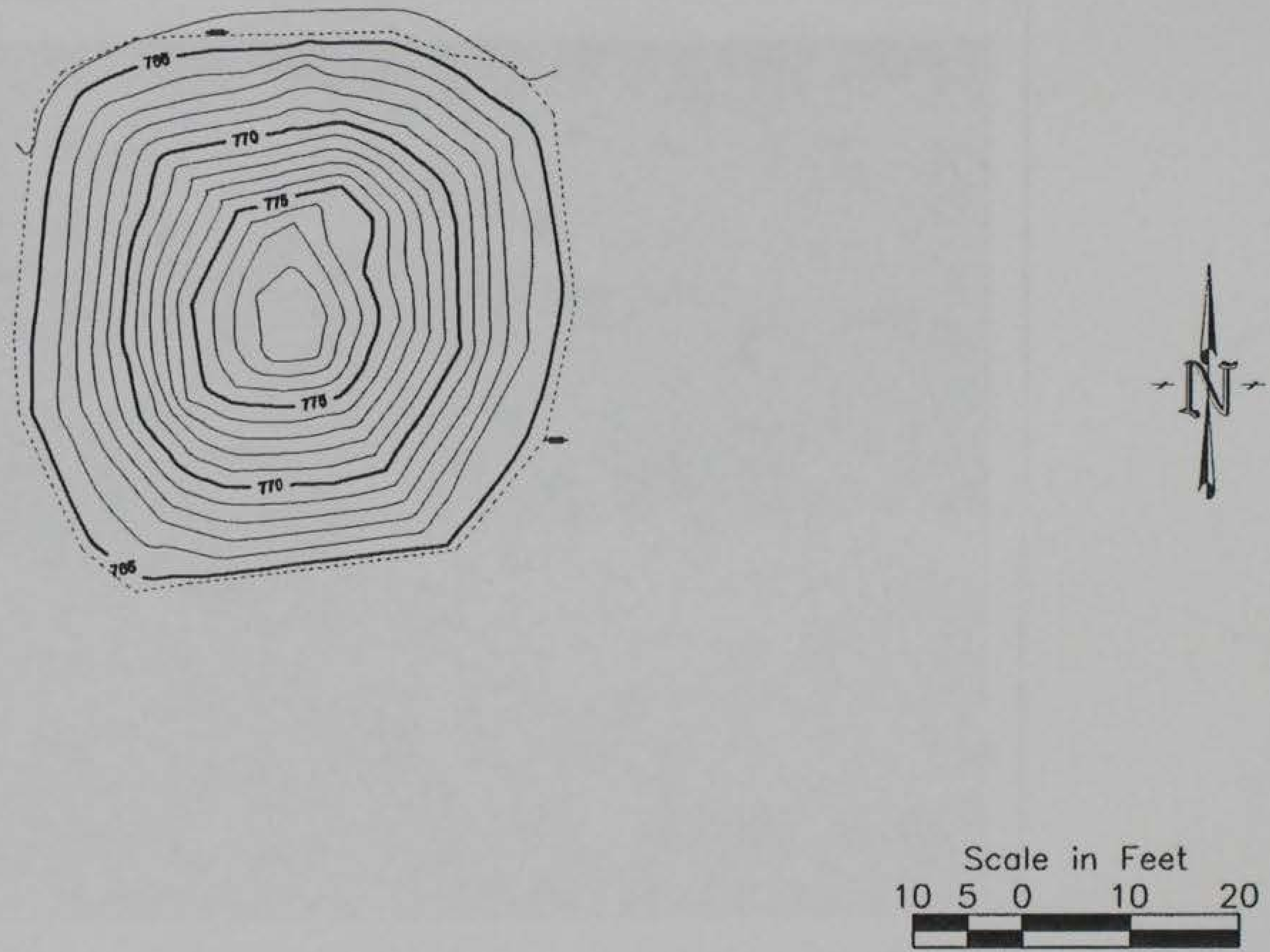


Figure B-22. Elevation contour plot of Pile #20, New Haven Depot, IN

Figure B-23. Pile #23A (back), New Haven Depot, IN



Pad Type: Soil/Gravel

Elevation Contour Interval: 1.0 Ft.
Elevation: 964 Ft. MSL at base
Computed Ore Pile Volume: 495.5 Cu.Yds.
Reported Gross Weight: 3,151,400 lbs.–Piles 23A & 23B combined

LEGEND
TOE OF PILE
MAJOR CONTOUR
MINOR CONTOUR
PILE SIGN
GRAVITY STATION

New Haven Depot, IN
Pile # 23A, Ferromanganese Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 20 OCT 97 | Sheet 12 of 21

