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Rock and Soil Geochemical and Natural-Water Hydrogeochemical Surveys and Environmental Implications, Fort McClellan, AL

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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CONTENTS

Page

Sample Collection

Sample Preparation

Analytical Procedures

Geochemical Results

Discussion

Environmental Concerns

ILLUSTRATIONS

ILLUSTRATIONS (continued)

TABLES

ABSTRACT

Rock and soil geochemical and hydrogeochemical studies were conducted on Fort McClellan and Pelham Range, AL. The rock and soil studies indicate that sulfide mineralization and metals emplacement occurs throughout a large portion of the study area. The various constituents found in the natural waters show the metals in the rocks and soils are reaching the aqueous environment.

The mineralization is believed to originate from a series of "black smokers" that arose along a zone of structural weakness like the Jacksonville Fault. The observed mineralization and alteration fits well with this type of orogenic process.

The geochemical findings and geological observations will impact future land use management decisions and environmental concerns. The biggest challenge will be separating the anthropogenic contribution of metals such as Pb from the natural sources. For example, Pb concentrations related to sulfide mineralizations reach 500 ppm in soil samples. The natural environment is all too often ignored as a source of metals.

INTRODUCTION

A rock and soil geochemical study of Fort McClellan, AL was conducted after visiting areas showing extensive hydrothermal alteration and finding large gossan nodules. The gossan boulders indicated the weathering of pyrite and probably other sulfide minerals. The extensive iron rich veining and alteration indicated significant hydrothermal activity had impacted the original mineral composition of the host rocks throughout the area. Both of these mineralizing events are often genetically related to the emplacement of base and precious metals. Geochemical characterization of the mineralization on Fort McClellan and Pelham Range will impact the environmental issues related to base clean up and possible base closure.

An initial study was conducted from March to June of 1993. Rocks and soils from 61 sites were collected. This phase focused on characterizing the geochemical signature of the natural environment and identifying any areas of heavy metals enrichment or mineralization. The goal of the study was to use the geochemical data to examine the effects of possible heavy metal migrations into the soils or groundwaters in the secondary environment and the possible environmental impacts.

During the course of the initial study it became evident that extensive hydrothermal alterations cross cut all rock types. The alteration ranged from small iron rich veinlets in the sandstones of the Chilhowee Group on the eastern side of Fort McClellan to meter-thick veins near Truitt Hill. Large areas in the southwestern part of Fort McClellan showed extensive alteration with cross cutting iron rich veins of varying thickness.

In the Trench Hill area, excavations exposed pyritic boulders up to a meter in diameter. These boulders have weathering rinds up to 15 cm thick. The soil in this area is deep red and contains marble to fist-sized gossan pebbles.

The mineralized areas identified during this study indicate the geology of the area is more complex than previously recognized (Osborne and Szabo, 1983). There are many complex environmental concerns as well. To further our understanding of the environmental impact the mineralization may have in the area, samples from fourteen springs and creeks were collected on July 30-31, 1994. Rock and soil samples from an additional six sites were also collected on Pelham Range.

GENERAL GEOLOGY

The geology of the study area was examined as part of a larger study of the Jacksonville Fault Zone. The geologic section descriptions are summarized from Jay (1982) and Osborne and Szabo (1983). Figure 1 is a geologic map of Fort McClellan.

Chilhowee Group, undifferentiated

older than 560 million years old, Lower Cambrian

The Chilhowee Group is course to fine-grained clastic sandstones with conglomeratic lenses. The rocks are predominantly fine grained vitreous quartzite and friable orthoquartzitic sandstones. There are interbedded intervals of arenaceous and micaceous shales and mudstones. This rock group makes up the bulk of the highlands throughout Fort McClellan.

Shady Dolomite

approximately 560 million years old, Lower Cambrian

Rocks of the Chilhowee Group are overlain by some 500 feet of poorly exposed carbonate rocks assigned to the Shady Dolomite. These rocks are generally light-gray, argillaceous to sandy, laminated dolomite and dolomitic limestone. These rocks crop out in the northern portion of Fort McClellan. The best exposures are northeast of Reservoir Ridge.

Rome Formation

approximately 540 million years old, Lower Cambrian

Overlying the Shady Dolomite is approximately 1000 feet of predominantly clastic rocks assigned to the Rome Formation. The formation is characterized by grayish red purple and pale-olive interbedded mudstone, siltstone, and sandstone. The significant facies difference occurs in the presence of interbedded layers of sandstone or dolomite. This formation occurs in a small band about 300 m wide just north of Galloway Gate along the western boundary of Fort McClellan. The hills west of post in this area are mapped as Rome Formation.

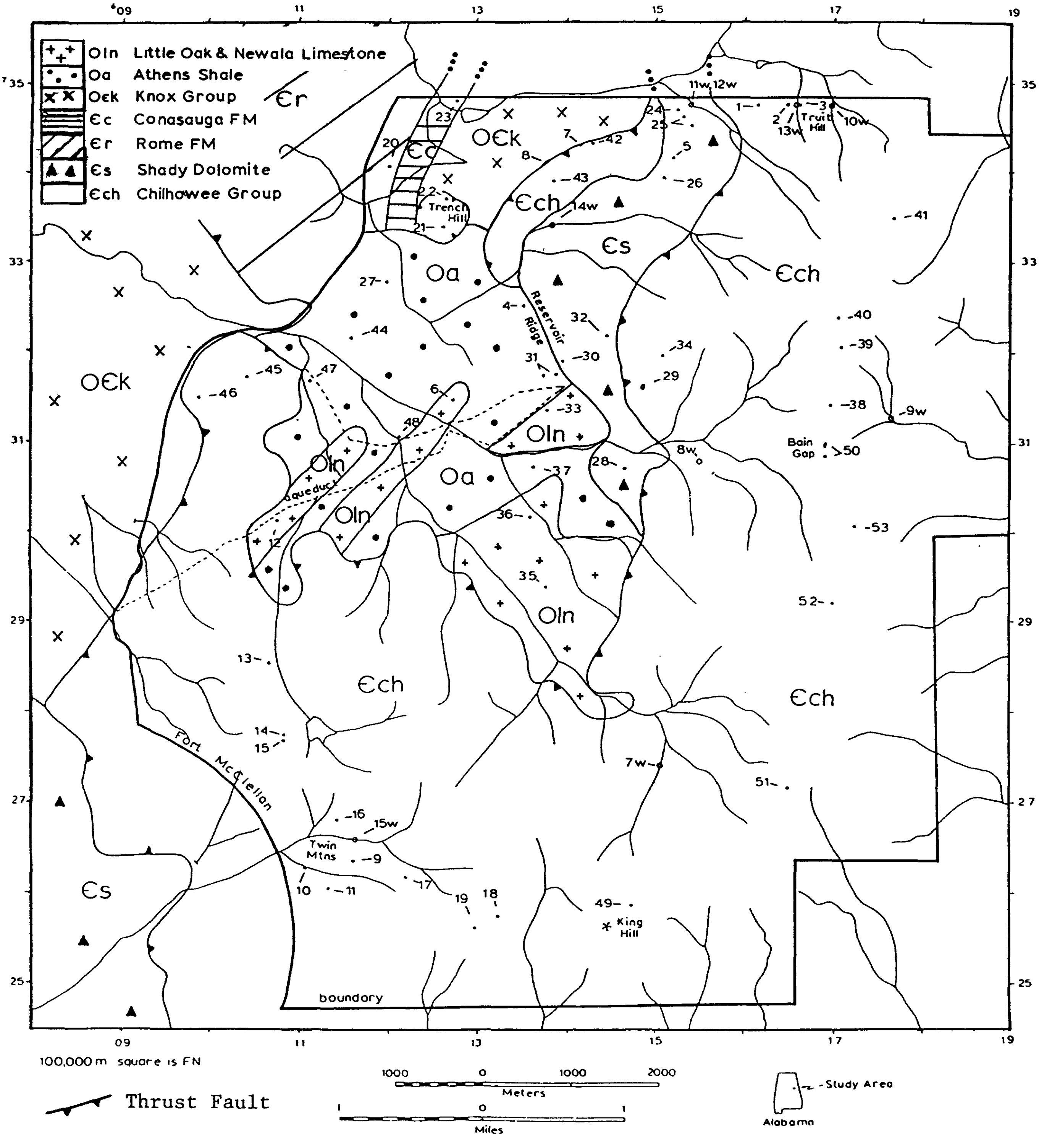

Figure 1. Geologic map and the rock, soil, and water sample locations on Fort McClellan, AL.

Conasauga Formation

approximately 510 million years old, Middle Cambrian

The Rome Formation is overlain by the Conasauga Formation. This formation is primarily very thin-bedded, pale-olive mudstone, and shale with local interbeds of limestone. The limestone is generally dark gray, thin bedded, micritic, argillaceous, and locally oolitic. This formation occurs in a small band about 300 m wide just to the east of the Canasuaga Formation and abuts Trench Hill on the south end of its exposure. The Rome and the Conasuaga Formations are difficult to identify in outcrop.

Knox Group, undifferentiated

between 510 and 470 million years old, Upper Cambrian

The Conasauga Formation is overlain by the Knox Group. This formation is a thick sequence of light to medium gray siliceous dolomite. This formation occurs along a fairly wide band north of Trench Hill. The best exposures occur in the walls of the old rifle range and borrow pit near site 7 and 8.

Newala and Little Oak Limestones, undifferentiated

approximately 470 million years old, Middle to Upper Ordovician

The Newala and Little Oak Limestones overlie the Knox Group. These rocks are Ordovician carbonates. The Newala Limestone is sometimes included with the Knox Group at other localities. The best exposures of these rocks are just to the south of the bridge that crosses the south branch of Cane Creek (just east of the traffic circle) in and along the banks of the creek.

Athens Shale

Middle to Upper Ordovician

The Athens Shale overlies the undifferentiated Newala and Little Oak Limestones. These rocks are a thick sequence of dark gray to black shale and shaly mudstone. There is some confusion as to the actual structural relationship and age of the unit. The Athens Shale and the Newala and Little Oak Limestones interlace throughout the central portion of Fort McClellan. These formations generally form the lower elevations of the post. Some of the best exposures of the Athens Shale occur along the stream banks, e.g. sites 48, 33, and 37.

Quaternary Alluvium

The stream beds all contain Quaternary alluvial gravels and sands associated with recent erosion. The rocks are generally rounded Chilhowee Group rocks. These deposits are not mapped.

SAMPLE COLLECTION

a. Rocks and Soils

The rock and soil samples were collected throughout Fort McClellan (figure 1) and Pelham Range (figure 2). Samples were collected on an approximate 1 km grid on much of Fort McClellan except within the impact zones. The sampling on Pelham Range predominately follows the northern access road. Most of the sites are near roads for greater accuracy in site location and outcrop exposure. At an outcrop, approximately 400 g of fresh rock was collected. At several sites, the outcrop was a highly altered hard clay. Samples of any interesting veins or altered rocks at or near a site were also collected.

The soil samples were generally collected between 15-30 cm depth. A hole 20 cm in diameter was dug until a B horizon was encountered or upon reaching a depth of 30 cm. After reaching the desired depth, the soil from a vertical zone of about 10 cm was loosened from around the hole and the soil was hand mixed. A composite sample of about 400 g was placed in a paper bag and allowed to air dry. The sites with intense alteration or weathering did not always show the characteristic B horizon iron enrichment due to the dark red color of the soil. At these sites, the sample was collected from about 25 cm to 30 cm depth. Duplicate rock samples were collected at six sites. Duplicate soil samples were collected at four sites. These duplicate samples were collected between 2 and 4 m from the original sample.

b. Water Samples.

At fourteen sites water samples were collected from springs and small creeks on Fort McClellan and Pelham Range (figures 1 and 2 respectively). The water samples are denoted by a "W" after the site number. At each collection site, two water samples were collected. The first sample is 500 ml of untreated water collected in a clean polyethelene bottle. The second sample was filtered through a 0.45 um membrane filter into a 60 ml polyethylene bottle. The sample bottle was rinsed with a 10 percent nitric acid solution before coming to the field. This water sample was then acidified with reagent grade concentrated nitric acid to a pH less than 1. Each bottle was rinsed with the sample water at the site. One duplicate site sample was collected.

SAMPLE PREPARATION

a. Rocks.

The rock samples were crushed and the small fragments split to save a representative sample that fit in a 3 oz cardboard container. This sample was pulverized using ceramic plates. The resulting powder was placed in the cardboard container for analysis.

b. Soils.

The soils were disaggregated, sieved, and the minus-80-mesh fraction was saved in a 3 oz cardboard container for analysis.

c. Waters.

The water samples required no preparation.

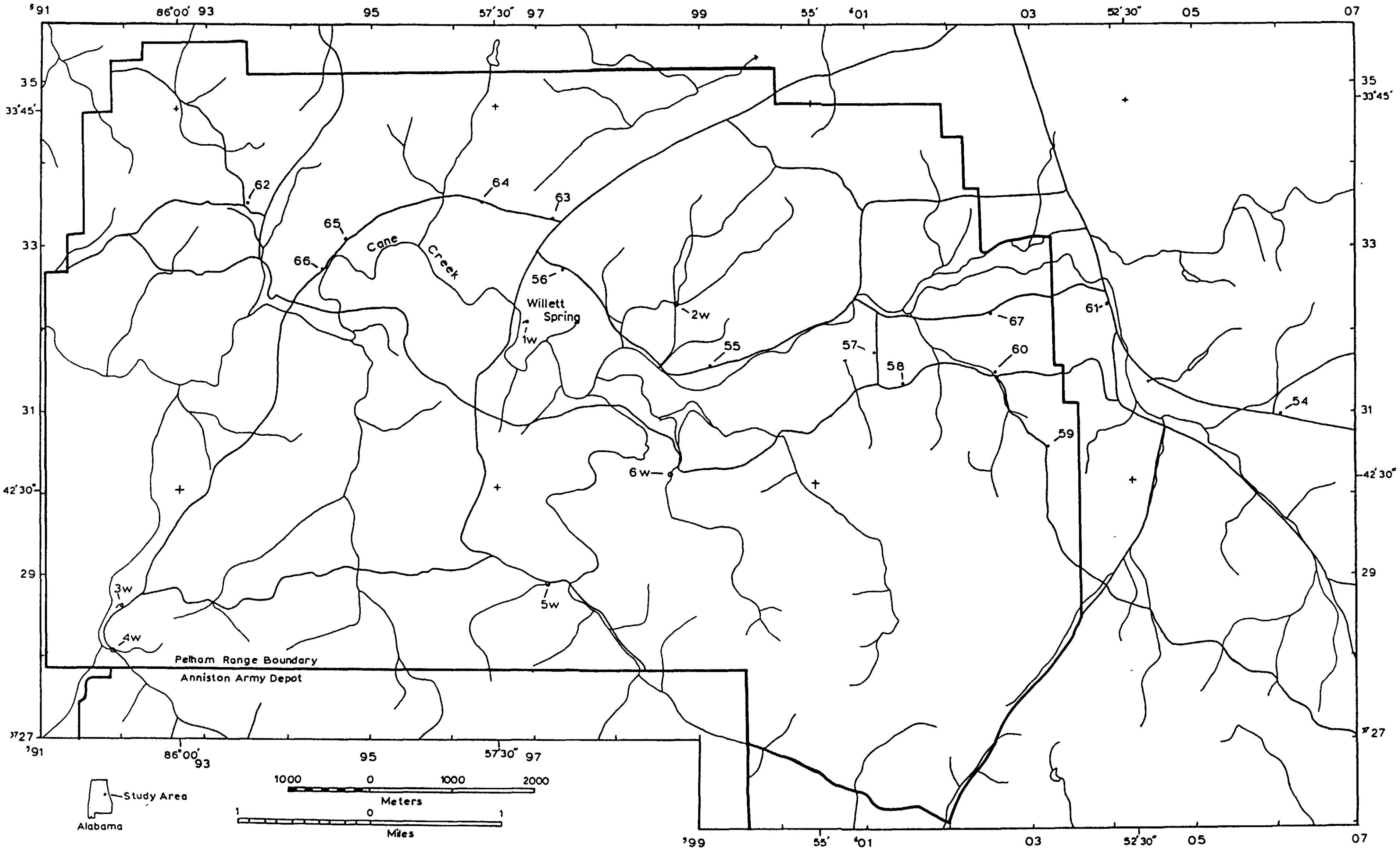

Figure 2. Rock and soil and water sample locations on Pelham Range, Fort McClellan, AL.

ANALYTICAL PROCEDURES

a. Rock and soils.

The rock and soil samples were analyzed by the six-step D.C.-arc semiquantitative emission spectrographic method (Grimes and Maranzino, 1968) for 35 elements. All of the analytical values are reported as six steps per order of magnitude (1, 1.5, 2, 3, 5, 7 or multiples of 10). These values approximate the geometric midpoints of successive concentration ranges (Grimes and Maranzino, 1968).