Figure B-24. Elevation contour plot of Pile #23A, New Haven Depot, IN

Figure B-25. Pile #23B (center), New Haven Depot, IN

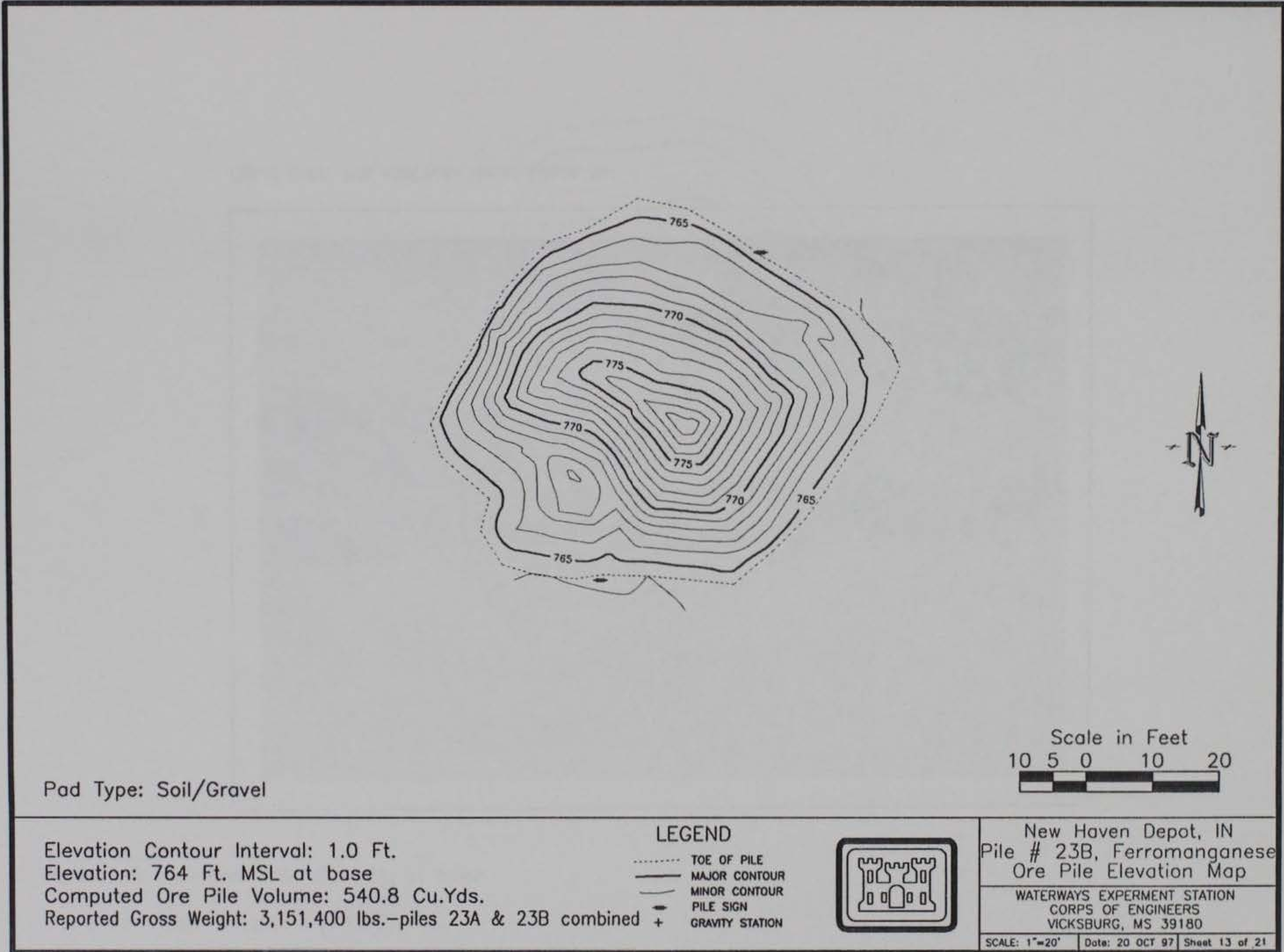


Figure B-26. Elevation contour plot of Pile #23B, New Haven Depot, IN

Figure B-27. Pile #28, New Haven Depot, IN

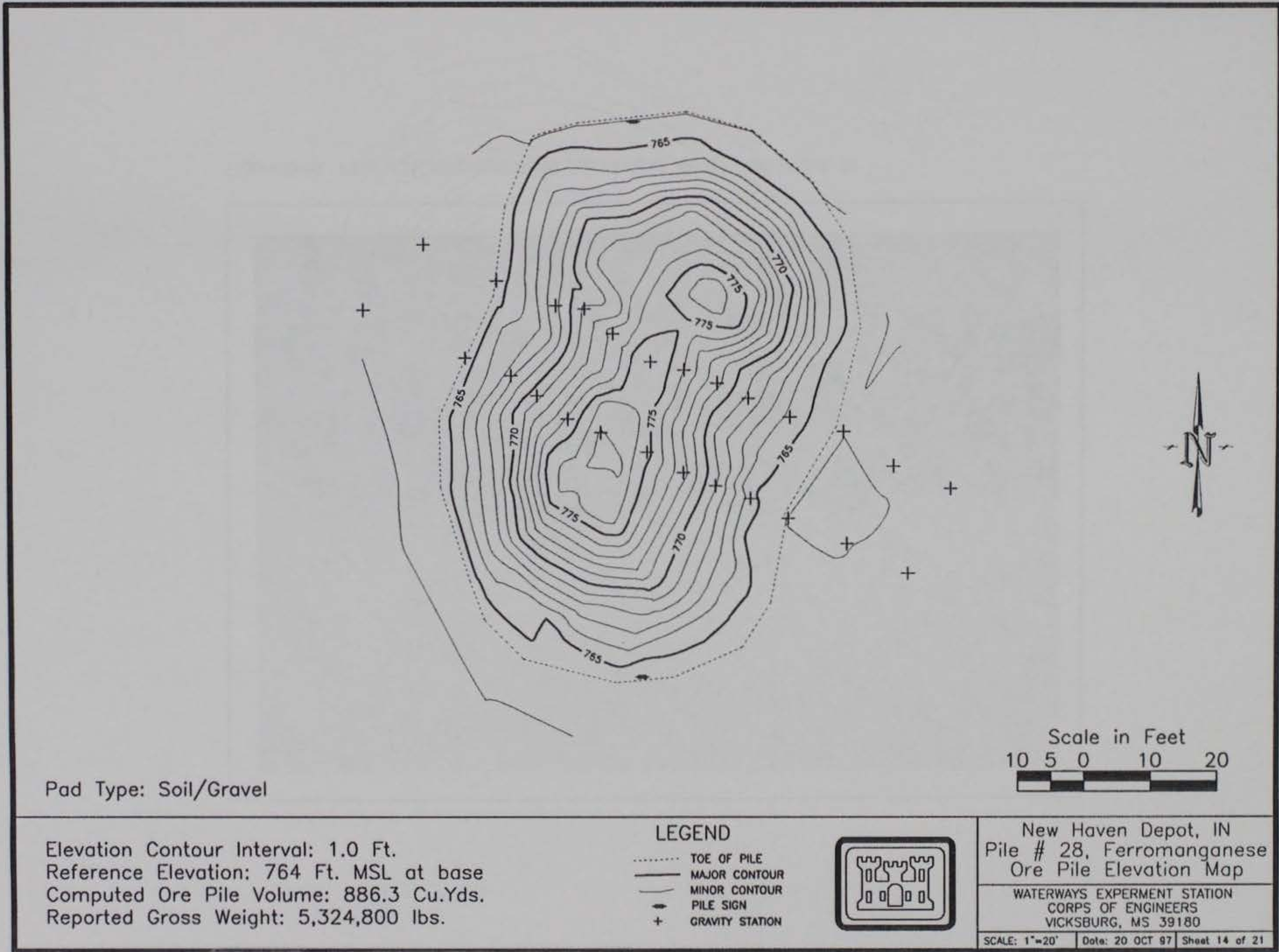


Figure B-28. Elevation contour plot of Pile #28, New Haven Depot, IN

Figure B-29. Piles #31, #32, and #23B (left to right), New Haven Depot, IN

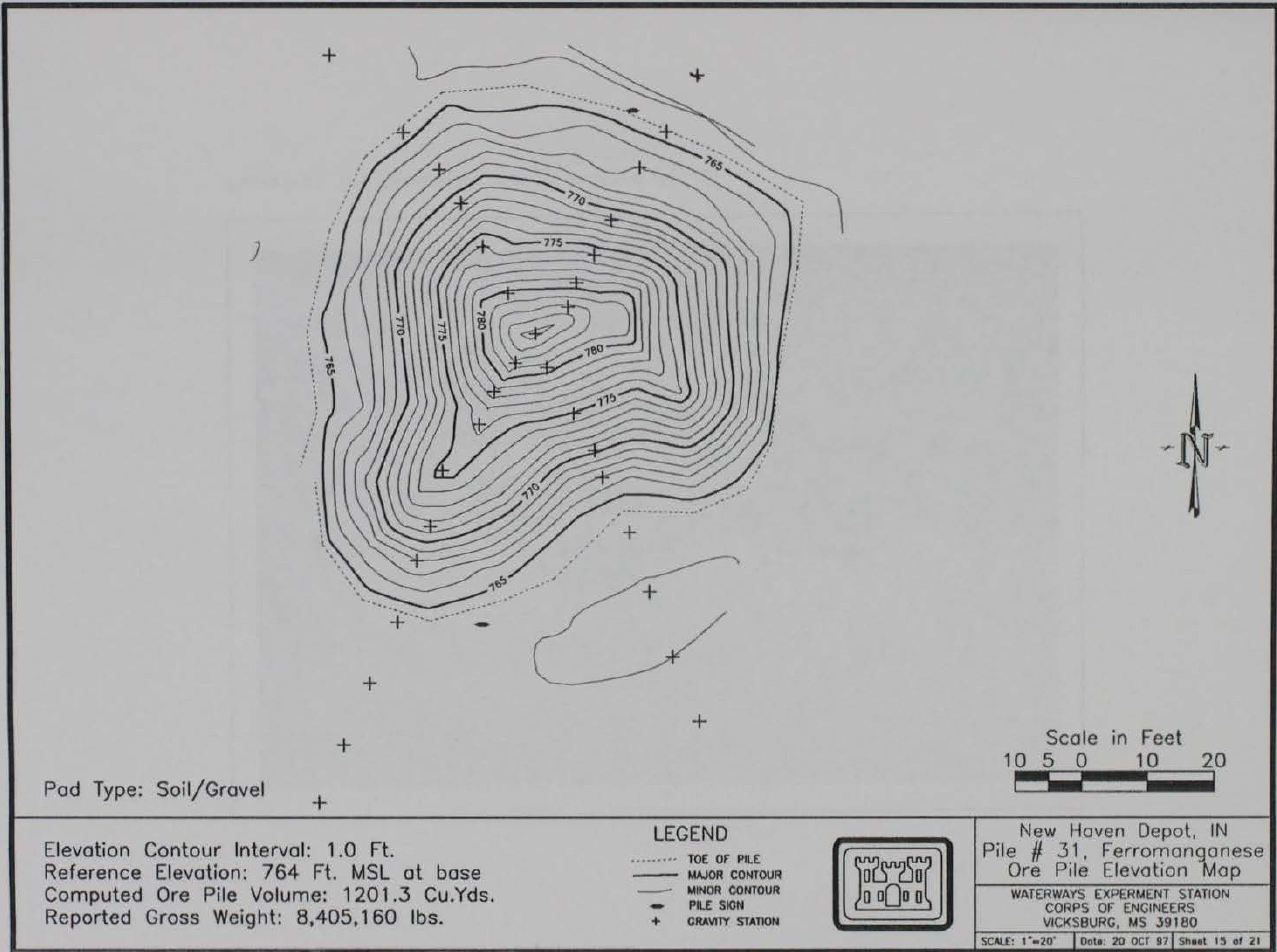


Figure B-30. Elevation contour plot of Pile #31, New Haven Depot, IN

Figure B-31. Pile #32 (center), New Haven Depot, IN

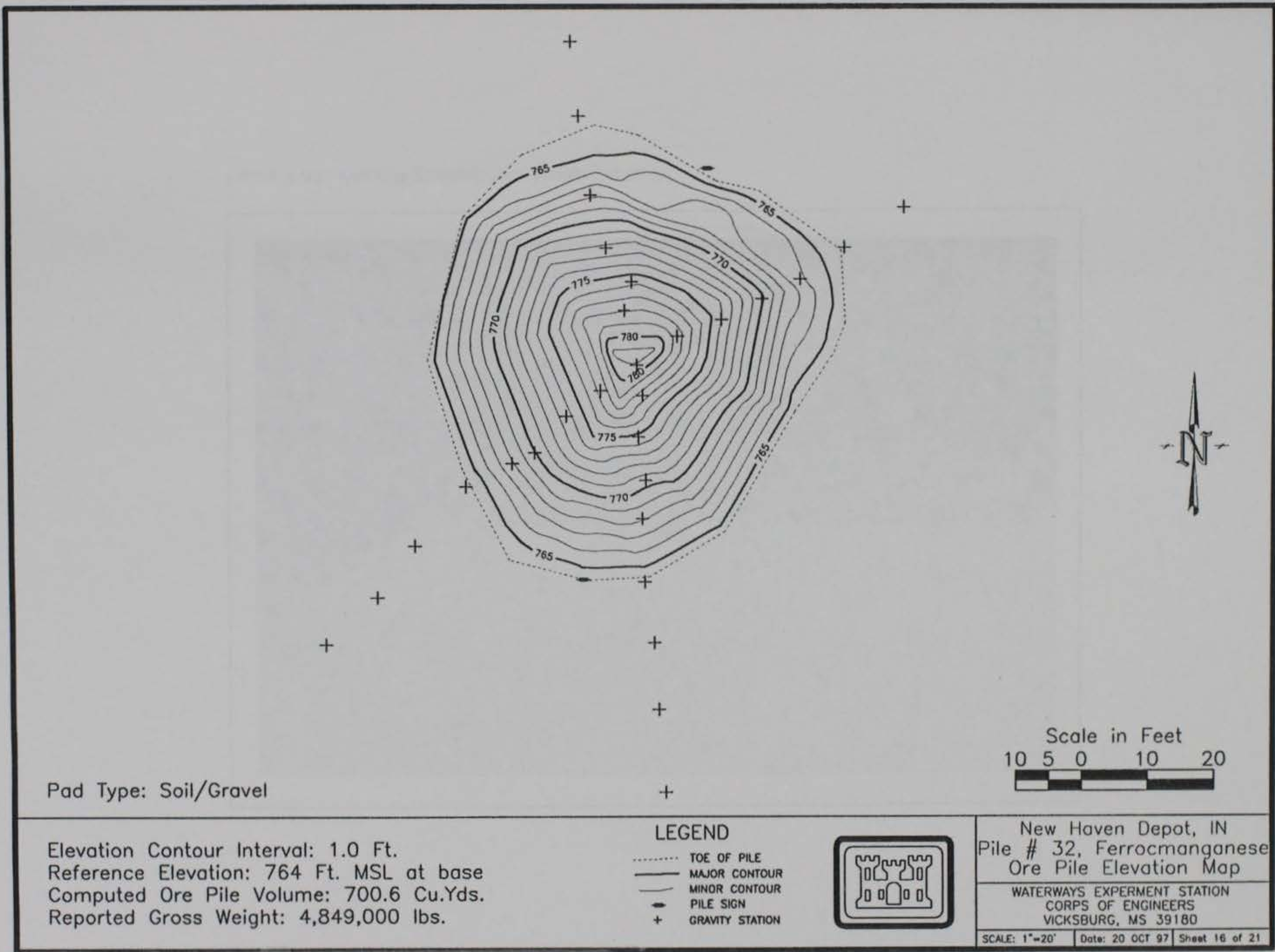


Figure B-32. Elevation contour plot of Pile #32, New Haven Depot, IN

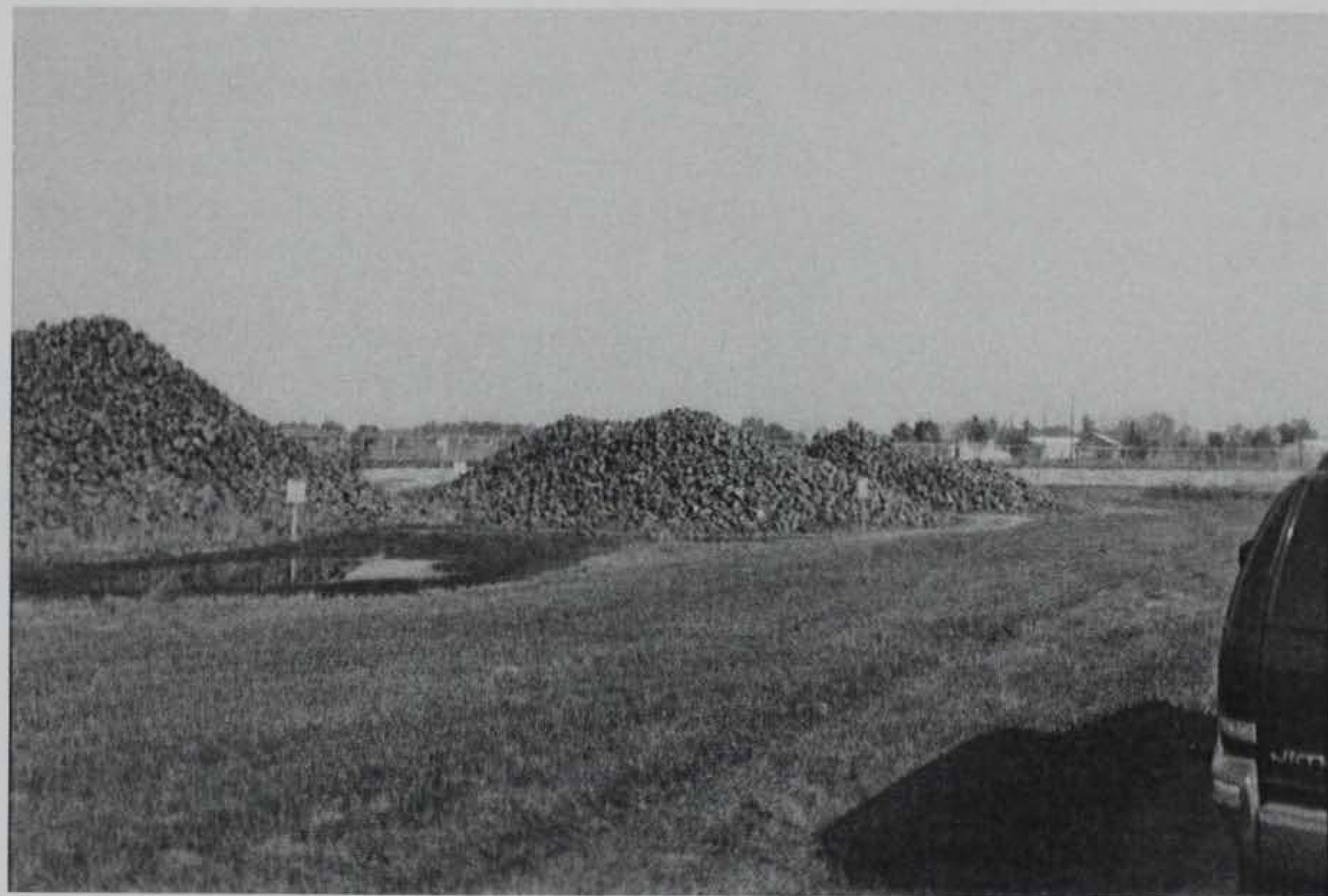


Figure B-33. Pile #34 (center), New Haven Depot, IN

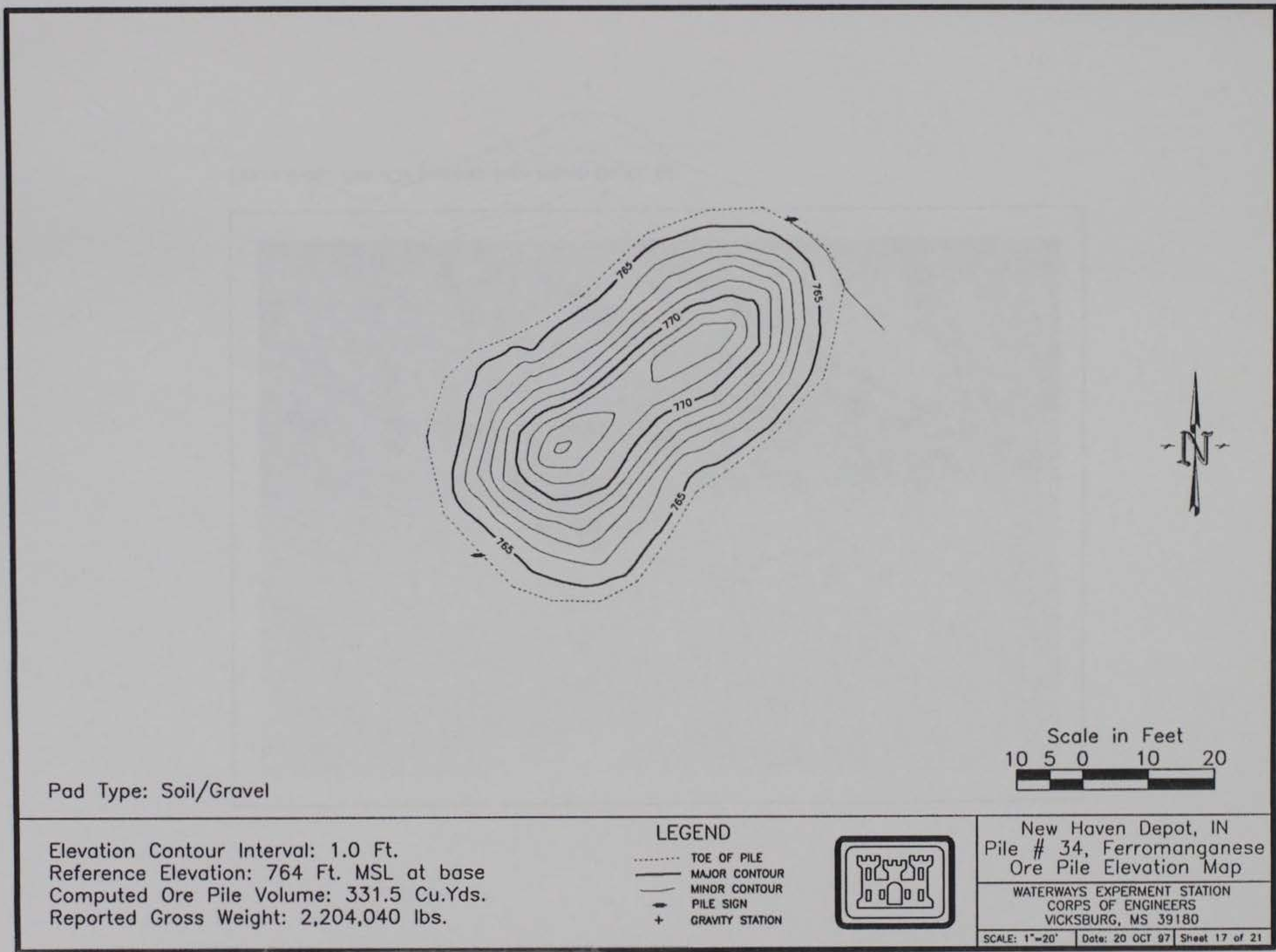


Figure B-34. Elevation contour plot of Pile #34, New Haven Depot, IN

Figure B-35. Pile #37 (center), New Haven Depot, IN

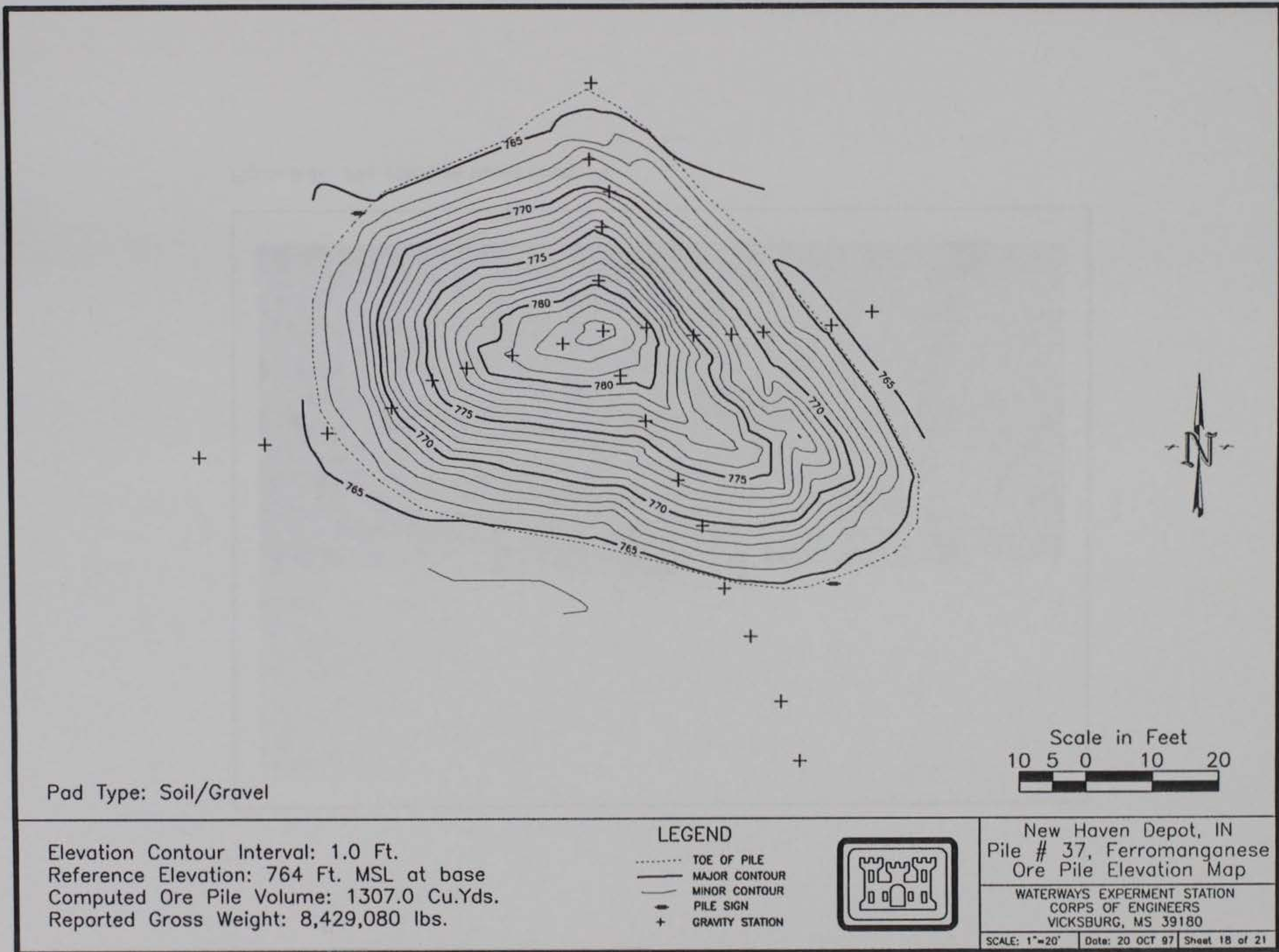


Figure B-36. Elevation contour plot of Pile #37, New Haven Depot, IN

Figure B-37. Pile #38, New Haven Depot, IN

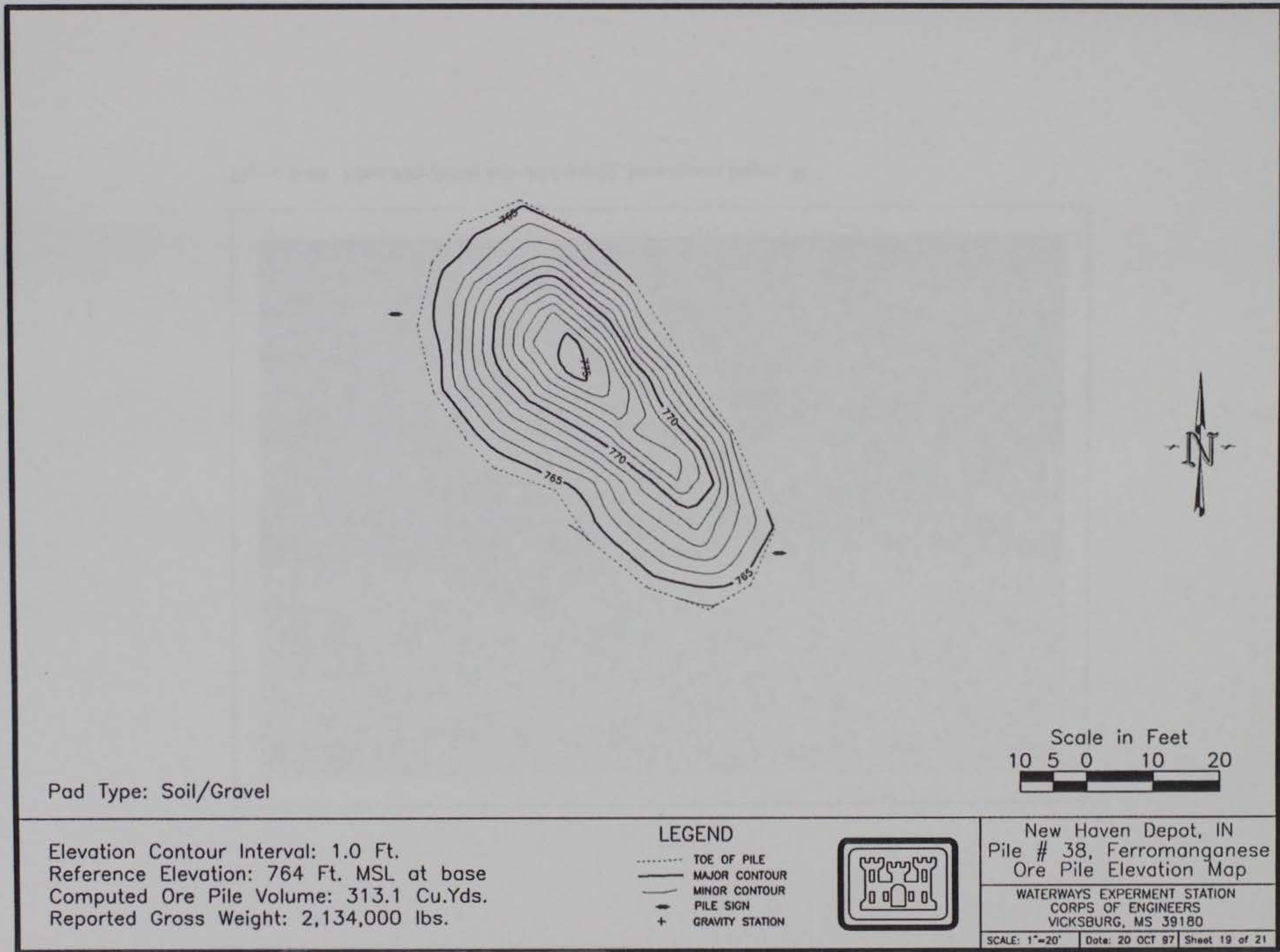


Figure B-38. Elevation contour plot of Pile #38, New Haven Depot, IN

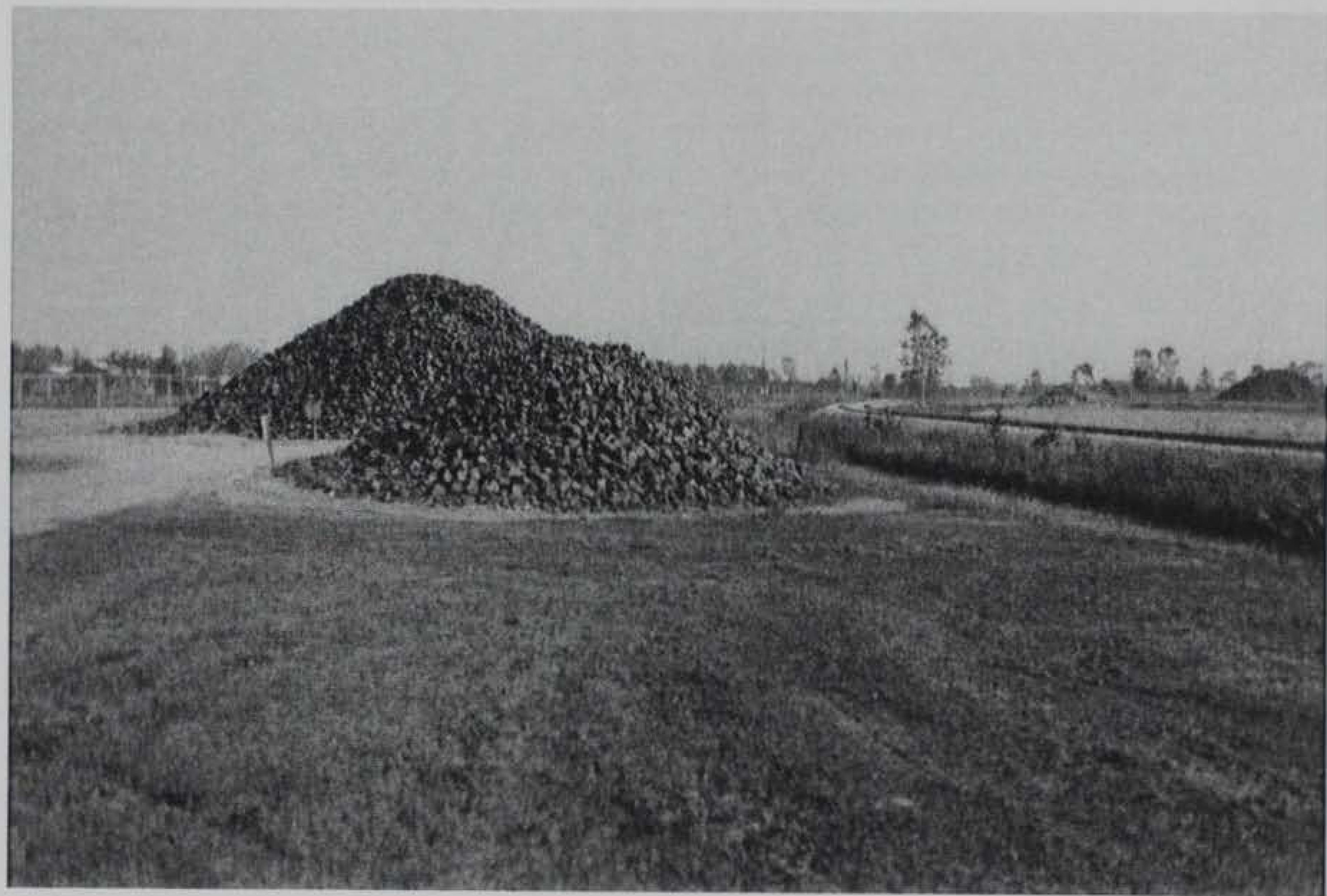


Figure B-39. Piles #39 (front) and #37 (back), New Haven Depot, IN

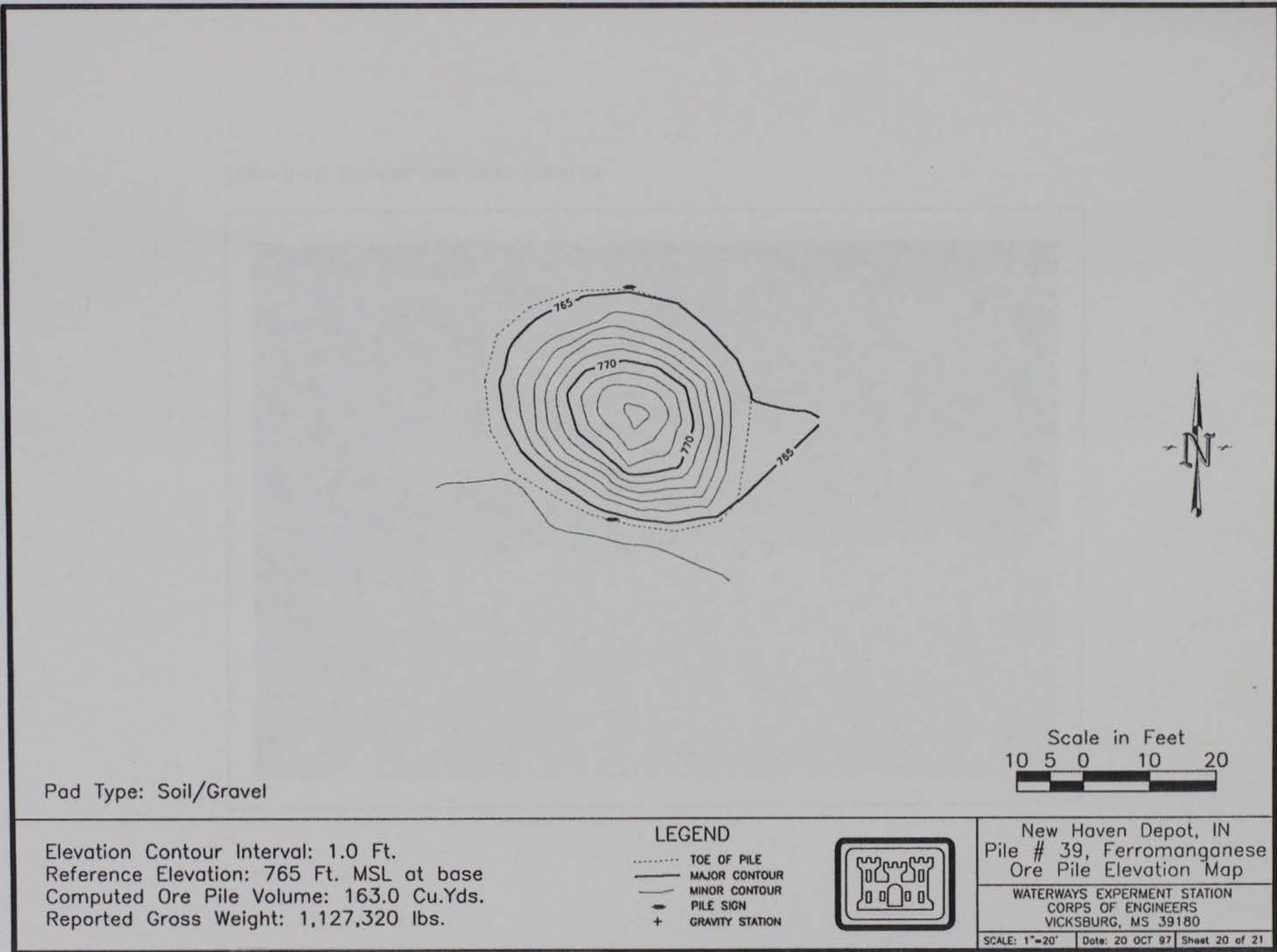


Figure B-40. Elevation contour plot of Pile #39, New Haven Depot, IN

Figure B-41. Pile #45, New Haven Depot, IN

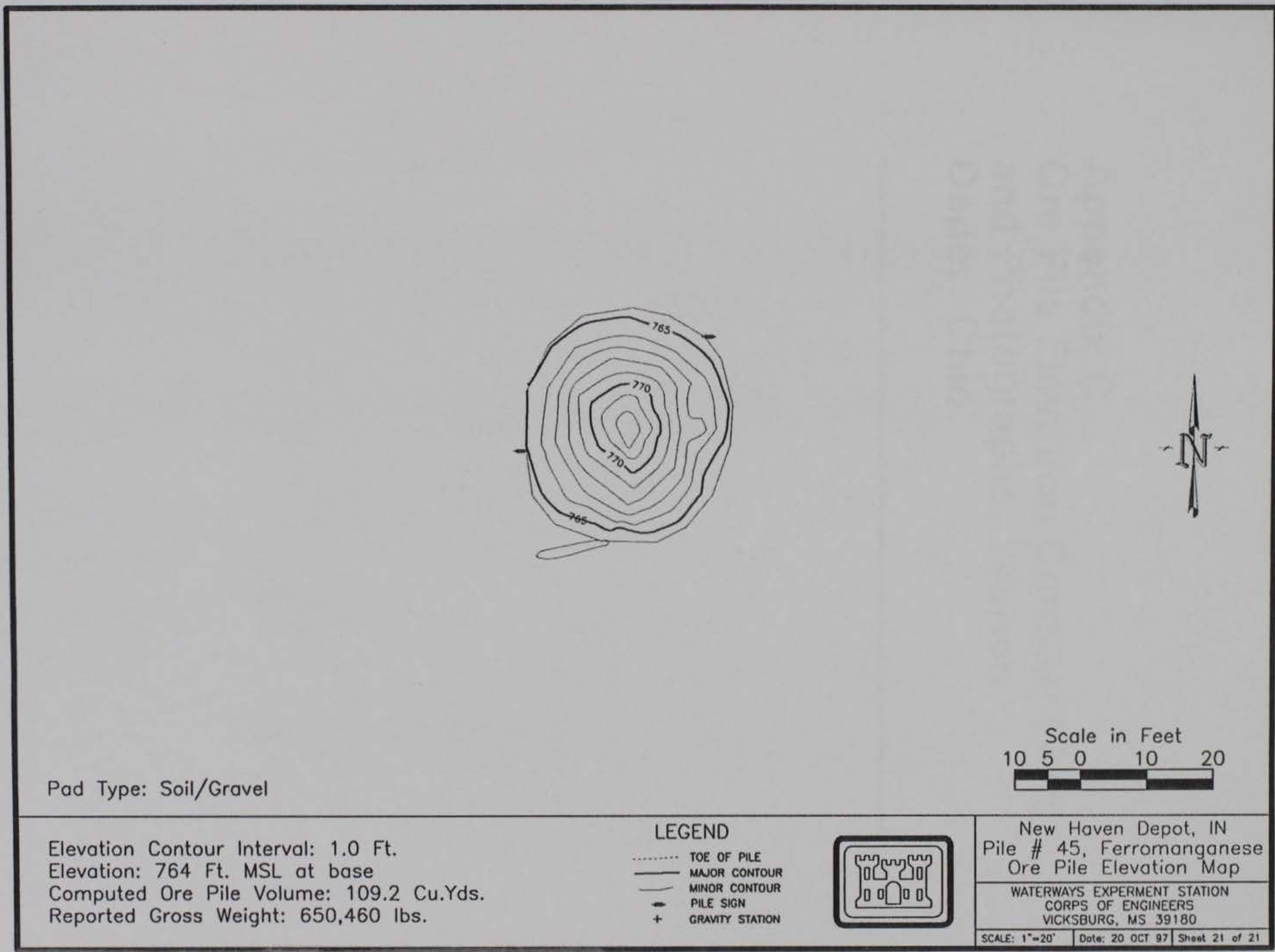


Figure B-42. Elevation contour plot of Pile #45, New Haven Depot, IN

Appendix C
Ore Pile Elevation Contour Plots and Photographs, Warren Depot, Ohio

Figure C-1. Pile #25, Warren Depot, OH

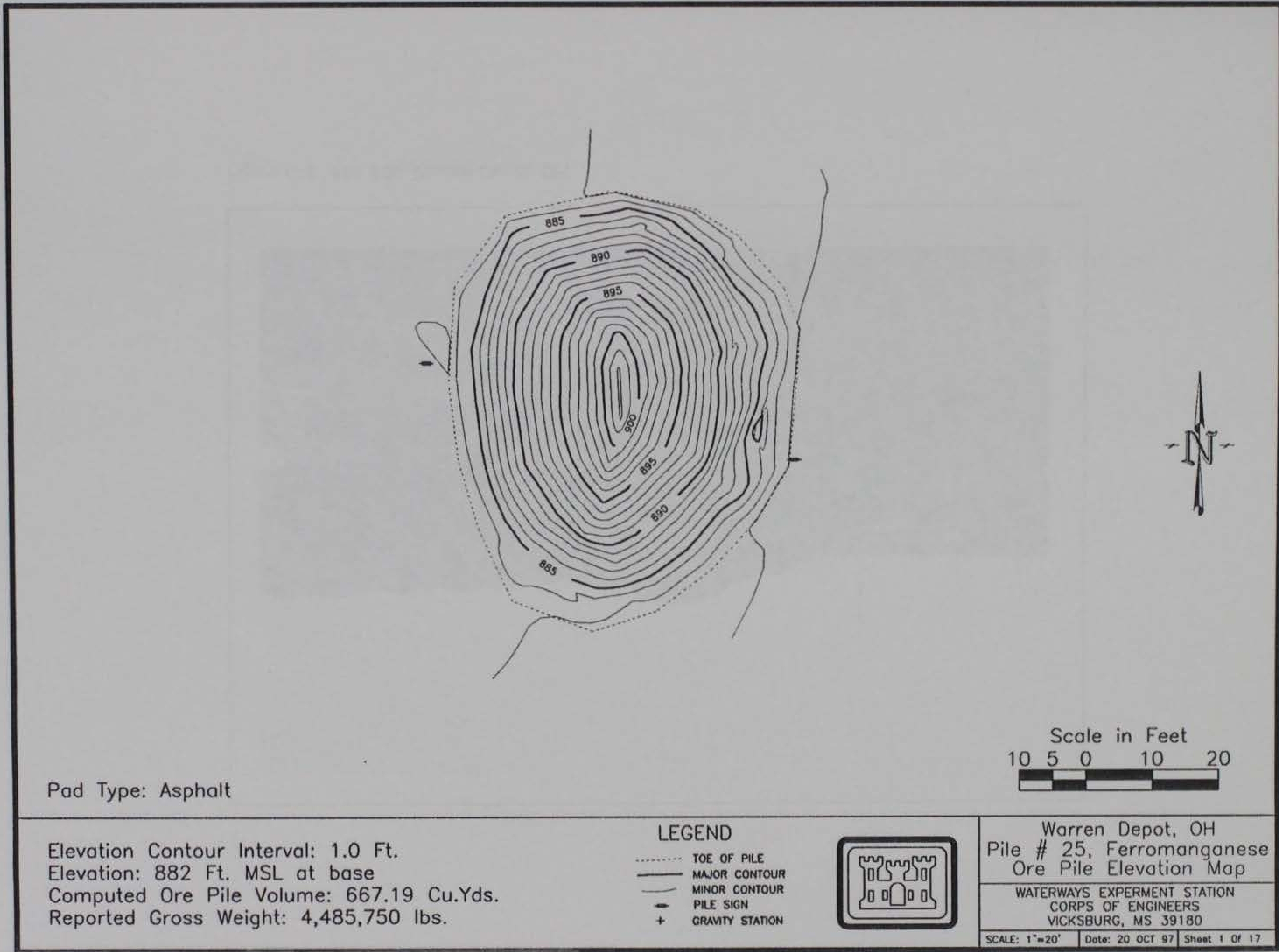


Figure C-2. Elevation contour plot of Pile #25, Warren Depot, OH

Figure C-3. Pile #26, Warren Depot, OH

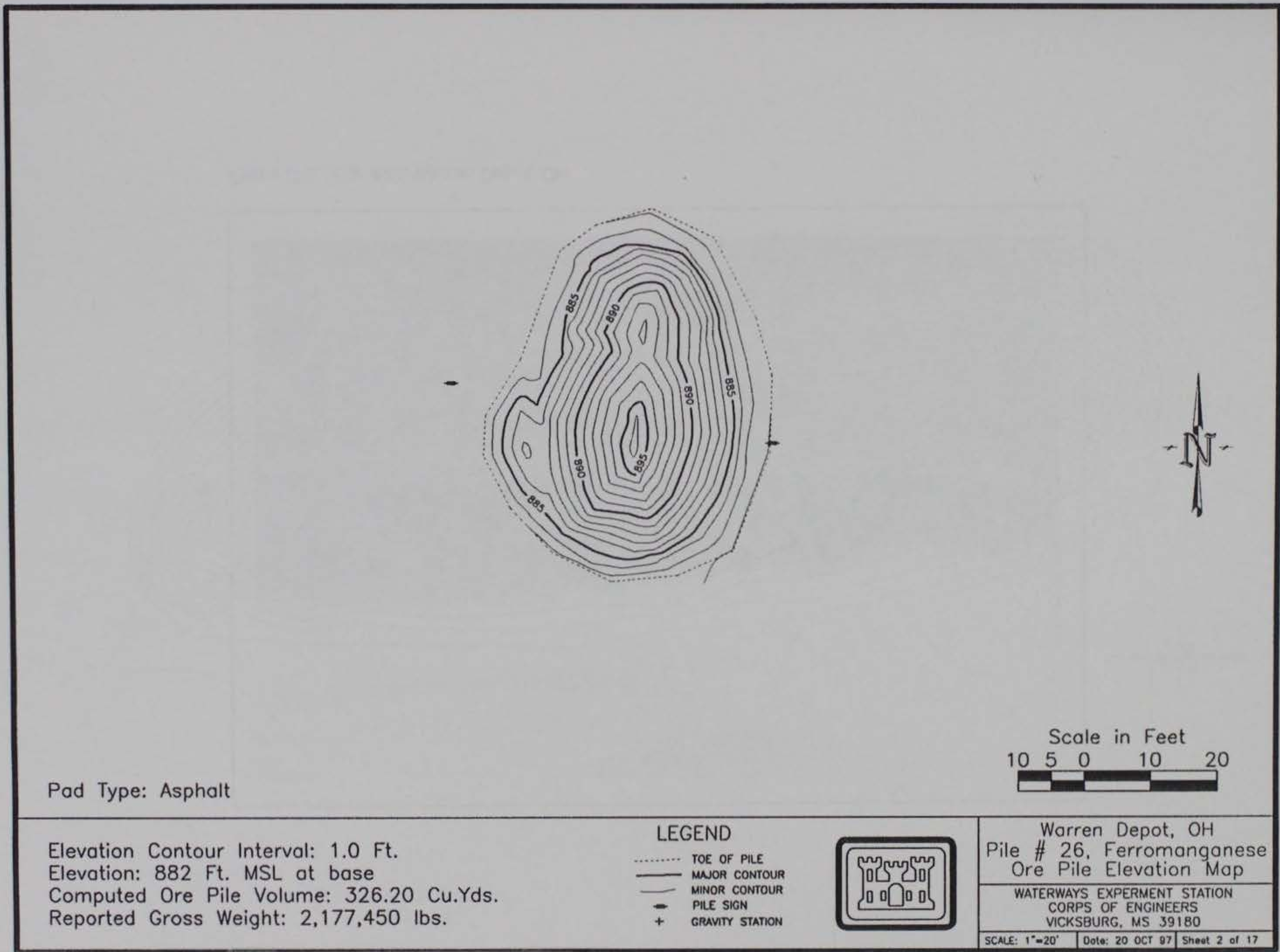


Figure C-4. Elevation contour plot of Pile #26, Warren Depot, OH

Figure C-5. Pile #27, Warren Depot, OH

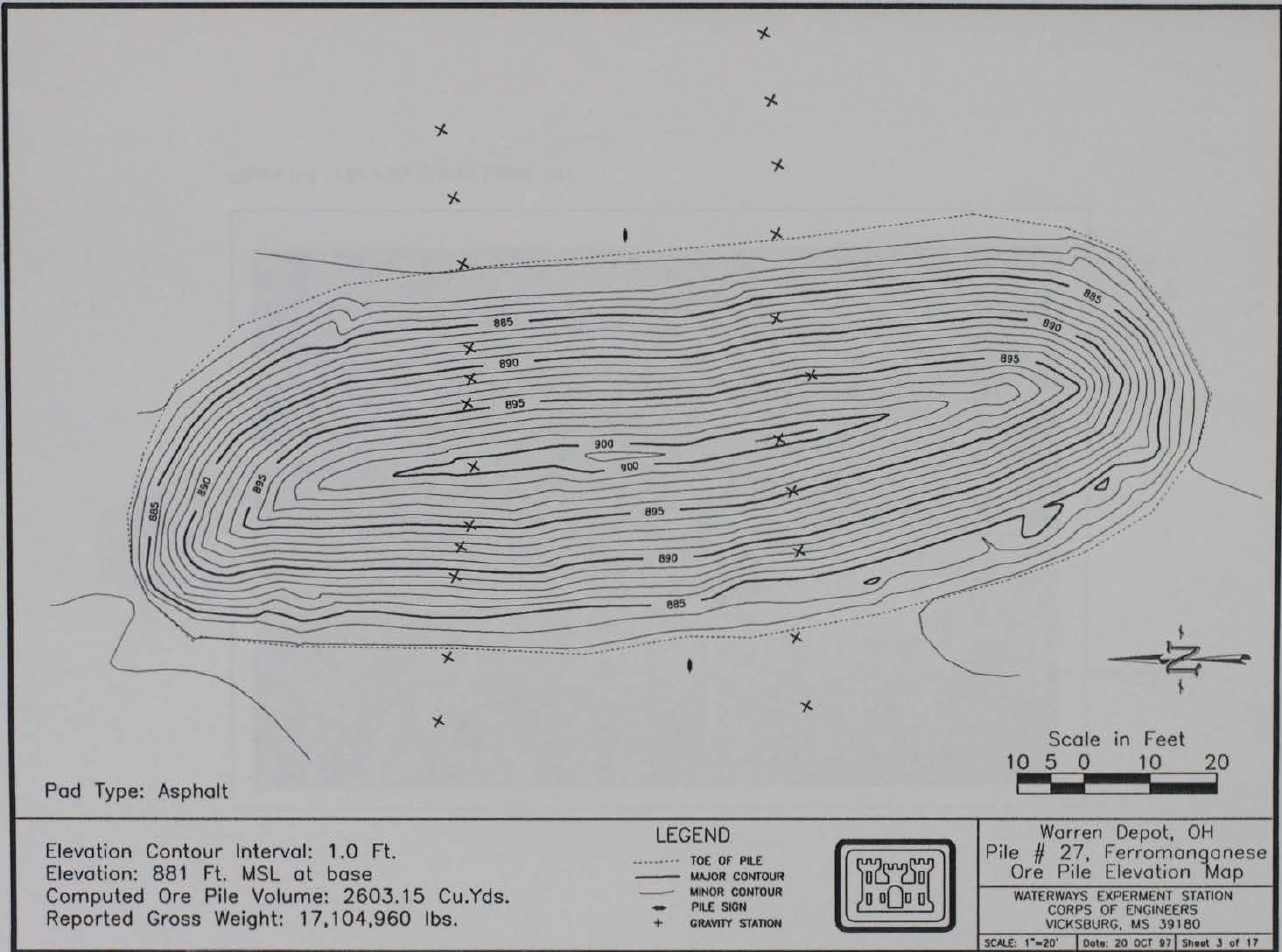


Figure C-6. Elevation contour plot of Pile #27, Warren Depot, OH

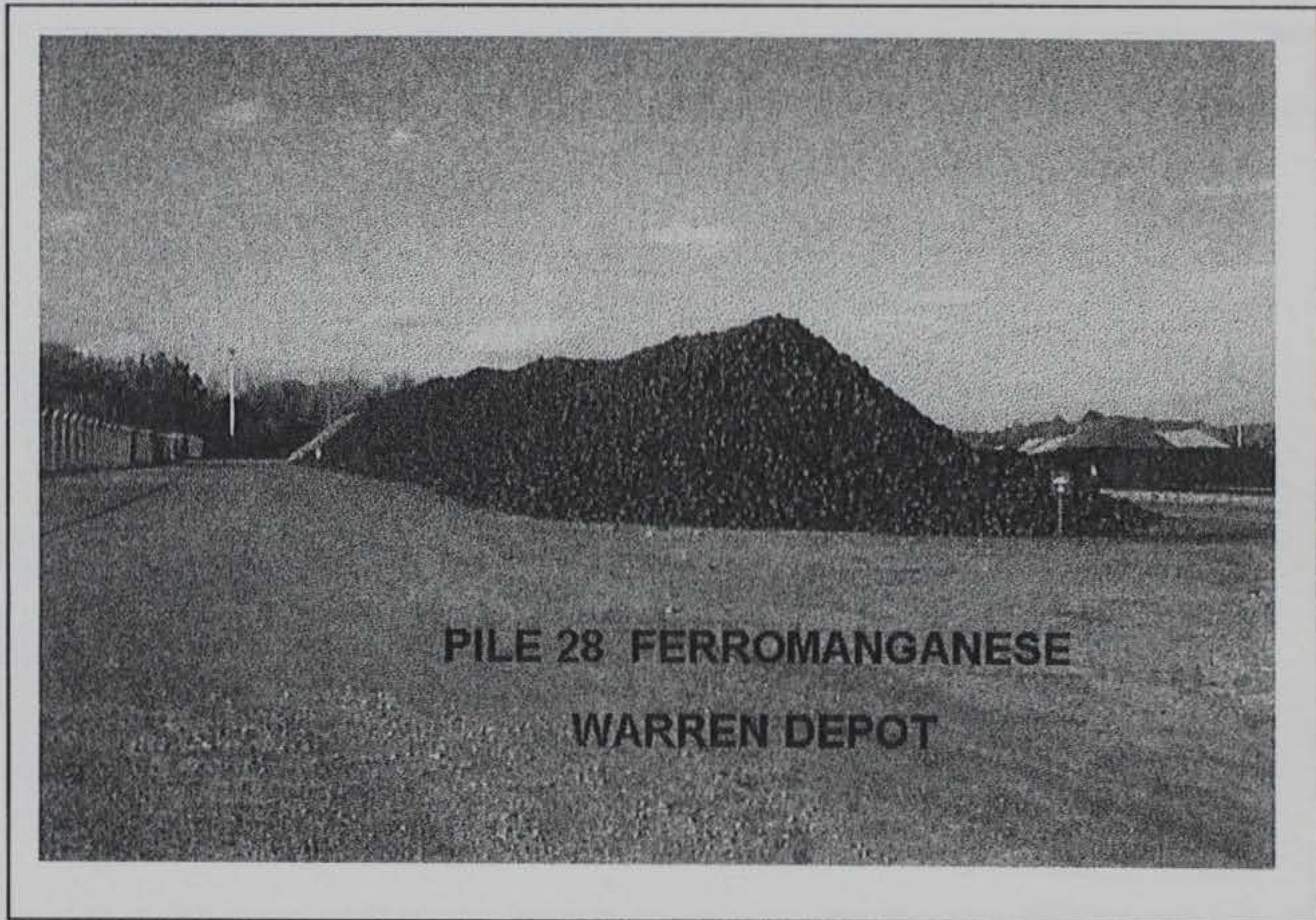


Figure C-7. Pile #28, Warren Depot, OH

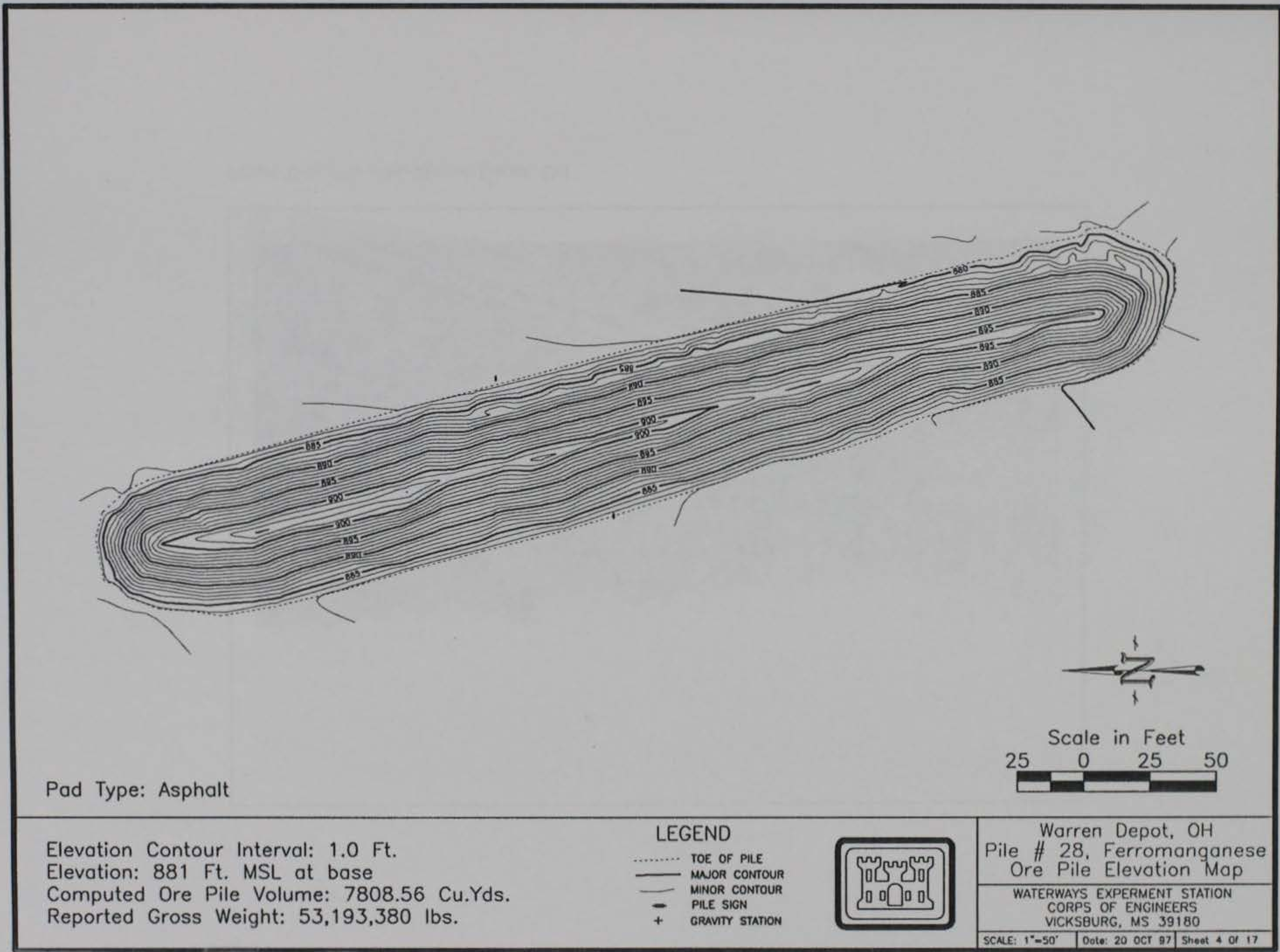


Figure C-8. Elevation contour plot of Pile #28, Warren Depot, OH

Figure C-9. Pile #34, Warren Depot, OH

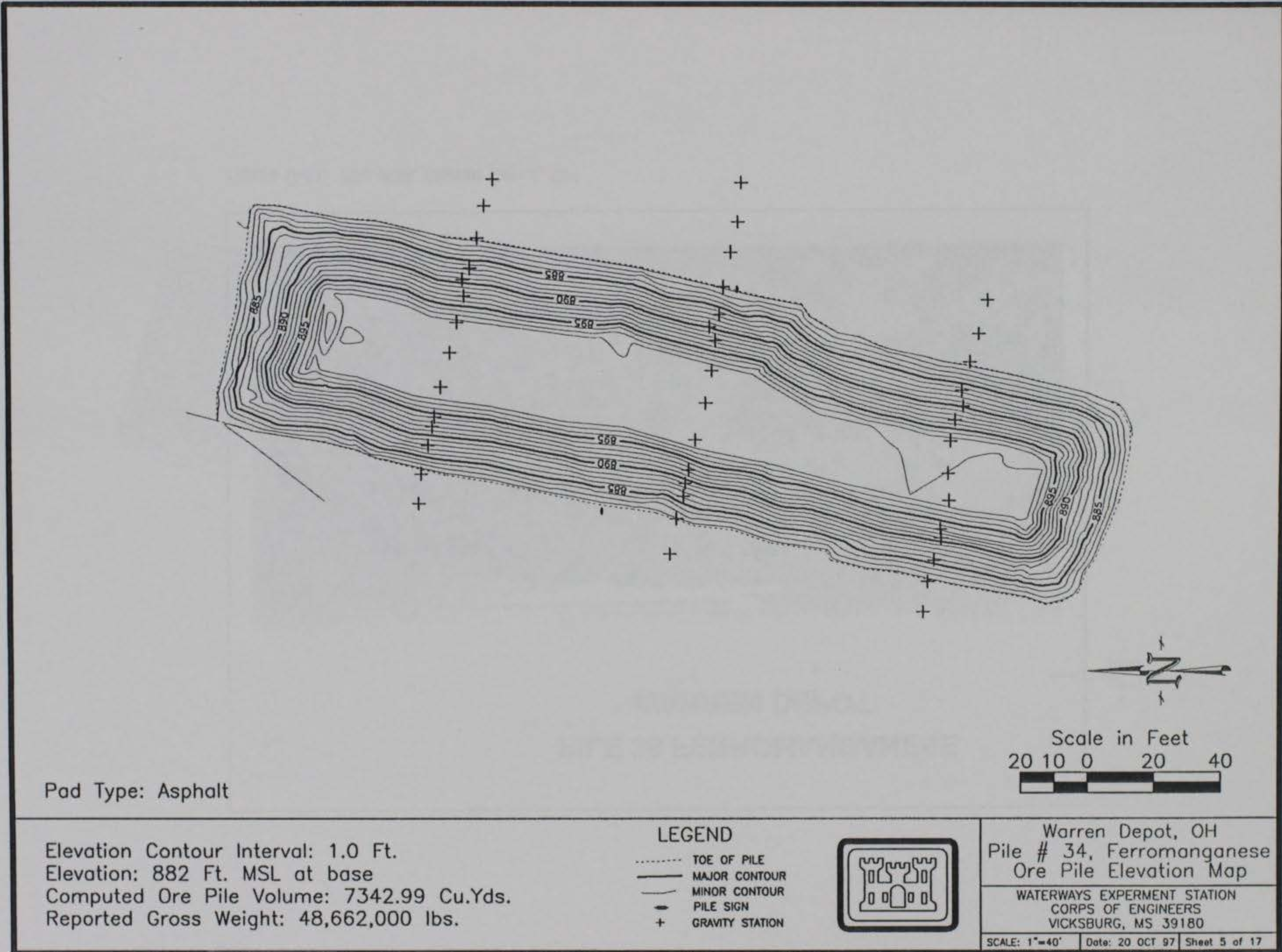


Figure C-10. Elevation contour plot of Pile #34, Warren Depot, OH

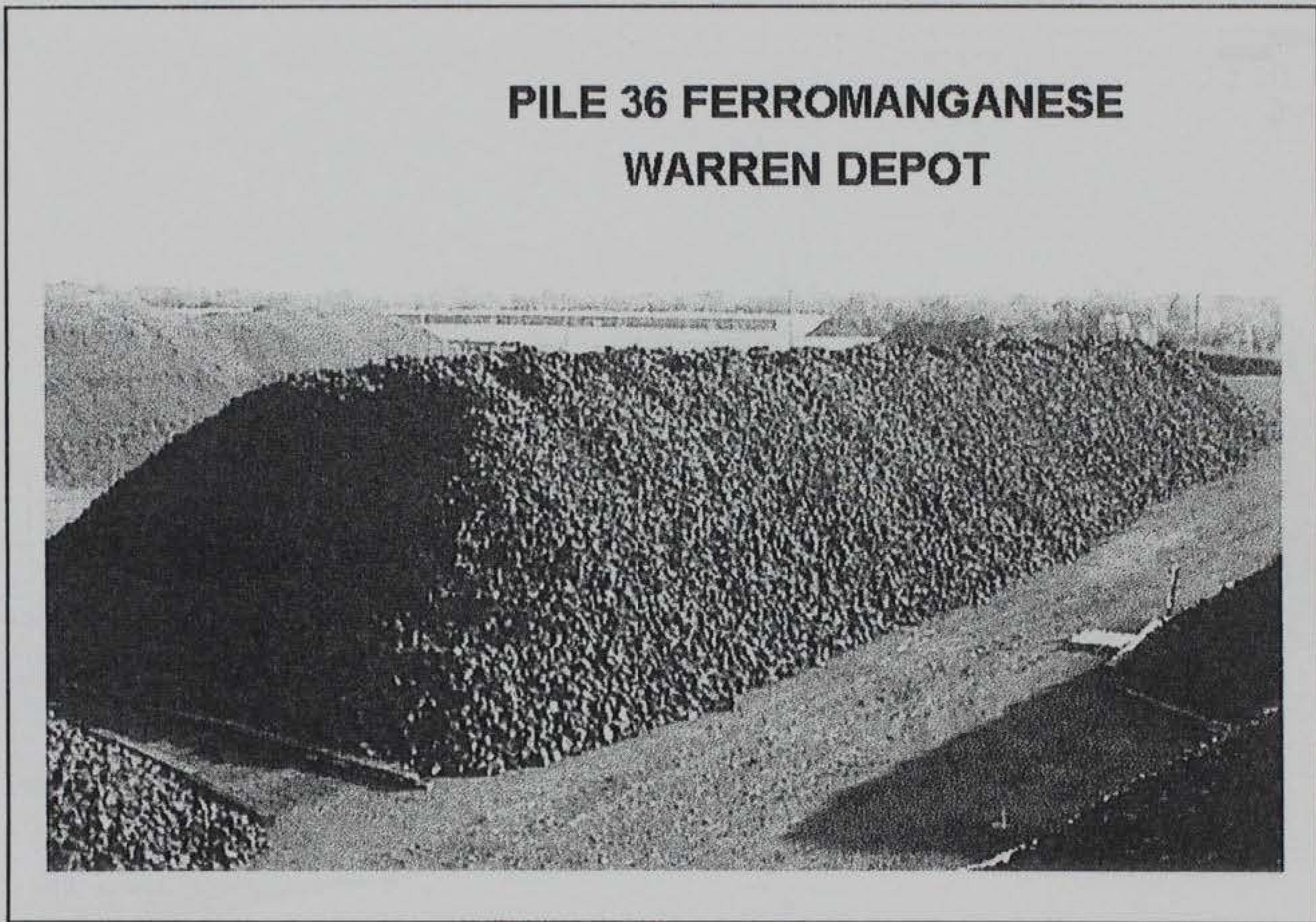
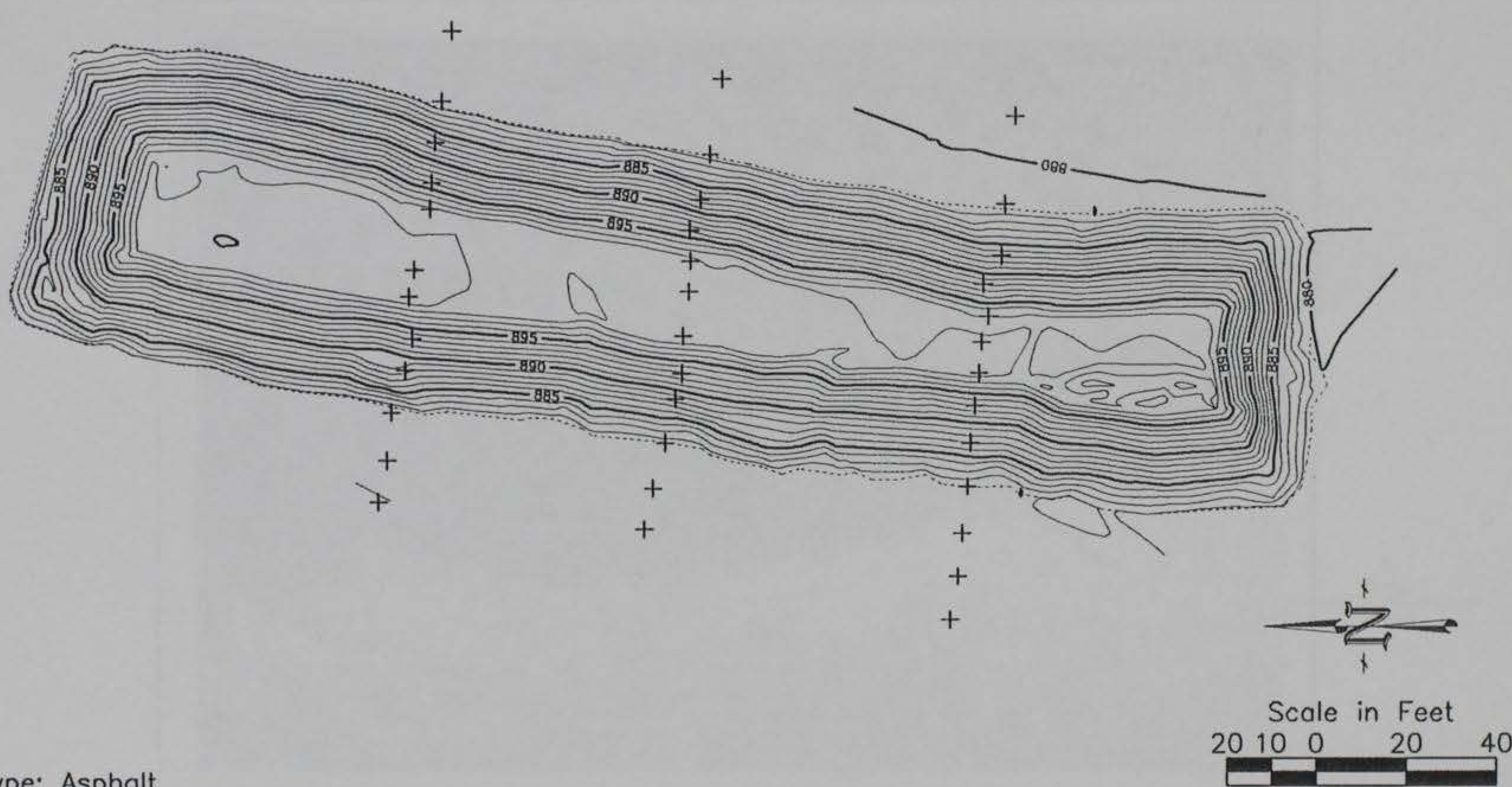


Figure C-11. Pile #36, Warren Depot, OH



Pad Type: Asphalt

Elevation Contour Interval: 1.0 Ft.
Elevation: 880 Ft. MSL at base
Computed Ore Pile Volume: 7597.91 Cu.Yds.
Reported Gross Weight: 50,098,553 lbs.

LEGEND

- TOE OF PILE
- MAJOR CONTOUR
- MINOR CONTOUR
- PILE SIGN
- GRAVITY STATION

Warren Depot, OH
Pile # 36, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=40' | Date: 20 OCT 97 | Sheet 6 of 17

Figure C-12. Elevation contour plot of Pile #36, Warren Depot, OH

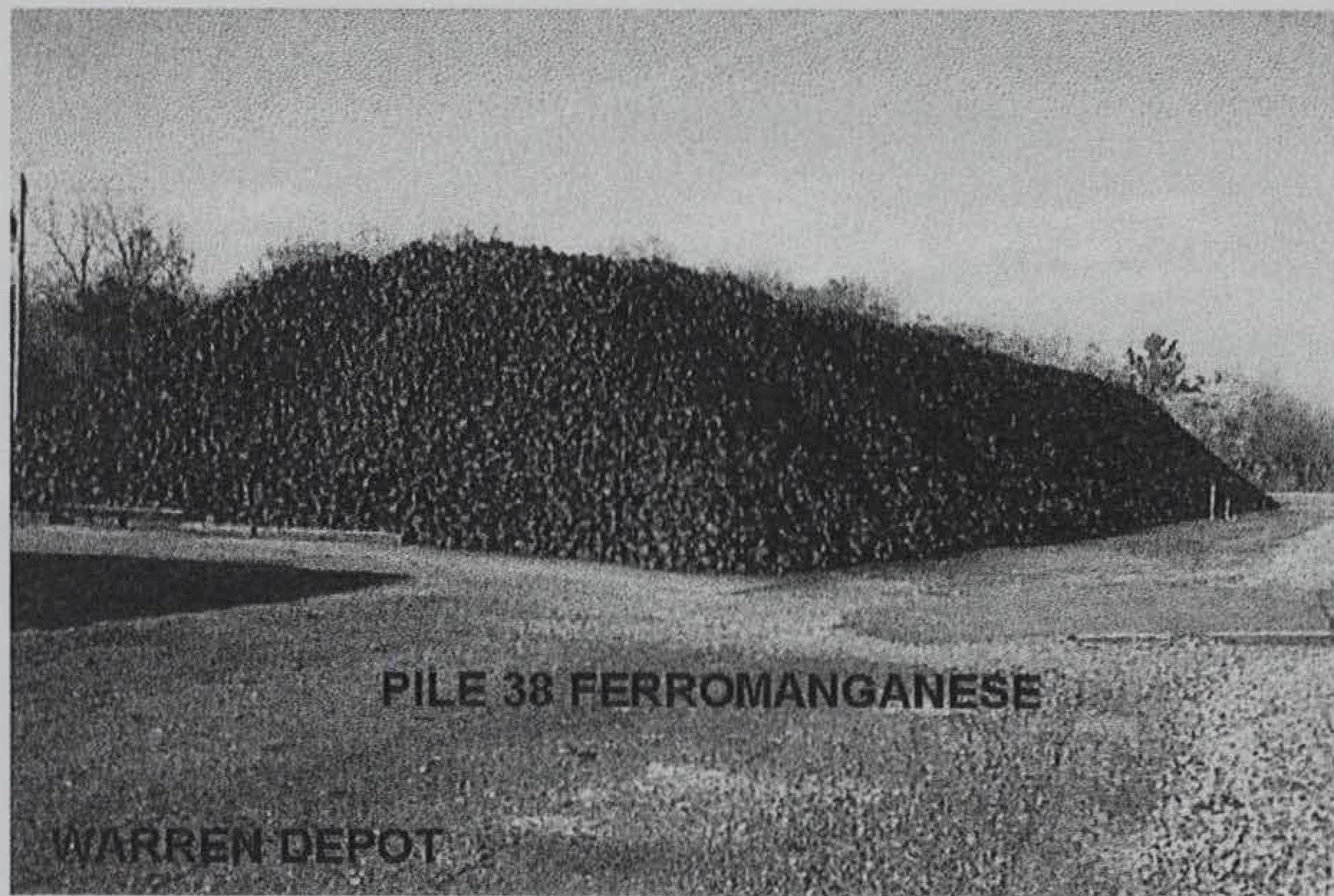


Figure C-13. Pile #38, Warren Depot, OH

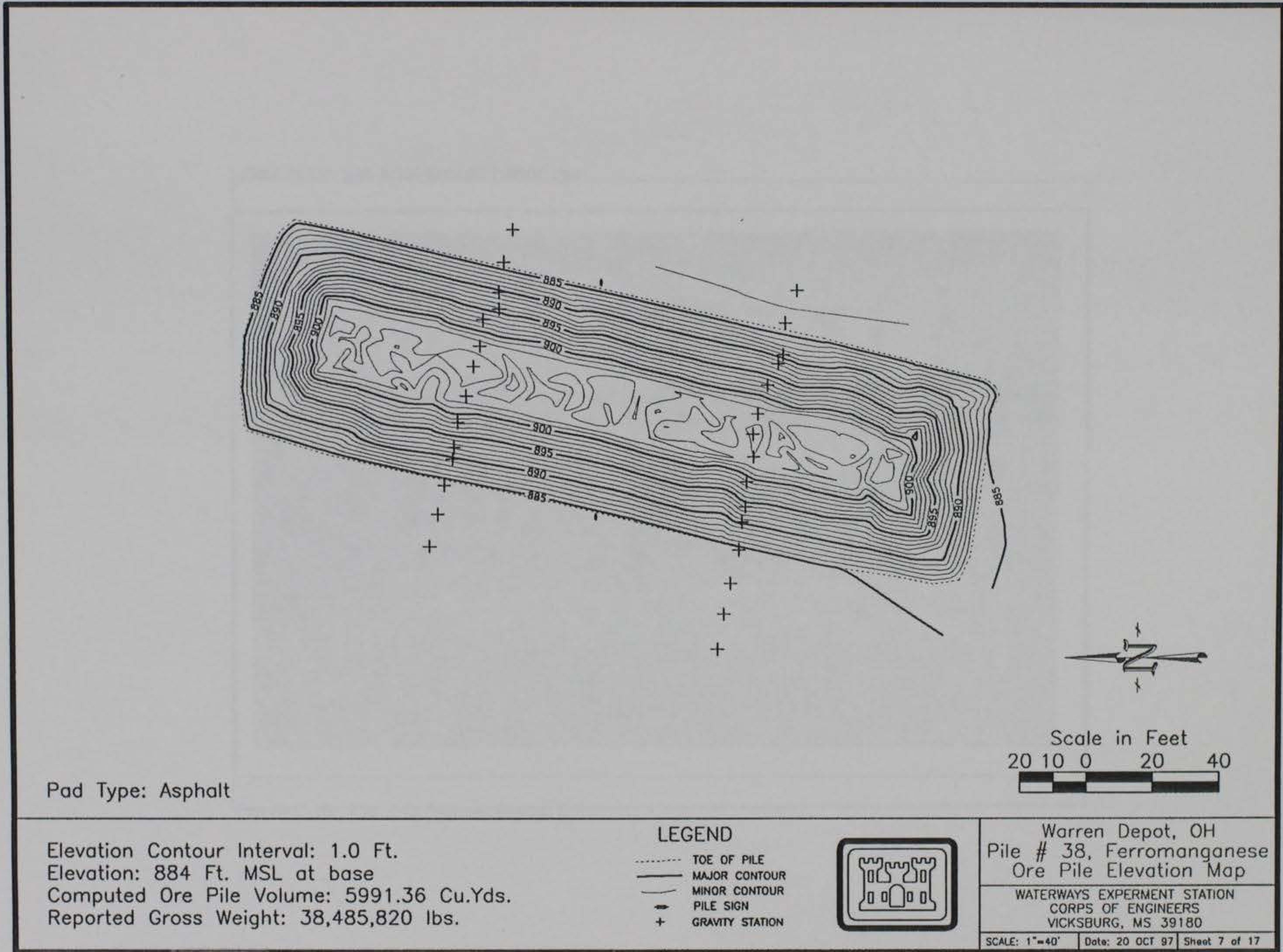


Figure C-14. Elevation contour plot of Pile #38, Warren Depot, OH

Figure C-15. Pile #39, Warren Depot, OH

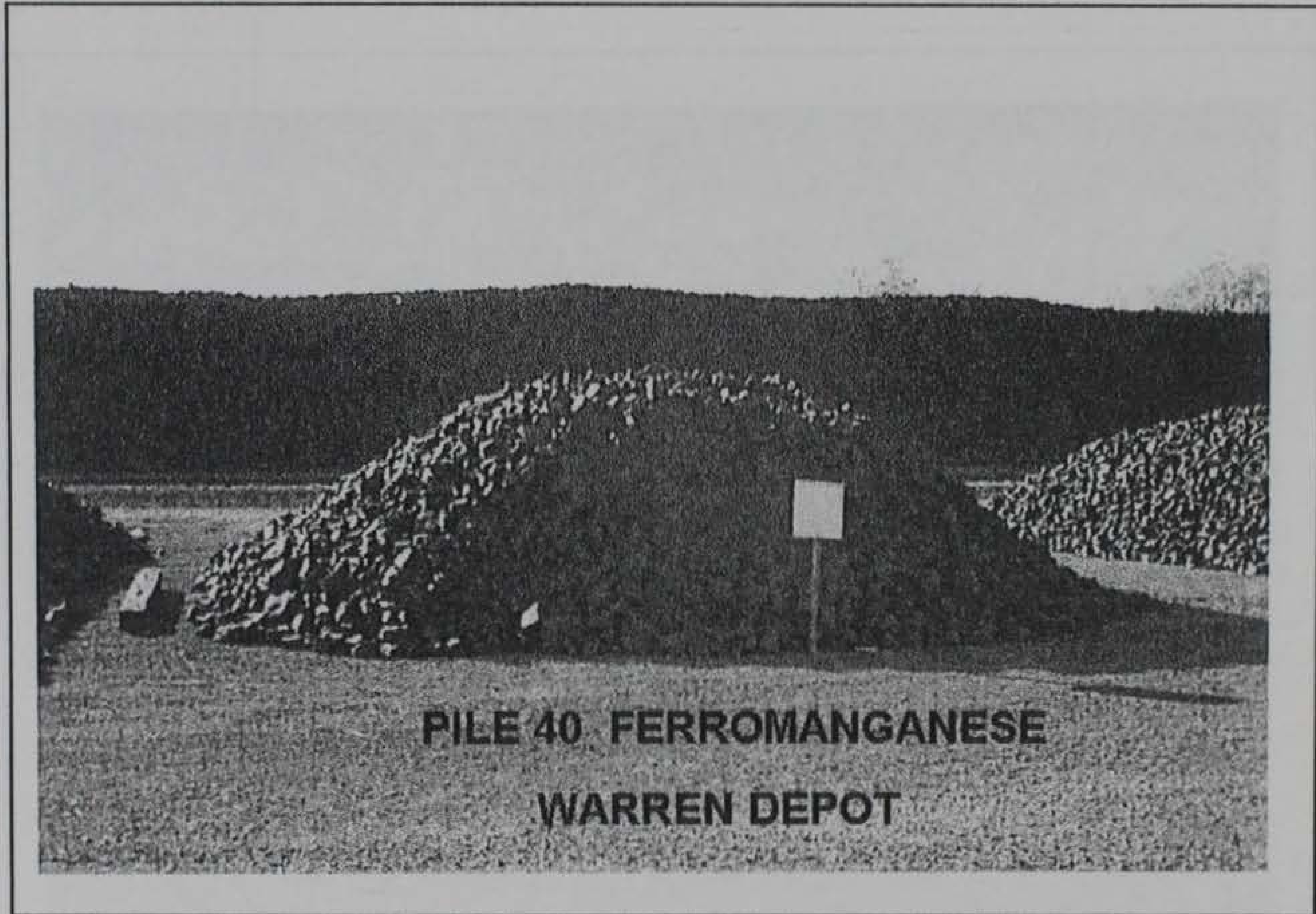


Figure C-16. Pile #40, Warren Depot, OH

Figure C-17. Pile #41, Warren Depot, OH

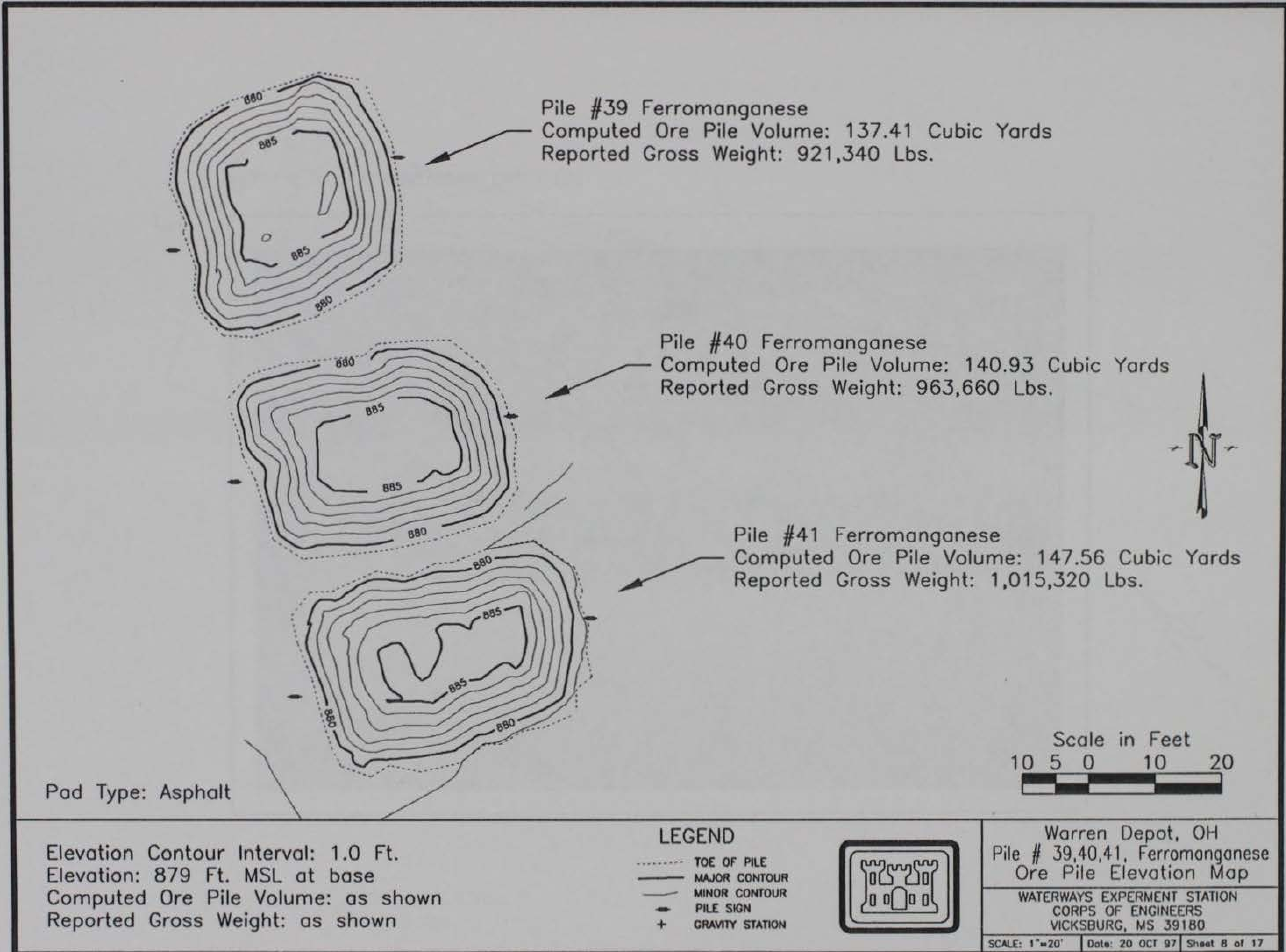


Figure C-18. Elevation contour plots of Piles #39, #40, and #41, Warren Depot, OH

Figure C-19. Pile #42, Warren Depot, OH

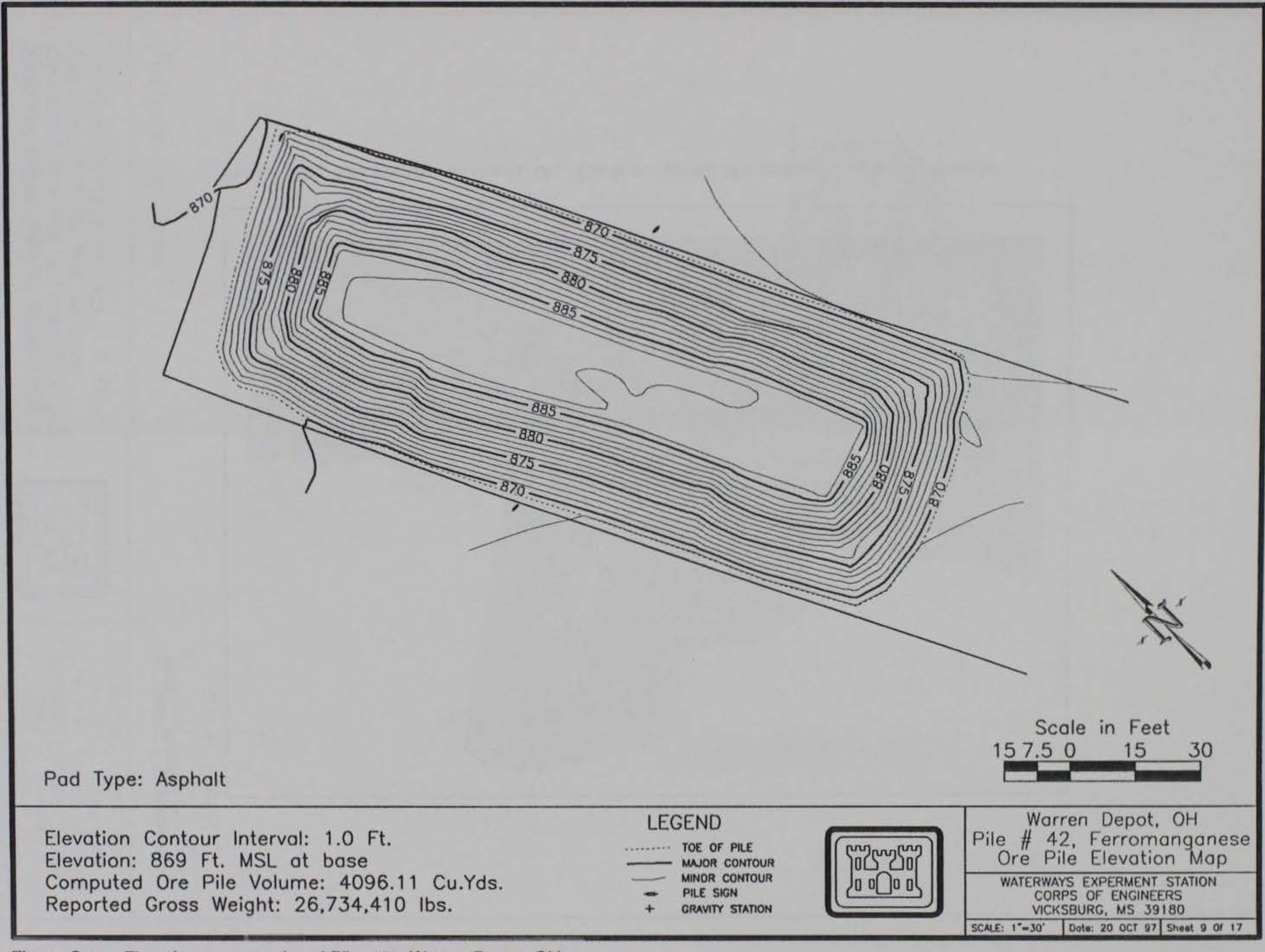


Figure C-20. Elevation contour plot of Pile #42, Warren Depot, OH

Figure C-21. Pile #3, Warren Depot, OH. Pile is composed of metallurgical, grade A fluorspar

Figure C-22. Elevation contour plot of fluorspar Pile #3, Warren Depot, OH

Figure C-23. Pile #3A (back right), Warren Depot, OH

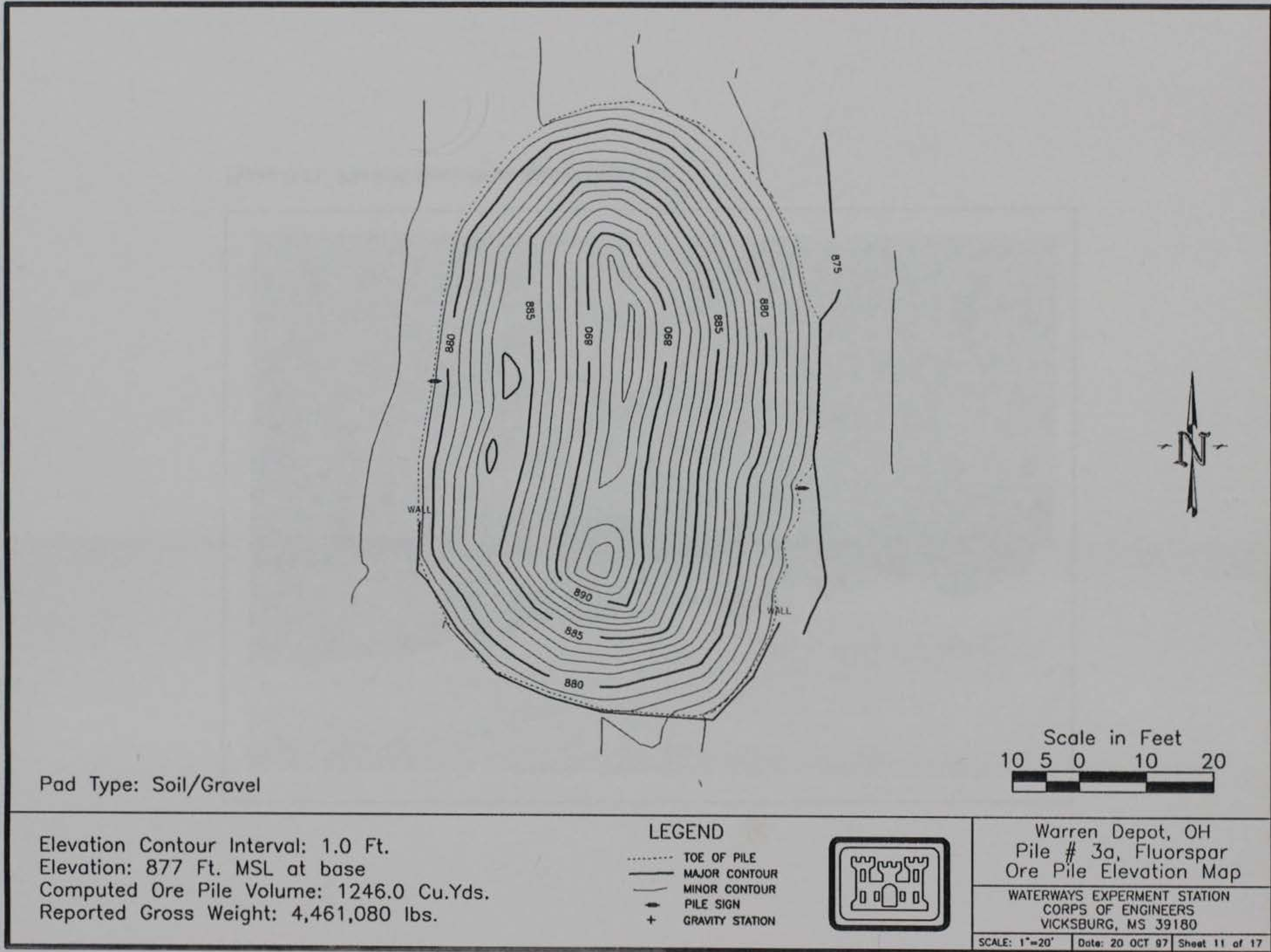


Figure C-24. Elevation contour plot of Pile #3A, Warren Depot, OH

Figure C-25. Pile #4, Warren Depot, OH

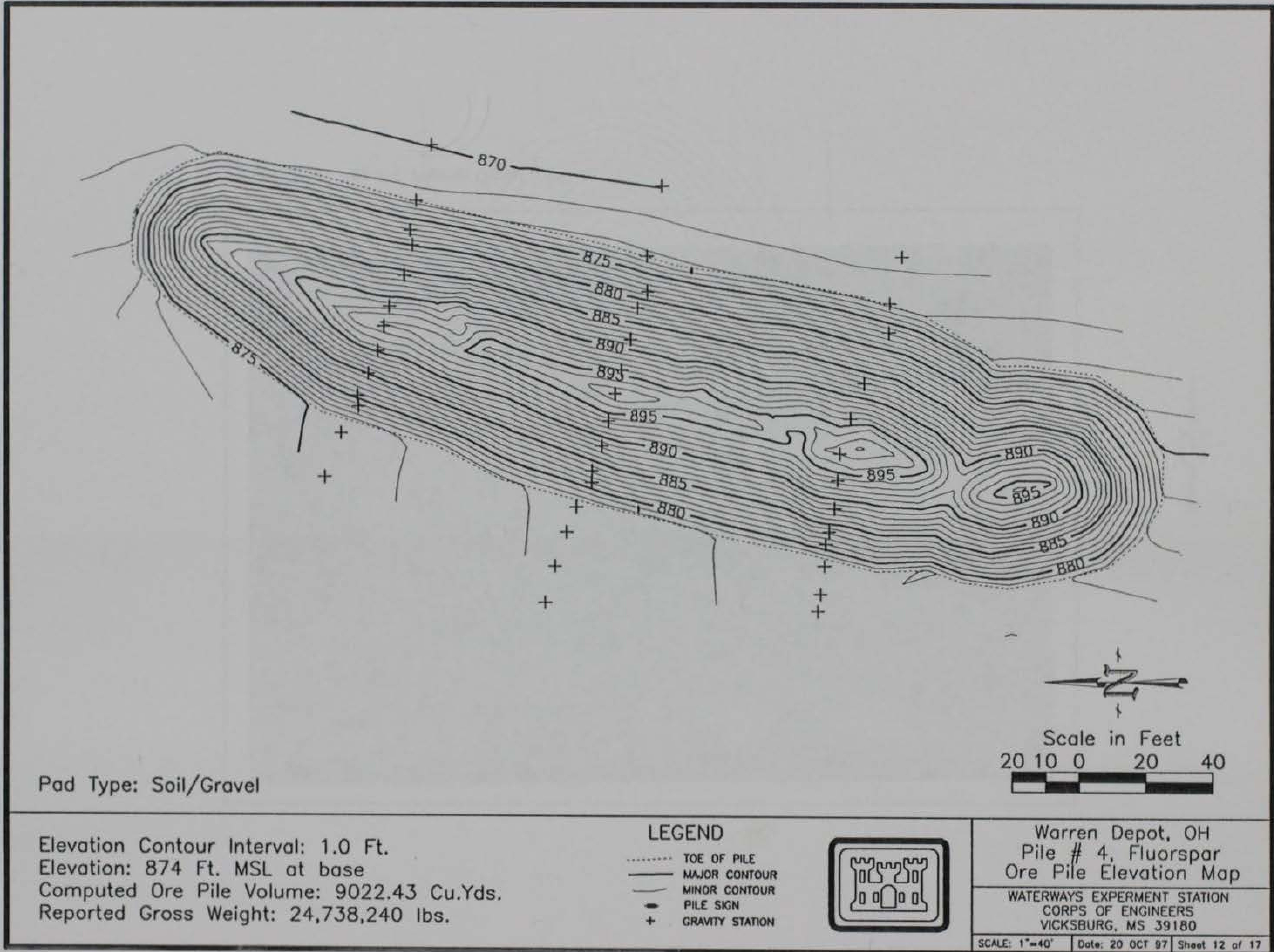


Figure C-26. Elevation contour plot of Pile #4, Warren Depot, OH

Figure C-27. Pile #3, Warren Depot, OH. Pile is composed of high-carbon ferrochrome