This analytical method compares a series of elemental standards against the elemental concentrations in the sample. The elemental concentration in the sample is visually compared with the standards. The largest source of error is interpolating a sample concentration that lies between two standards. The six-step D.C.-arc emission spectrographic method provides reproducibility within one geometric interval of the reported value approximately 86 percent of the time and within two geometric intervals of the reported value approximately 96 percent of the time (Motooka and Grimes, 1976).

If a sample contains elemental concentrations above the highest standard used, the elemental concentration is represented by a "G" in front of the upper standard. If a sample contains elemental concentrations below the lowest standard, the concentrations can have two code designations. If the sample concentration is slightly below the lowest standard, the elemental concentration is represented by an "L" in front of the lowest standard. If the sample concentration is not detected, an "N" is used. The gold analysis was done using the flameless atomic absorption method described in the USGS standard methods manual (O'Leary and Meier, 1986).

Table 1 lists the analytical results for the rock samples. Table 2 lists the analytical results for the soil samples. Duplicate samples have a "D" after the sample number. The duplicate sample analyses are within the precision of this analytical method. The variations for some elements in sample 37R probably reflects the mineralized nature of the rock and not heterogeneity in the sample or the analytical method.

b. Waters.

Water temperature and pH were measured at the sample site. The following constituents were analyzed from the untreated sample: sulfate, fluoride, chloride, nitrate, alkalinity, and specific conductance. Alkalinity measures the total acid-neutralizable constituents in water and is generally due to the presence of carbonate and bicarbonate ions. Table 3 gives the specific methods used for each analysis.

The concentrations of calcium, magnesium, sodium, potassium, silica, and iron were measured from the filtered and acidified sample using flame atomic absorption spectrophotomety. The concentrations of all other metal ions were measured using the Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES). Table 4 lists the concentrations of the species determined for this study.

The results of charge balance calculations are listed in Table 4. For the three samples with detectable HCO3, the charge balance is under 5%, indicating the analyses are very good. A value of 7 ppm for HCO3 was used for the other samples. The charge balance for all but three samples is still under the acceptable range of 10%. Adjusting the HCO3 value a few ppm for the three samples brings their charge balance under 10% also.

Table 1. Analytical results from the rock samples collected in the Fort McClellan-Pelham Range study area, Fort McClellan, AL.

Sample	UTM-FN	Au ppb	Ag	Cu	Pb	Zn	Fe %	Ba	Mn	Mo	Be	Ca %	Mg %	Na %	Ti %	B	Co	Cr	Ga	La	Ni	Sc	V	Y	Zr
FM 1R1	1616 3475	L1	N0.5	N5	N10	N200	0.3	20	50	N5	N1	L0.05	0.03	N0.2	0.1	L10	N10	L10	L5	N50	L5	N5	10	20	500
FM 3R1	1660 3477	50	1	20	100	700	G20	30	100	N5	3	N0.05	0.15	N0.2	0.1	L10	15	70	15	N50	30	30	200	70	20
FM 3R2	1660 3477	240	0.7	20	70	N200	20	70	30	20	1.5	N0.05	0.1	N0.2	0.1	10	N10	50	70	N50	20	20	100	15	20
FM 4R1	1355 3251	2	N0.5	100	70	200	7	700	3000	10	3	N0.05	0.3	L0.2	0.3	30	100	100	70	L50	150	20	150	30	70
FM 4R2	1355 3251	4	N0.5	15	150	N200	5	70	300	N5	3	L0.05	0.07	N0.2	0	L10	10	15	5	N50	20	5	70	10	15
FM 5R1	1520 3413	2	N0.5	10	N10	N200	1.5	30	150	N5	1	N0.05	0.03	N0.2	0.1	20	15	N10	5	N50	20	N5	30	L10	70
FM 5R2	1520 3413	L1	0.5	20	70	N200	10	70	150	7	2	L0.05	0.03	N0.2	0	L10	50	50	15	N50	70	N5	20	15	30
FM 6R1	1278 3145	1	N0.5	30	50	L200	3	500	150	L5	2	L0.05	1	1.5	0.3	30	50	100	70	L50	50	10	70	20	50
FM 7R1	1384 3415	1	N0.5	15	50	N200	5	70	15	L5	N1	N0.05	0.07	N0.2	0.3	15	N10	100	50	L50	20	7	70	15	150
FM 7R2	1384 3415	1	1.5	30	150	N200	15	L20	150	10	1	N0.05	0.07	N0.2	0	N10	30	30	50	N50	30	7	30	20	50
FM 7R3	1384 3415	L1	N0.5	N5	N10	N200	0.15	L20	L10	N5	N1	N0.05	L0.02	N0.2	0.2	L10	N10	L10	N5	N50	L5	N5	L10	N10	150
FM 7R4	1384 3415	L1	N0.5	7	N10	N200	0.7	20	L10	N5	1	N0.05	0.07	N0.2	0.2	L10	N10	15	L5	N50	5	L5	20	L10	300
FM 8R1	1376 3405	3	N0.5	15	100	N200	5	1000	5000	N5	1.5	N0.05	0.07	N0.2	0.1	10	70	30	15	L50	30	10	50	20	50
FM 8R2	1376 3405	L1	N0.5	7	N10	N200	1	30	30	N5	N1	N0.05	0.03	N0.2	0.5	10	N10	30	5	N50	7	L5	50	15	500
FM 8R3	1376 3405	2	N0.5	30	150	N200	7	200	500	N5	1	L0.05	0.1	N0.2	0.3	30	L10	70	30	50	30	15	100	30	200
FM 8R4	1376 3405	1	N0.5	20	50	N200	3	200	700	N5	L1	L0.05	0.07	N0.2	0.3	20	N10	70	20	L50	15	7	100	20	200
FM 9R1	1162 636	15	N0.5	30	50	N200	20	1000	3000	N5	3	N0.05	0.05	N0.2	0	N10	200	50	50	N50	50	10	70	50	10
FM 10R1	1109 2626	L1	N0.5	20	15	N200	2	50	30	N5	1	N0.05	0.05	N0.2	0.2	15	L10	30	30	N50	15	5	50	15	100
FM 12R1	1079 3013	1	N0.5	30	50	L200	7	150	100	L5	1.5	L0.05	0.5	N0.2	0.3	50	15	70	30	N50	30	15	100	30	150
FM 12R2	1079 3013	1	N0.5	L5	L10	N200	0.3	50	20	N5	N1	L0.05	0.03	N0.2	0.03	N10	N10	10	N5	N50	7	N5	10	N10	10
FM 12R3	1079 3013	1	N0.5	30	10	N200	3	70	70	N5	L1	L0.05	0.3	N0.2	0.2	20	L10	70	10	N50	20	10	50	L10	100
FM 13R1	1068 2836	L1	N0.5	10	30	N200	3	70	50	N5	1	L0.05	L0.02	N0.2	0.7	20	N10	100	50	N50	N5	15	150	50	700
FM 13R2	1068 2836	L1	N0.5	N5	N10	N200	0.2	70	10	N5	N1	L0.05	L0.02	N0.2	0.1	N10	N10	15	N5	N50	L5	N5	L10	N10	100
FM 14R1	1084 2776	2	N0.5	20	50	N200	7	150	50	N5	2	N0.05	0.2	N0.2	0.3	30	N10	100	50	L50	15	20	150	30	300
FM 14R2	1084 2776	L1	N0.5	15	30	N200	20	L20	500	N5	1.5	L0.05	0.05	N0.2	0.2	N10	L10	50	30	N50	15	15	50	50	500
FM 15R1	1085 2770	L1	N0.5	N5	N10	N200	0.7	100	10	N5	N1	L0.05	0.02	N0.2	0.05	N10	N10	15	N5	N50	7	N5	L10	10	70
FM 16R1	1144 2681	L1	N0.5	20	70	N200	3	1000	50	N5	1	L0.05	0.05	N0.2	0.5	20	N10	70	50	100	5	20	150	70	700
FM 16R2	1144 2681	L1	N0.5	N5	N10	N200	0.2	70	L10	N5	N1	L0.05	L0.02	N0.2	0.07	N10	N10	10	N5	N50	5	N5	L10	L10	150
FM 17R1	1222 2618	1	N0.5	20	20	N200	5	200	50	N5	2	L0.05	0.3	N0.2	0.5	50	L10	100	30	L50	20	15	100	50	500
FM 17R2	1222 2618	1	N0.5	10	10	N200	15	70	70	N5	5	N0.05	0.2	N0.2	0.03	N10	N10	10	30	N50	20	L5	10	10	100
FM 18R1	1327 2574	1	N0.5	10	30	N200	10	150	70	N5	7	N0.05	0.2	N0.2	0.7	50	N10	70	30	100	10	20	100	150	G1000
FM 18R2	1327 2574	2	N0.5	10	30	N200	1.5	200	L10	N5	1.5	N0.05	0.1	N0.2	0.7	20	N10	20	30	L50	7	7	50	50	700
FM 18R3	1327 2574	1	N0.5	30	50	N200	20	200	500	N5	5	N0.05	0.2	N0.2	0.2	50	30	70	50	N50	20	10	50	20	70
FM 18R4	1327 2574	L1	N0.5	5	N10	N200	1.5	70	50	N5	L1	N0.05	0.03	N0.2	0.03	10	N10	L10	5	N50	15	N5	15	10	100
FM 19R1	1301 2561	L1	N0.5	5	10	N200	0.2	100	15	N5	N1	L0.05	0.02	N0.2	0.15	L10	N10	L10	N5	N50	5	N5	15	L10	300
FM 22R1	1266 3370	1	N0.5	70	100	N200	G20	50	700	15	2	L0.05	0.1	N0.2	0.03	N10	30	200	30	N50	50	7	100	20	N10
FM 22R2	1266 3370	1	N0.5	50	100	L200	7	700	5000	N5	7	L0.05	0.2	N0.2	0.2	50	50	70	30	70	50	20	100	70	100
FM 22R3	1266 3370	35	3	100	70	N200	>20	50	70	30	N1	N0.05	L0.02	N0.2	.005	N10	N10	15	30	N50	50	N5	100	N10	N10
FM 22R4	1266 3370	2	N0.5	70	100	L200	5	1500	300	N5	2	0.3	1.5	L0.2	0.5	100	20	150	50	50	70	20	150	30	100

Table 1. (continued) Analytical results from the rock samples collected in the Fort McClellan-Pelham Range study area, Fort McClellan, AL.

Sample	UTM-FN	Au ppb	Ag	Cu	Pb	Zn	Fe %	Ba	Mn	Mo	Be	Ca %	Mg %	Na %	Ti %	B	Co	Cr	Ga	La	Ni	Sc	V	Y	Zr
FM 22R5	1266 3370	3	N0.5	70	150	L200	5	300	G5000	N5	3	L0.05	0.2	N0.2	0.15	20	200	70	20	50	70	15	100	50	70
FM 23R1	1280 3480	1	N0.5	50	70	N200	7	150	100	N5	2	L0.05	0.7	N0.2	0.5	150	L10	100	50	L50	30	15	150	20	150
FM 24R1	1527 3471	L1	N0.5	30	70	N200	3	300	700	N5	L1	L0.05	0.07	N0.2	1	30	20	70	15	L50	20	7	150	50	G1000
FM 25R1	1544 3451	L1	1.5	5	N10	N200	0.3	70	30	N5	L1	L0.05	0.07	N0.2	0.07	10	N10	10	L5	N50	L5	L5	30	N10	30
FM 25R2	1544 3451	L1	0.5	50	150	200	5	200	70	L5	3	L0.05	0.5	N0.2	0.5	30	50	100	20	50	70	20	300	30	150
FM 26R1	1510 3392	L1	N0.5	L5	N10	N200	0.3	100	20	N5	N1	L0.05	0.02	N0.2	0.5	N10	N10	10	L5	L50	L5	N5	15	15	700
FM 27R1	1202 3277	1	N0.5	50	50	L200	5	700	50	L5	2	0.05	0.7	N0.2	0.5	50	10	100	50	50	30	15	150	30	150
FM 28R1	1468 3072	L1	N0.5	7	15	N200	0.3	200	200	N5	N1	0.05	0.07	N0.2	0.02	N10	N10	L10	N5	N50	15	N5	15	N10	10
FM 28R1	1468 3072	1	N0.5	30	30	N200	5	300	70	N5	2	L0.05	0.7	N0.2	0.5	70	L10	100	30	50	30	15	150	30	300
FM 28R2	1468 3072	1	N0.5	30	30	N200	5	200	70	N5	2	L0.05	1	N0.2	0.5	70	L10	100	30	50	30	15	150	30	200
FM 28R3	1468 3071	L1	N0.5	10	L10	N200	0.7	150	200	N5	L1	0.05	0.1	N0.2	0.05	L10	N10	L10	N5	N50	15	N5	15	N10	15
FM 29R1	1486 3159	1	N0.5	20	30	N200	5	500	70	N5	1.5	N0.05	0.15	N0.2	0.7	50	10	150	50	70	20	15	100	50	300
FM 29R2	1486 3159	L1	N0.5	10	20	N200	15	1000	150	N5	2	L0.05	0.07	N0.2	0.5	15	10	20	20	70	15	20	150	100	700
FM 30R1	1395 3190	L1	N0.5	20	N10	N200	1	700	500	L5	2	L0.05	0.07	N0.2	0.02	N10	10	15	5	N50	30	N5	15	L10	20
FM 30R2	1395 3190	L1	N0.5	10	L10	N200	1	200	700	N5	2	0.05	0.07	N0.2	0.03	N10	N10	15	L5	N50	20	N5	20	N10	15
FM 31R1	1393 3171	1	N0.5	70	30	N200	7	1000	50	7	1.5	0.07	0.5	N0.2	0.7	70	L10	100	50	50	20	20	200	30	150
FM 32R1	1448 3215	1	N0.5	50	30	N200	3	700	70	N5	2	L0.05	1	L0.2	0.5	50	15	100	50	50	50	10	100	20	150
FM 32R2	1448 3215	1	N0.5	10	20	N200	5	300	70	N5	2	L0.05	0.7	N0.2	0.5	100	15	150	30	L50	30	15	150	30	150
FM 33R1	1380 3135	1	N0.5	50	50	N200	7	700	70	10	2	L0.05	0.7	N0.2	0.5	70	15	100	50	50	50	20	150	30	150
FM 33R1	1380 3135	1	N0.5	70	70	N200	5	700	50	10	2	L0.05	0.5	L0.2	0.5	50	N10	100	50	50	20	15	150	30	150
FM 34R1	1510 3196	L1	L0.5	N5	N10	N200	0.2	70	10	N5	N1	L0.05	L0.02	N0.2	0.2	N10	N10	L10	N5	N50	L5	N5	15	15	150
FM 34R1	1510 3196	1	N0.5	N5	N10	N200	0.2	70	15	N5	N1	L0.05	L0.02	N0.2	0.15	N10	N10	15	N5	N50	L5	N5	10	L10	200
FM 35R1	1378 2940	L1	N0.5	L5	N10	N200	0.7	70	300	N5	L1	L0.05	0.02	N0.2	0.15	N10	N10	L10	N5	N50	L5	L5	15	L10	200
FM 37R1	1376 3072	2	N0.5	50	50	N200	2	1000	50	15	1	L0.05	0.5	N0.2	0.5	30	N10	100	30	50	7	15	300	30	150
FM 37R1	1376 3072	3	N0.5	150	50	N200	7	1000	30	7	1	L0.05	0.5	N0.2	0.3	30	N10	150	50	50	7	15	200	20	100
FM 38R1	1700 3143	L1	N0.5	20	15	N200	5	1000	700	N5	1.5	L0.05	0.3	N0.2	0.7	30	20	70	30	50	30	15	70	50	700
FM 39R1	1710 3210	1	N0.5	15	15	N200	7	700	70	N5	3	L0.05	0.07	N0.2	0.2	15	L10	50	15	L50	10	7	50	30	700
FM 39R2	1710 3210	1	N0.5	100	30	N200	20	3000	G5000	N5	5	L0.05	0.02	N0.2	0.2	N10	100	70	30	200	30	20	50	100	700
FM 40R1	1710 3236	L1	N0.5	N5	N10	N200	0.7	100	100	N5	N1	L0.05	L0.02	N0.2	0.15	N10	N10	15	N5	N50	L5	N5	15	10	300
FM 41R1	1766 3350	1	N0.5	30	20	N200	7	300	300	N5	3	N0.05	0.7	N0.2	0.5	70	20	100	50	70	50	20	100	50	150
FM 41R2	1766 3350	2	N0.5	30	30	N200	3	150	50	N5	3	L0.05	0.2	N0.2	0.5	50	L10	100	30	50	20	15	150	50	300
FM 41R3	1766 3350	L1	N0.5	L5	N10	N200	0.7	70	20	N5	N1	L0.05	L0.02	N0.2	0.07	N10	N10	10	N5	N50	7	N5	10	L10	100
FM 42R1	1416 3426	L1	N0.5	20	30	N200	7	150	100	N5	1	L0.05	0.15	N0.2	0.3	30	15	70	15	L50	30	15	100	20	500
FM 42R2	1416 3426	L1	N0.5	30	70	N200	7	200	700	N5	3	L0.05	0.15	N0.2	0.2	20	30	50	15	50	50	15	70	50	500
FM 42R3	1416 3426	1	N0.5	15	30	L200	15	500	G5000	N5	3	L0.05	0.03	N0.2	0.03	N10	150	L10	20	N50	50	7	15	50	15
FM 43R1	1386 3389	L1	N0.5	N5	N10	N200	0.5	70	500	N5	N1	L0.05	L0.02	N0.2	0.1	N10	N10	10	N5	N50	7	N5	10	15	300
FM 44R1	1161 3217	2	N0.5	50	30	L200	5	700	300	7	1.5	L0.05	1	1	0.3	50	30	150	50	70	70	15	150	50	150
FM 44R1	1161 3217	1	N0.5	50	30	L200	5	700	500	N5	1.5	L0.05	1	0.7	0.3	30	30	100	30	50	70	15	150	30	100

Table 1. (continued) Analytical results from the rock samples collected in the Fort McClellan-Pelham Range study area, Fort McClellan, AL.

Sample	UTM-FN	Au ppb	Ag	Cu	Pb	Zn	Fe %	Ba	Mn	Mo	Be	Ca %	Mg %	Na %	Ti %	B	Co	Cr	Ga	La	Ni	Sc	V	Y	Zr
FM 48R1	1212 3104	1	N0.5	70	50	L200	5	1000	300	7	2	0.2	1	1	0.3	50	30	100	50	70	70	15	200	30	100
FM 48R2	1212 3104	L1	N0.5	N5	L10	N200	0.15	20	70	N5	N1	20	0.5	N0.2	.015	L10	N10	L10	N5	N50	L5	N5	15	N10	L10
FM 48R3	1212 3104	2	N0.5	30	70	N200	1.5	150	100	7	L1	15	2	0.3	0.15	30	15	70	20	N50	70	5	70	L10	50
FM 49R1	1478 2588	1	N0.5	10	20	N200	1	1000	10	N5	L1	0.15	0.1	L0.2	0.5	10	L10	50	20	L50	7	7	50	30	700
FM 49R2	1478 2588	1	N0.5	30	15	N200	3	500	70	N5	5	L0.05	0.7	N0.2	0.7	50	20	100	50	70	50	15	100	50	200
FM 50R1	1693 3098	1	N0.5	70	30	N200	G20	700	1000	N5	5	L0.05	L0.02	N0.2	0.01	N10	50	10	50	N50	30	10	15	15	15
FM 50R2	1693 3098	2	N0.5	30	50	N200	20	200	50	N5	3	N0.05	0.15	N0.2	0.5	50	L10	100	50	L50	20	10	50	30	200
FM 50R3	1693 3098	4	L0.5	50	50	N200	15	150	150	N5	3	L0.05	L0.02	N0.2	0.03	L10	15	15	30	N50	20	7	20	20	100
FM 50R4	1693 3098	3	N0.5	150	15	300	2	5000	G5000	N5	2	L0.05	0.05	N0.2	0.1	L10	500	15	10	L50	200	7	30	70	100
FM 50R5	1693 3098	3	N0.5	50	100	N200	15	1000	5000	N5	5	L0.05	0.1	N0.2	0.3	20	50	20	30	100	50	10	70	150	200
FM 51R1	1652 2718	1	N0.5	30	50	N200	5	700	100	N5	1.5	L0.05	0.5	N0.2	1	30	10	150	30	70	20	15	100	100	700
FM 51R1	1652 2718	L1	N0.5	20	20	N200	5	1000	70	N5	2	L0.05	0.7	N0.2	1	50	N10	100	50	70	15	15	150	50	300
FM 52R1	1704 2920	1	N0.5	5	N10	N200	1	70	30	N5	N1	L0.05	0.05	N0.2	0.7	10	N10	20	5	N50	N5	L5	20	15	1000
FM 53R1	1·723 3006	L1	N0.5	5	30	N200	15	500	100	N5	1.5	N0.05	0.07	N0.2	0.15	10	N10	15	30	N50	L5	7	70	20	700
FM 53R2	1726 3006	1	N0.5	10	N10	N200	5	100	70	N5	2	L0.05	L0.02	N0.2	0.1	L10	N10	10	7	N50	10	N5	10	10	100
FM 54R1	0606 3096	8	N0.5	50	20	700	G20	N20	1000	N5	5	L0.05	0.07	N0.2	0.02	L10	200	50	30	N50	300	10	70	70	N10
FM 55R1	9914 3156	L1	N0.5	7	N10	N200	1	100	70	N5	N1	L0.05	0.03	N0.2	.007	20	N10	15	N5	N50	7	N5	15	N10	10
FM 55R2	9914 3156	1	N0.5	30	20	N200	10	70	300	L5	L1	L0.05	0.05	N0.2	0.03	10	20	50	20	N50	30	L5	20	20	10
FM 57R1	0112 3173	L1	N0.5	70	70	500	G20	100	1500	5	1.5	N0.05	0.07	N0.2	0.03	N10	100	2000	100	N50	200	15	150	70	150
FM 57R2	0112 3173	4	N0.5	5	N10	N200	1	50	50	N5	N1	L0.05	0.05	N0.2	0.05	20	N10	20	5	N50	10	N5	20	N10	30
FM 58R1	0146 3134	1	N0.5	30	50	N200	5	70	100	7	1	L0.05	0.15	N0.2	0.2	20	L10	50	20	50	30	10	100	10	70
FM 60R1	0257 3150	L1	N0.5	50	50	L200	7	100	300	N5	2	L0.05	0.7	N0.2	0.3	50	20	100	30	50	70	15	150	150	150
FM 60R2	0257 3150	1	N0.5	L5	N10	N200	0.3	50	70	N5	N1	L0.05	0.03	N0.2	0.01	15	N10	10	N5	N50	5	N5	10	L10	L10
FM 61R1	0396 3230	12	N0.5	50	L10	N200	3	50	100	N5	L1	L0.05	0.1	N0.2	0.1	20	10	15	5	N50	15	10	70	L10	30
FM 62R1	9350 3350	1	0.5	30	100	200	2	150	70	N5	1.5	0.05	0.3	N0.2	0.3	20	20	150	15	70	150	10	100	100	1000
FM 62R2	9350 3350	1	N0.5	5	L10	N200	0.3	20	10	N5	N1	L0.05	0.07	N0.2	0.3	15	N10	20	5	N50	20	7	15	30	G1000
FM 64R1	9637 3354	3	N0.5	20	30	N200	1.5	500	15	7	1	L0.05	0.3	N0.2	0.5	30	N10	100	30	50	7	15	150	20	100
FM 64R2	9637 3352	3	N0.5	70	100	300	20	300	200	N5	1.5	L0.05	0.15	N0.2	0.2	30	70	100	70	N50	20	15	100	10	30
FM 64R3	9637 3354	1	N0.5	5	L10	N200	0.7	50	20	N5	N1	L0.05	0.05	N0.2	0	10	N10	20	5	N50	7	N5	15	N10	20
FM 65R1	9470 3310	14	1	7	150	N200	0.7	1000	15	100	1	L0.05	0.15	N0.2	0.7	50	20	70	15	50	100	7	70	20	300
FM 65R2	9470 3310	1	N0.5	7	L10	N200	3	200	15	5	1	L0.05	0.05	N0.2	0.1	10	20	20	7	N50	50	5	30	20	300
FM 67R1	0252 3220	L1	N0.5	L5	L10	N200	0.3	20	20	N5	N1	0.05	0.02	N0.2	0	10	N10	15	N5	N50	5	N5	10	N10	10
FM 67R2	0252 3220	5	N0.5	700	500	200	1.5	5000	G5000	15	2	0.15	0.07	N0.2	0.1	10	200	20	N5	N50	500	70	100	20	30

Table 2. Analytical results from the soil samples collected in the Fort McClellan-Pelham Range study area, Fort McClellan, AL.

Sample	Fe %	Cu	Pb	Au ppb	Mn	Ba	Ni	Co	V	Ca%	Mg %	P%	Ti%	B	Be	Cr	Ga	La	Nb	Sc	Y	Zr
FM 01S	0.7	15	20	3	150	100	7	N10	30	L0.05	0.07	L0.2	0.3	15	L1	30	7	N50	L20	L5	15	300
FM 02S	3	20	30	2	200	100	30	10	100	N.05	0.1	N0.2	0.3	20	1.5	70	15	L50	L20	10	20	150
FM 03S1	3	15	15	5	10	15	15	L10	100	N.05	0.03	N0.2	0.1	15	1.5	20	7	N50	N20	30	7	30
FM 03S2	1.5	15	50	2	300	300	5	N10	70	L0.05	0.07	L0.2	1	30	L1	50	10	50	20	7	30	1500
FM 04S	15	50	70	2	1500	500	100	70	70	N.05	0.3	L0.2	0.1	50	5	50	50	N50	N20	15	30	30
FM 05S	3	30	70	2	300	150	30	15	50	L0.05	0.1	L0.2	0.2	20	1.5	30	15	L50	L20	5	20	300
FM 08S	3	50	100	2	3000	500	50	15	100	L0.05	0.1	L0.2	0.7	30	1.5	70	20	100	20	7	50	500
FM 11S	1	15	15	L1	30	100	10	L10	30	L0.05	0.05	L0.2	1	15	N1	30	7	L50	L20	5	20	700
FM 12S	0.7	15	20	2	300	300	10	10	70	L0.05	0.1	L0.2	1	30	L1	30	7	L50	20	7	30	1000
FM 13S	1	10	30	2	70	150	5	N10	70	L0.05	0.05	L0.2	1	20	L1	15	10	50	30	7	50	1500
FM 15S	1.5	15	30	2	70	200	5	N10	70	L0.05	0.07	L0.2	0.7	30	L1	50	20	50	20	7	50	1500
FM 18S	1.5	5	10	L1	100	300	5	N10	70	L0.05	0.07	L0.2	1	20	1	20	10	70	30	7	50	1500
FM 20S	3	20	30	1	300	200	50	L10	100	L0.05	0.3	L0.2	0.7	30	1.5	30	20	50	L20	7	30	300
FM 21S	3	20	30	2	700	150	50	L10	150	L0.05	0.15	L0.2	0.7	50	2	50	30	50	20	10	30	300
FM 22S	3	20	20	1	700	300	30	10	100	0.05	0.15	L0.2	0.7	30	1.5	50	15	50	20	7	30	700
FM 23S	2	20	30	1	300	150	20	N10	70	L0.05	0.15	L0.2	0.7	30	1	30	30	L50	L20	7	30	500
FM 24S	3	20	150	1	1000	300	30	20	100	L0.05	0.2	L0.2	1	50	1	100	30	50	20	10	70	1000
FM 25S	1.5	7	7	1	100	200	10	N10	70	L0.05	0.1	L0.2	1	50	L1	30	10	L50	30	7	30	1000
FM 26S	2	10	10	5	70	300	10	N10	100	L0.05	0.07	L0.2	1	30	L1	70	10	50	20	7	70	1500
FM 28S	1.5	10	15	L1	70	500	15	N10	70	L0.05	0.15	L0.2	1	70	L1	70	15	L50	20	7	30	1000
FM 28SD	1.5	10	15	L1	70	500	15	N10	70	L0.05	0.15	L0.2	1	70	L1	70	15	50	20	7	50	700
FM 30S	1.5	15	15	L1	300	300	10	N10	70	L0.05	0.1	L0.2	1	50	1	70	15	L50	30	7	30	1000
FM 30SD	2	20	15	1	500	500	30	L10	100	L0.05	0.15	L0.2	1	50	1	70	15	50	30	7	50	700
FM 31S	3	30	20	1	70	500	30	15	150	L0.05	0.2	L0.2	1	50	1.5	50	20	70	30	10	30	500
FM 32S	1.5	7	15	L1	300	300	10	L10	70	L0.05	0.1	L0.2	G1	30	L1	70	10	L50	30	7	70	1500
FM 34S	1.5	15	30	L1	100	300	10	N10	70	L0.05	0.1	0.2	G1	30	1.5	70	20	100	30	10	70	1000
FM 35S	2	20	20	1	700	300	30	10	100	0.05	0.15	L0.2	1	30	1	70	15	L50	30	7	70	1500
FM 36S	2	20	10	L1	300	500	20	L10	100	0.05	0.15	L0.2	G1	30	L1	70	10	L50	30	7	70	1500
FM 37S	2	30	30	12	500	300	L5	10	100	L0.05	0.1	L0.2	1	30	1	50	15	L50	L20	5	30	700
FM 37SD	5	50	30	1	100	700	20	L10	200	0.05	0.3	L0.2	1	50	1	100	30	50	20	10	30	700

Table 2. (continued) Analytical results form the soil samples collected in the Fort McClellan-Pelham Range study area, Fort McClellan, AL.

Sample	Fe %	Cu	Pb	Au ppb	Mn	Ba	Ni	Co	V	Ca%	Mg %	P%	Ti %	B	Be	Cr	Ga	La	Nb	Sc	Y	Zr
FM 40S	2	20	50	1	70	300	10	N10	100	L0.05	0.15	L0.2	1	20	L1	100	30	50	L20	7	50	1000
FM 41S	2	20	30	1	70	150	15	N10	70	L0.05	0.15	L0.2	1	30	L1	70	20	50	20	7	50	1500
FM 42S	3	30	30	1	300	500	50	15	100	L0.05	0.15	L0.2	1	30	L1	70	30	70	20	10	70	1000
FM 43S	0.7	50	500	L1	300	300	15	N10	50	0.05	0.1	L0.2	0.7	15	1	30	10	L50	L20	5	20	500
FM 44S	5	50	100	1	100	500	30	10	150	L0.05	0.7	L0.2	1	50	2	150	70	70	20	15	30	300
FM 45S	0.7	10	10	L1	200	200	L5	N10	70	L0.05	0.07	L0.2	1	20	L1	30	5	L50	30	7	30	1500
FM 46S	3	50	50	2	500	200	50	15	150	L0.05	0.15	L0.2	0.7	30	1	70	30	L50	20	10	30	500
FM 47S	1.5	15	15	L1	500	200	15	30	100	0.07	0.1	L0.2	G1	20	L1	50	5	50	30	7	50	1500
FM 49S	2	10	50	1	200	700	15	10	100	L0.05	0.2	L0.2	0.7	20	2	70	30	50	20	10	50	700
FM 50S	2	20	50	1	70	200	5	N10	100	L0.05	0.07	L0.2	0.7	15	1	50	20	50	20	7	50	700
FM 51S	2	20	70	L1	300	1000	15	L10	100	L0.05	0.3	L0.2	0.7	30	1.5	70	50	70	20	10	70	700
FM 51SD	3	20	50	L1	500	1000	20	L10	100	L0.05	0.5	L0.2	1	30	2	70	30	70	20	15	70	700
FM 52S	1.5	5	20	L1	150	500	15	N10	70	L0.05	0.1	L0.2	1	20	L1	70	7	50	20	7	30	1000
FM 53S	3	15	50	2	700	1000	15	L10	100	L0.05	0.2	L0.2	1	30	1.5	100	50	50	30	10	50	1000
FM 55S	1.5	20	150	L1	700	300	15	L10	70	0.07	0.1	L0.2	0.7	20	1	70	7	70	20	5	50	700
FM 56S	2	30	150	1	3000	700	50	20	100	0.05	0.15	L0.2	1	30	1.5	70	30	100	20	10	100	500
FM 57S	3	30	50	2	500	150	50	15	100	L0.05	0.15	L0.2	0.7	30	1	50	20	L50	L20	7	100	300
FM 59S	2	30	30	2	2000	200	30	30	70	0.05	0.15	L0.2	1	30	1.5	50	20	L50	20	7	70	700
FM 63S	7	50	100	1	100	100	50	10	150	L0.05	0.15	L0.2	0.5	15	1	100	30	50	20	10	10	150
FM 64S	2	30	70	2	300	150	20	15	70	0.05	0.1	L0.2	0.3	15	L1	70	10	L50	L20	5	15	300
FM 65S	1.5	30	30	4	5000	500	30	15	50	0.05	0.05	0.3	0.2	15	1.5	30	L5	50	L20	5	30	200
FM 66S	1.5	15	L10	1	70	300	15	10	50	L0.05	0.07	L0.2	0.7	20	L1	30	5	L50	20	5	20	500
FM 67S	1.5	20	L10	3	100	100	15	10	70	0.05	0.1	L0.2	0.7	20	L1	50	7	L50	20	5	15	300

Table 3. Analytical methods used for water analysis, Fort McClellan study area, Fort McClellan, AL

Constituent	Method	Reference
Alkalinity	Gran's plot potentiometric titration	Orion Research Inc (1975)
Sulfate	Ion chromatography	Smee and Hall (1978)
Chloride	Ion chromatography	Smee and Hall (1978)
Fluoride	Ion chromatography	Smee and Hall (1978)
Calcium	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Magnesium	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Sodium	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Potassium	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Aluminum	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Iron	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Silica	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976)
Specific Conductance	Conductivity bridge	Brown and others (1970)
All other cations	ICP-AES	Environmental Protection Agency, SW 846 methods 620

Table 4. Summary of inorganic constituents from stream and spring waters collected from Fort McClellan and Pelham Range, Fort McClellan, AL.