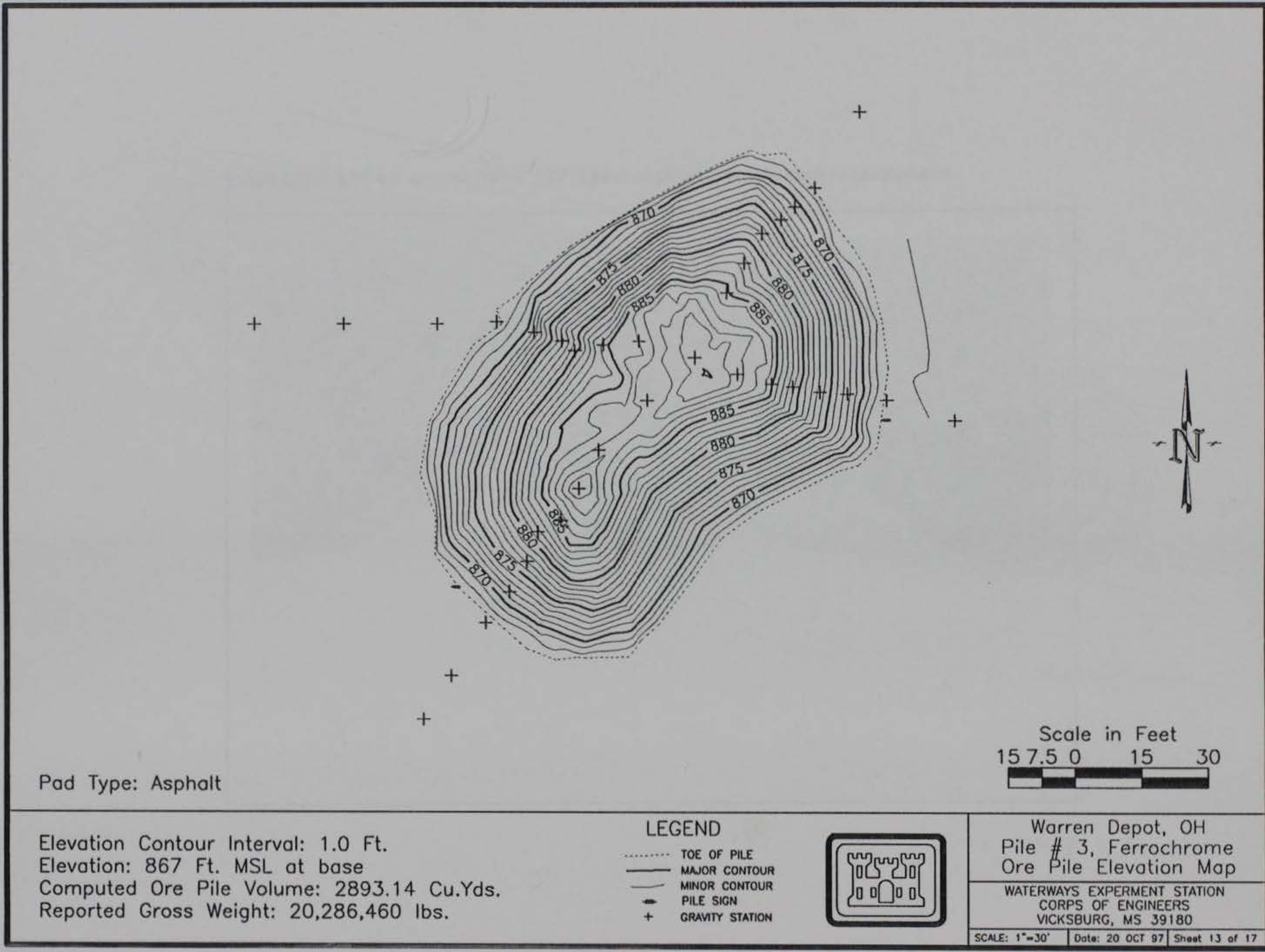


Figure C-28. Elevation contour plot of ferrochrome Pile #3, Warren Depot, OH

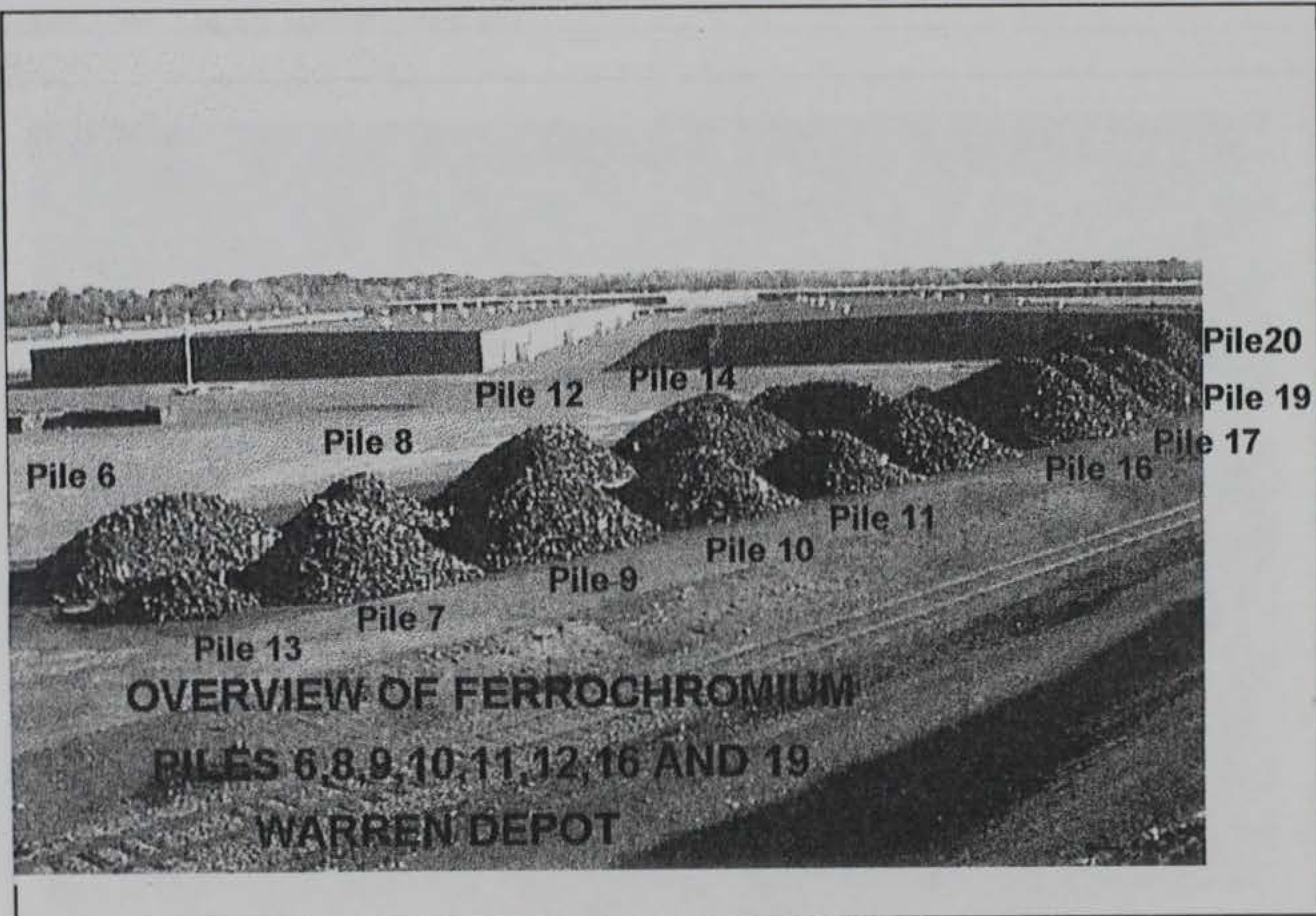


Figure C-29. Overview of Piles #6 through #20, Warren Depot, OH as seen from the top of fluorspar Pile #3. Individual pile designations are noted on the photograph

Figure C-30. Pile #6, Warren Depot, OH

Figure C-31. Pile #9, Warren Depot, OH

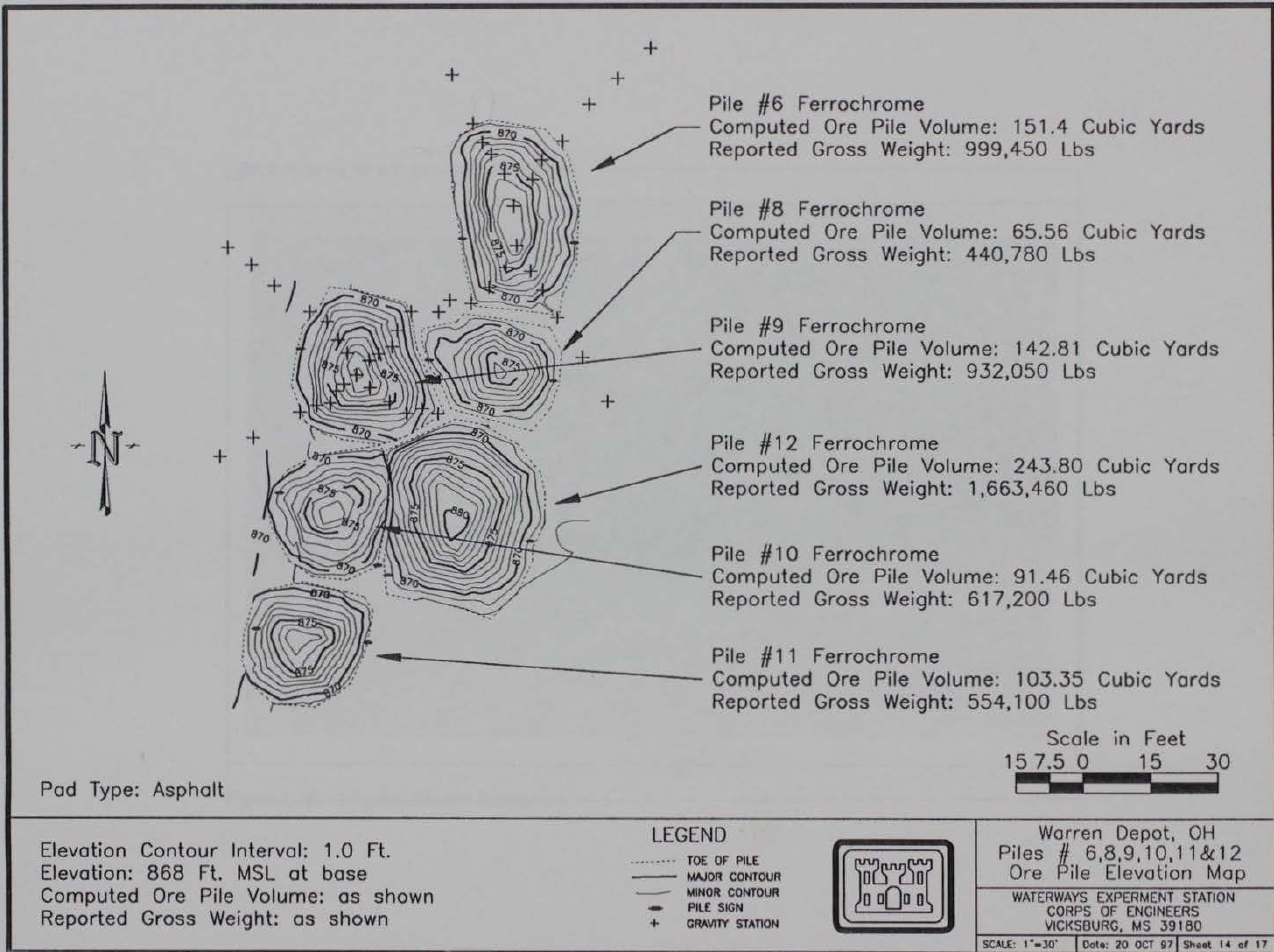


Figure C-32. Elevation contour plots of Piles #6, #8, #9, #10, #11, and #12, Warren Depot, OH

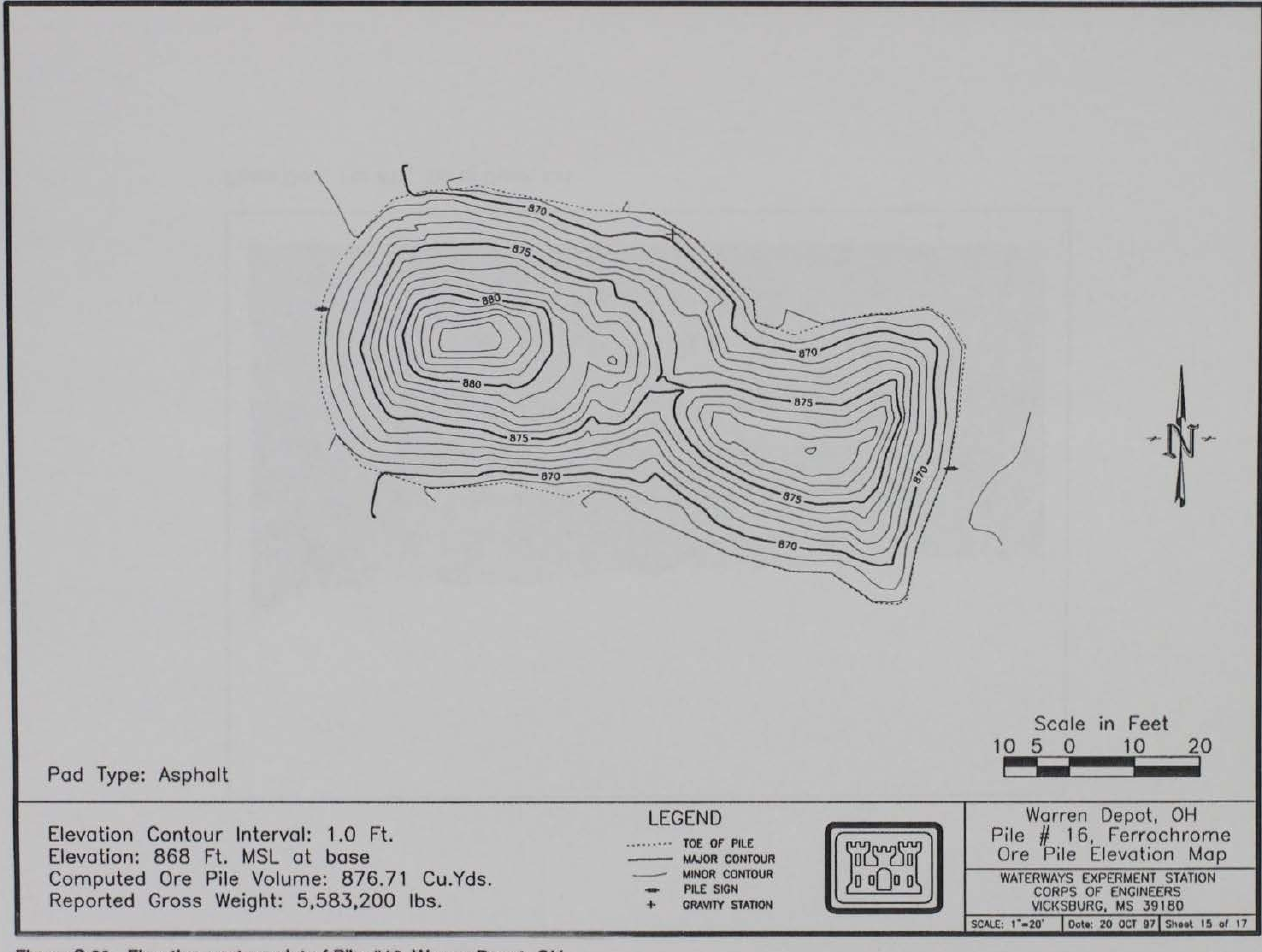


Figure C-33. Elevation contour plot of Pile #16, Warren Depot, OH

Figure C-34. Pile #19, Warren Depot, OH

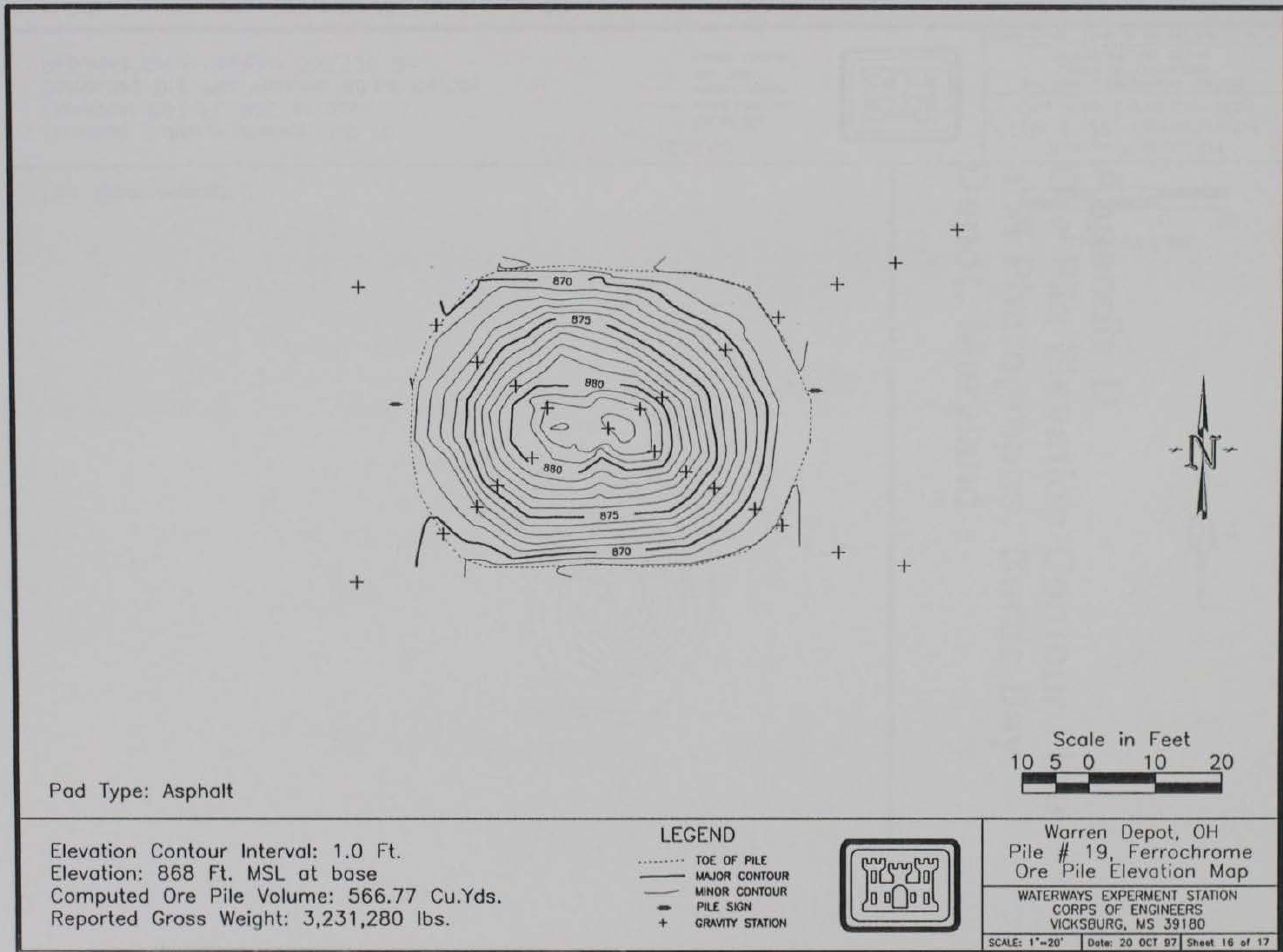
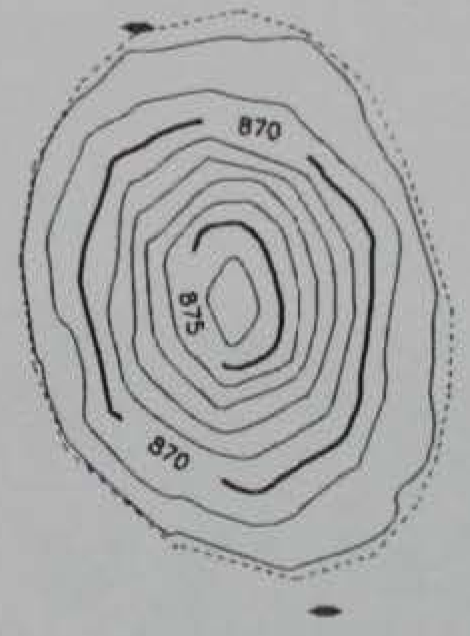


Figure C-35. Elevation contour plot of Pile #19, Warren Depot, OH



Scale in Feet
10 5 0 10 20

Pad Type: Asphalt

Elevation Contour Interval: 1.0 Ft.
Elevation: 867 Ft. MSL at base
Computed Ore Pile Volume: 86.64 Cu.Yds.
Reported Gross Weight: 557,120 lbs.

LEGEND
TOE OF PILE
MAJOR CONTOUR
MINOR CONTOUR
PILE SIGN
+ GRAVITY STATION

Warren Depot, OH
Pile # 22, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 20 OCT 97 | Sheet 17 of 17

Figure C-36. Elevation contour plot of Pile #22, Warren Depot, OH

Appendix D
Ore Pile Elevation Contour Plots and Photographs, Curtis Bay Depot, Maryland

Figure D-1. Pile #159, Curtis Bay Depot, MD as viewed from the top of Pile #24

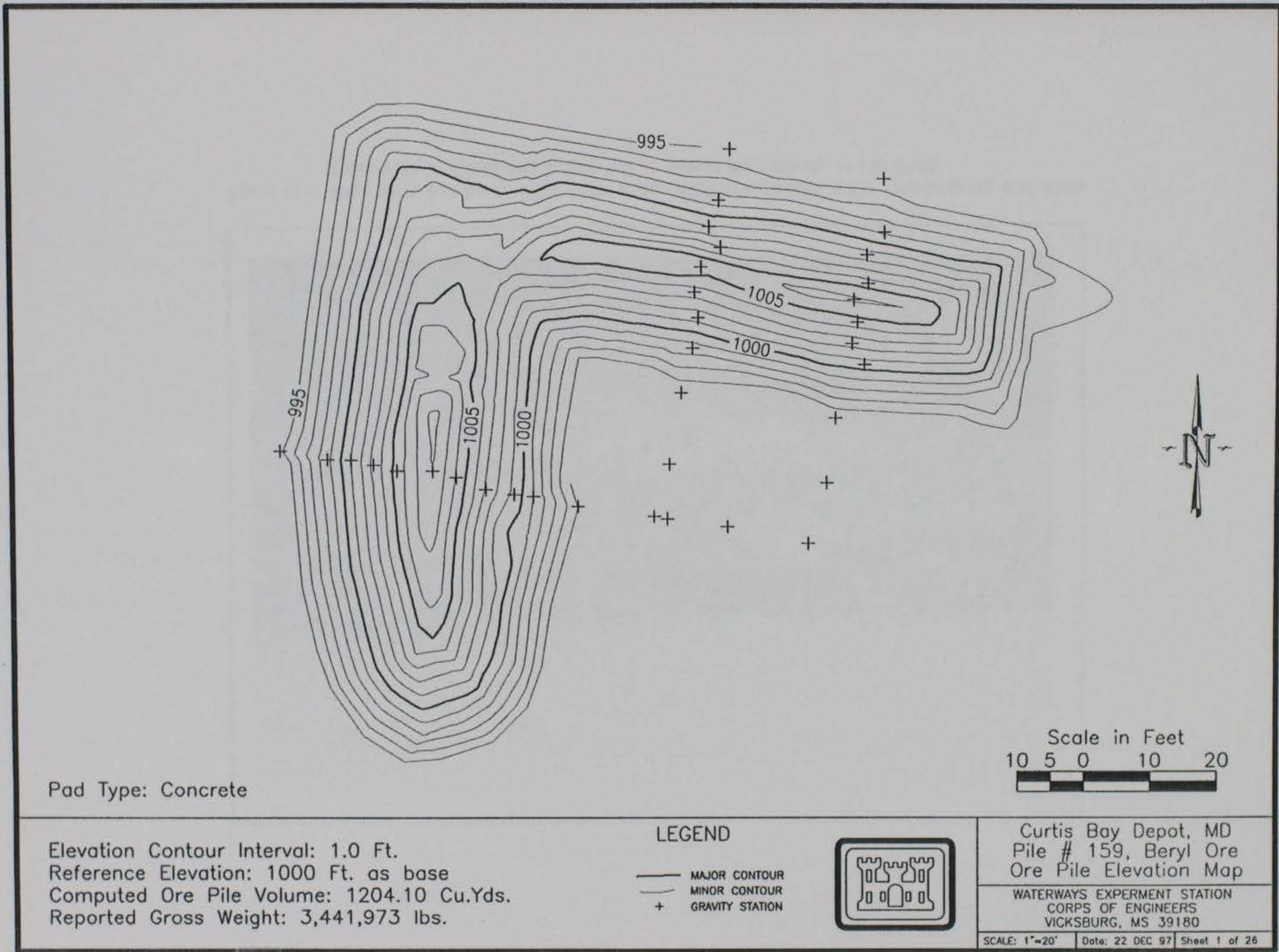


Figure D-2. Elevation contour plot of Pile #159, Curtis Bay Depot, MD

Figure D-3. Piles #210 (left front), #208 (right front), #209 (middle left), #207 (middle right), and #159 (center back), Curtis Bay Depot, MD as viewed from the top of Pile #108

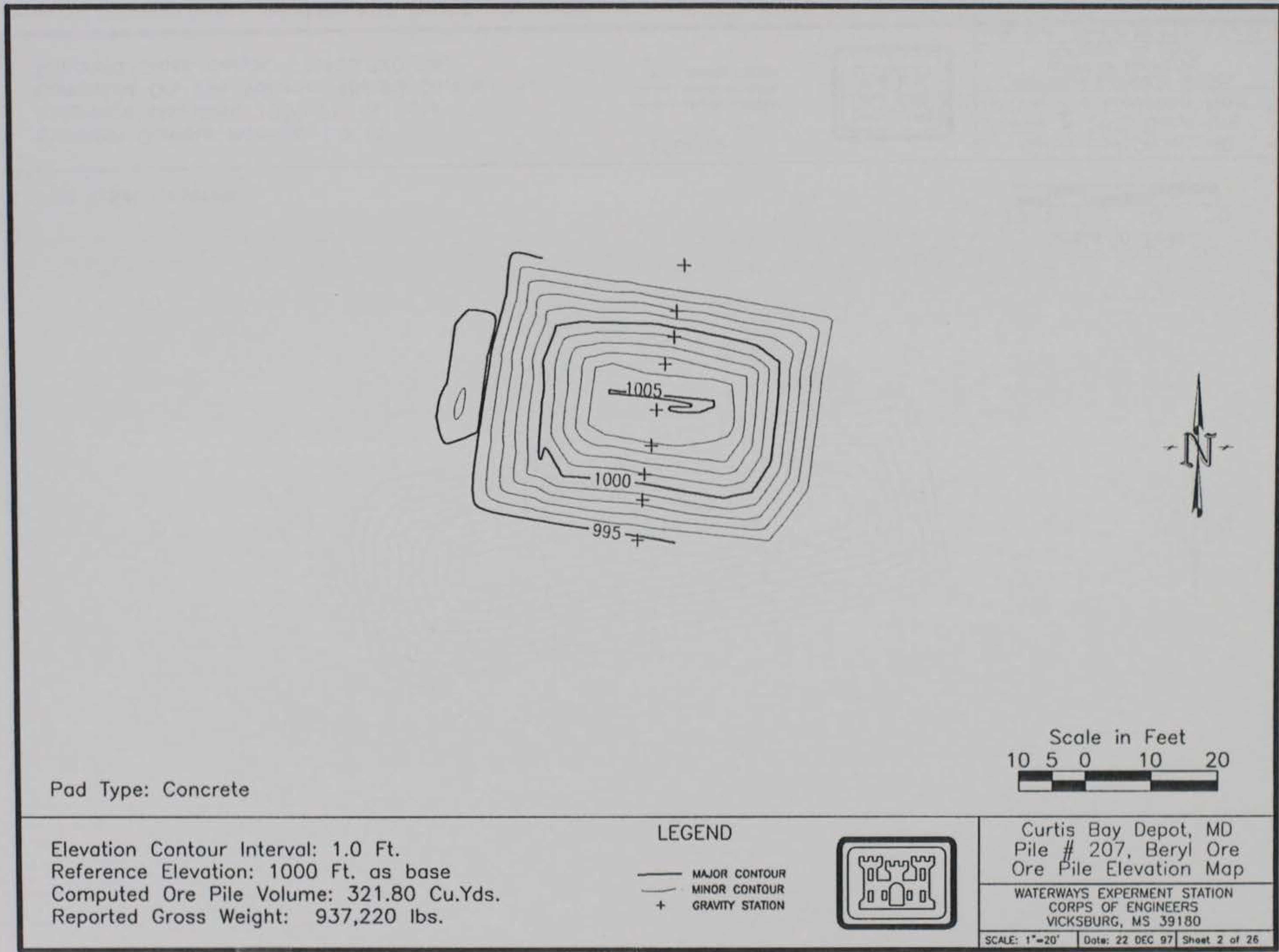


Figure D-4. Elevation contour plot of Pile #207, Curtis Bay Depot, MD

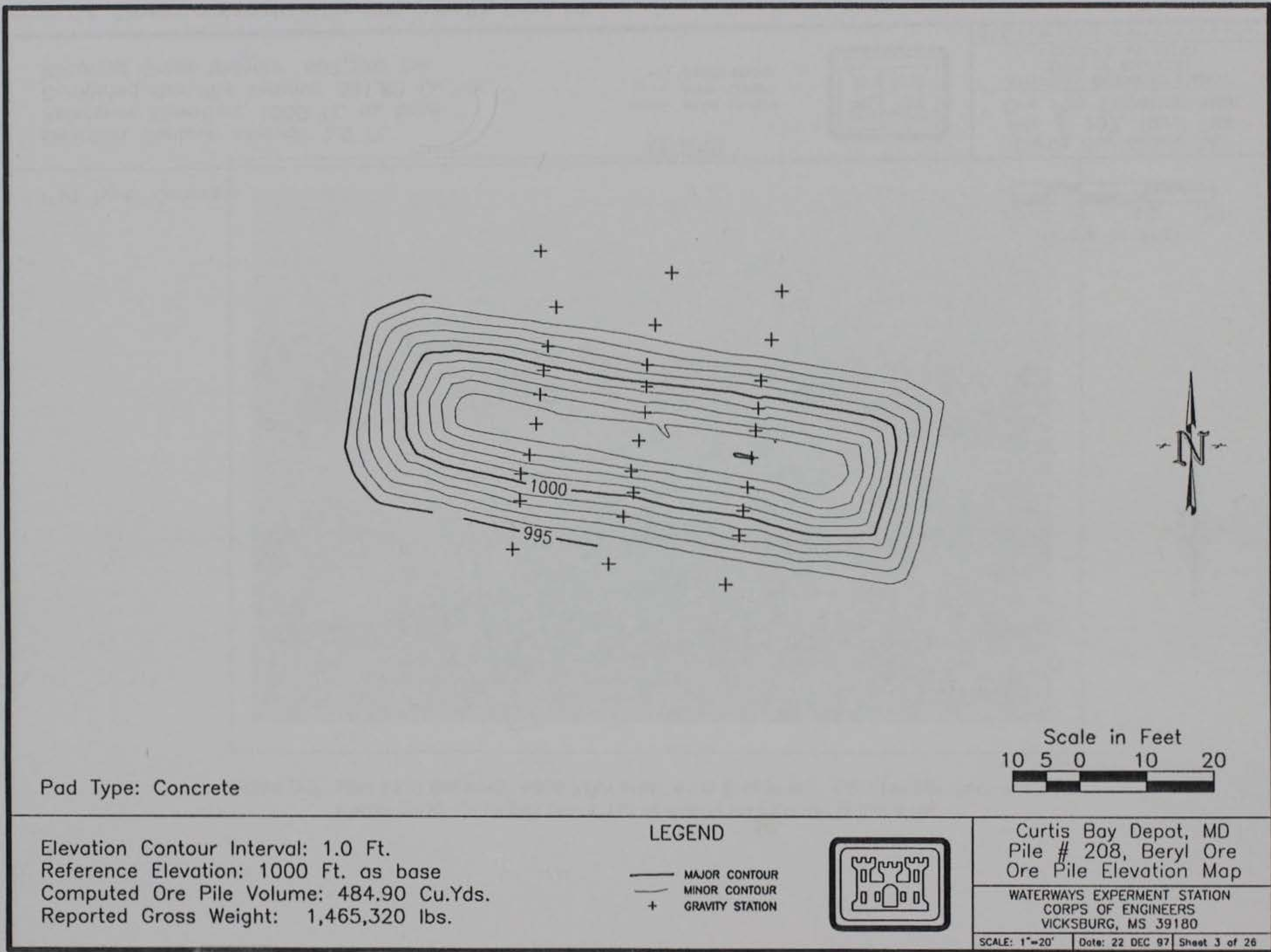


Figure D-5. Elevation contour plot of Pile #208, Curtis Bay Depot, MD

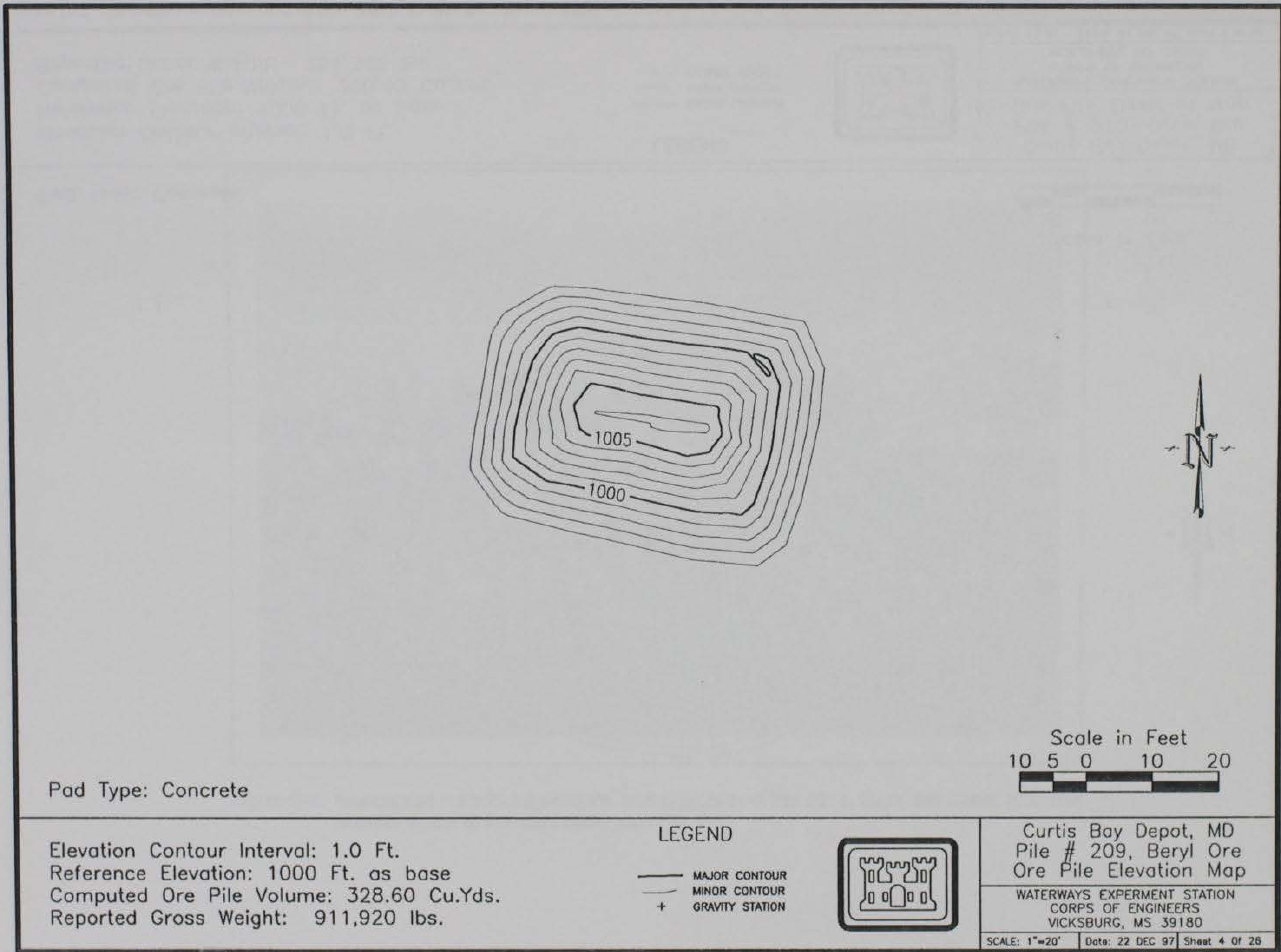
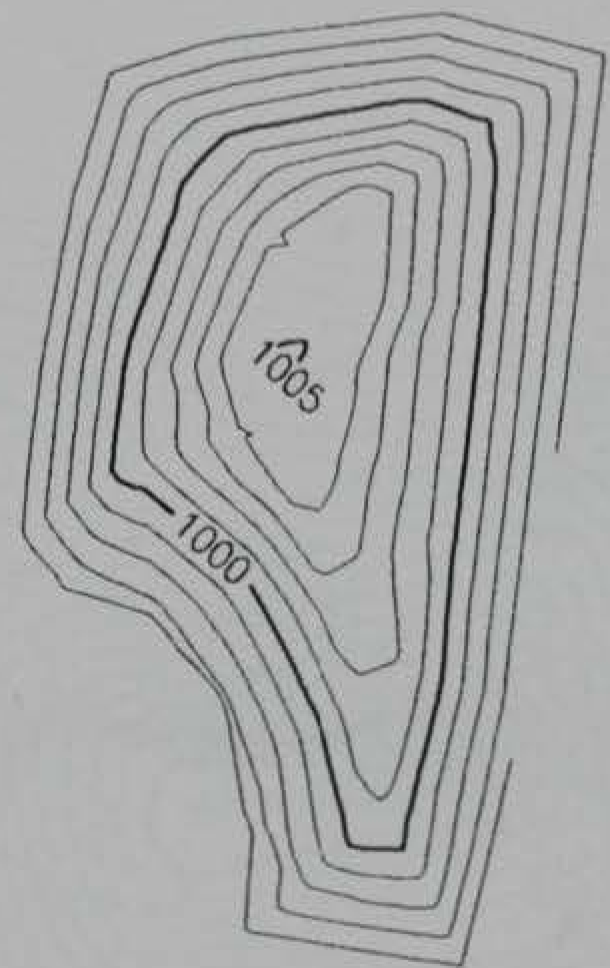
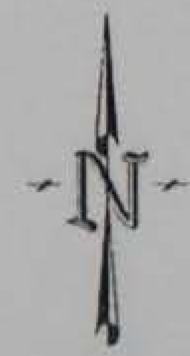


Figure D-6. Elevation contour plot of Pile #209, Curtis Bay Depot, MD





Scale in Feet
10 5 0 10 20

Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 260.40 Cu.Yds.
Reported Gross Weight: 764,360 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 210, Beryl Ore
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 22 DEC 97 | Sheet 5 of 26

Figure D-7. Elevation contour plot of Pile #210, Curtis Bay Depot, MD

Figure D-8. Fine-grained material following the sorting process of Pile #211, Curtis Bay Depot, MD. This material is one of five piles designated Pile #211

Figure D-9. Pile #211 (2 of 5), Curtis Bay Depot, MD

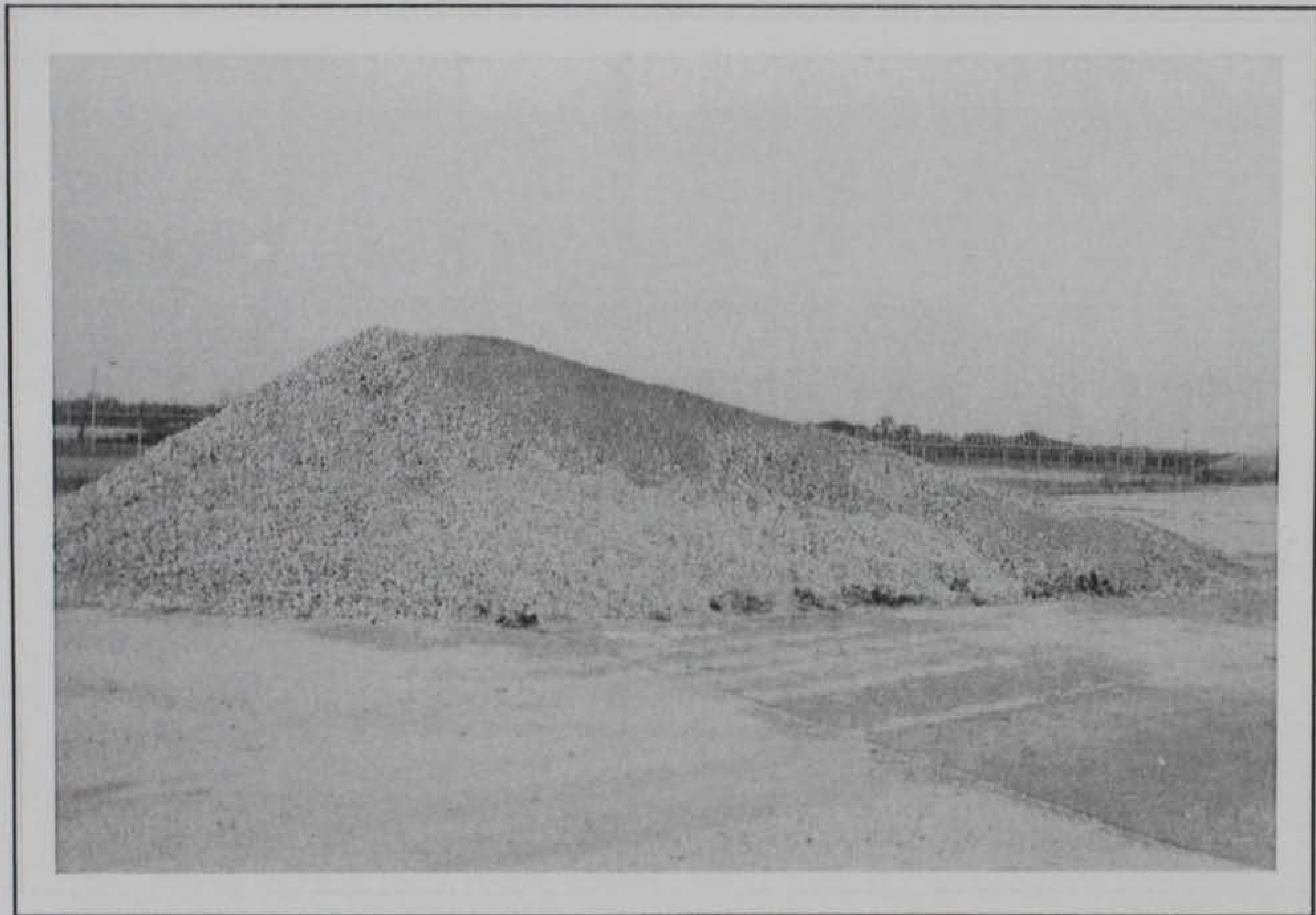


Figure D-10. Pile #211 (3 of 5), Curtis Bay Depot, MD

Figure D-11. Pile #211 (4 of 5), Curtis Bay Depot, MD

Figure D-12. Pile #211 (5 of 5), Curtis Bay Depot, MD

Figure D-13. Elevation contour plots of all piles designated Pile #211, Curtis Bay Depot, MD

Figure D-14. Pile #212 (1 of 3), Curtis Bay Depot, MD

Figure D-15. Pile #212 (2 of 3), Curtis Bay Depot, MD

Figure D-16. Pile #212 (3 of 3), Curtis Bay Depot, MD

Pad Type: Asphalt

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 1161.79 Cu.Yds.
Reported Gross Weight: 3,086,080 lbs. (Cumulative)

LEGEND

- MAJOR CONTOUR
- MINOR CONTOUR
- + GRAVITY STATION

Curtis Bay Depot, MD
Pile # 212, Beryl Ore
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=25' | Date: 22 DEC 97 | Sheet 7 of 26

Figure D-17. Elevation contour plots of all piles designated Pile #212, Curtis Bay Depot, MD

Figure D-18. Fine-grained materials from the sorting process of both Piles #212 and #213, Curtis Bay Depot, MD

Figure D-19. Pile #213 (1 of 3), Curtis Bay Depot, MD

Figure D-20. Pile #213 (2 of 3), Curtis Bay Depot, MD

Figure D-21. Pile #213 (3 of 3), Curtis Bay Depot, MD

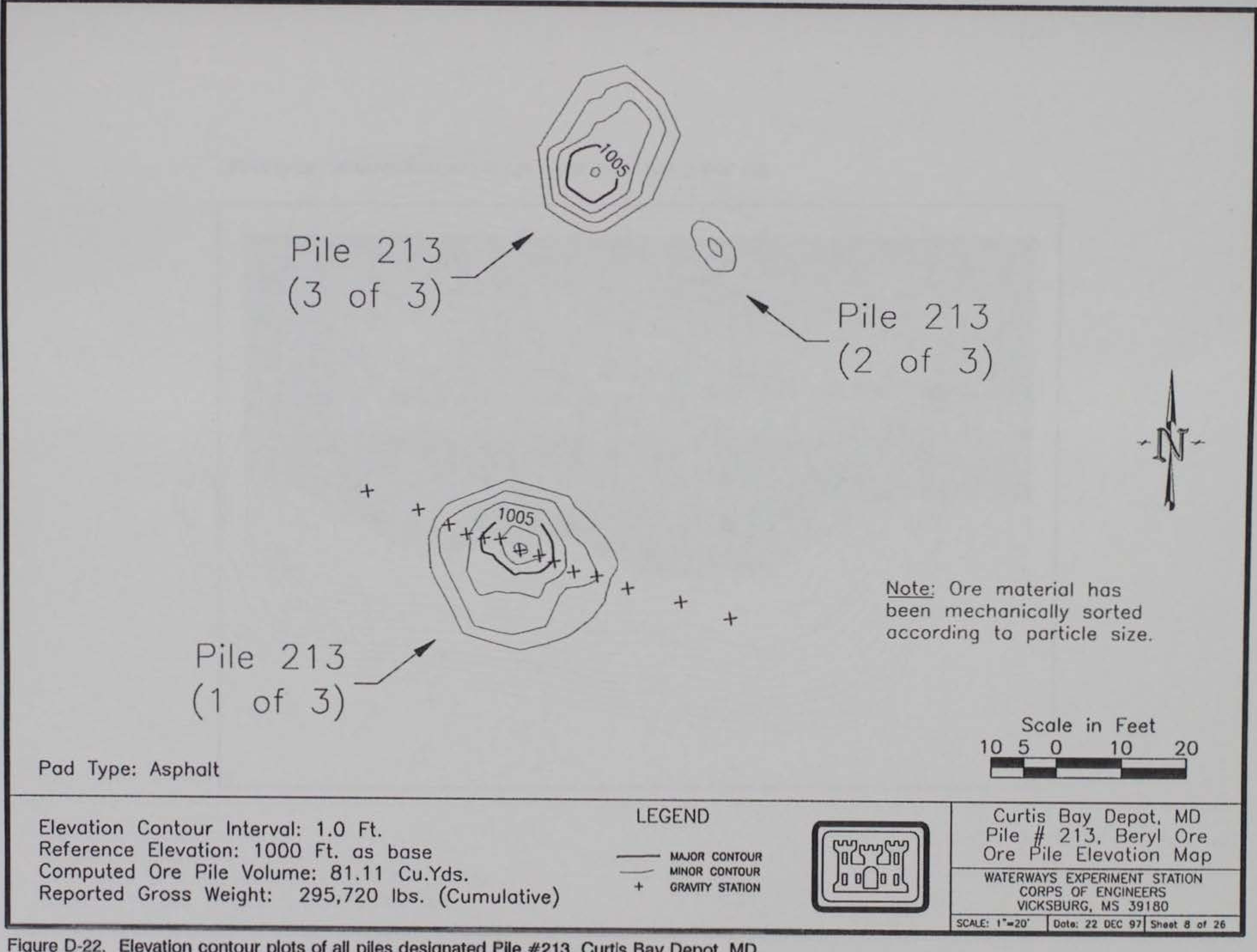


Figure D-22. Elevation contour plots of all piles designated Pile #213, Curtis Bay Depot, MD

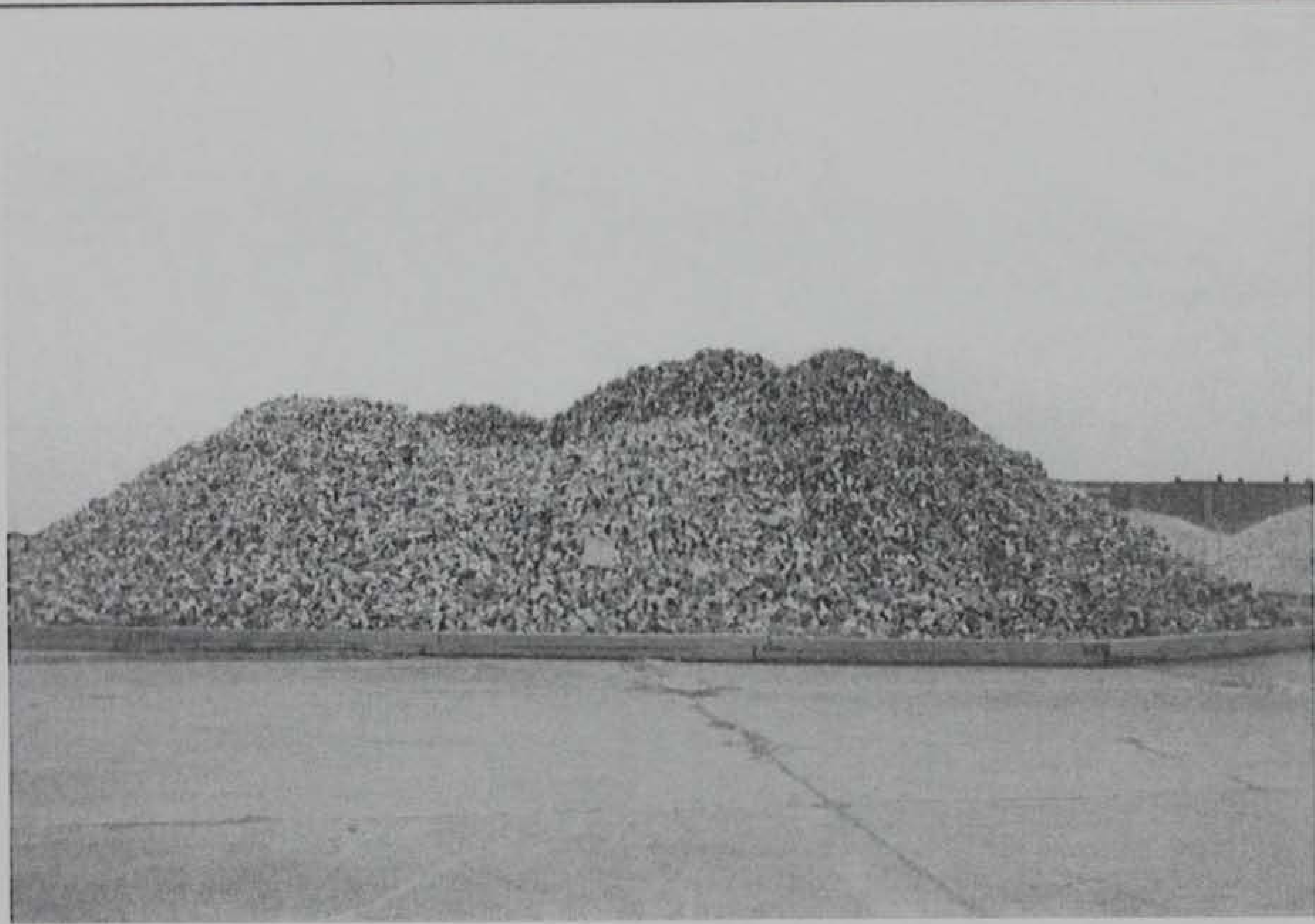


Figure D-23. Northwestern end of Pile #108, Curtis Bay Depot, MD

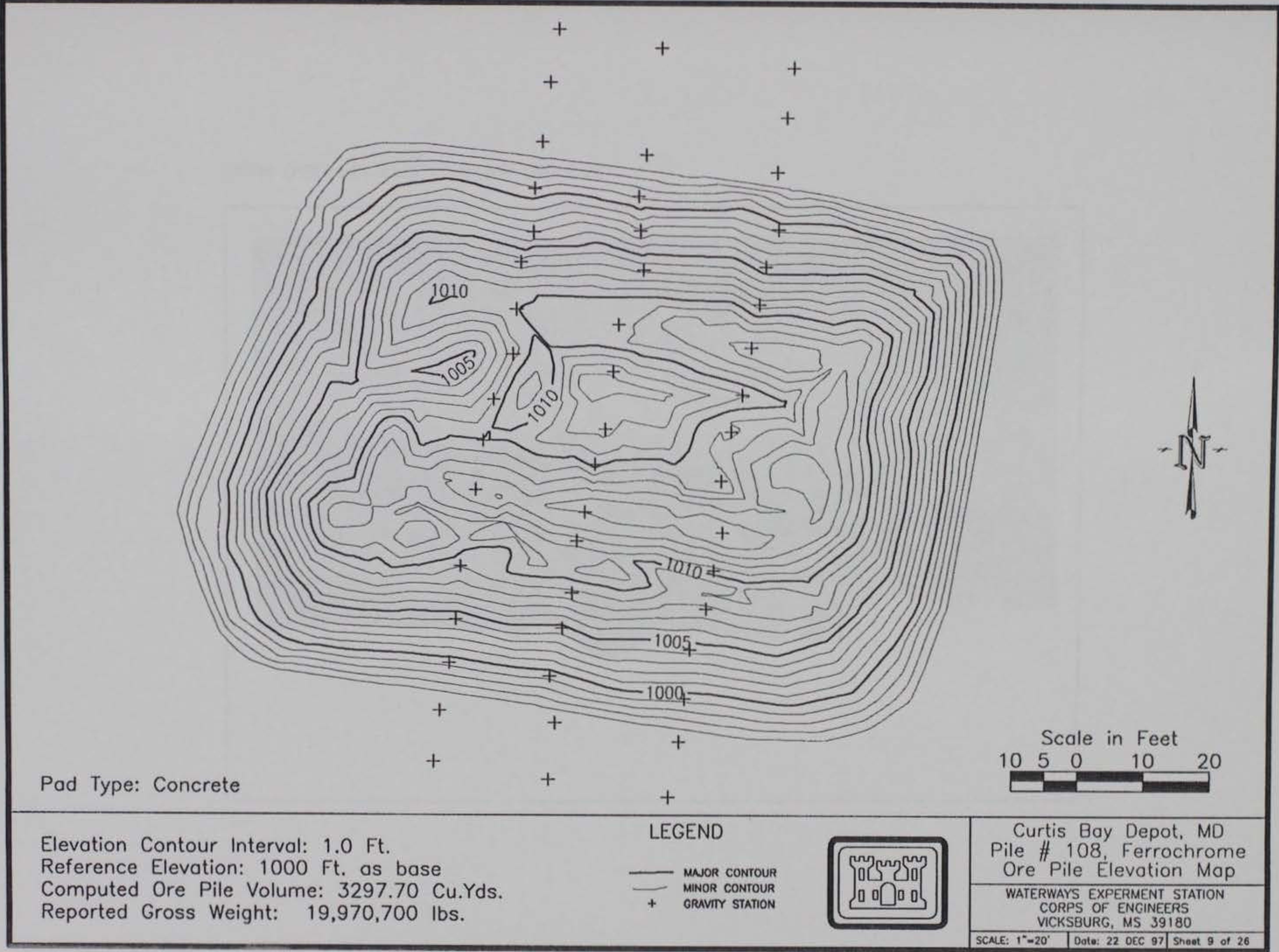


Figure D-24. Elevation contour plot of Pile #108, Curtis Bay Depot, MD

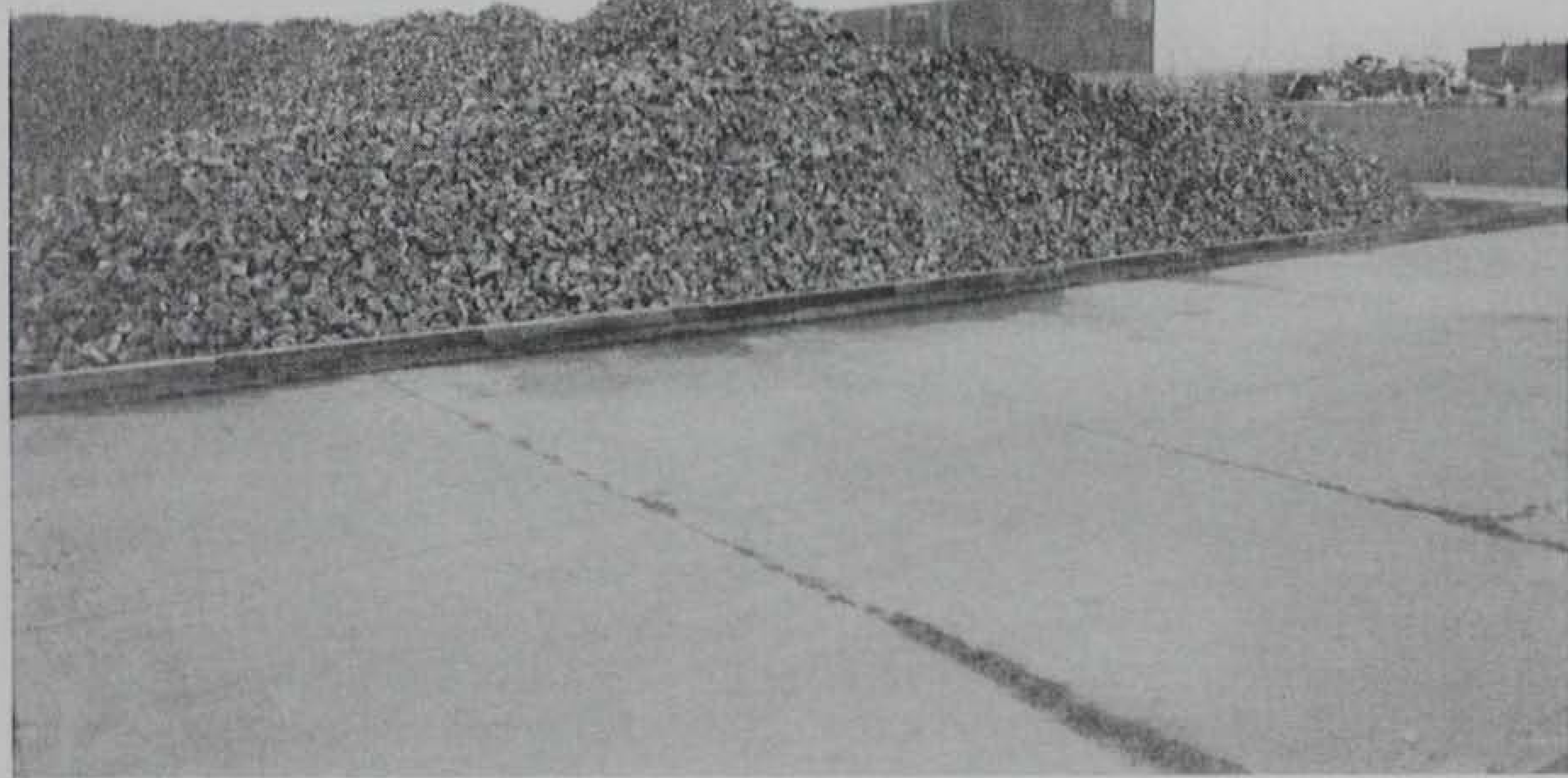
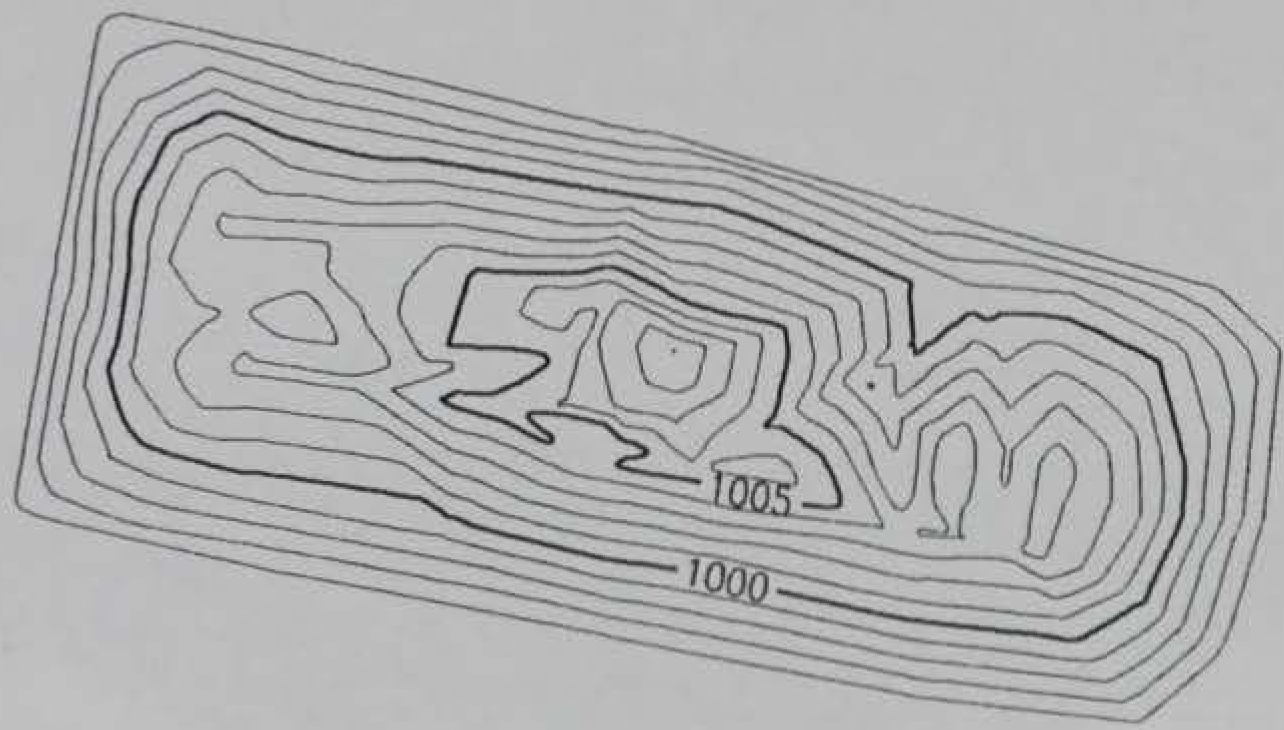


Figure D-25. Pile #110, Curtis Bay Depot, MD



N

Scale in Feet
10 5 0 10 20

Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 497.50 Cu.Yds.
Reported Gross Weight: 4,307,668 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 110, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'	Date: 22 DEC 97	Sheet 10 of 26