			Cond		Temp	Charge	PPM							
Sample	place	UTM FN	M/S	pH	C	Balance	Ca	Na	K	Mg	Cl	SO4	NO3	Alkalinity
FMW 01	Willet Spring, PR	9692 3203	225	7.6	16	-1.4	25	0.92	0.33	14	1.6	0.99	1.1	140
dup ICP	Willet Spring, PR	9692 3203												
FMW 02	brook, north PR	9874 3232	17	8.3	19	-2.9*	2.2	0.57	0.40	0.7	1.0	2.3	<0.2	<10
FMW 03	spring, central PR	9201 2861	254	6.3	14	1.9	28	0.68	0.40	16	1.1	1.8	<0.2	170
FMW 04	stream, south PR	9195 2808	180	7.0	17	3.8	19	0.71	0.41	11	1.2	2.0	<0.2	120
FMW 05	brook, south PR	9726 2891	19	6.7	19	-5.8*	2.2	0.66	0.45	1.0	0.97	3.1	<0.2	<10
FMW 06	brook, central PR	9867 3025	18	6.4	20	-4.9*	2.2	0.57	0.32	0.9	0.76	2.9	<0.2	<10
FMW 07	brook, Range 24A	1506 2752	18	7.3	18	1.2*	1.4	0.87	1.9	0.6	1.1	3.1	<0.2	<10
FMW 08	spring, Range 21	1550 3083	14	6.7	19	0.98*	1.3	0.83	1.5	0.4	0.98	1.6	<0.2	<10
FMW 09	brook, Bain Gap	1774 3126	17	6.6	19	1.2*	1.5	0.72	1.6	0.6	0.99	2.8	<0.2	<10
FMW 10	brook, Truitt Hill	1690 3476	15	7.0	18	15*	1.1	0.60	0.77	0.7	1.0	3.4	<0.2	<10
FMW 11	stream, north FM	1532 3475	20	7.4	18	-11*	2.2	0.66	0.85	1.1	1.1	2.6	<0.2	<10
dup ICP	stream, north FM	1532 3475												
FMW 12D	duplicate of W11	1532 3475	20	7.4	18	-11*	2.2	0.65	0.85	1.1	1.1	2.6	<0.2	<10
FMW 13	brook, French Hill	1647 3476	15	6.3	18	10*	1.3	0.63	0.30	0.6	1.1	1.8	<0.2	<10
FMW 14	stream, Res Ridge	1360 3335	13	6.7	20	7.0*	1.4	0.62	0.55	0.7	1.1	2.3	<0.2	<10
FMW 15	brook, Twin Peaks	1160 2660	15	6.7	18	2.6*	1.4	0.64	1.1	0.7	1.0	2.4	<0.2	<10

* Assumed a HCO3 concentration of 7 ppm. For samples 10 and 13, decreasing the HCO3 to 5 ppm reduced the charge balance to 6.7% and 0.39% respectively. For sample 11, increasing the HCO3 to 8 ppm decreased the charge balance to -7.3%.

$$\text{charge balance} = \frac{A - C}{A + C} \times 100 \qquad A = \frac{(Cl)}{35.5} + \frac{(SO4)}{48} + \frac{(HCO3)}{61} + \frac{(NO3)}{62} \qquad C = \frac{(Na)}{23} + \frac{(K)}{39.1} + \frac{(Ca)}{20} + \frac{(Mg)}{12.2}$$

The following elements were not detected at the 0.1 ppb level unless noted, number in parentheses is the detection limit or the sample where the element was detected and the value: Ag, As (0.6), Au, Be (1), Bi (1), Cd (3), Cr (0.9), Cs (W2 and W6 at 0.2), Dy, Er, Eu, Ga, (0.3), Ge (0.4), Hf, Ho, Li (2), Nb (1), Nd (0.2) and W2 at 0.6), Pr (W2 at 0.2), Re, Sm, Sn (1), Ta, Tb, Te (2), Ti (1), Th (0.8), Tl (0.6), Tm, U (0.2), V (0.2, W1 and W3 at 0.2, W2 and W4 at 0.3), W, Yb, Zr (W2 at 0.3).

Table 4. Summary of inorganic constituents from stream and spring waters collected from Fort McClellan and Pelham Range, Fort McClellan, AL.

		PPB					PPM		PPB										
Sample	**place**	**Cu**	**Pb**	**Zn**	**Mo**	**Mn**	**Fe**	**SiO2**	**Co**	**Ni**	**Y**	**Ba**	**Rb**	**Sr**	**Sb**	**La**	**Ce**	**Al**
FMW 01	Willet Spring, PR	0.6	<0.5	6	0.5	7.9	<.01	8	<0.1	0.8	<0.1	12	0.4	17	<0.1	0.3	<.01	<.1
dup ICP	Willet Spring, PR	<0.6	<0.5	<3	0.3	<0.4	▨	▨	<0.1	0.8	<0.1	11	0.4	16	<0.1	0.2	<.01	▨
FMW 02	brook, north PR	0.9	<0.5	6	<0.2	27	0.08	7	<0.1	0.6	0.6	22	1.0	10	<0.1	0.5	1.7	<.1
FMW 03	spring, central PR	<0.6	<0.5	<3	0.3	2.4	<.01	7	<0.1	0.8	0.2	13	0.4	18	<0.1	0.2	<.01	<.1
FMW 04	stream, south PR	2.5	<0.5	7	0.5	75	0.05	7	0.2	1.0	<0.1	26	0.3	22	<0.1	0.2	<.01	<.1
FMW 05	brook, south PR	0.8	0.6	8	<0.2	24	<.01	8	0.1	0.5	<0.1	25	0.8	9.7	<0.1	0.1	0.3	<.1
FMW 06	brook, central PR	4.2	<0.5	9	<0.2	7.4	<.01	8	<0.1	0.9	0.2	17	0.6	8.3	<0.1	0.2	0.5	<.1
FMW 07	brook, Range 24A	<0.7	<0.5	3	<0.2	7.6	0.07	11	<0.1	0.4	<0.1	19	2.0	6.0	<0.1	0.2	0.2	<.1
FMW 08	spring, Range 21	6.1	16	4	<0.2	5.5	0.08	13	0.2	<0.3	<0.1	13	2.3	4.6	0.5	0.1	0.2	<.1
FMW 09	brook, Bain Gap	<0.6	<0.5	<3	<0.2	2.3	<.01	11	<0.1	<0.3	0.1	22	2.1	8.9	<0.1	0.2	0.2	<.1
FMW 10	brook, Truitt Hill	<0.6	<0.5	3	<0.2	10	<.01	6	<0.1	0.3	0.2	24	1.2	7.6	<0.1	<.1	0.2	<.1
FMW 11	stream, north FM	<0.6	<0.5	<3	<0.2	29	0.03	7	0.3	0.5	0.2	28	1.7	6.7	<0.1	0.2	0.3	<.1
dup ICP	stream, north FM	<0.6	<0.5	<3	<0.2	26	▨	▨	0.2	1.1	0.2	27	1.6	6.6	<0.1	0.2	0.2	▨
FMW 12D	duplicate of W11	<0.6	<0.5	<3	<0.2	27	0.02	7	0.2	0.5	0.2	29	1.4	5.9	<0.1	0.1	0.2	<.1
FMW 13	brook, French Hill	<0.6	<0.5	3	<0.2	54	0.05	6	0.1	2.4	0.7	20	0.6	6.0	<0.1	0.2	0.6	<.1
FMW 14	stream, Res Ridge	2.4	2	4	<0.2	15	0.03	7	0.2	0.4	0.3	20	0.9	8.9	0.3	0.2	0.4	<.1
FMW 15	brook, Twin Mtns	<0.6	<0.5	<3	<0.2	10	0.02	8	0.1	<0.3	0.1	19	1.7	6.3	0.2	0.1	0.2	<.1

The following elements were not detected at the 0.1 ppb level unless noted, number in parentheses is the detection limit or the sample where the element was detected and the value: Ag, As (0.6), Au, Be (1), Bi (1), Cd (3), Cr (0.9), Cs (W2 and W6 at 0.2), Dy, Er, Eu, Ga (0.3), Ge (0.4), Hf, Ho, Li (2), Nb (1), Nd (0.2 and W2 at 0.6), Pr (W2 at 0.2), Re, Sm, Sn (1), Ta, Tb, Te (2), Ti (1), Th (0.8), Tl (0.6), Tm, U (0.2), V (0.2, W1 and W3 at 0.2, W2 and W4 at 0.3), W, Yb, Zr (W2 at 0.3).

GEOCHEMICAL RESULTS

a. Rocks.

The concentrations of thirty five elements were determined from the rocks collected for this study. The elements As, Bi, Cd, Ge, Sb, Sn, Sr, Th, and W were not detected in any sample or in only a few of the samples (see Table 1).

The elements chosen for data interpretation fall into three broad groups. The first group contains the base metals Cu, Pb, Mo, and Zn. These metals are found in small concentrations in many rock forming minerals. Elevated concentrations of these metals in a rock generally indicate mineralization processes are superimposed on the original rock signature. The presence of these metals in the rocks will virtually exclude any anthropogenic input.

The second elemental grouping consists of the precious metals Au and Ag. The presence of these metals strongly indicates that hydrothermal events superimposed a geochemical imprint on the original rock compositions within the study area. The presence of these metals in the rocks virtually excludes any anthropogenic activities and points to mineralizing events as the source of the metals.

The third elemental grouping contains elements often found in low concentrations within a variety of rock forming minerals but are also strong indicators of mineralization processes when found in high concentrations or with certain minerals. For example, Ba will substitute into feldspars but Ba in barite generally indicates the presence of hydrothermal activity and alteration. The elements Ni and V will substitute into mafic minerals and into iron oxide minerals such as magnetite. These elements also concentrate in hydrothermal solutions and precipitate with iron oxides within the host rock. Elevated concentrations of these elements can indicate hydrothermal activity associated with mineralizing events

There is a natural concentration distribution of an element in a mineral or host rock. This background variation generally fits a typical log normal distribution (Davis, 1973; Levinson, 1974). This log normal elemental distribution can be greatly altered by circulating hydrothermal solutions and/or a mineralizing event. A particular element could be leached from the host rock or could be increased in concentration due to precipitation within a vein or host rock. Examining outcrop data is an excellent method of determining the effects of various geochemical process on the host rock (Alminas and others, 1994; Krauskopf, 1967; Tucker, J.D., and others, 1981; Tucker, R.E., and others, 1981, 1985).

An important factor in analyzing the data is assigning or determining the limits of geochemically interesting concentrations or anomalously high or low concentrations. For this study, elemental concentrations that fall outside of a log normal distribution or the highest (or lowest) 20% of the samples can be considered as anomalous or having some geochemical interest.

The range in Cu concentrations varies from “Not Detected” at a 5 ppm lower limit of detection to 150 ppm. The histogram shows a weakly bimodal distribution (or a long skew toward lower concentrations). Figures 3 and 4 show the distribution of Cu on Fort McClellan and Pelham Range, respectively. The elevated values delineate the highly altered or mineralized areas at site 22 (Trench Hill), site 50 (Bain Gap), a line of sites from the south end of Reservoir Ridge (site 31 to site 33, to site 37), and sites 54, 57, 64, and 67 on Pelham Range.

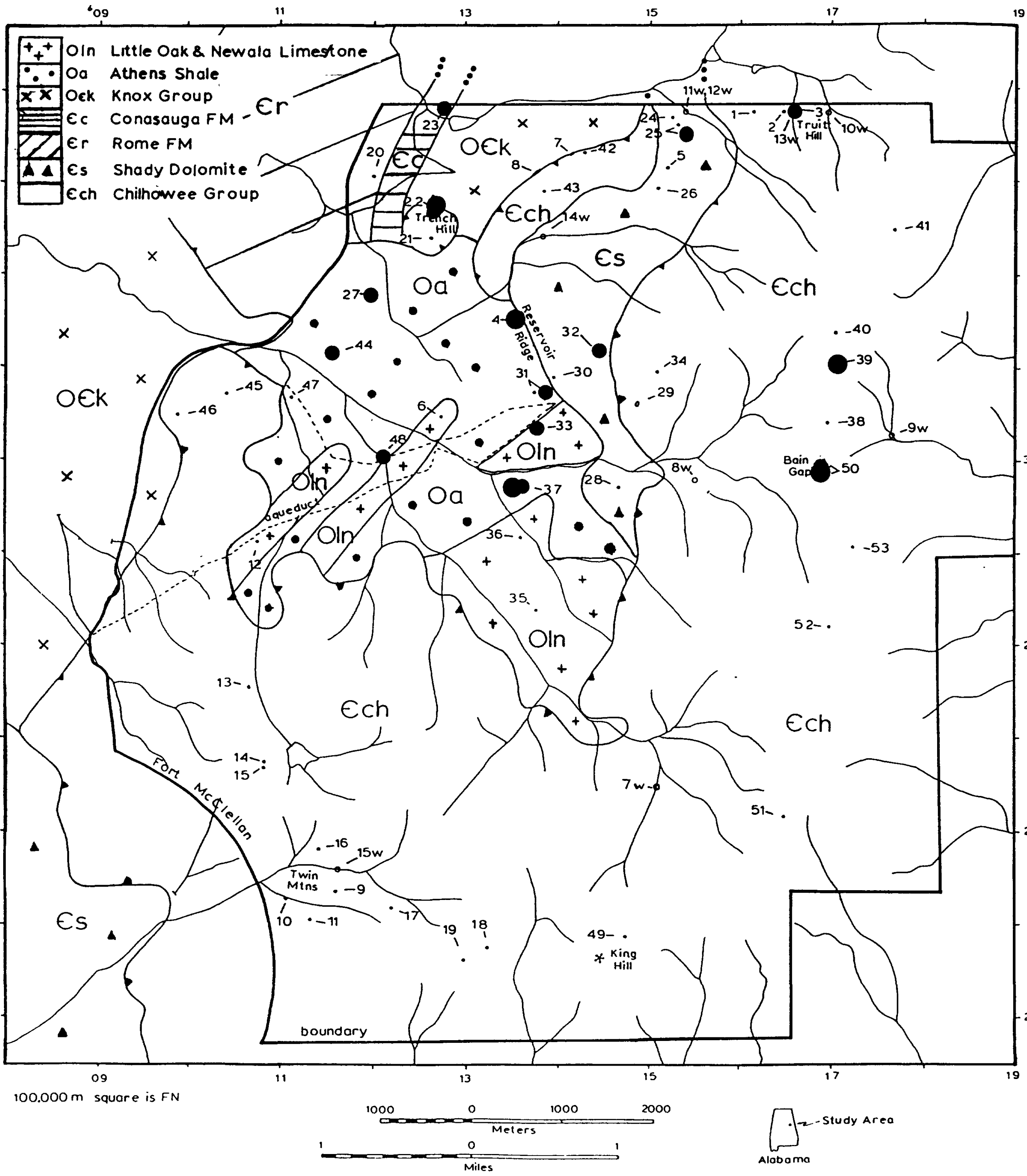

Figure 3. Distribution of elevated Cu concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Cu in ppm