Figure D-26. Elevation contour plot of Pile #110, Curtis Bay Depot, MD

Figure D-27. Pile #111, Curtis Bay Depot, MD

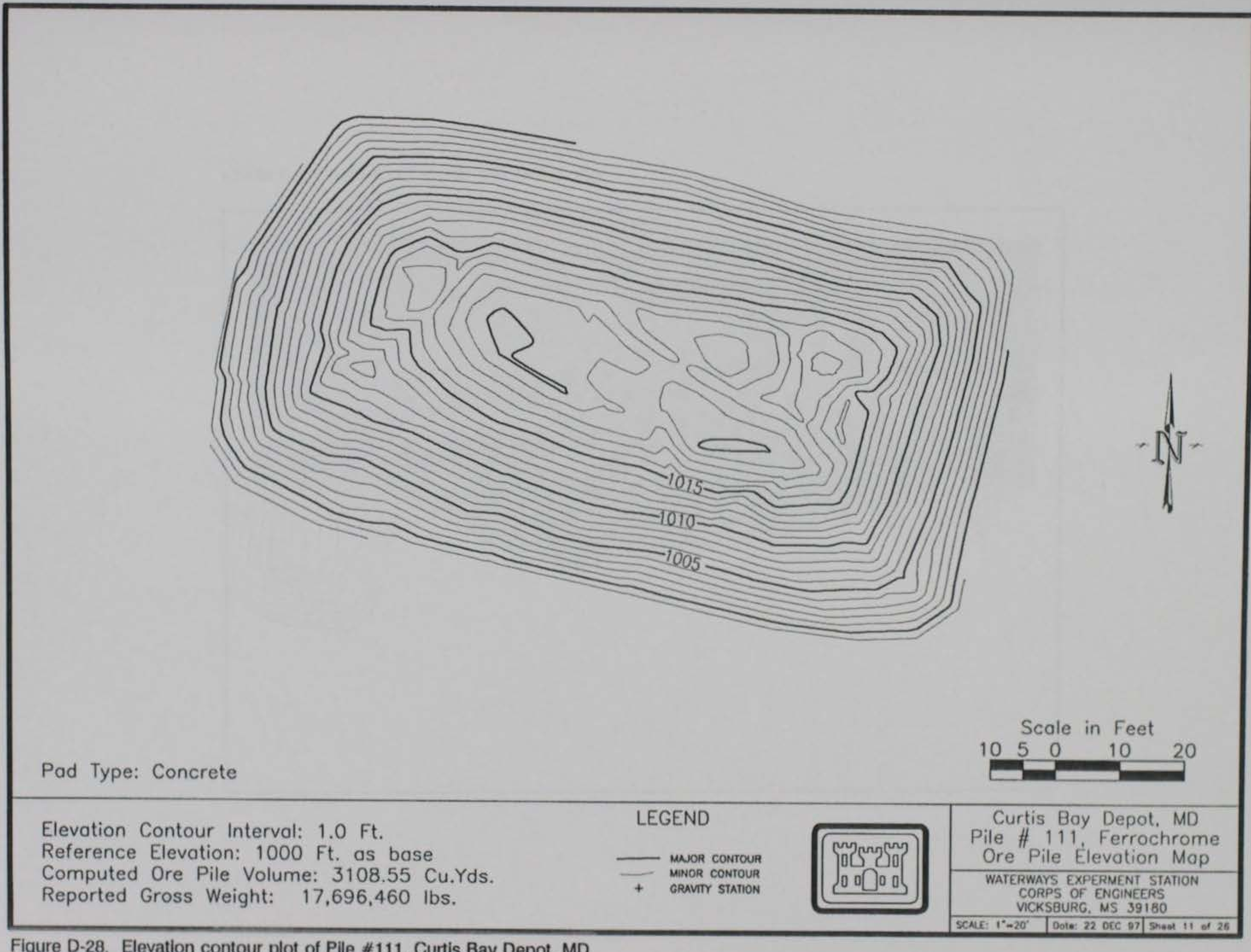


Figure D-28. Elevation contour plot of Pile #111, Curtis Bay Depot, MD

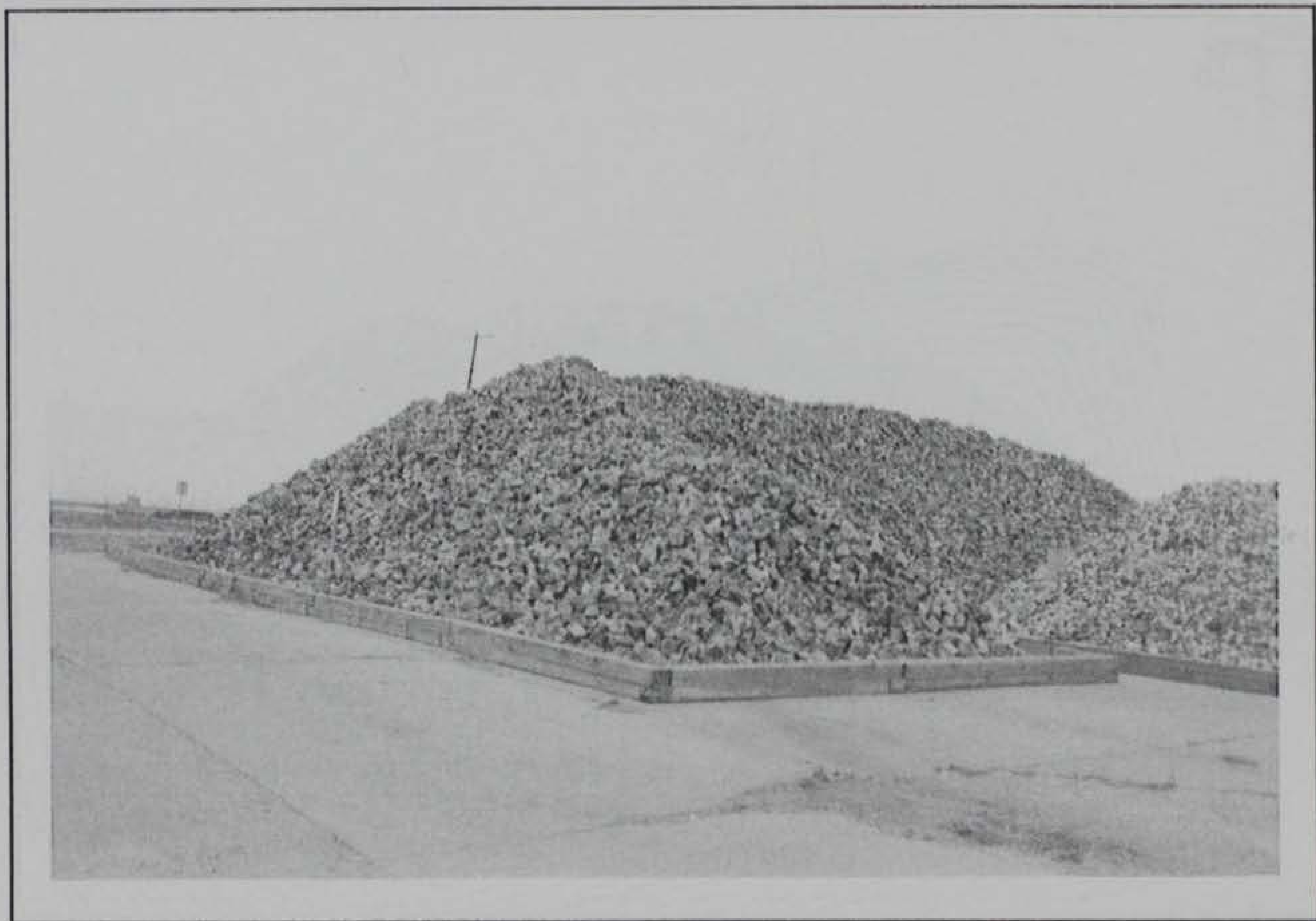


Figure D-29. Pile #112, Curtis Bay Depot, MD

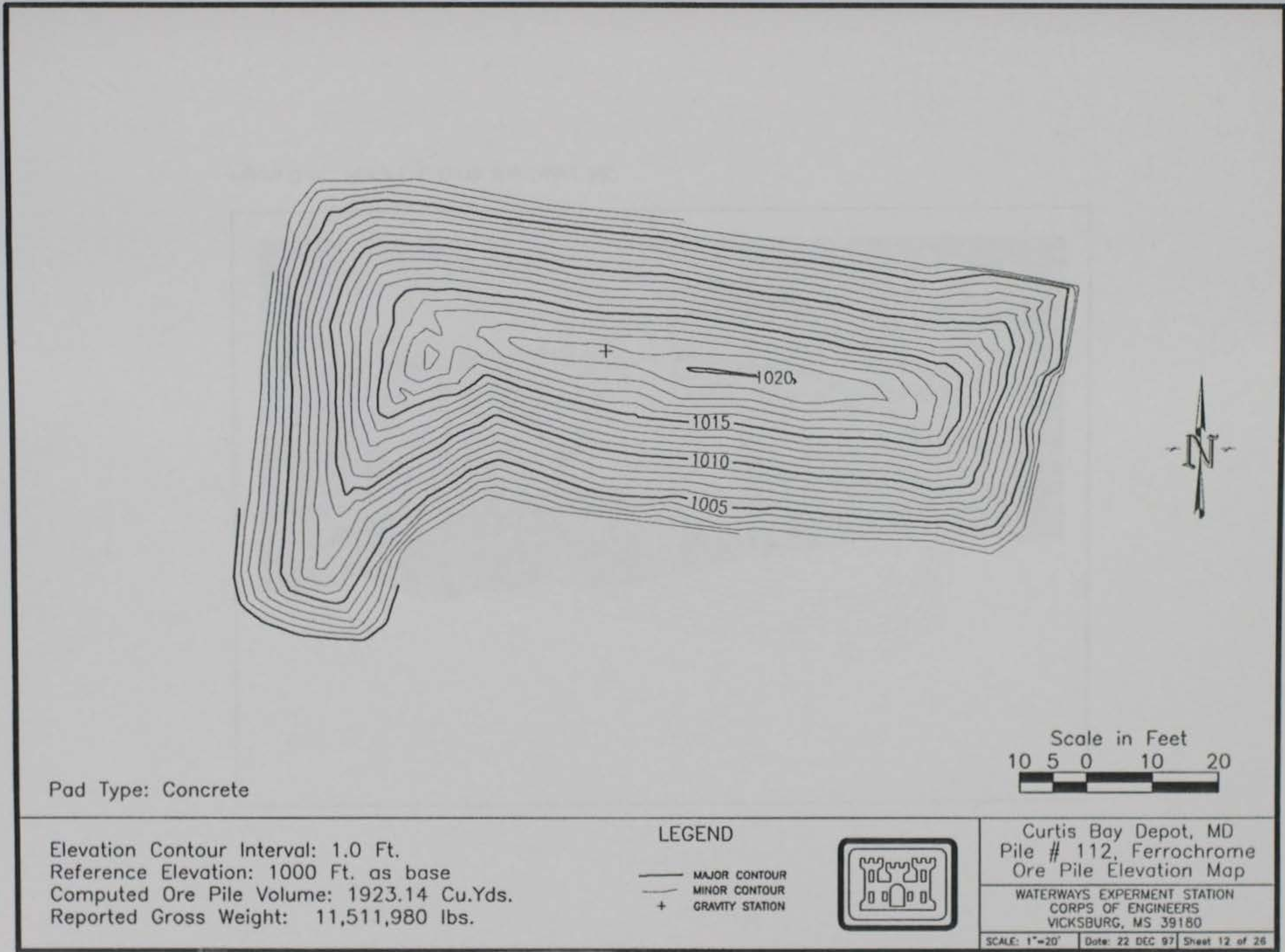
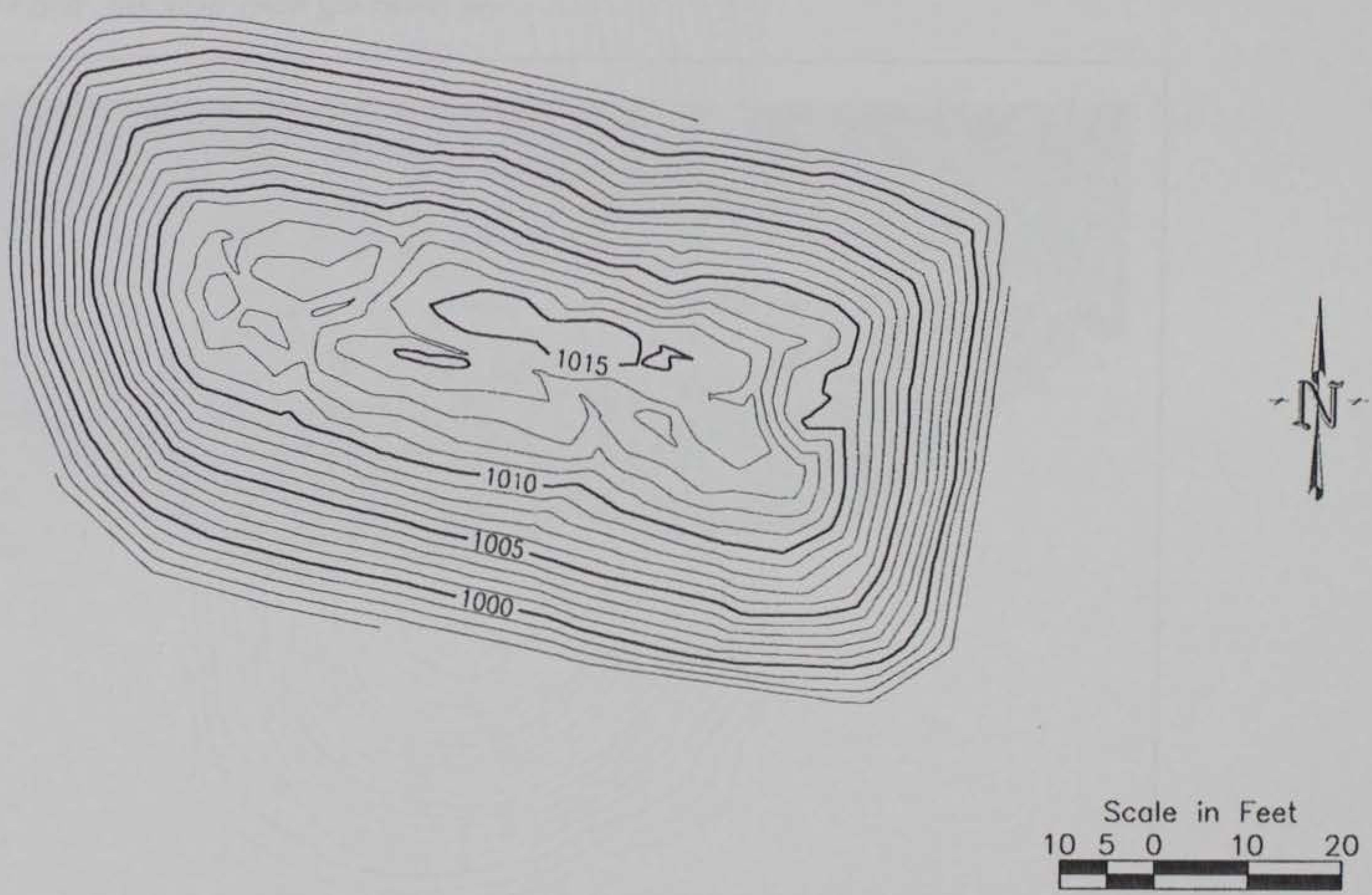


Figure D-30. Elevation contour plot of Pile #112, Curtis Bay Depot, MD

Figure D-31. Pile #114, Curtis Bay Depot, MD



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 2178.96 Cu.Yds.
Reported Gross Weight: 13,477,380 lbs.

LEGEND

- MAJOR CONTOUR
- MINOR CONTOUR
- + GRAVITY STATION

Curtis Bay Depot, MD
Pile # 114, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'	Date: 22 DEC 97	Sheet 13 of 26

Figure D-32. Elevation contour plot of Pile #114, Curtis Bay Depot, MD

Figure D-33. Pile #118, Curtis Bay Depot, MD

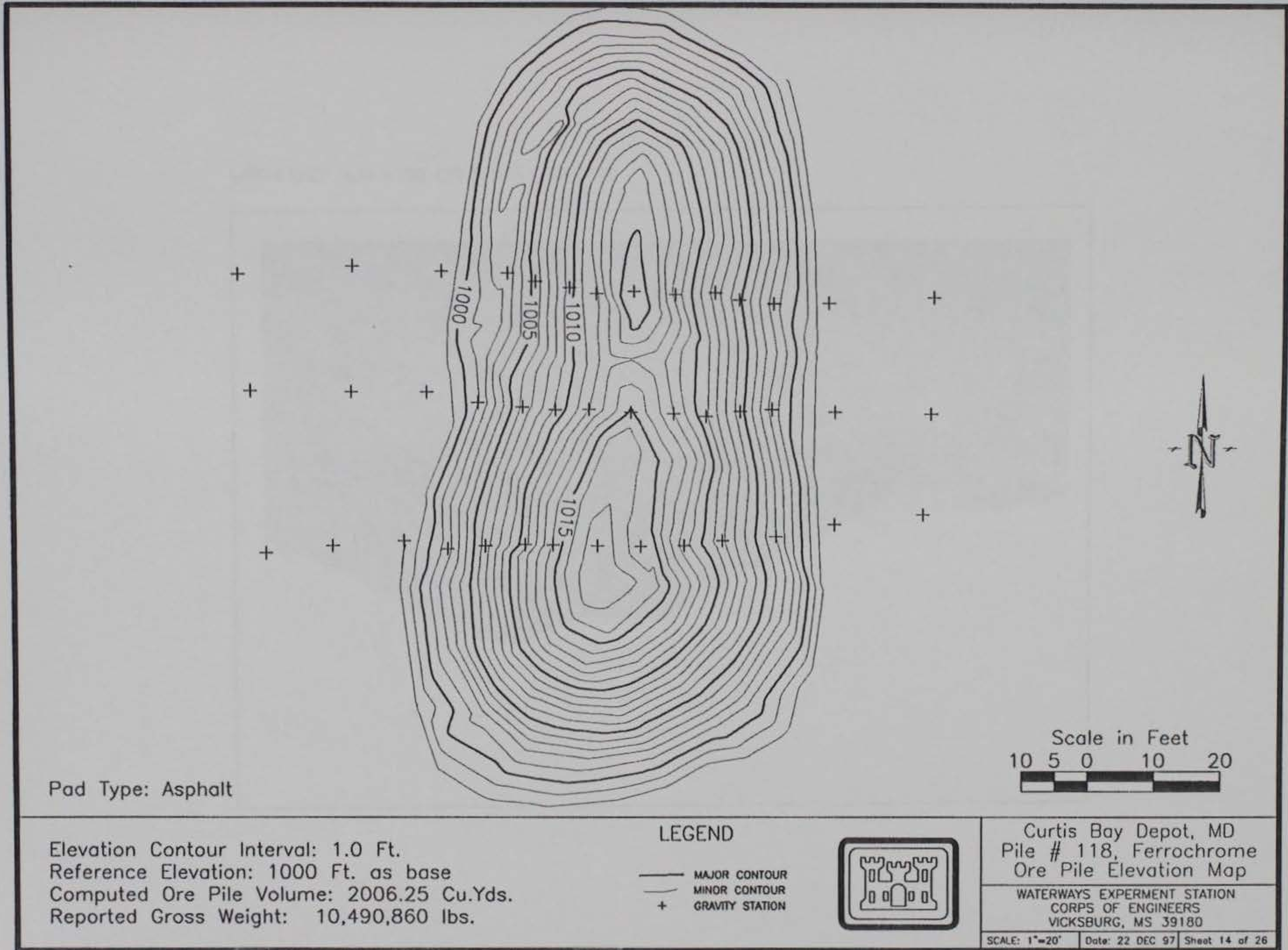


Figure D-34. Elevation contour plot of Pile #118, Curtis Bay Depot, MD

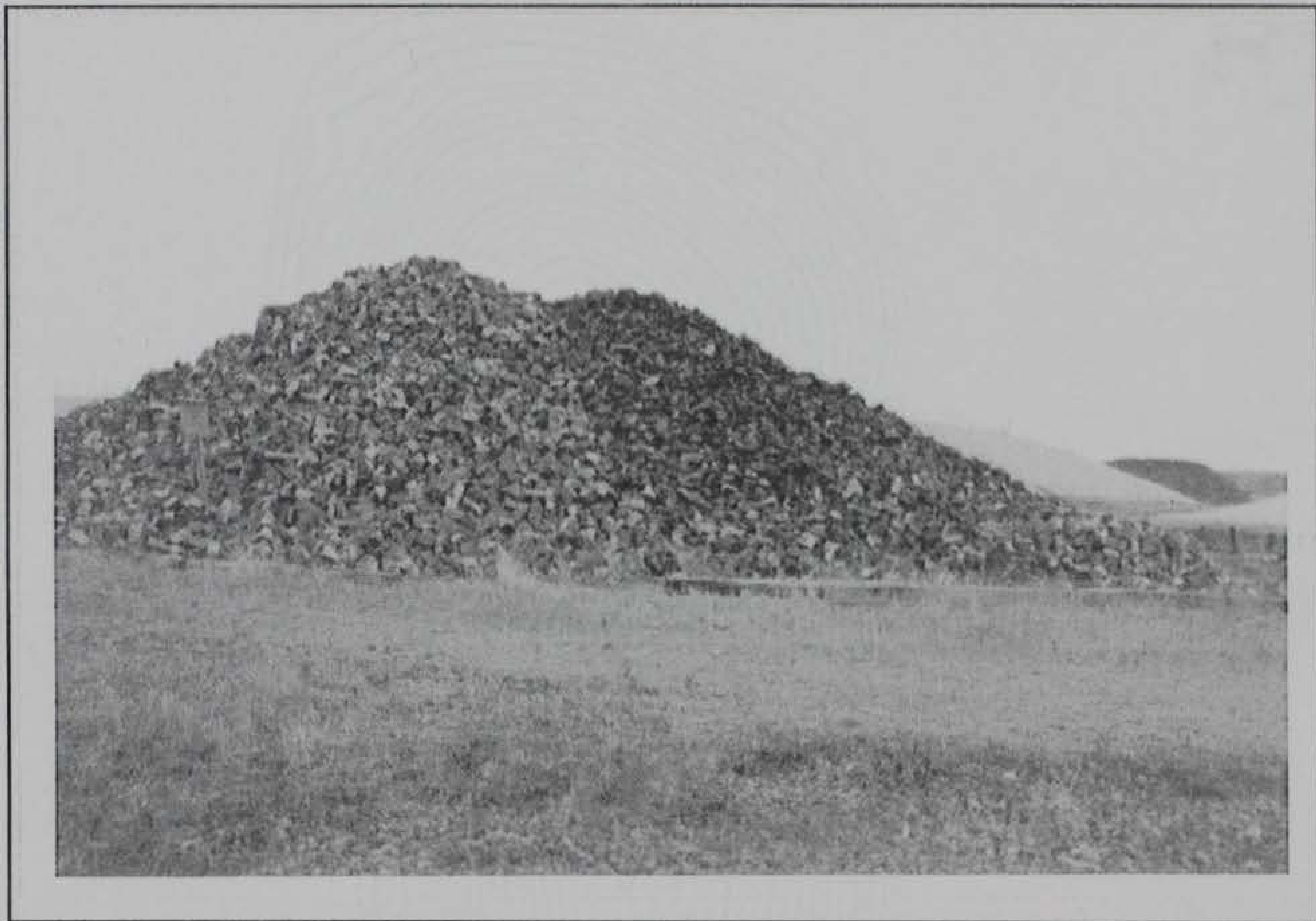


Figure D-35. Pile #120, Curtis Bay Depot, MD

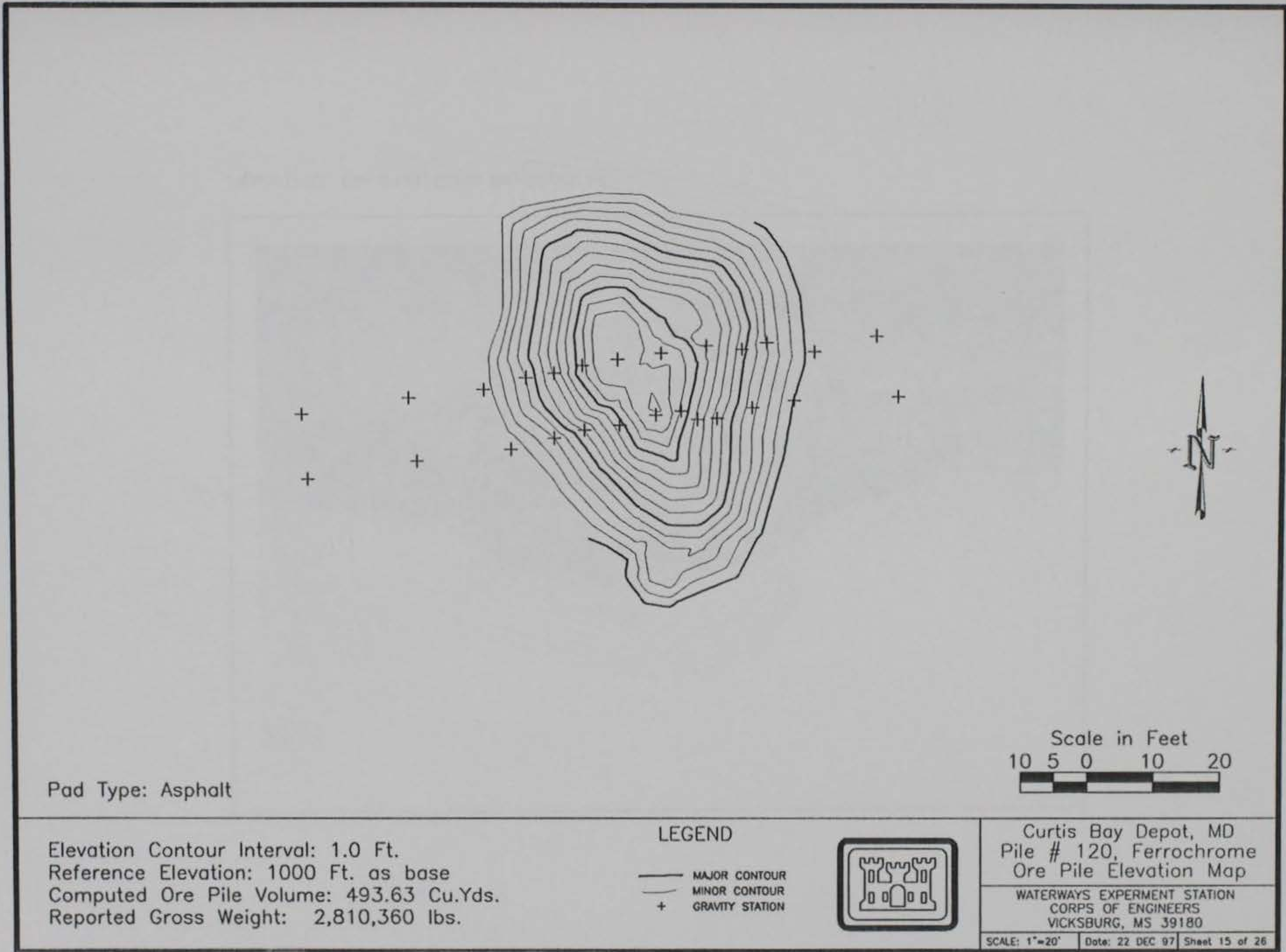
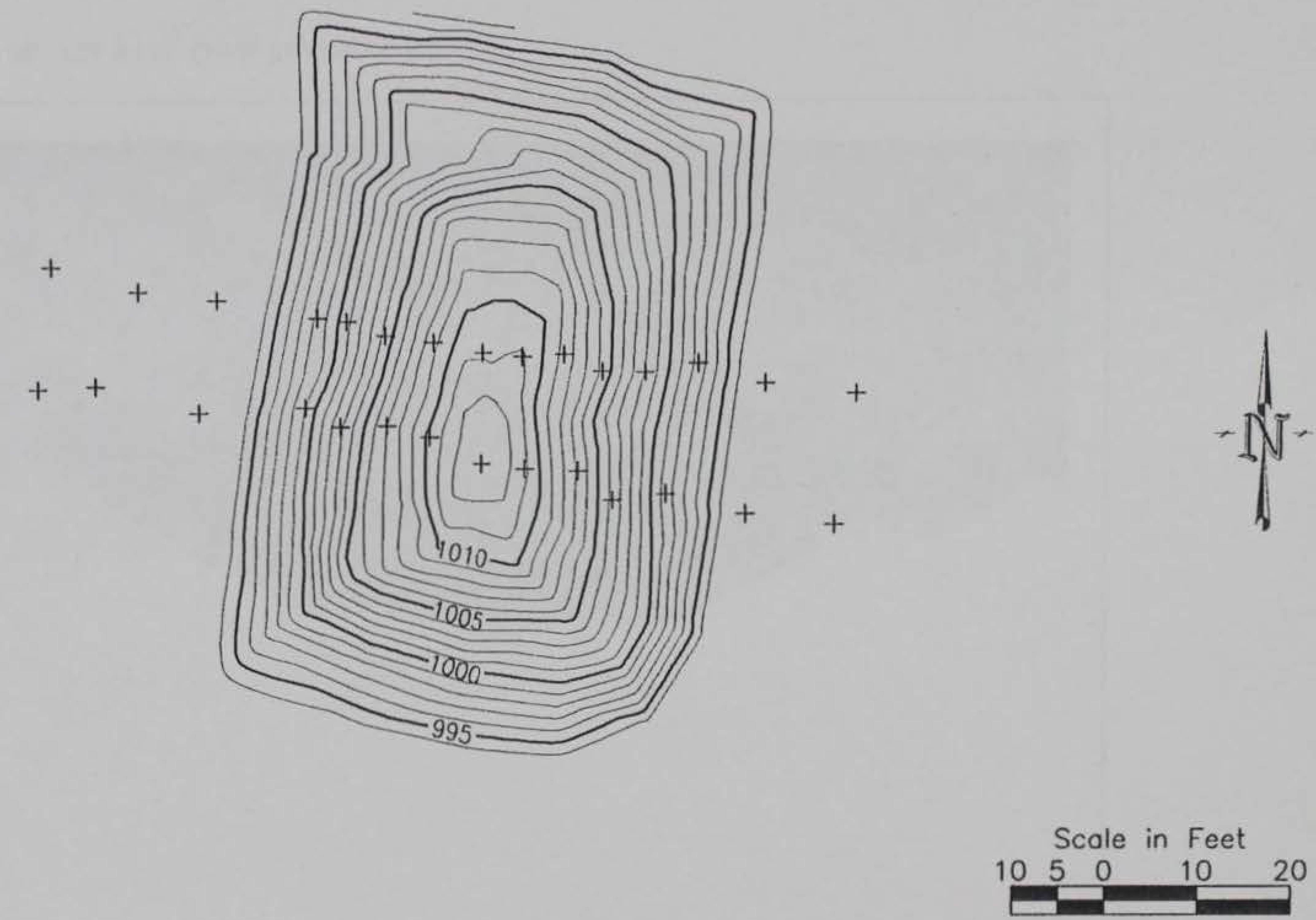


Figure D-36. Elevation contour plot of Pile #120, Curtis Bay Depot, MD

Figure D-37. Pile #121, Curtis Bay Depot, MD



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 1232.93 Cu.Yds.
Reported Gross Weight: 6,969,460 lbs.

LEGEND

- MAJOR CONTOUR
- MINOR CONTOUR
- \+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 121, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 22 DEC 97 | Sheet 16 of 26

Figure D-38. Elevation contour plot of Pile #121, Curtis Bay Depot, MD

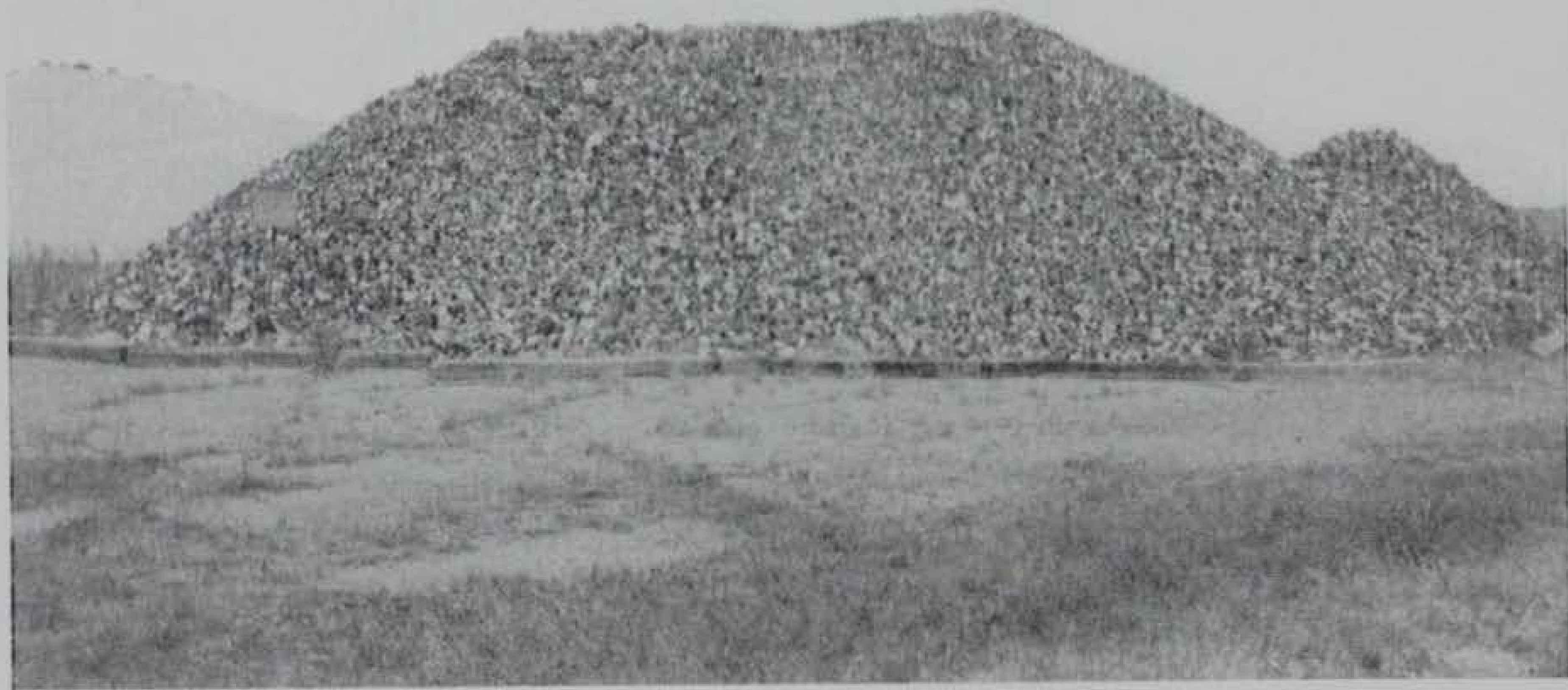


Figure D-39. Pile #125, Curtis Bay Depot, MD

Pad Type: Asphalt

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 896.00 Cu.Yds.
Reported Gross Weight: 4,981,160 lbs.

LEGEND

- MAJOR CONTOUR
- MINOR CONTOUR
- \+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 125, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'	Date: 22 DEC 97	Sheet 17 of 26

Figure D-40. Elevation contour plot of Pile #125, Curtis Bay Depot, MD

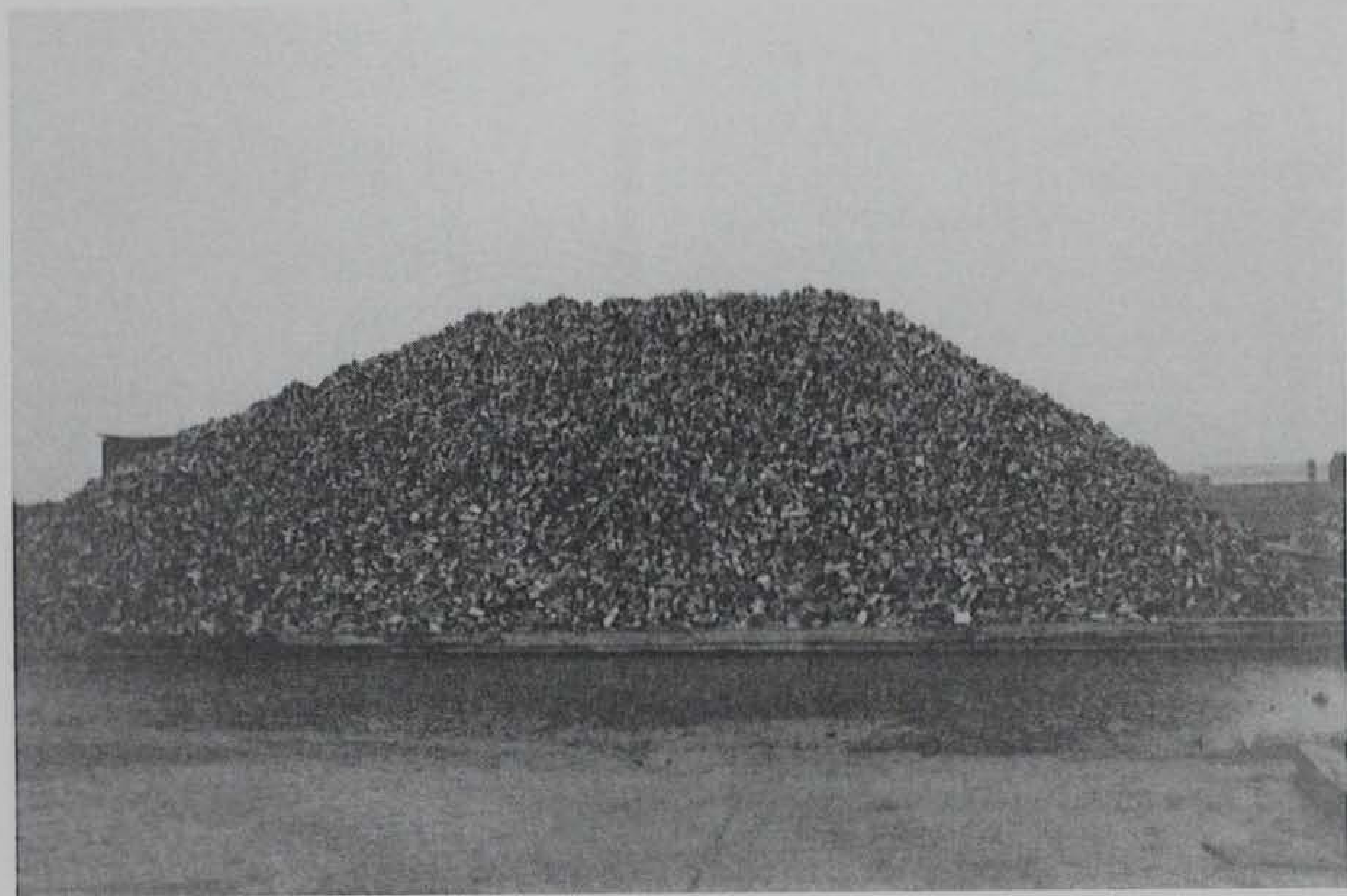


Figure D-41. Pile #203, Curtis Bay Depot, MD

Figure D-42. Elevation contour plot of Pile #203, Curtis Bay Depot, MD

Figure D-43. Piles #18 and #25 (back left), Curtis Bay Depot, MD

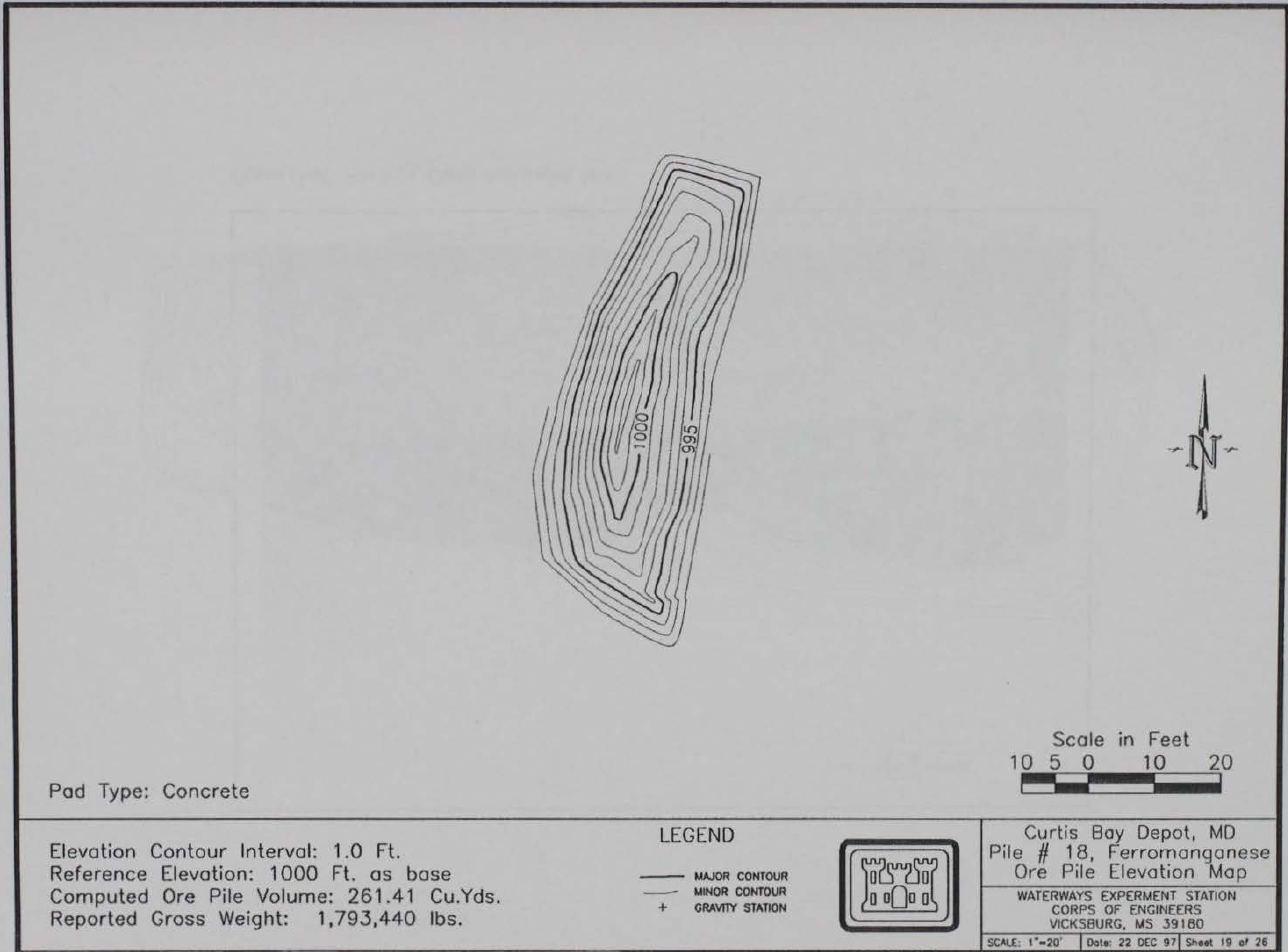


Figure D-44. Elevation contour plot of Pile #18, Curtis Bay Depot, MD

Figure D-45. Pile #24, Curtis Bay Depot, MD

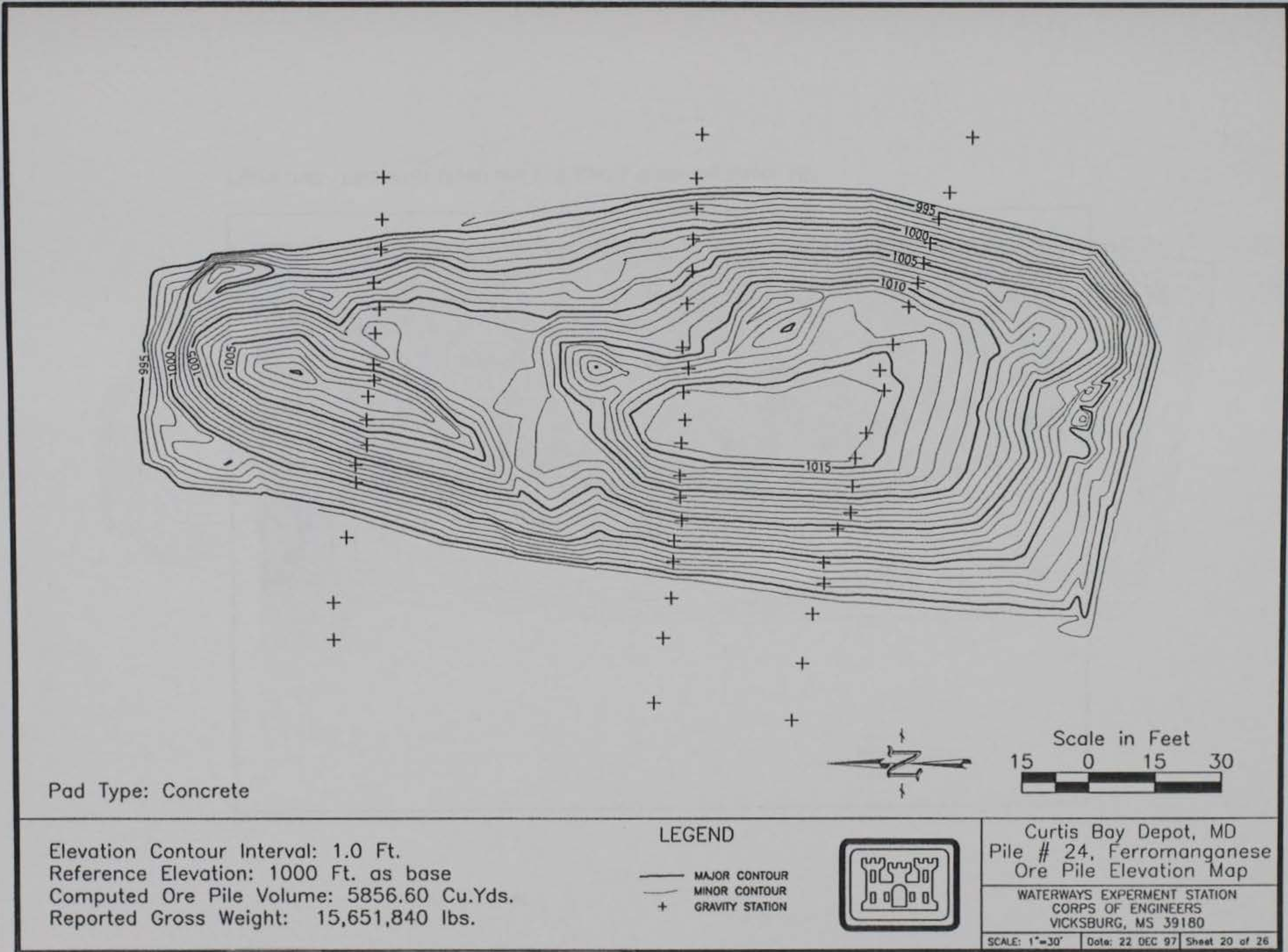
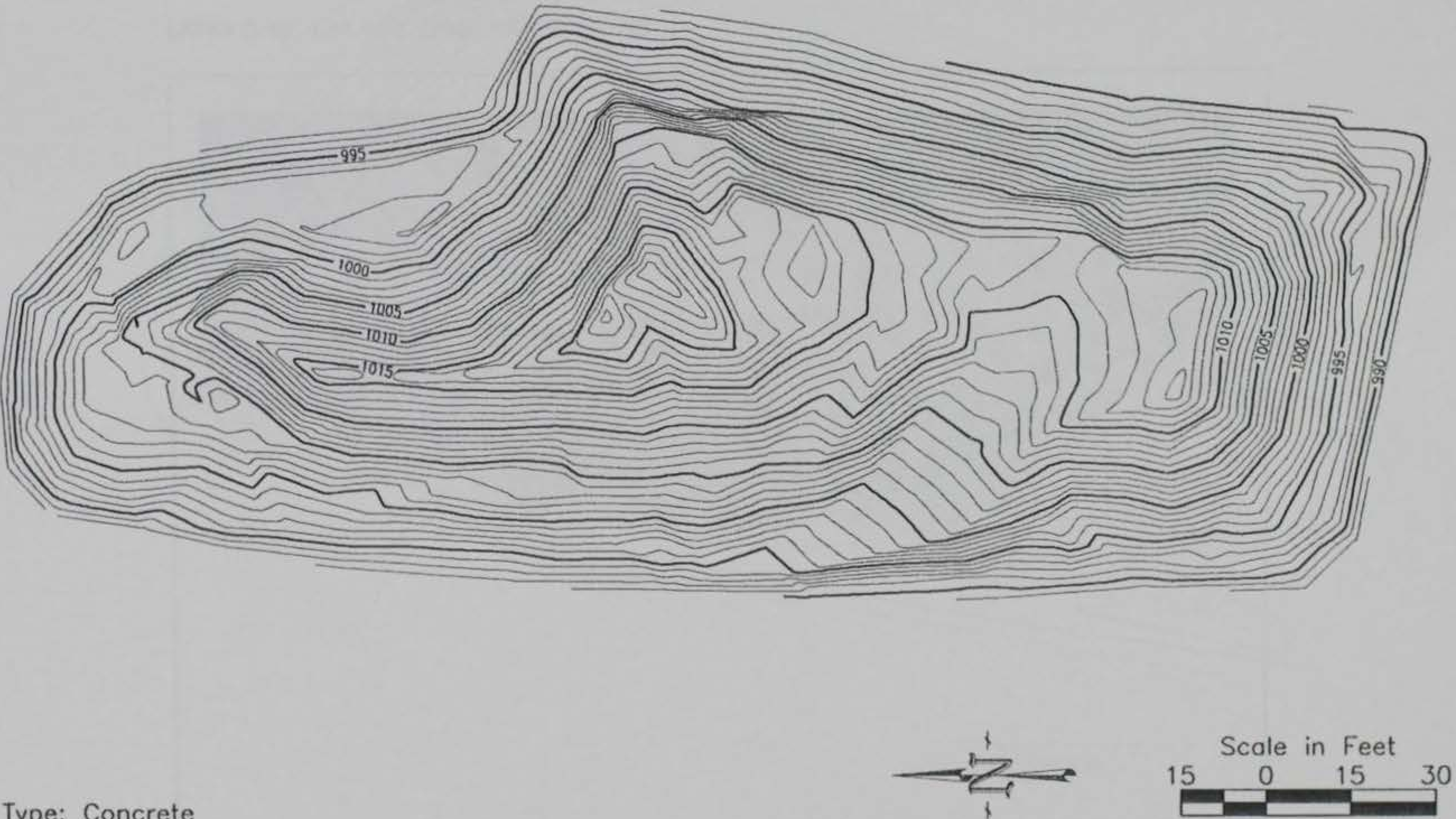


Figure D-46. Elevation contour plot of Pile #24, Curtis Bay Depot, MD

Figure D-47. Piles #161 (front) and #25 (back), Curtis Bay Depot, MD



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 11,339.88 Cu.Yds.
Reported Gross Weight: 72,392,040 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 25, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=30' | Date: 22 DEC 97 | Sheet 21 of 26

Figure D-48. Elevation contour plot of Pile #25, Curtis Bay Depot, MD

Figure D-49. Pile #26, Curtis Bay Depot, MD

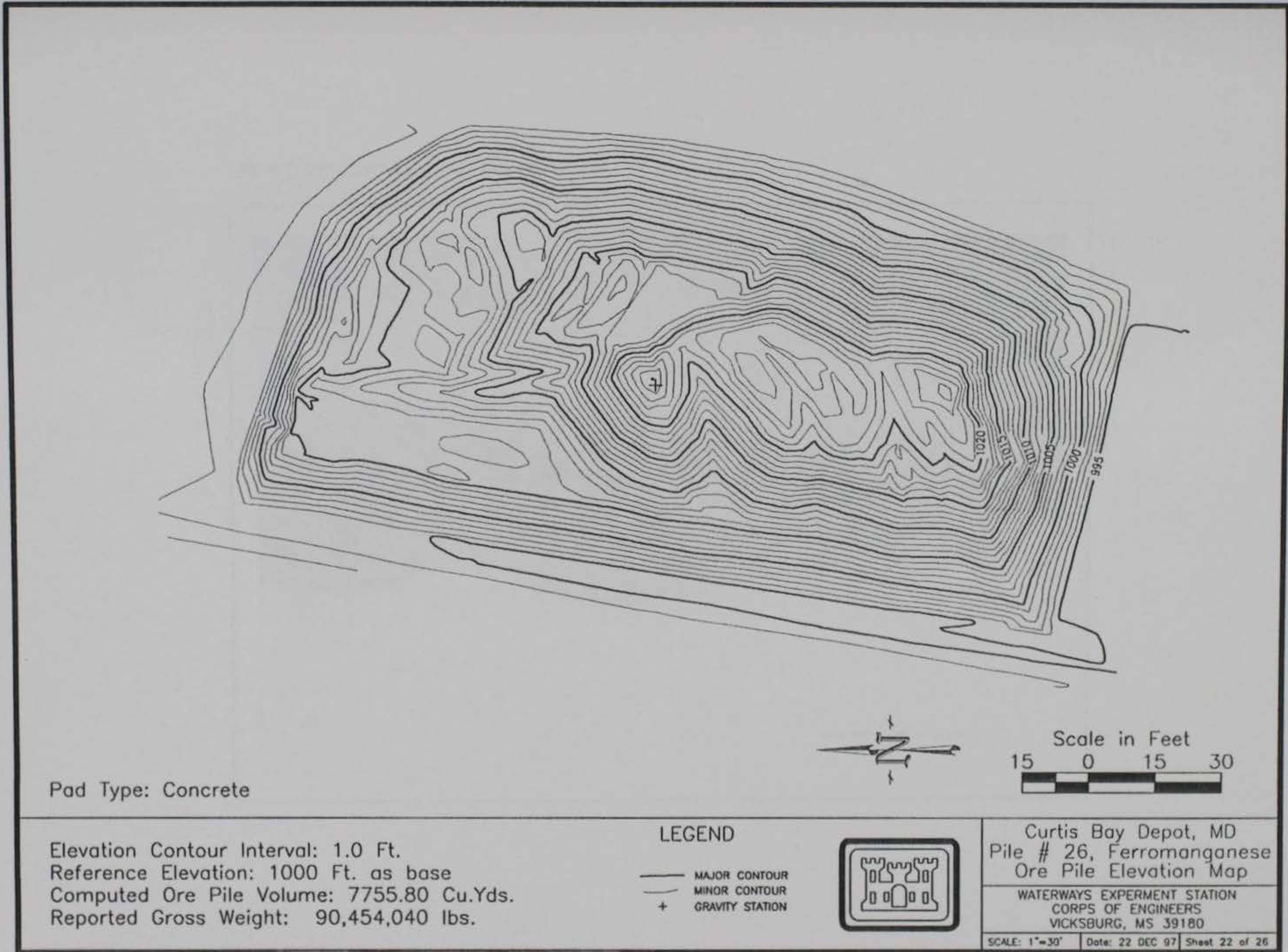
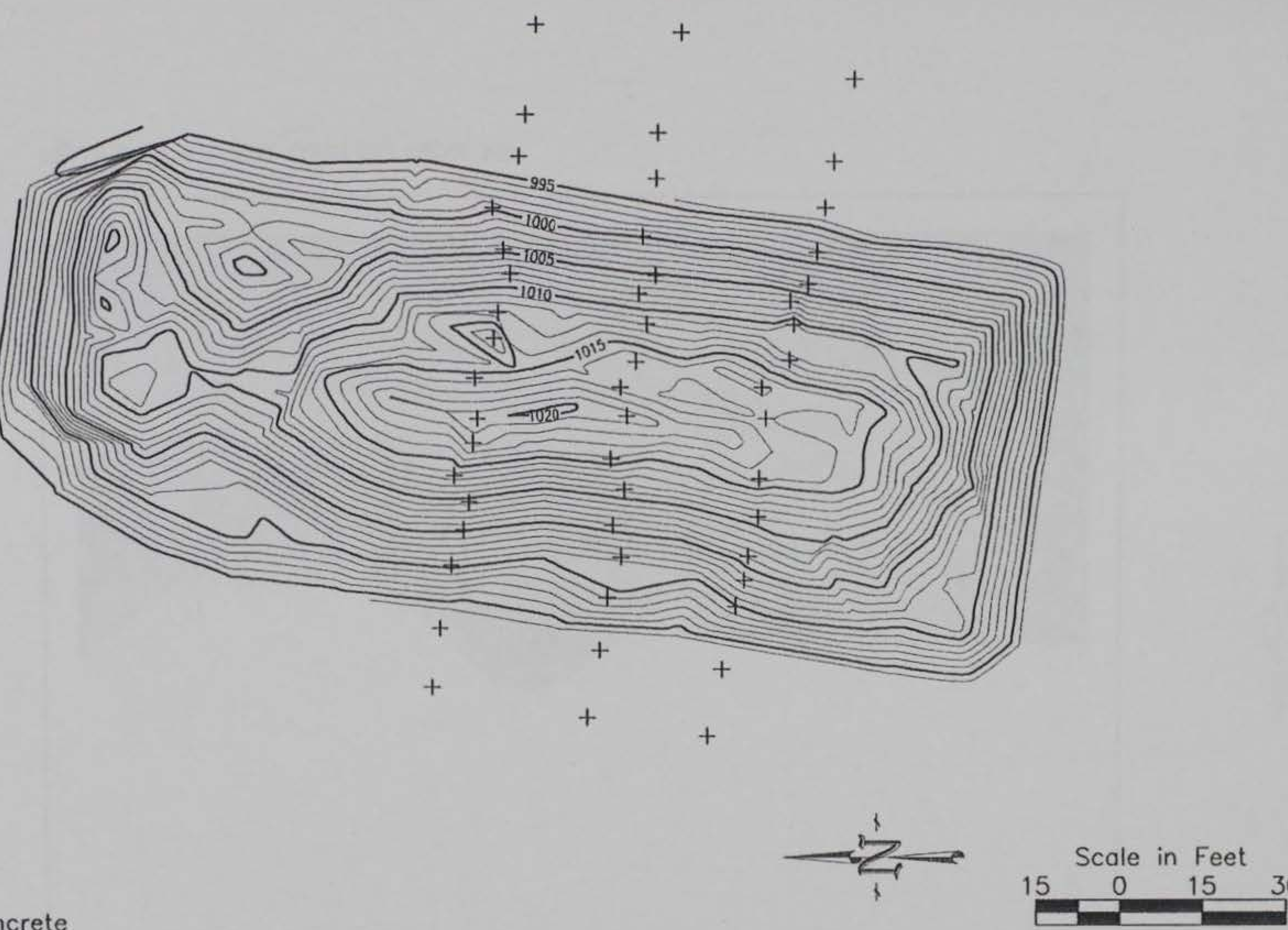


Figure D-50. Elevation contour plot of Pile #26, Curtis Bay Depot, MD

Figure D-51. Pile #27, Curtis Bay Depot, MD



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 7058.60 Cu.Yds.
Reported Gross Weight: 44,067,100 lbs.

LEGEND

- MAJOR CONTOUR
- MINOR CONTOUR
- + GRAVITY STATION

Curtis Bay Depot, MD
Pile # 27, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=30' | Date: 22 DEC 97 | Sheet 23 of 26

Figure D-52. Elevation contour plot of Pile #27, Curtis Bay Depot, MD

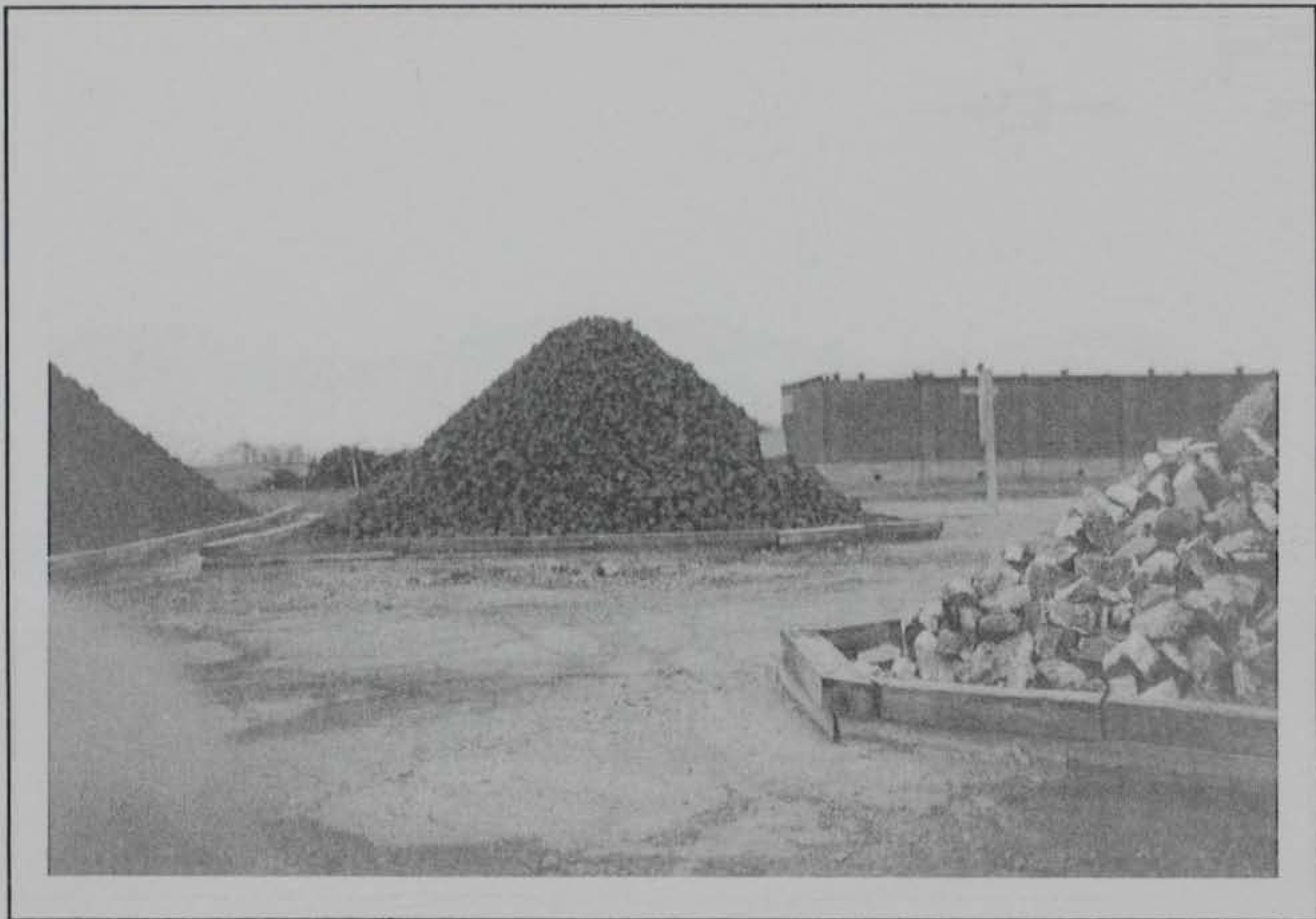
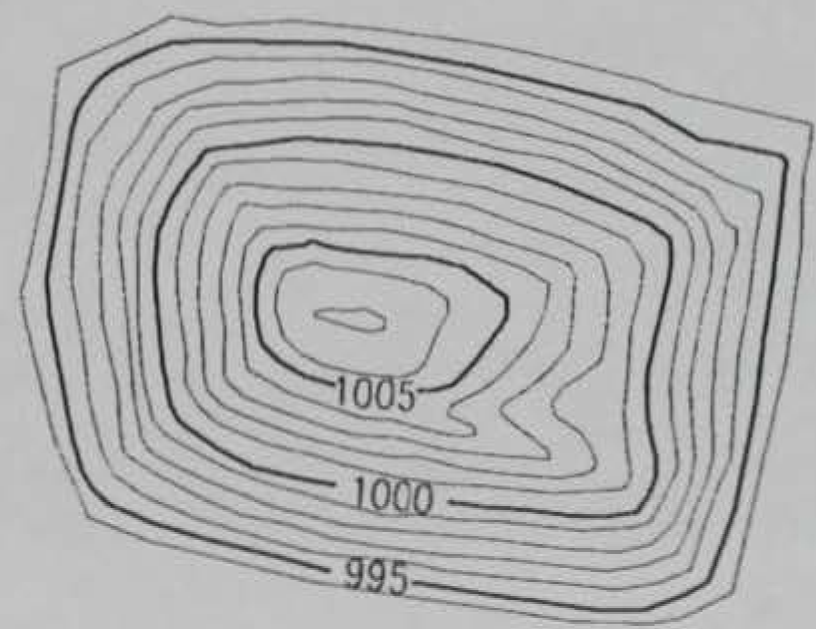


Figure D-53. Pile #99, Curtis Bay Depot, MD



Scale in Feet
10 5 0 10 20

Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 344.70 Cu.Yds.
Reported Gross Weight: 2,290,420 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 99, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 22 DEC 97 | Sheet 24 of 26

Figure D-54. Elevation contour plot of Pile #99, Curtis Bay Depot, MD

Figure D-55. Eastern side of Pile #153 as of 21 November 1997, Curtis Bay Depot, MD. Material was being removed from both ends of the ore pile during the investigation

Note: Pile #153 was being removed from the site during this investigation. This plot illustrates Pile #153 as of 14 November 1997.

Pad Type: Soil/Gravel

Scale in Feet
15 0 15 30

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 32,172.40 Cu.Yds. (as of 14 Nov 1997)
Reported Gross Weight: 249,162,520 lbs. (Original Weight) / 227,944,400 lbs. (as of 14 Nov 1997)

LEGEND
MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 153, Ferromanganese Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=30' | Date: 22 DEC 97 | Sheet 25 of 28

Figure D-56. Elevation contour plot of Pile #153, Curtis Bay Depot, MD

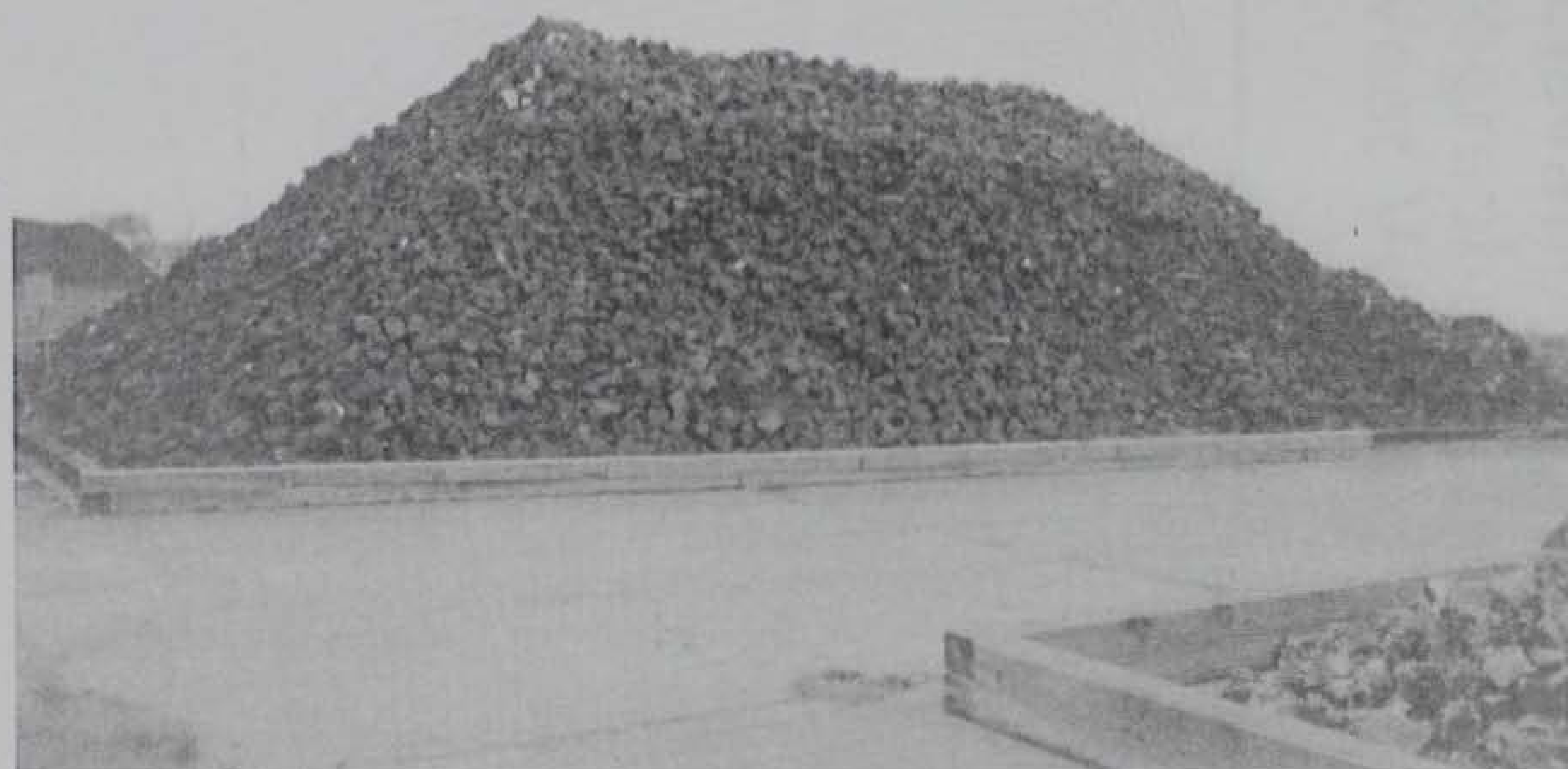
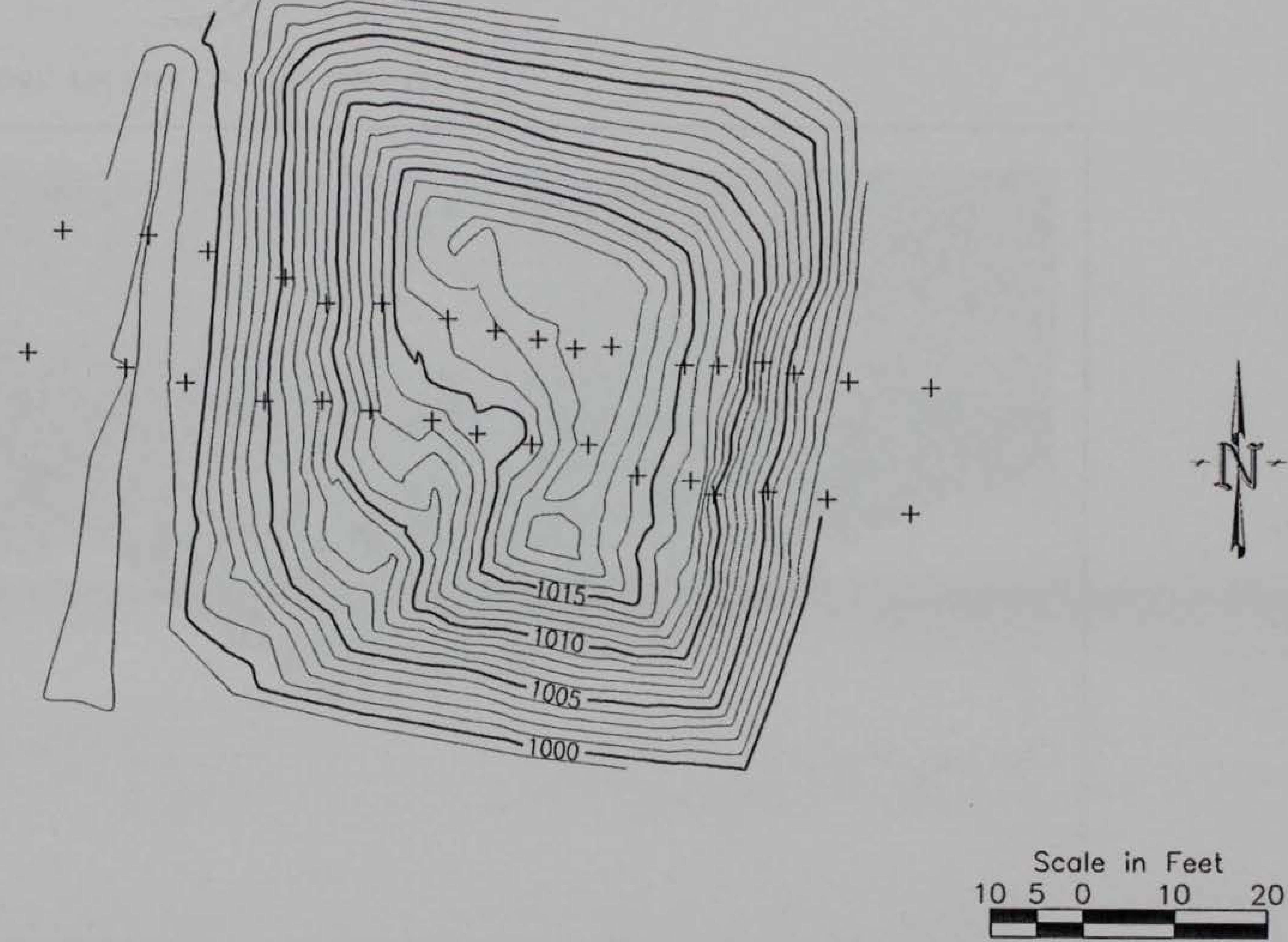


Figure D-57. Pile #154, Curtis Bay Depot, MD



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 1000 Ft. as base
Computed Ore Pile Volume: 1880.62 Cu.Yds.
Reported Gross Weight: 12,033,700 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Curtis Bay Depot, MD
Pile # 154, Ferromanganese
Ore Pile Elevation Map

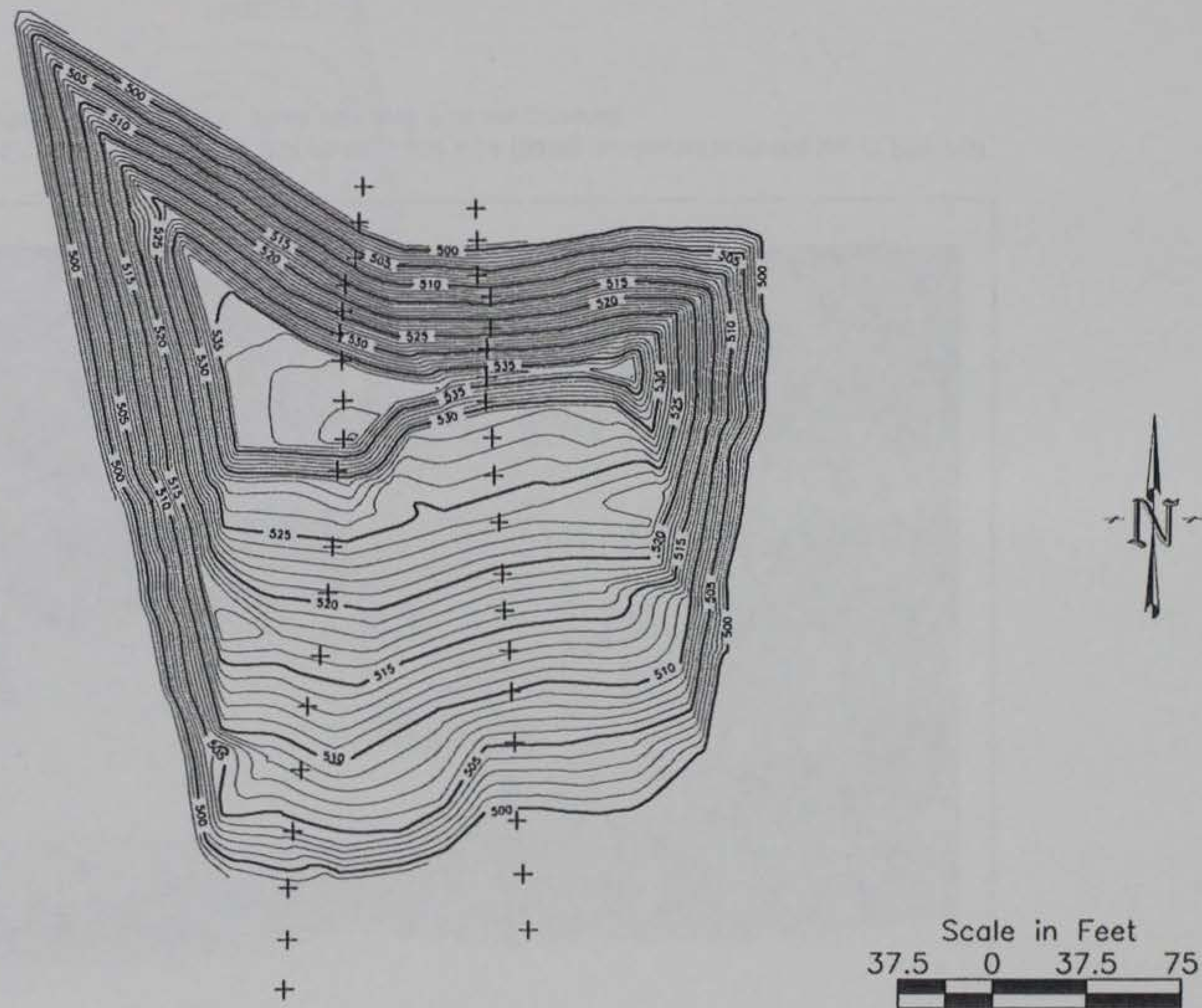
WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20' | Date: 22 DEC 97 | Sheet 26 of 26

Figure D-58. Elevation contour plot of Pile #154, Curtis Bay Depot, MD

Appendix E
Ore Pile Elevation Contour Plots and Photographs, Point Pleasant Depot, West Virginia

Figure E-1. South side of Pile #62, Point Pleasant Depot, WV



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 500 Ft. as base
Computed Ore Pile Volume: 44558.37 Cu.Yds.
Reported Gross Weight: 279,054,660 lbs.