● ≥ 100

● 50-70

· ≤ 30

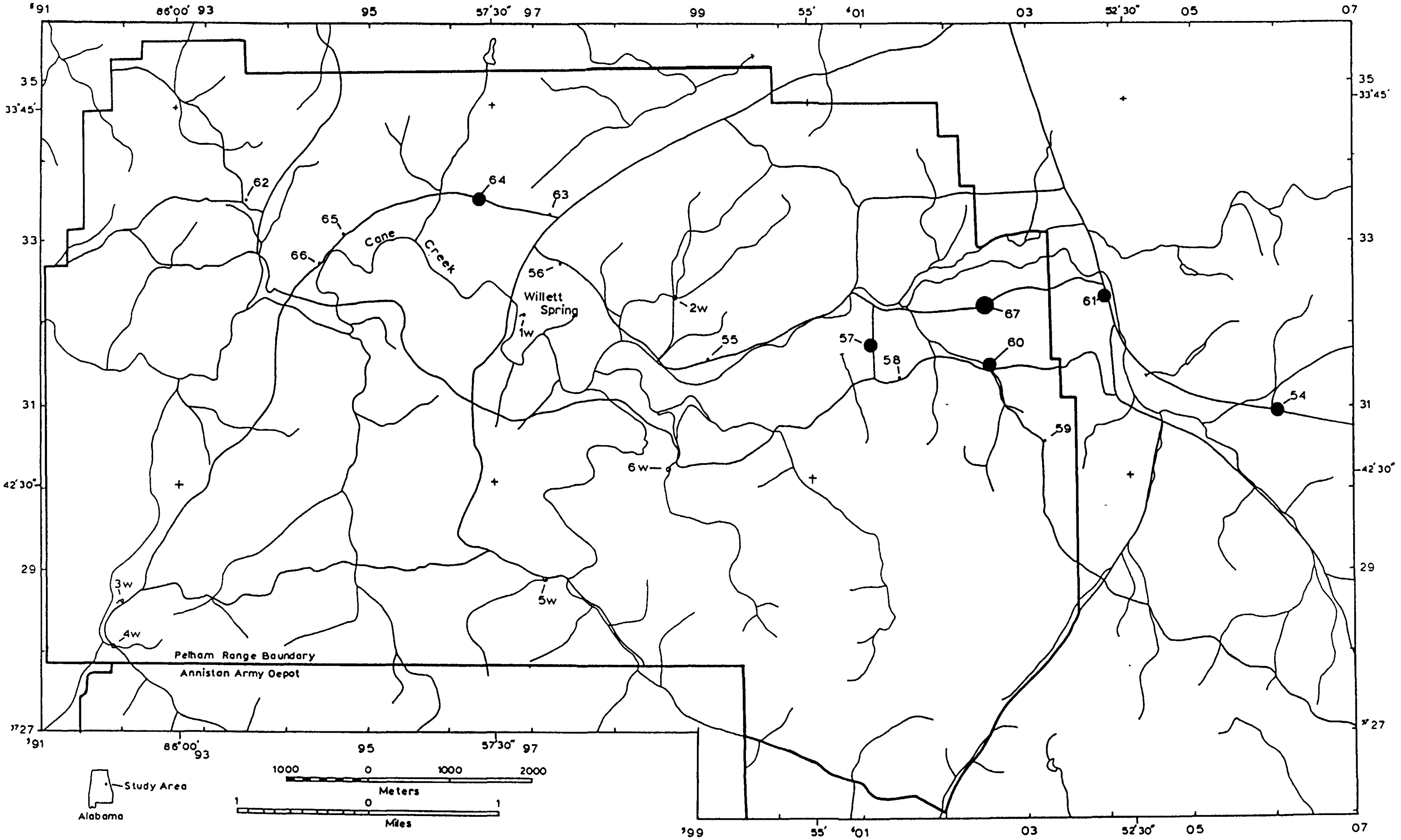

Figure 4. Distribution of elevated Cu concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Cu in ppm

● ≥100

● 50-70

· ≤ 30

Lead concentrations range from "Not Detected" at a 10 ppm lower limit of detection to 500 ppm. Nearly 30% of the Pb values fall below the lower limit of detection, suggesting a bimodal distribution. The limestone and shales that comprise much of the study area would not normally contain Pb. The sandstones and conglomerates of the Chilhowee Group contain more feldspars and consequently should show a higher lead background concentration. Superimposed on the Pb background values is the mineralization sequence which coincides rather closely with the elevated Cu concentrations. Figures 5 and 6 show the distribution of Pb concentrations on Fort McClellan and Pelham Range, respectively.

Molybdenum was detected in 24 samples from 19 sites. Most of the samples with detectable Mo also have elevated concentrations of Cu and/or Pb. Molybdenum is a strong indicator of a felsic-derived mineralization sequence. Figures 7 and 8 show the distribution of Mo from Fort McClellan and Pelham Range, respectively.

Zinc was detected in 17 samples. The highest concentration of 700 ppm occurs at sites 3 and 54. The other sites with detectable Zn also contain elevated concentrations of Cu and/or Pb

The precious metals Ag and Au are very good indicators of mineralization. Silver was detected in eight samples from seven sites (3, 22, 25, 34, 50, 62, and 65). These sites also contain elevated concentrations of Cu, Pb, Zn, or Mo. Gold was detected in over half of the samples above the 1 ppb level of detection. Samples from site 3 have the highest Au concentrations at 240 and 50 ppb. The pyrite at site 22 contains 35 ppb Au. Figures 9 and 10 show the distribution of elevated Ag and Au concentrations on Fort McClellan and Pelham Range respectively. The wide spread distribution of low level Au indicates the occurrence of mineralizing events throughout the study area.

Several examples of distributions for elements commonly found in most rocks are illustrative of the many complex geochemical interactions found in nature. Iron concentrations range from 0.15 to greater than 20 percent. The distribution pattern is at least bimodal. The highest concentrations occur in sites with iron veins or sulfide minerals present. Figures 11 and 12 show the distribution of high and low Fe concentrations from Fort McClellan and Pelham Range respectively. Some of the highest Fe concentrations occur associated with elevated concentrations of the base and precious metal at sites 3, 22, 39, 50, 54, 57, and 64. Elevated Fe concentrations from samples at sites 14, 17, 18, 29, and 42 are from veins or zones of iron enrichment but do not contain elevated concentrations of base or precious metals.

The lowest Fe concentrations are found in samples from the Shady Dolomite (sites 25, 26, and 28) or the Chilhowee Formations (sites 13, 16, 19, 34, and 48). These rocks would not generally contain high Fe. The occurrence of elevated Fe and other metals at sites in these rocks indicates a mineralization process affected the original elemental composition.

Manganese concentrations range from "Not Detected" at a 10 ppm lower limit of detection to greater than 5000 ppm. The concentration distribution is bimodal. Figures 13 and 14 show the distribution of concentrations above 500 ppm on Fort McClellan and Pelham Range, respectively. Elevated Mn concentrations generally occur at sites with elevated Cu, Pb, or Mo (sites 22, 50, 54, 57, and 67). Other sites with high Mn occur peripheral to the base metal concentrations reflecting the more mobile nature of Mn in hydrothermal systems (sites 8, 39, 51 or 53).

Sites with the lowest Mn concentrations generally occur in rocks of the Chilhowee Group sandstones in the southwestern portion of Fort McClellan (figure 13). The hard quartzites at sites 34 and 41 may reflect a normal Mn concentration for certain rocks in

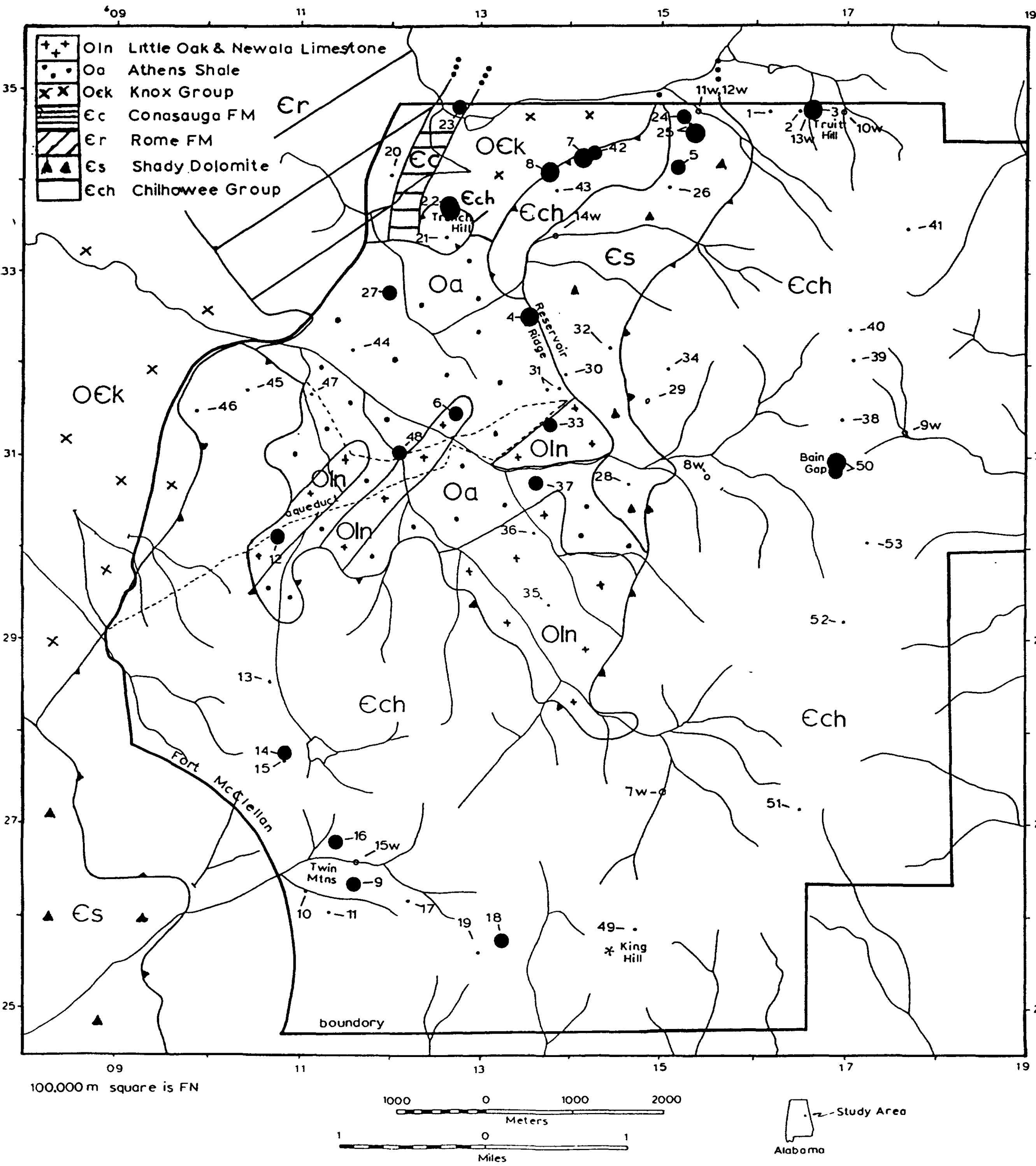

Figure 5. Distribution of elevated Pb concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Pb in ppm

● ≥ 100

● 50-70

· ≤ 30

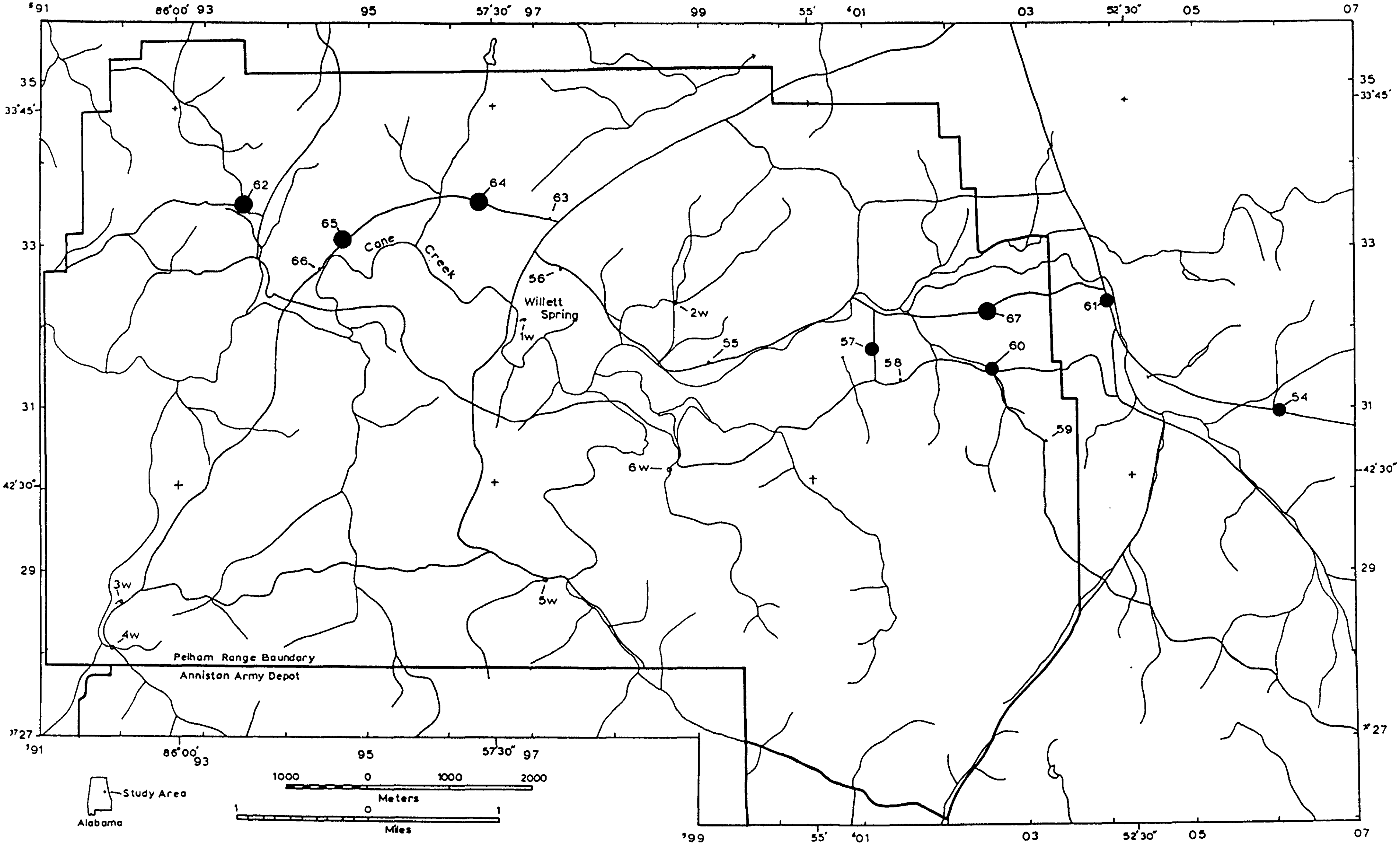

Figure 6. Distribution of elevated Pb concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

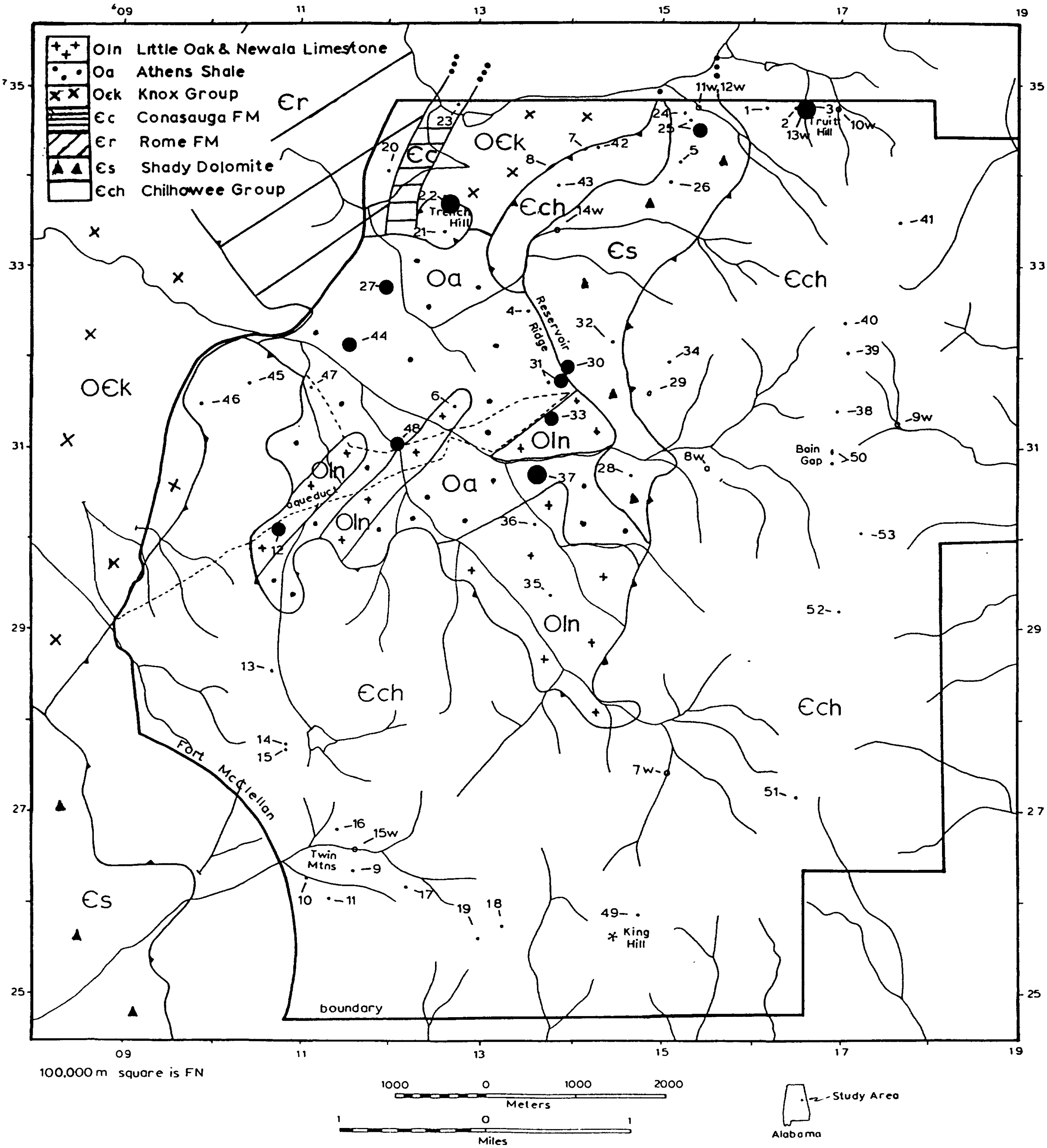

Figure 7. Distribution of elevated Mo concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Mo in ppm