LEGEND

—— MAJOR CONTOUR
—— MINOR CONTOUR
\+ GRAVITY STATION

Point Pleasant Depot, WV
Pile # 62, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=75'	Date: 20 OCT 97	Sheet 1 of 8

Figure E-2. Elevation contour plot of Pile #62, Point Pleasant Depot, WV

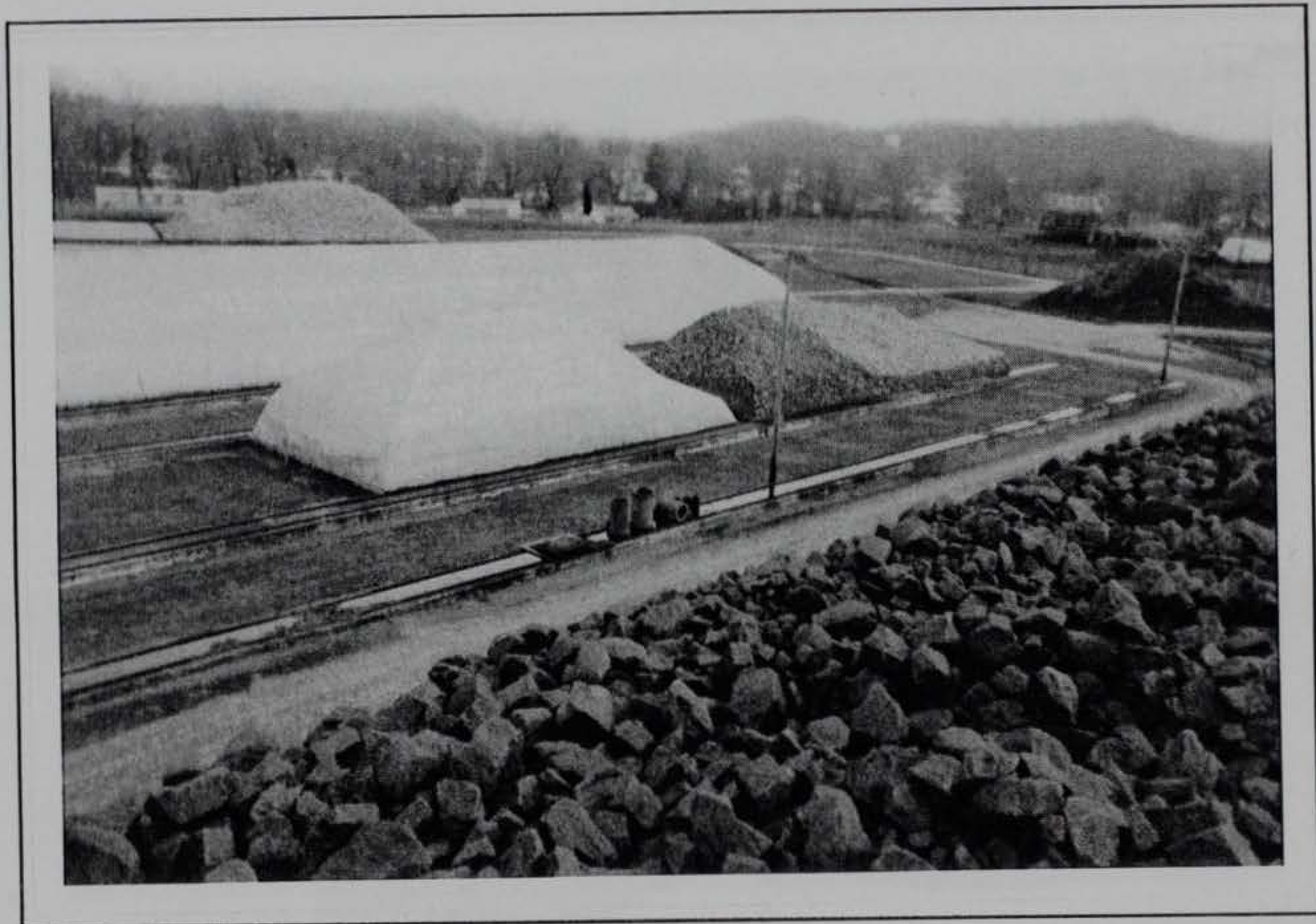
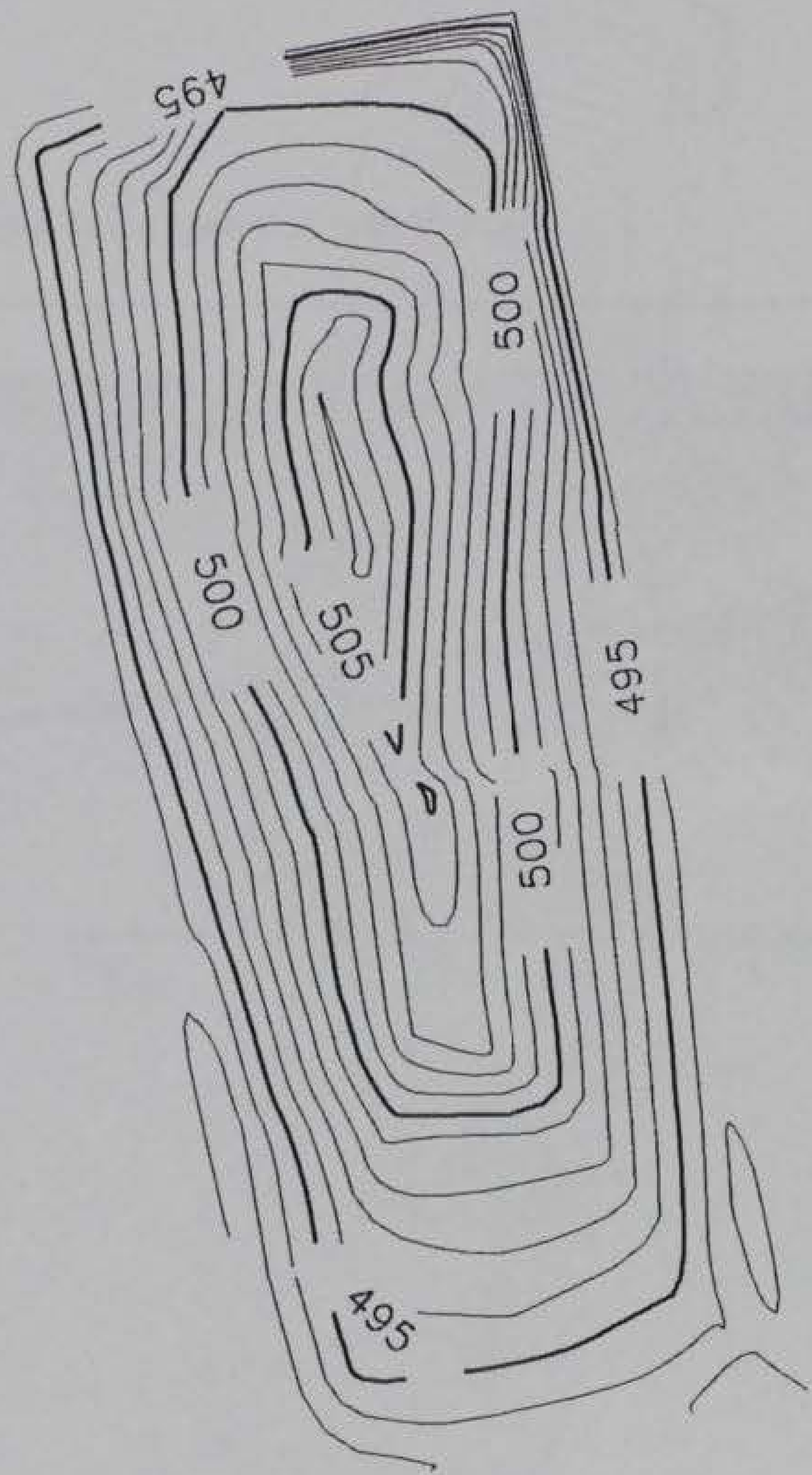


Figure E-3. Piles #57 (right center), #55 (left center), and #54 (back) as viewed from the top of Pile #61, Point Pleasant Depot, WV. Piles #54 and #55 are covered



Scale in Feet

10 0 10 20

Pad Type: Asphalt/Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 500 Ft. as base
Computed Ore Pile Volume: 1024.75 Cu.Yds.
Reported Gross Weight: 8,824,075 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR

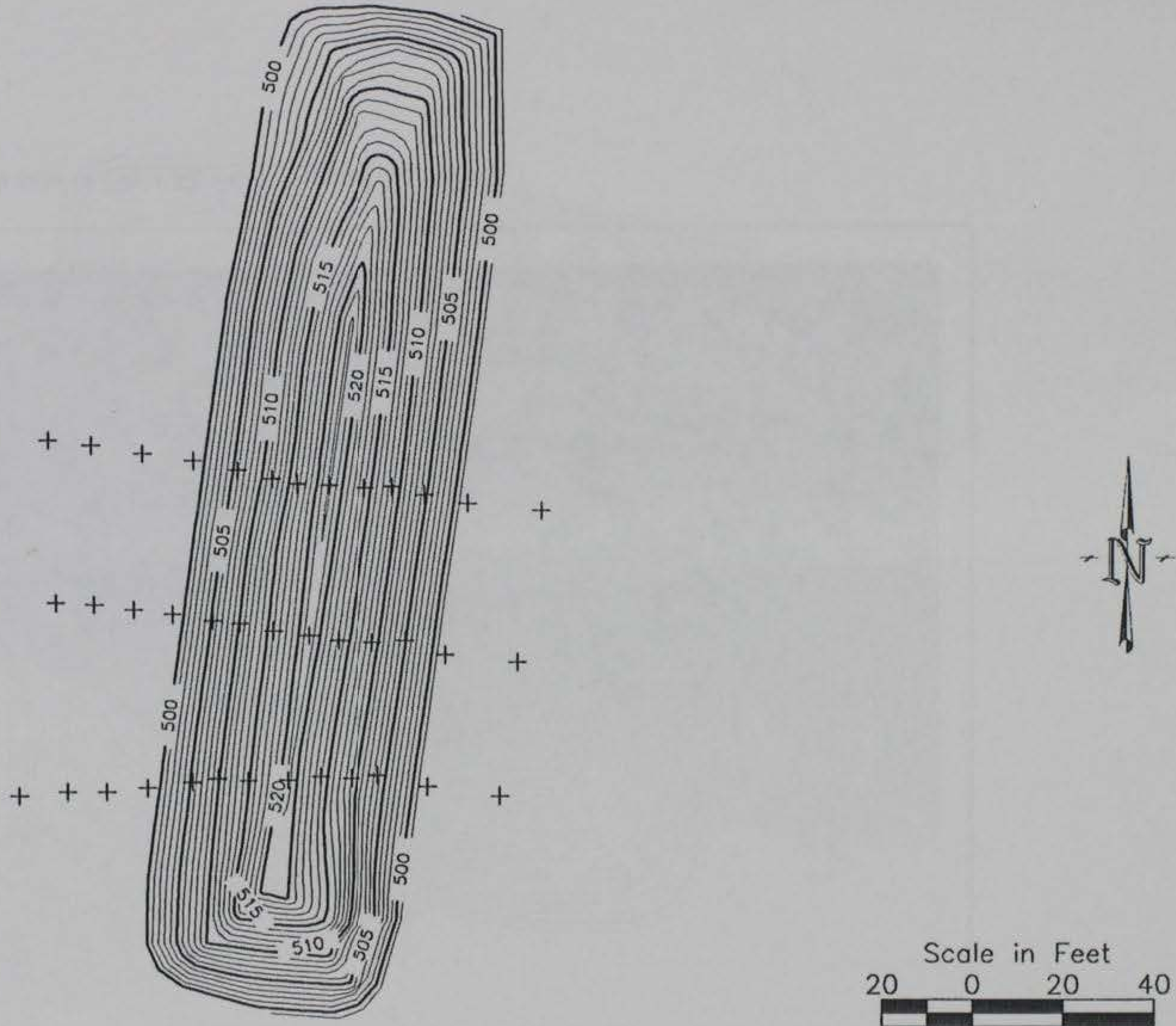
Point Pleasant Depot, WV
Pile # 57, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=20'	Date: 20 OCT 97	Sheet 2 of 8

Figure E-4. Elevation contour plot of Pile #57, Point Pleasant Depot, WV

Figure E-5. Pile #62A, Point Pleasant Depot, WV



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 500 Ft. as base
Computed Ore Pile Volume: 4668.99 Cu.Yds.
Reported Gross Weight: 34,154,246 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Point Pleasant Depot, WV
Pile # 62A, Ferrochrome
Ore Pile Elevation Map

WATERWAYS EXPERMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=40' | Date: 20 OCT 97 | Sheet 4 of 8

Figure E-6. Elevation contour plot of Pile #62A, Point Pleasant Depot, WV

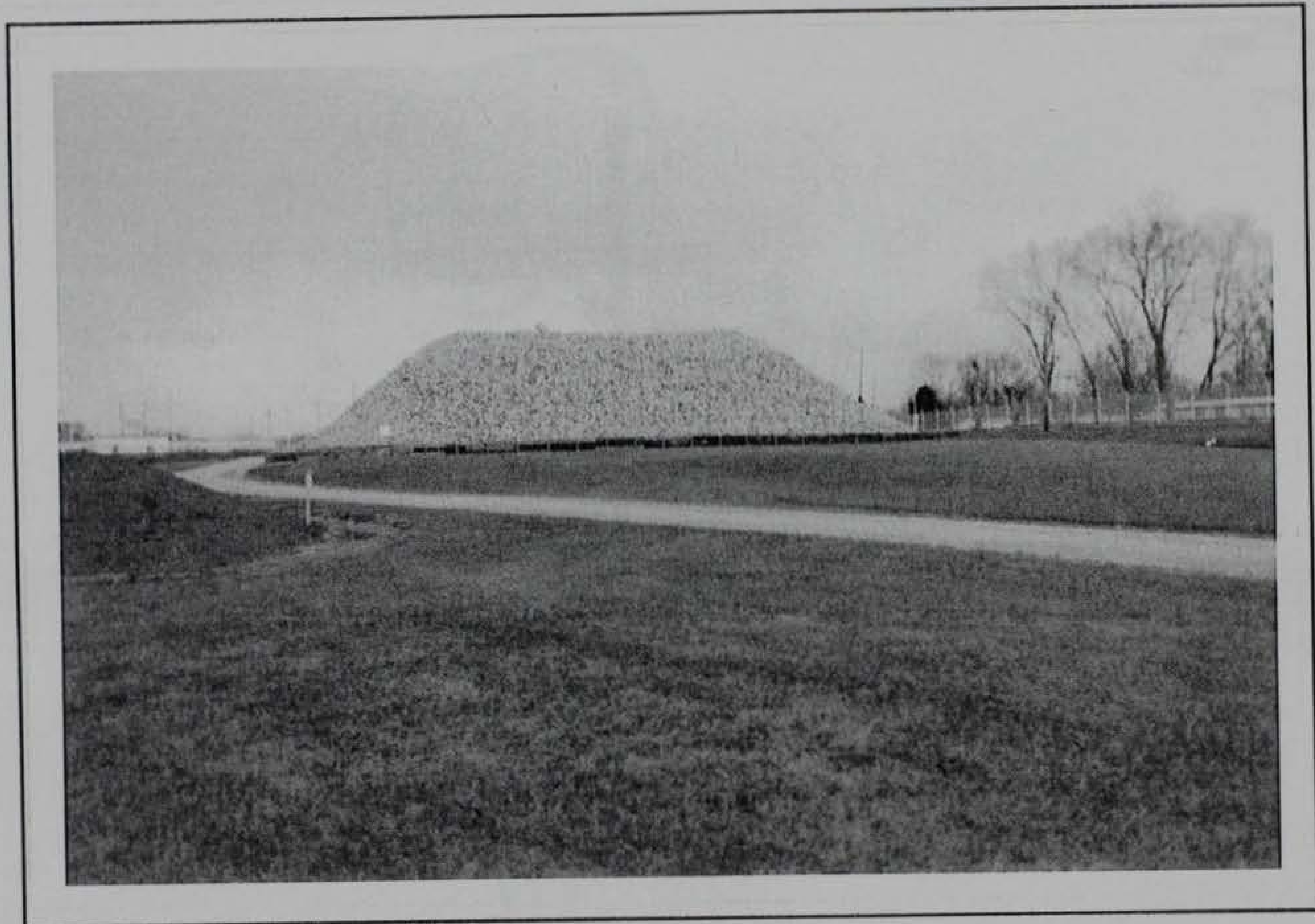


Figure E-7. South side of Pile #63, Point Pleasant Depot, WV

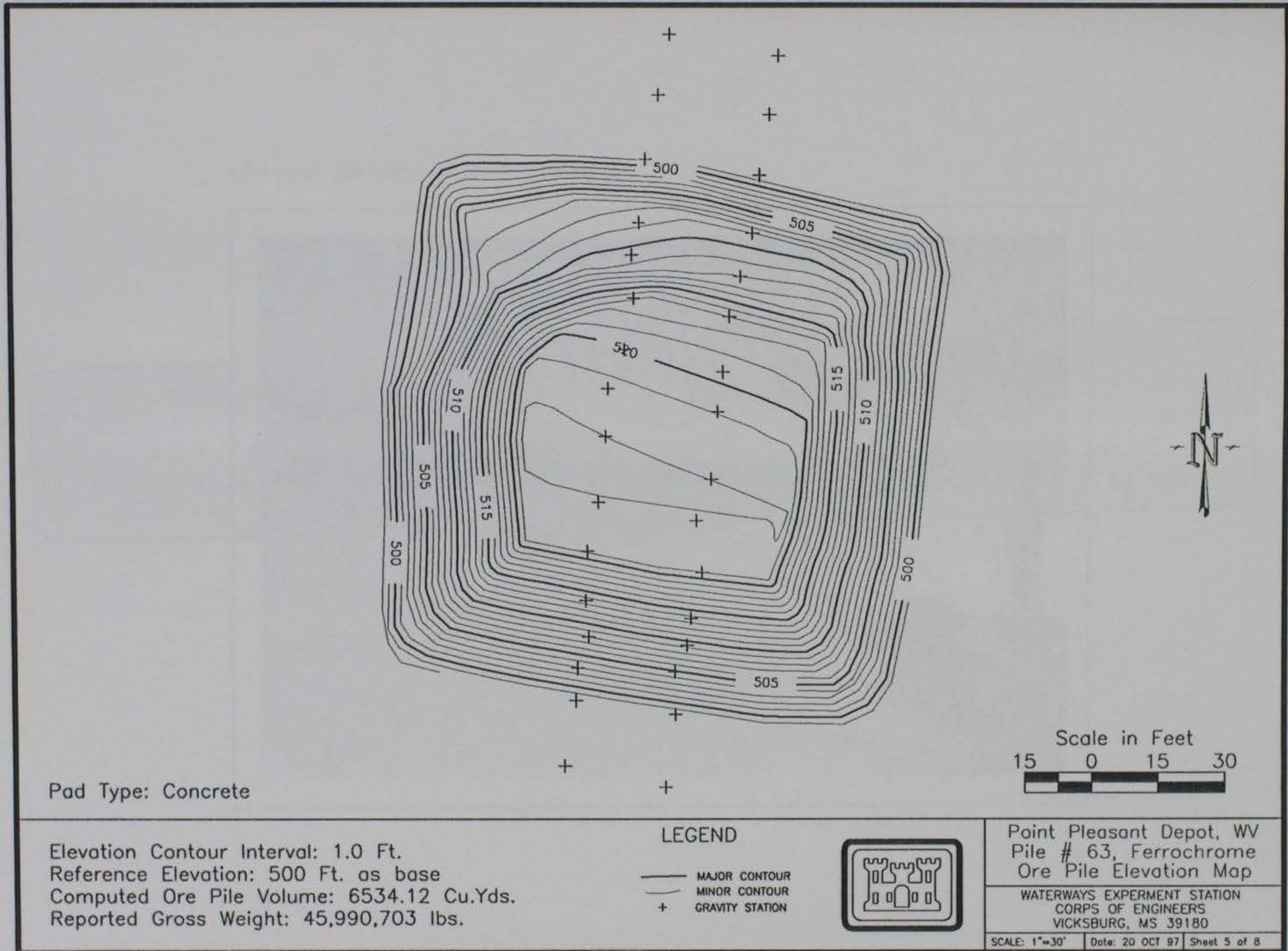
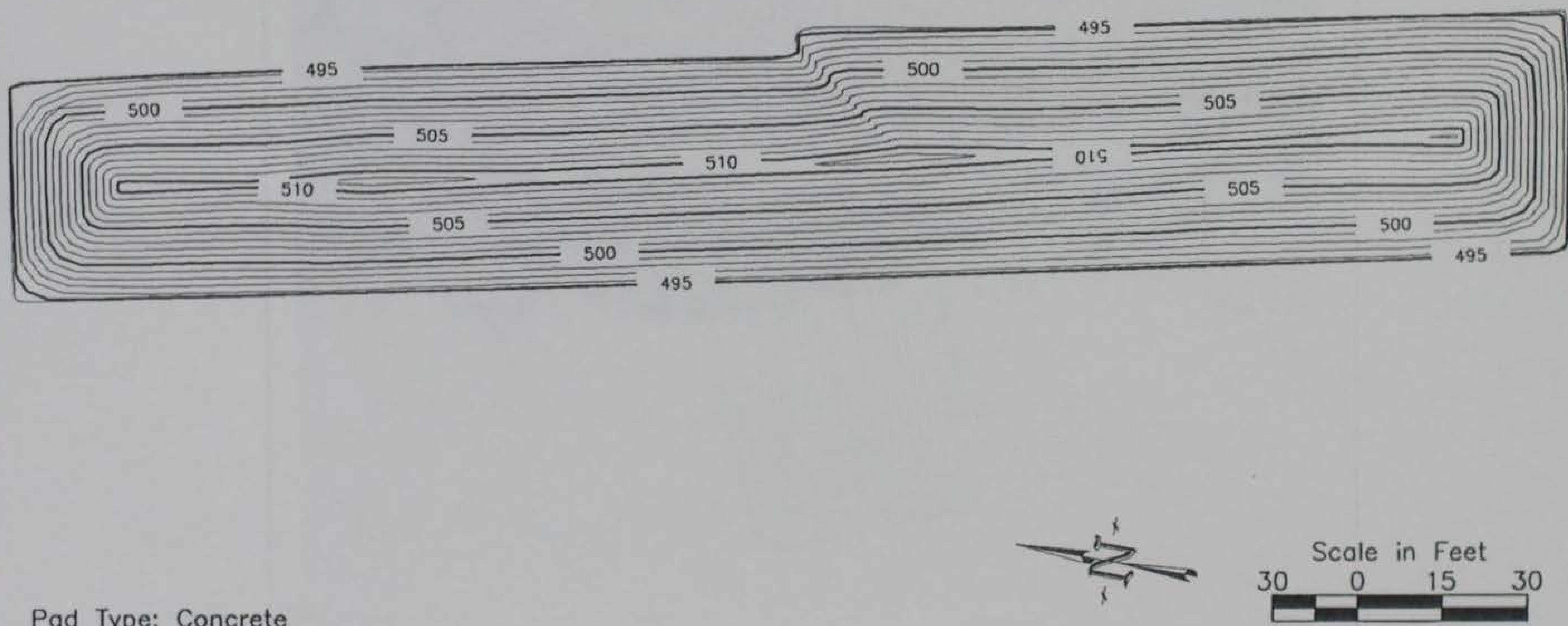


Figure E-8. Elevation contour plot of Pile #63, Point Pleasant Depot, WV

Figure E-9. Pile #59, Point Pleasant Depot, WV



Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 500 Ft. as base
Computed Ore Pile Volume: 3992.73 Cu.Yds.
Reported Gross Weight: 27,086,900 lbs.

LEGEND

MAJOR CONTOUR
MINOR CONTOUR

Point Pleasant Depot, WV
Pile # 59, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=30' | Date: 20 OCT 97 | Sheet 6 of 8

Figure E-10. Elevation contour plot of Pile #59, Point Pleasant Depot, WV

Figure E-11. Pile #60, Point Pleasant Depot, WV

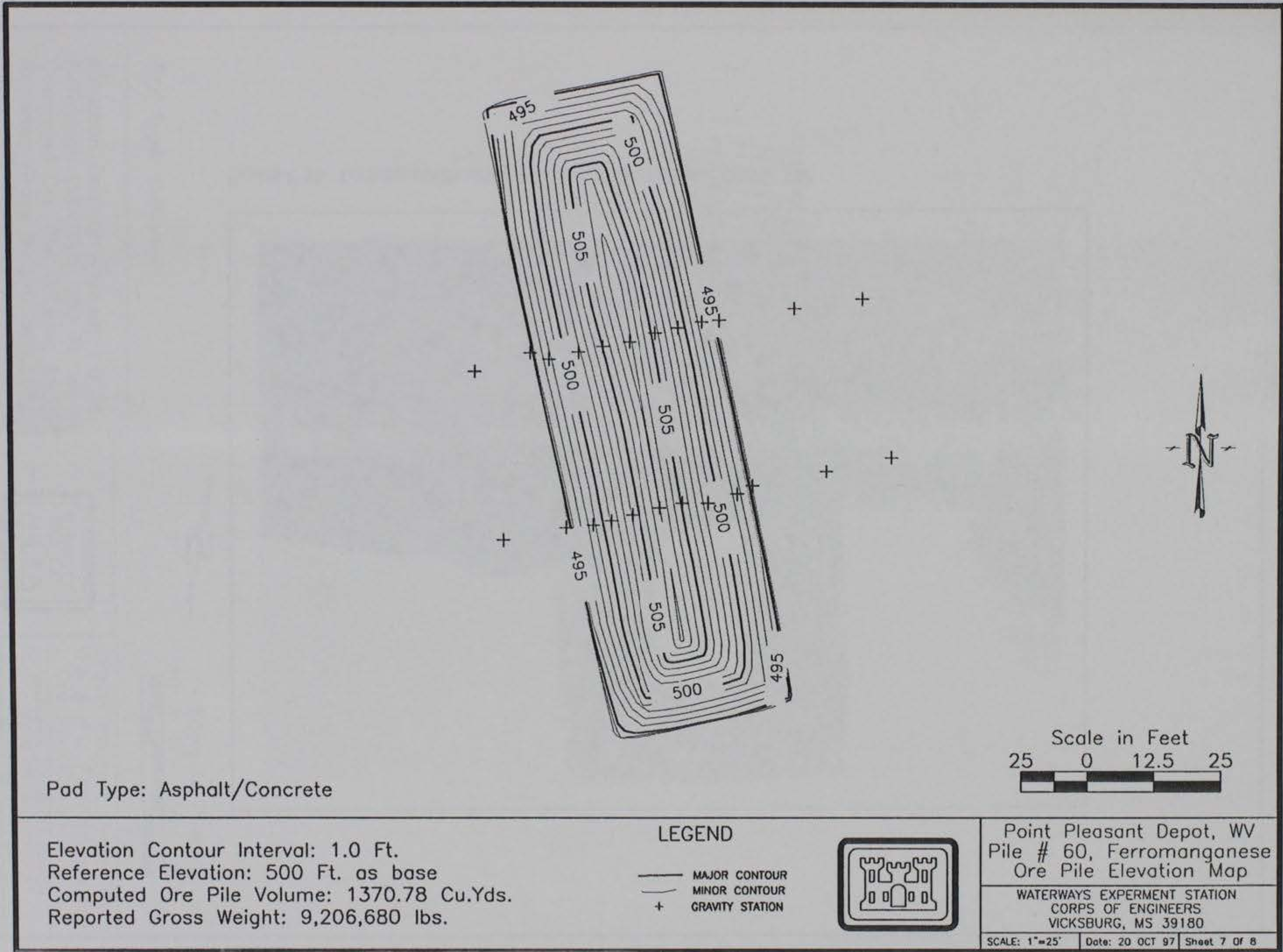
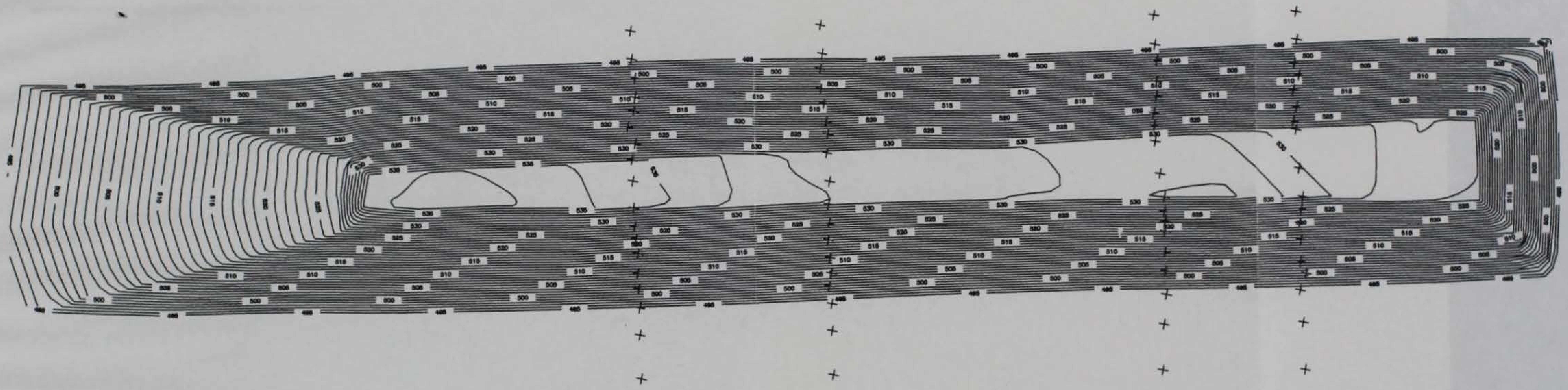


Figure E-12. Elevation contour plot of Pile #60, Point Pleasant Depot, WV

Figure E-13. Looking south along Pile #61, Point Pleasant Depot, WV



Scale in Feet
30 0 30 60

Pad Type: Concrete

Elevation Contour Interval: 1.0 Ft.
Reference Elevation: 500 Ft. as base
Computed Ore Pile Volume: 80,167.51 Cu.Yds.
Reported Gross Weight: 588,360,546 lbs.

LEGEND
MAJOR CONTOUR
MINOR CONTOUR
+ GRAVITY STATION

Point Pleasant Depot, WV
Pile # 61, Ferromanganese
Ore Pile Elevation Map

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
VICKSBURG, MS 39180

SCALE: 1"=60' | Date: 20 OCT 97 | Sheet 8 of 8

Figure E-14. Elevation contour plot of Pile #61, Point Pleasant Depot, WV

Appendix F
Ore Pile Elevation Contour Plots and Photographs, Anniston Army Depot, Alabama

Figure F-1. Pile #1, Anniston Army Depot, AL

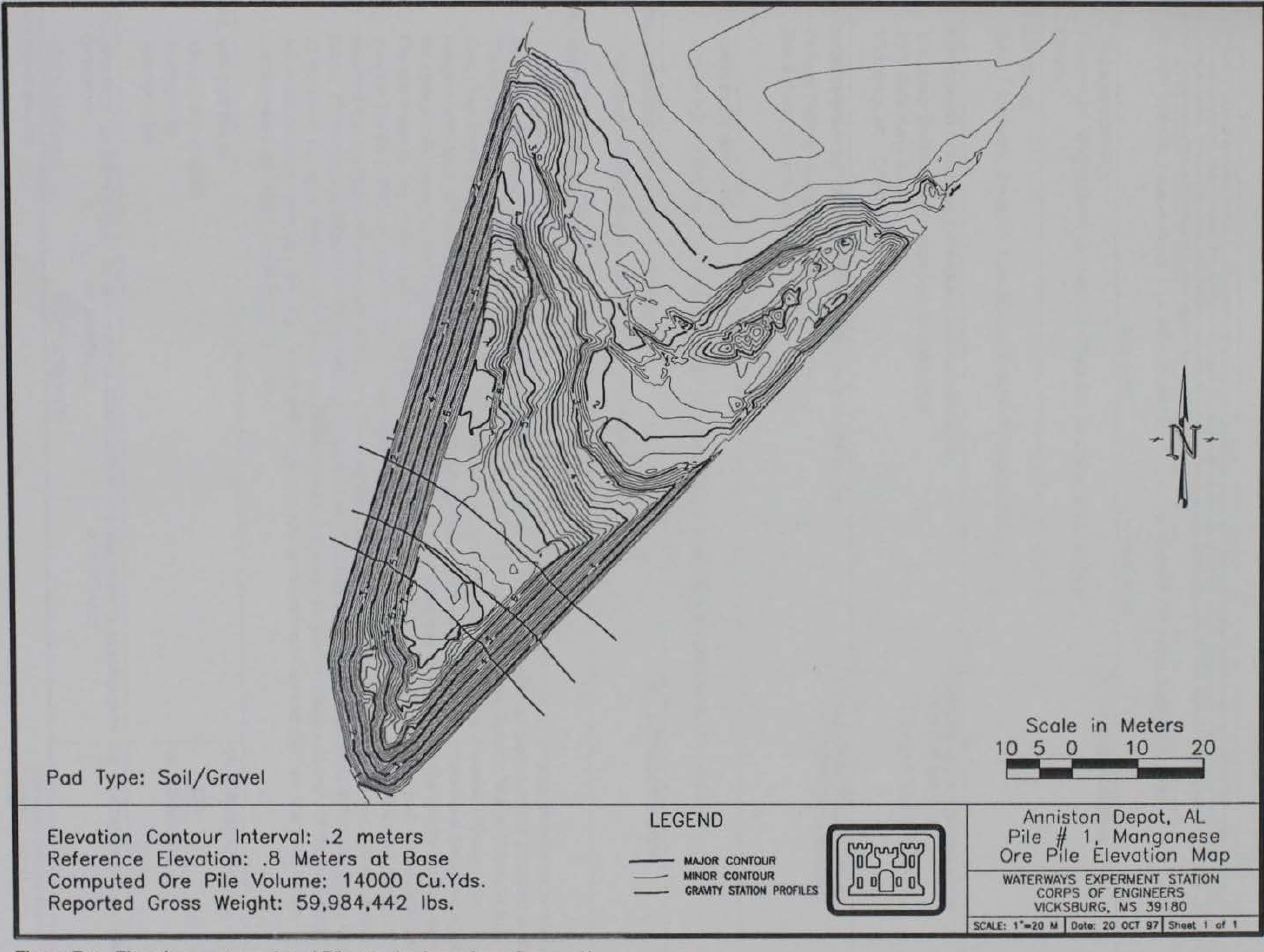


Figure F-2. Elevation contour plot of Pile #1, Anniston Army Depot, AL

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13. ABSTRACT *(Maximum 200 words)*

The Defense National Stockpile Center (DNSC) maintains stockpiles of high-grade ores at numerous installation locations throughout the country and has a requirement to produce current weight estimates for selected piles as part of a national audit. The ore piles for this study are located at the Hammond Depot, Indiana; New Haven Depot, Indiana; Warren Depot, Ohio; Curtis Bay Depot, Maryland; Point Pleasant Depot, West Virginia; and Anniston Army Depot, Alabama. Microgravity measurements were performed over selected ore piles to provide high-resolution surveys of the gravitational field from which the average bulk density of the ore material was determined. Parasnis' method was used to analyze the gravity anomaly data. Ore pile volumes were determined using standard land surveying methods. The computed weights for each ore stockpile are compared to the DNSC reported weights and differences should be within 10 to 15 percent. Results of this investigation indicated that the computed weights of 42 of the 82 piles surveyed are below or within the expected percent difference error range. Thirty-three ore piles have differences ranging from 15 to 25 percent and seven stockpiles had differences greater than 25 percent of the reported values. The greatest differences were computed over piles in which settlement of the ore material below the ground surface had taken place, site conditions were such that definition of the true pile base was poor, or pile documentation and reported weights are in error.

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Ore stockpiles

15. NUMBER OF PAGES
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