● ≥ 15

● L5-10

• not detected

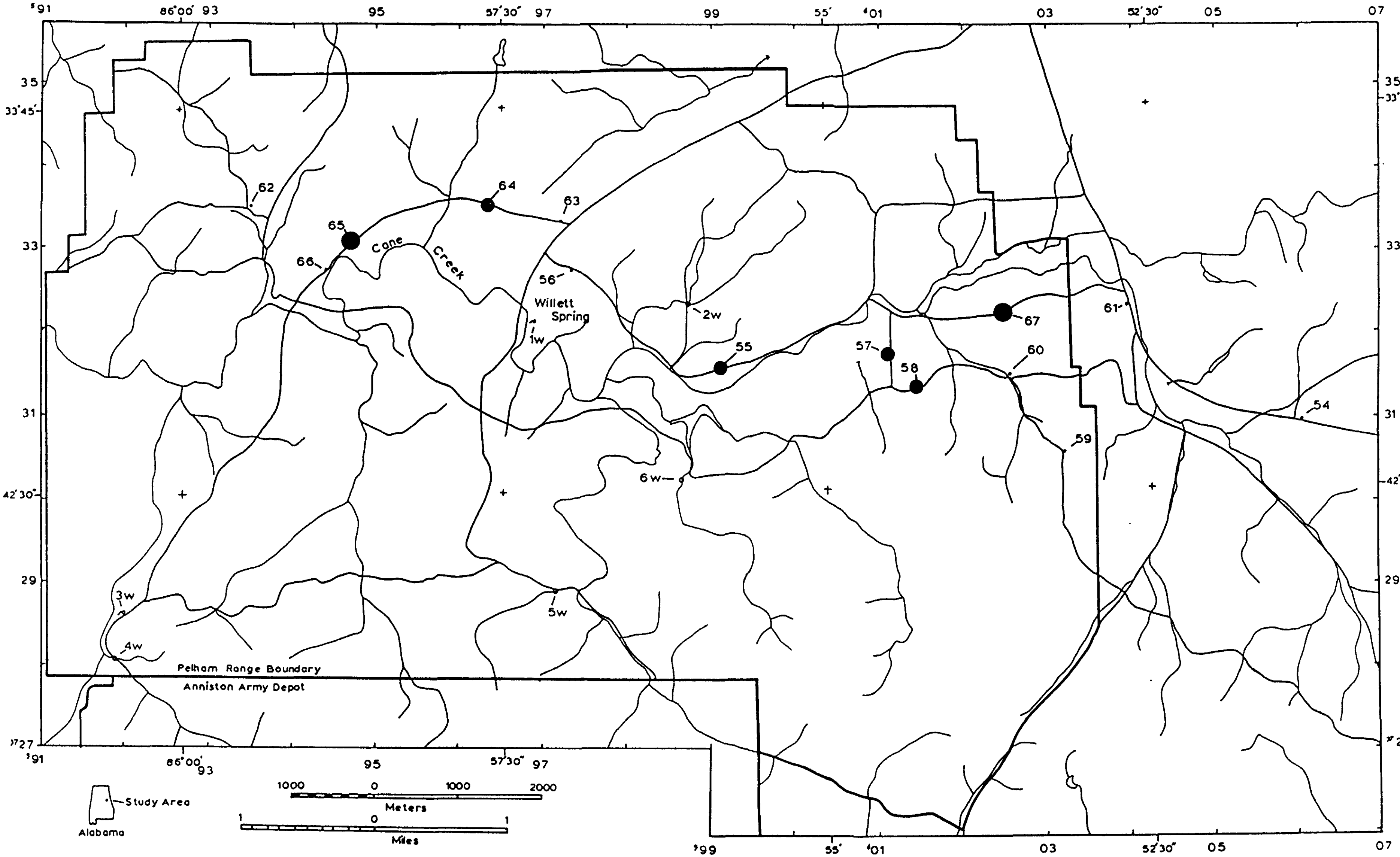

Figure 8. Distribution of elevated Mo concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Mo in ppm

● ≥ 15
● L5-10
• not detected

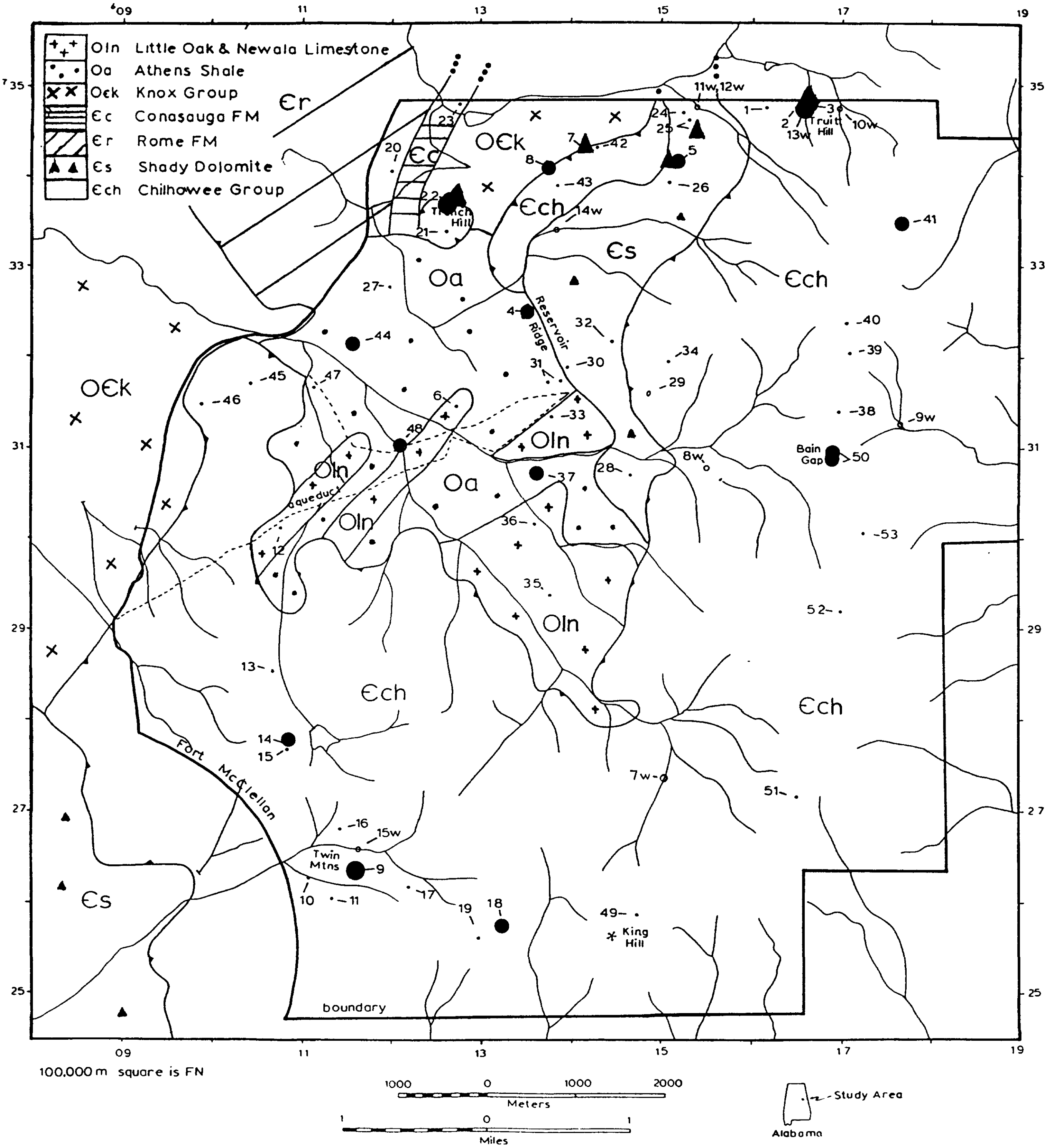

Figure 9. Distribution of elevated Au and Ag concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Au in ppb

● ≥ 9

● 2-8

Ag in ppm

▲ ≥ 0.5

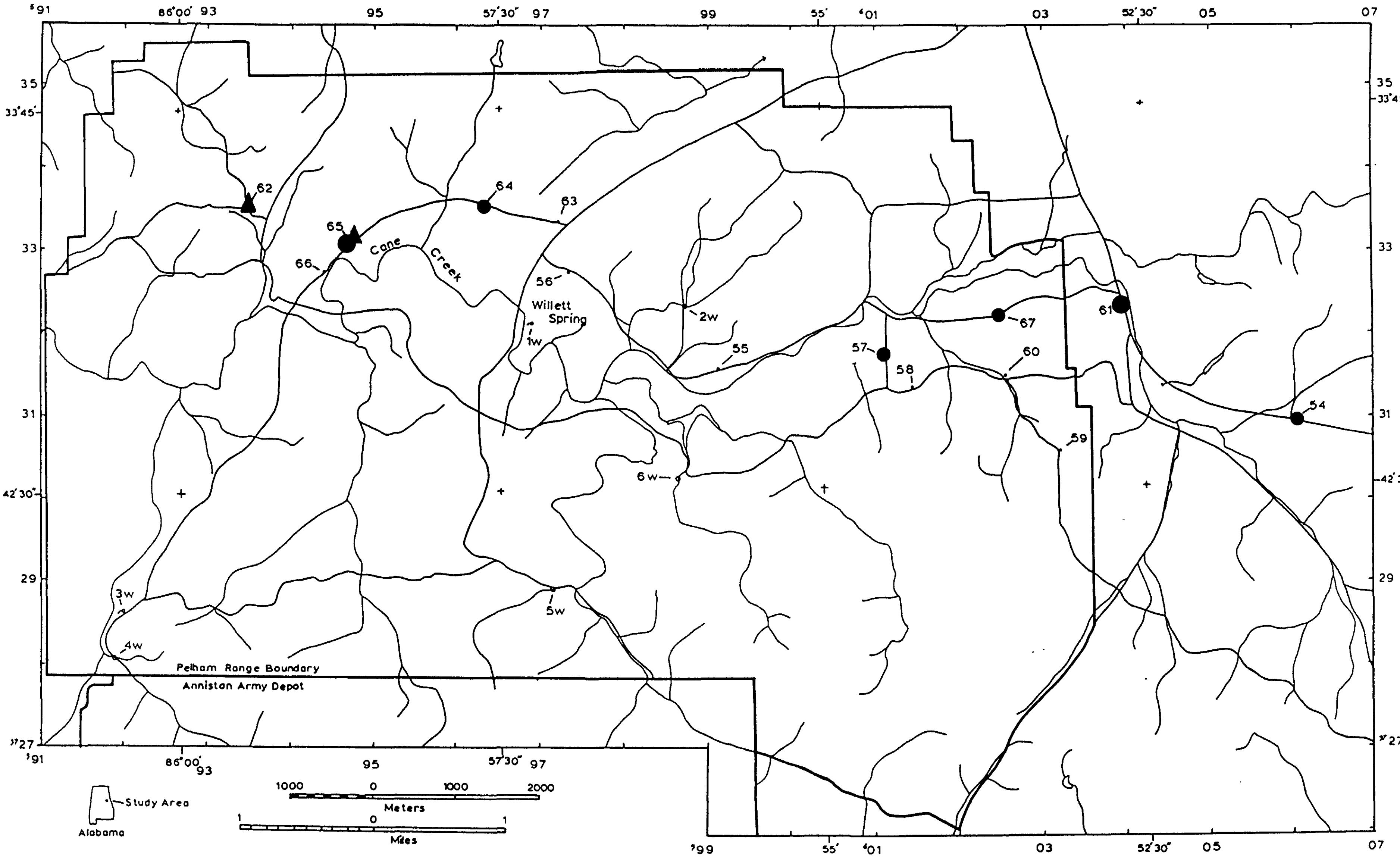

Figure 10. Distribution of elevated Au and Ag concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Au in ppb

● ≥ 9

● 2-8

Ag in ppm

▲ ≥0.5

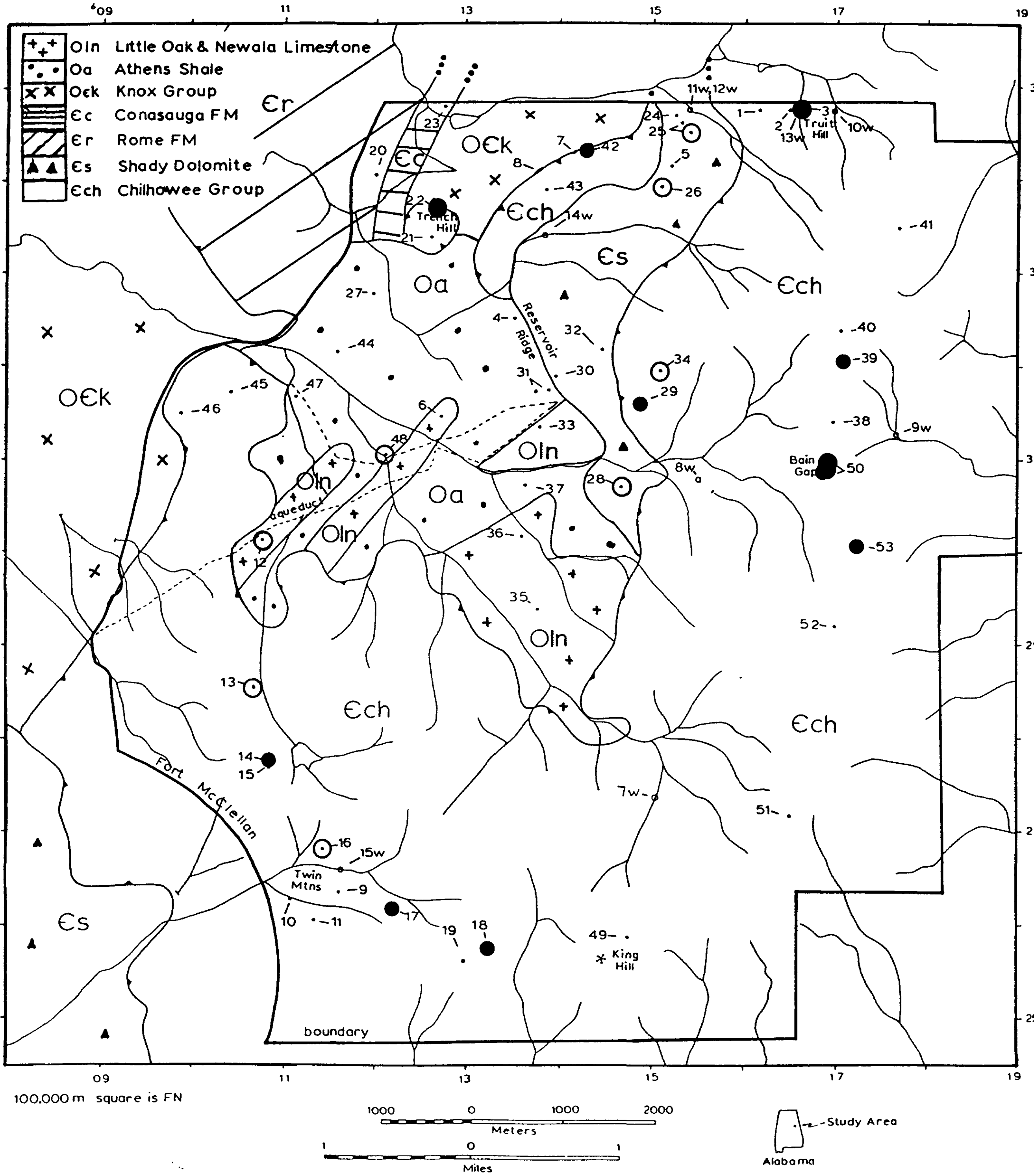

Figure 11. Distribution of elevated Fe concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Fe in percent

● > 20

● 15-20

• 0.5-10

○ ≤ 0.3

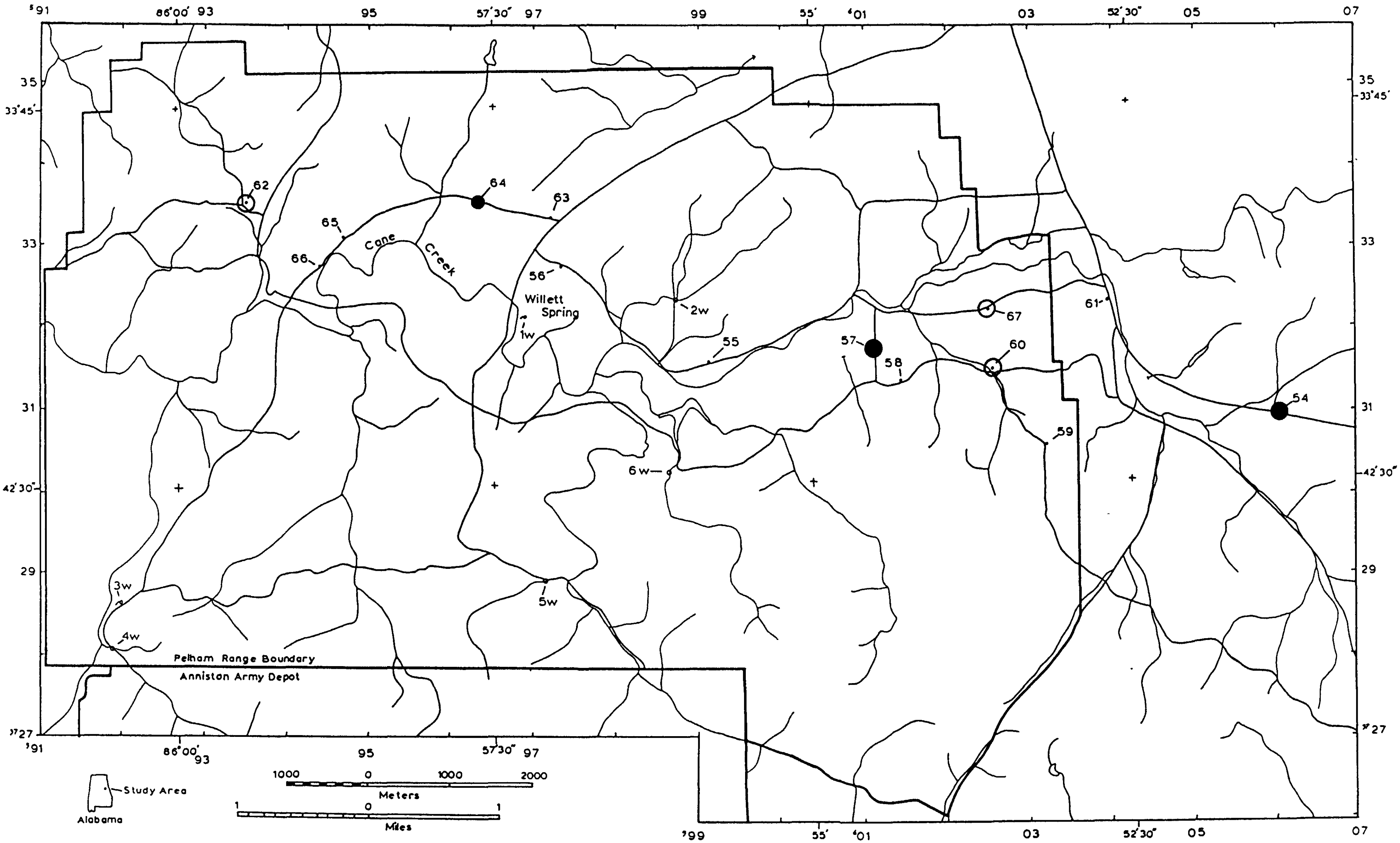

Figure 12. Distribution of elevated Fe concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Fe in percent

● > 20

● 15-20

• 0.5-10

○ ≤ 0.3

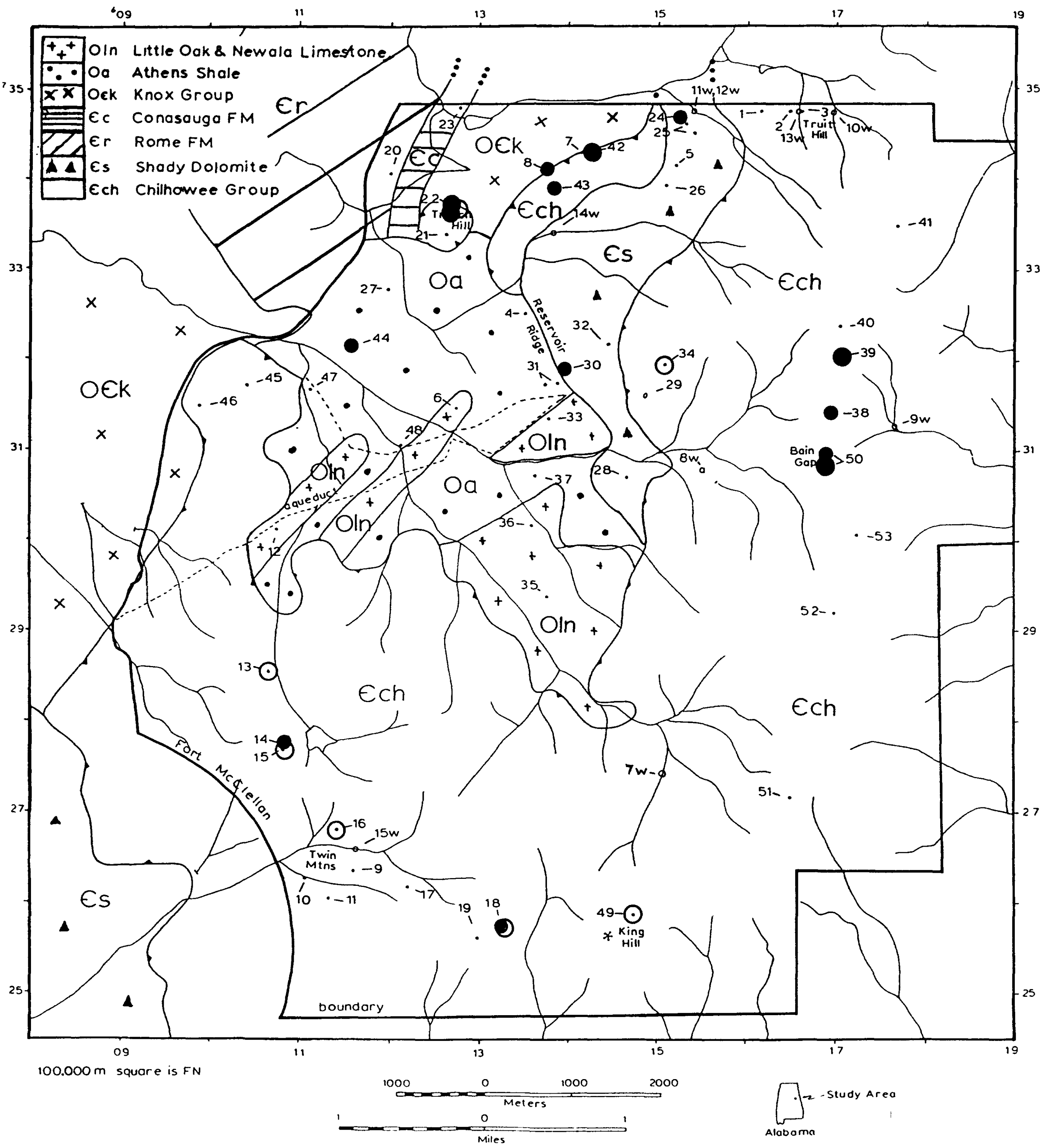

Figure 13. Distribution of elevated Mn concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Mn in ppm

● ≥ 5000
● 500-3000
• 20-300
○ ≤ 15

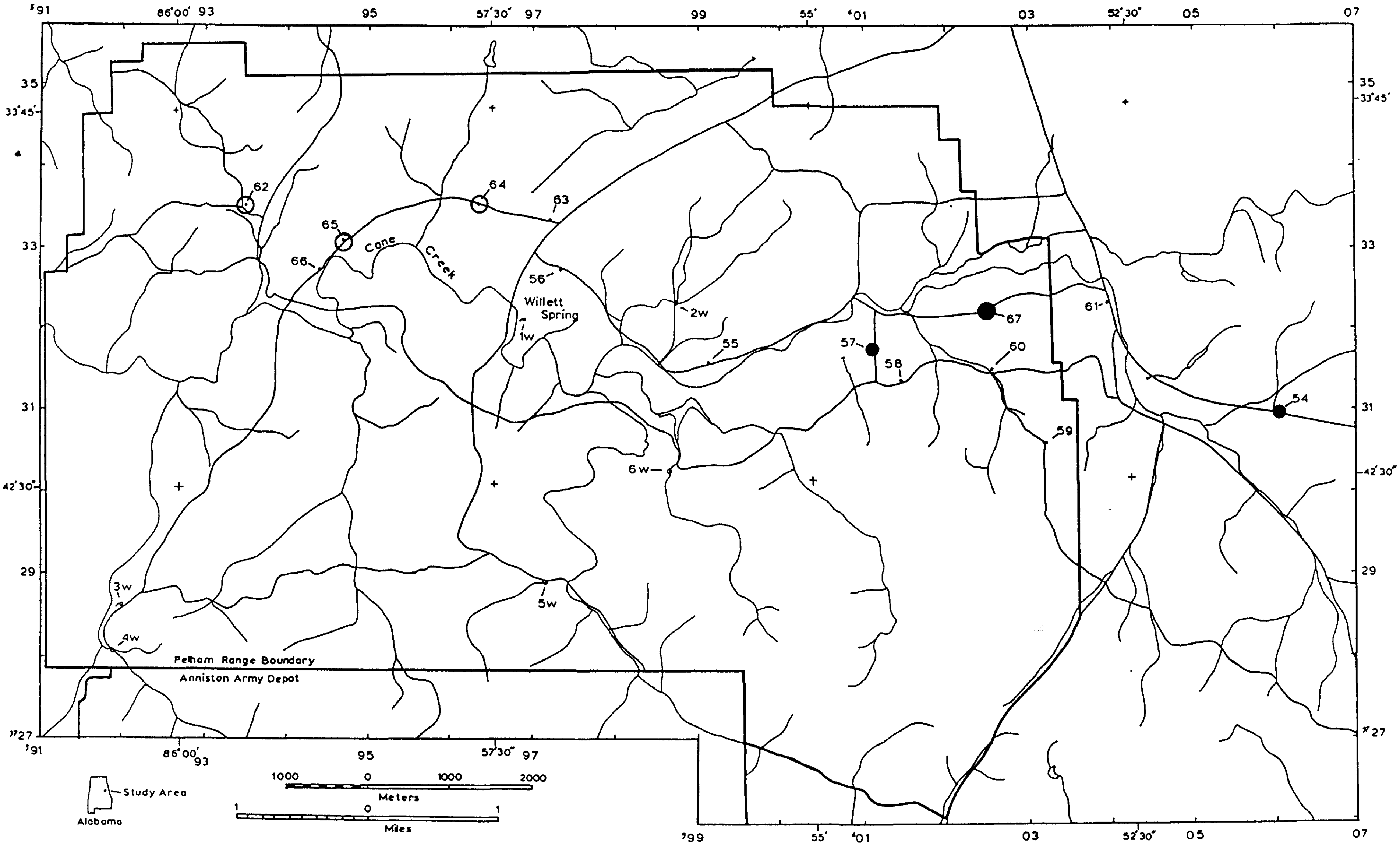

Figure 14. Distribution of elevated Mn concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Mn in ppm

● ≥ 5000
● 500-3000
· 20-300
○ ≤ 15

this formation. However, the rocks around sites 12, 13, 15, 16, 18, and 49 show typical hydrothermal alteration characteristics. It appears that the hydrothermal fluids interacting with the host rocks either contained very little Mn or the geochemical environment did not promote the deposition of Mn.

Barium concentrations range from "Not Detected" at the 20 ppm lower limit of detection to 5000 ppm. The concentration distribution is bimodal and very similar to Mn. Figures 15 and 16 show the distribution of Ba concentrations greater than 700 ppm on Fort McClellan and Pelham Range respectively. Elevated Ba concentrations generally occur in samples removed from the main mineralized zones. The lowest Ba concentrations occur in samples of gossan (3R1, 22R1, 54R1, and 57R2), sulfides (22R3), from highly altered rocks (14R2, 60R2, and 61R1), and from the Little Oak or Newala Limestone (48R2).

Barium in hydrothermal systems generally occurs as barite ($BaSO4$). The presence of barite is a good indicator that the hydrothermal solutions are oxidizing where sulfate is the predominate sulfur species. Metal sulfide deposits form in more reducing environments where sulfide is the predominate species. Finding Ba concentrations peripheral to the main mineralized areas suggests late stage hydrothermal event(s) occurred at these locations. This late stage hydrothermal activity would explain the extensive alteration throughout the study area and the localized nature of the mineralized areas because not all of the hydrothermal activity contained base and precious metal rich solutions.

Elements such as Be, Y, Ga, or Nb concentrate in late stage hydrothermal solutions due in part to their low abundance in the earth and their ionic size. (Mason, 1966). These elements do not readily substitute into common rock forming mineral phases. In a hydrothermal system, these elements tend to concentrate in the amorphous iron oxide rich precipitates within a host rock (Tucker, 1987). The presence of these elements in a sample suggests the cooling hydrothermal solutions were migrating within the host rock.

The distribution of elevated Be concentrations occur in samples from the mineralized areas and in samples from sites immediately adjacent to the mineralized zones. The distribution of elevated Be on Fort McClellan and Pelham Range is shown in figures 17 and 18. The samples with elevated Be concentrations adjacent to metal-rich sites suggests the hydrothermal activity occurred over a fairly widespread area but that metaliferous emanations occurred sporadically or were very localized.

Calcium has a limited distribution range from "Not Detected" at a 0.05 % lower limit of detection to 0.3 % for all but two samples. Samples 48R3 and 48R2 have concentrations of 15 and 20% respectively collected from the Little Oak/Newalla Limestone. Calcium concentrations above 0.05% occur in sites from the Shady Dolomite (28, 30), the Athens Shale (27), and the altered areas at site 49 and in sample 22R4. Calcium concentrations "Not Detected" at the 0.05% lower limit of detection occur from sites in the Chilhowee Formation (14, 17, 18, 29, 41, and 53), at the mineralized sites 3 and 50, and the gosson nodules at site 57.

Magnesium varies from "Less Than" the 0.02% lower limit of detection to 2%. The highest concentrations occur in samples from the Little Oak/Newalla Limestone and Athens Shale (sites 27, 33, 44, 48) and the Shady Dolomite (sites 28 and 32). A few sites in the Chilhowee Formation have elevated Mg concentrations (sites 41, 49, and 51). The sites with the lowest Mg concentrations occur in the Chilhowee Formation (13, 16, 22, 34, 40, 41, 43, 50, and 53). The low Mg concentrations in rocks from sites 13, 16, 22, 43, and 50 undoubtedly reflects the effects of acidic hydrothermal solutions or weathering under acidic conditions. The other sites with low Mg occur in the eastern highlands in relatively hard quartzite lens.

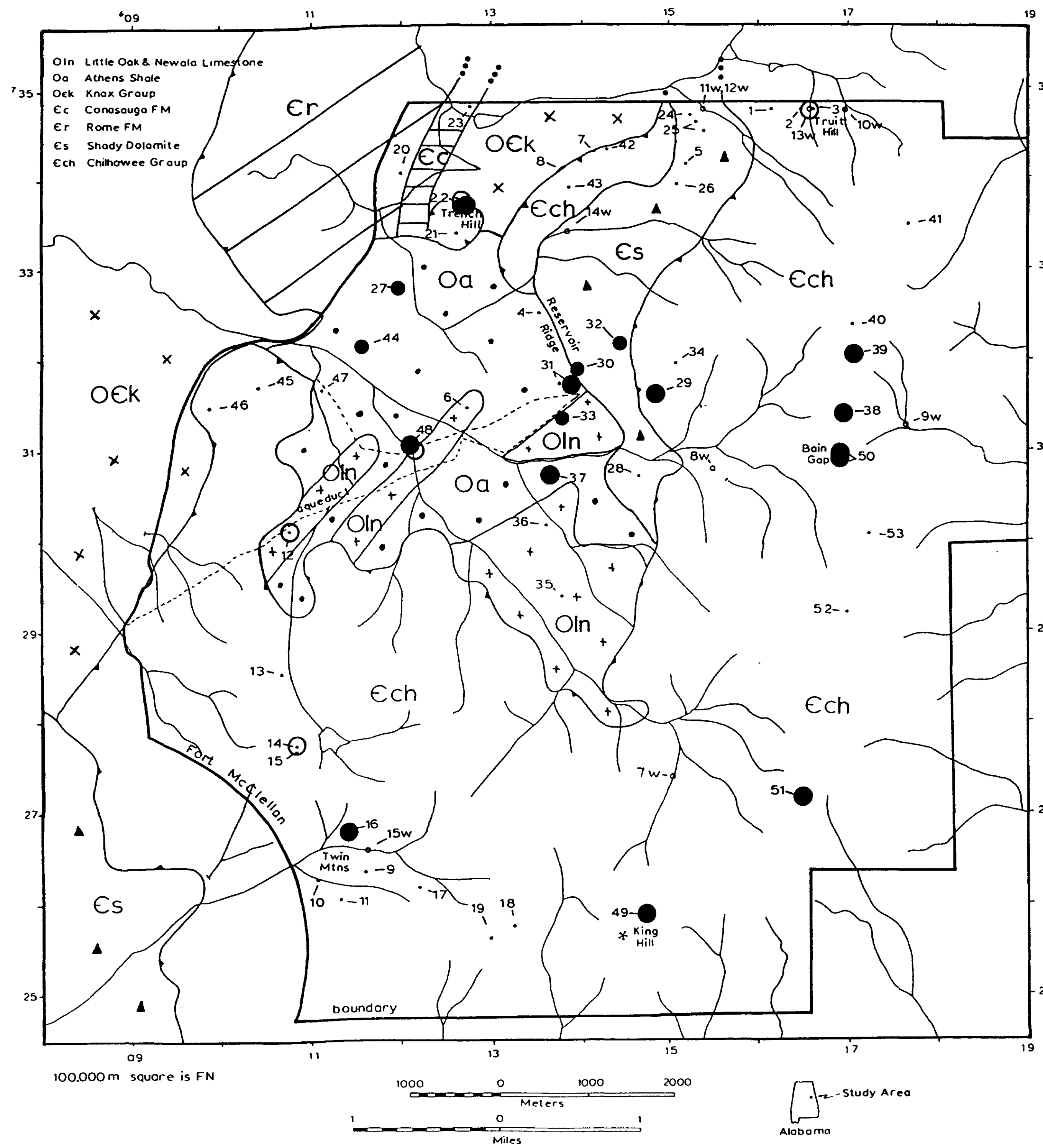

Figure 15. Distribution of elevated Ba concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Ba in ppm

● ≥ 1000

● 700

• 70–500

○ ≤ 50

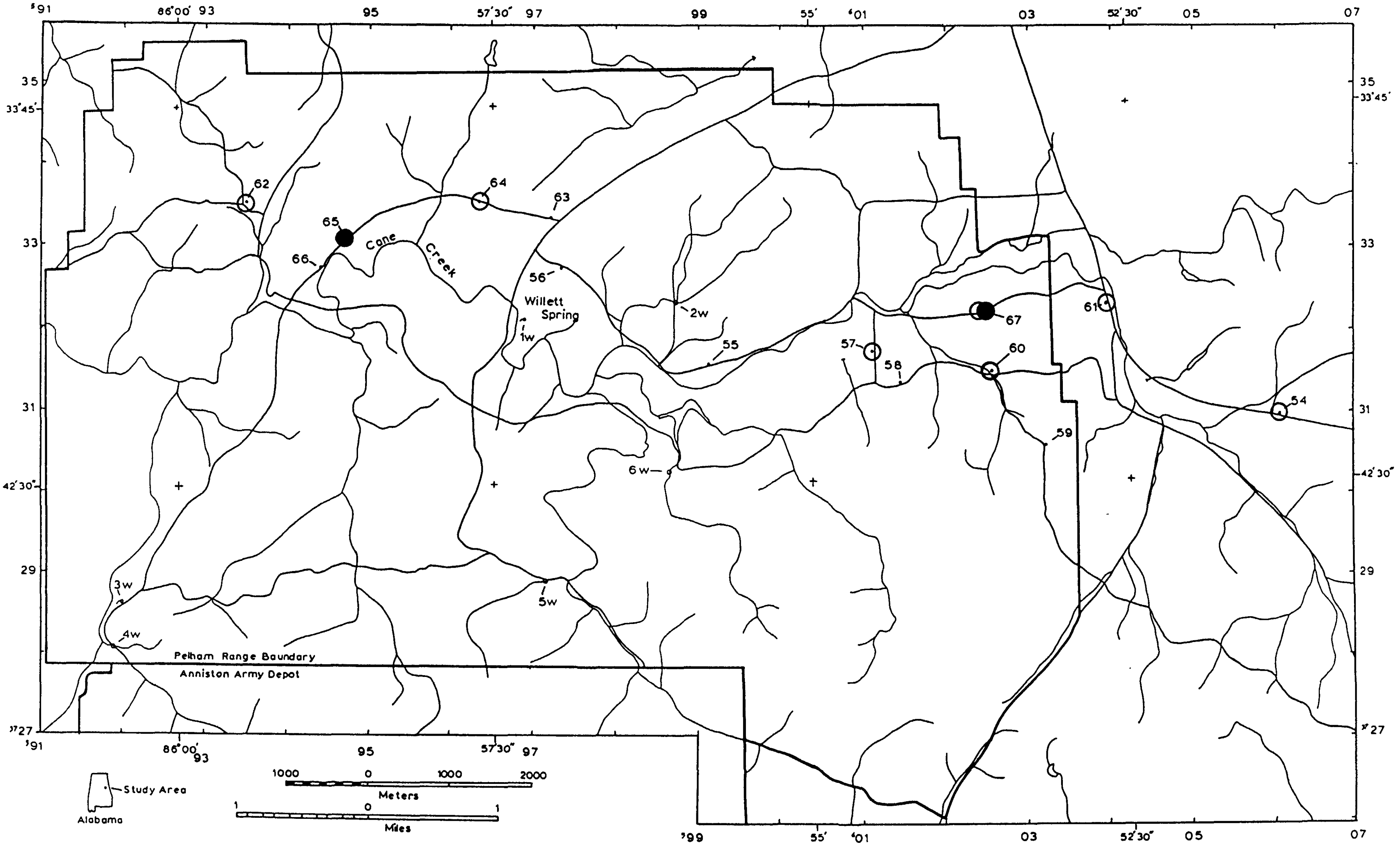

Figure 16. Distribution of elevated Ba concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Ba in ppm

● ≥ 1000
● 700
• 70-500
○ ≤ 50

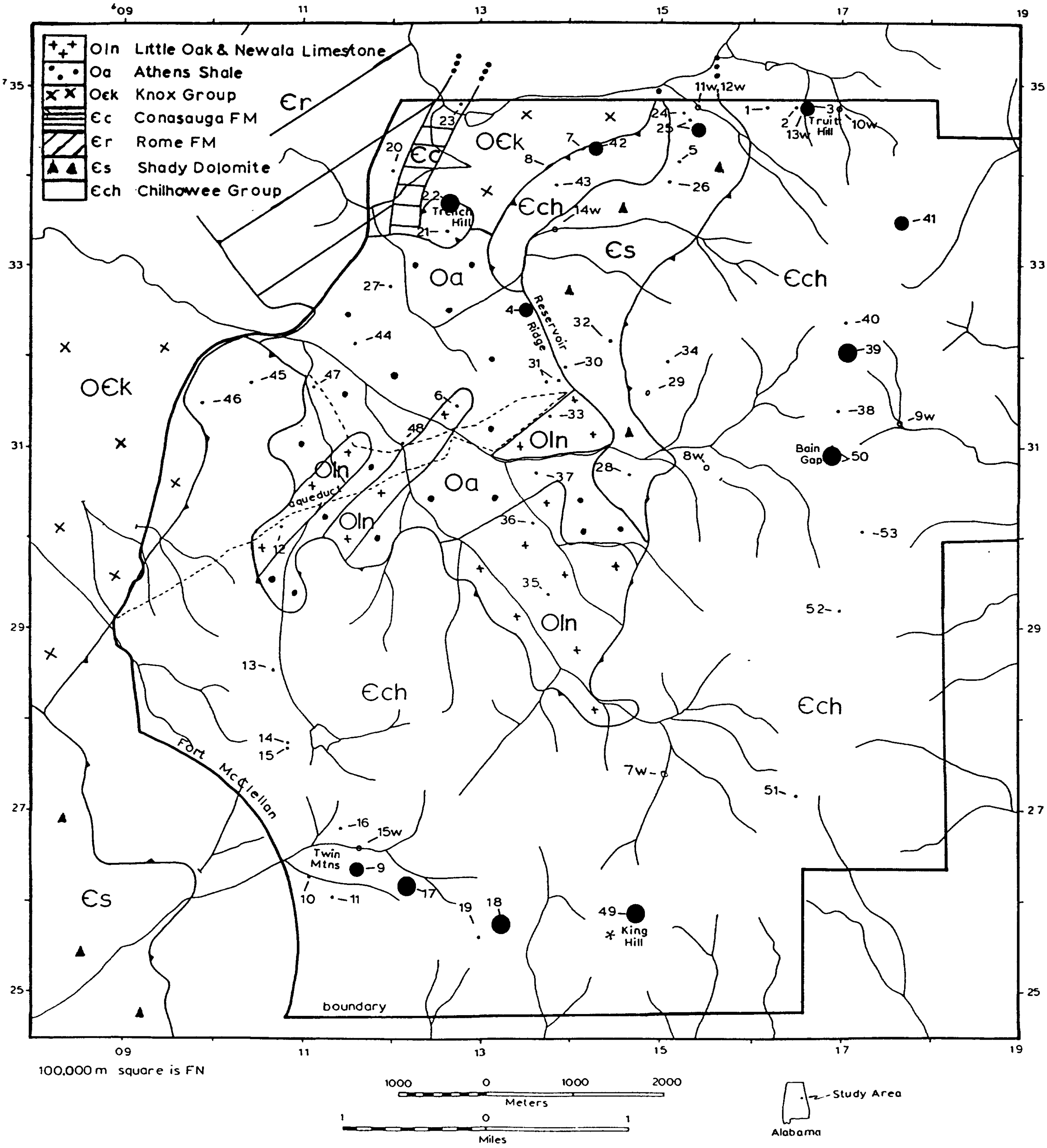

Figure 17. Distribution of elevated Be concentrations in rock samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Be in ppm

● ≥ 5

● 3

• ≤ 2

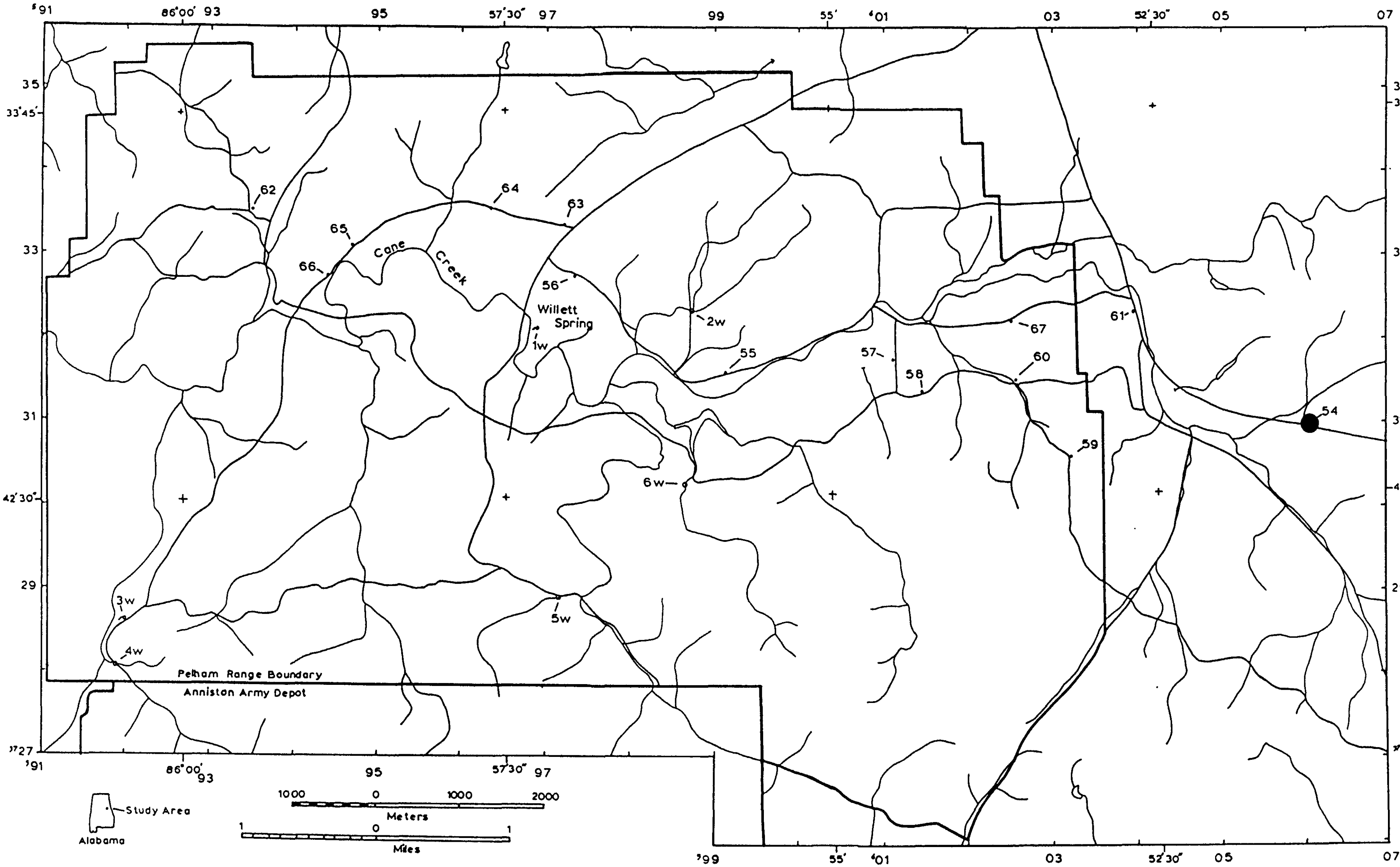

Figure 18. Distribution of elevated Be concentrations in rock samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Be in ppm

● ≥ 5
● 3
· ≤ 2

b. Soils

The weathering of bedrock begins the process of soil formation. There are many complex geochemical and biogeochemical interactions that form soil. During the process of soil formation, some elements are enriched while other elements get depleted compared to their initial concentration in the underlying bedrock.

The elements Ag, As, Bi, Cd, Ge, Sb, Sn, Sr, Th, W, and Zn were not detected in any samples and Mo was found in six samples (sites 37 dup, 56, 63, 64, 65, and 66). Most of the remaining elements show a narrow range of concentration (i.e. one order of magnitude) which makes defining anomalous concentrations difficult. Therefore, elevated or anomalous concentrations were defined as the highest 15-25% of the samples.

Copper concentrations range from 5 to 50 ppm. Figures 19 and 20 show the distribution of Cu on Fort McClellan and Pelham Range respectively. Site 46 is on the west side of Fort McClellan near Baker Gate. The soil is deep red-brown to at least 3 m depth. This soil looks quite similar to the soil on Trench Hill. The soils with elevated Cu concentrations coincide rather well with the previously delineated mineralized areas from the rock data.

Lead concentrations range from "Less Than" the 10 ppm lower limit of detection to 500 ppm. Figures 21 and 22 show the distribution of Pb concentrations on Fort McClellan and Pelham Range respectively. About half of the samples with high Pb concentrations come from very red soils such as above Trench Hill, sites 5, 46, 43, 57, 56, and 63.

Gold concentrations range from "Less Than" the 1 ppb lower limit of detection to 12 ppb. The six samples with concentrations greater than 3 ppb fall within the mineralized zones already identified (figures 23 and 24). Plotting Au at the 2 ppb level further delineates the mineralized zones. The widespread occurrence of Au throughout the study area reflects the pervasive nature of the mineralization.

Manganese concentrations range from 10 to 5000 ppm. The distribution of Mn is bimodal: one mode centered on 70 ppm and the other mode centered on 300 ppm. Plotting values greater than 500 ppm delineates the mineralized areas and areas showing hydrothermal alteration (figures 25 and 26).

High Fe content in the soils produces a deep red color. The weathering of sulfide minerals leaves a characteristically deep red staining on rocks or soils and gossan. In this study area, a 3% concentration of Fe in the soils delineates the mineralized areas as defined with elevated concentrations of Cu, Pb, Mn, or Au.

Barium concentrations range from 100 to 1000 ppm with the exception of one sample with a concentration less than 20 ppm. Samples with the concentrations greater than 700 ppm predominately occur in the Eastern Mountains (sites 49, 51, and 53). Barium concentrations of 500 ppm generally occur in sites peripheral to areas of known or suspected pyritic mineralization.

The concentration distribution of the elements B, Be, Cr, Ga, La, Mg, Nb, V, Y, and Zr are only about one order of magnitude and show a fairly normal distribution. Nickel is the notable exception, showing a weak bimodality with a range of just over one order of magnitude ("Less Than" 5 ppm to 100 ppm). It is interesting that the highest concentrations in these elements occur in sites with mineralization. For example, the highest Y is 100 ppm and occurs in sample 56. Seven of the eight samples with Ni concentrations greater than 50 ppm occur in the sites reflecting mineralization (sites 4, 8, 21, 42, 46, 56, and 57; Table 2).

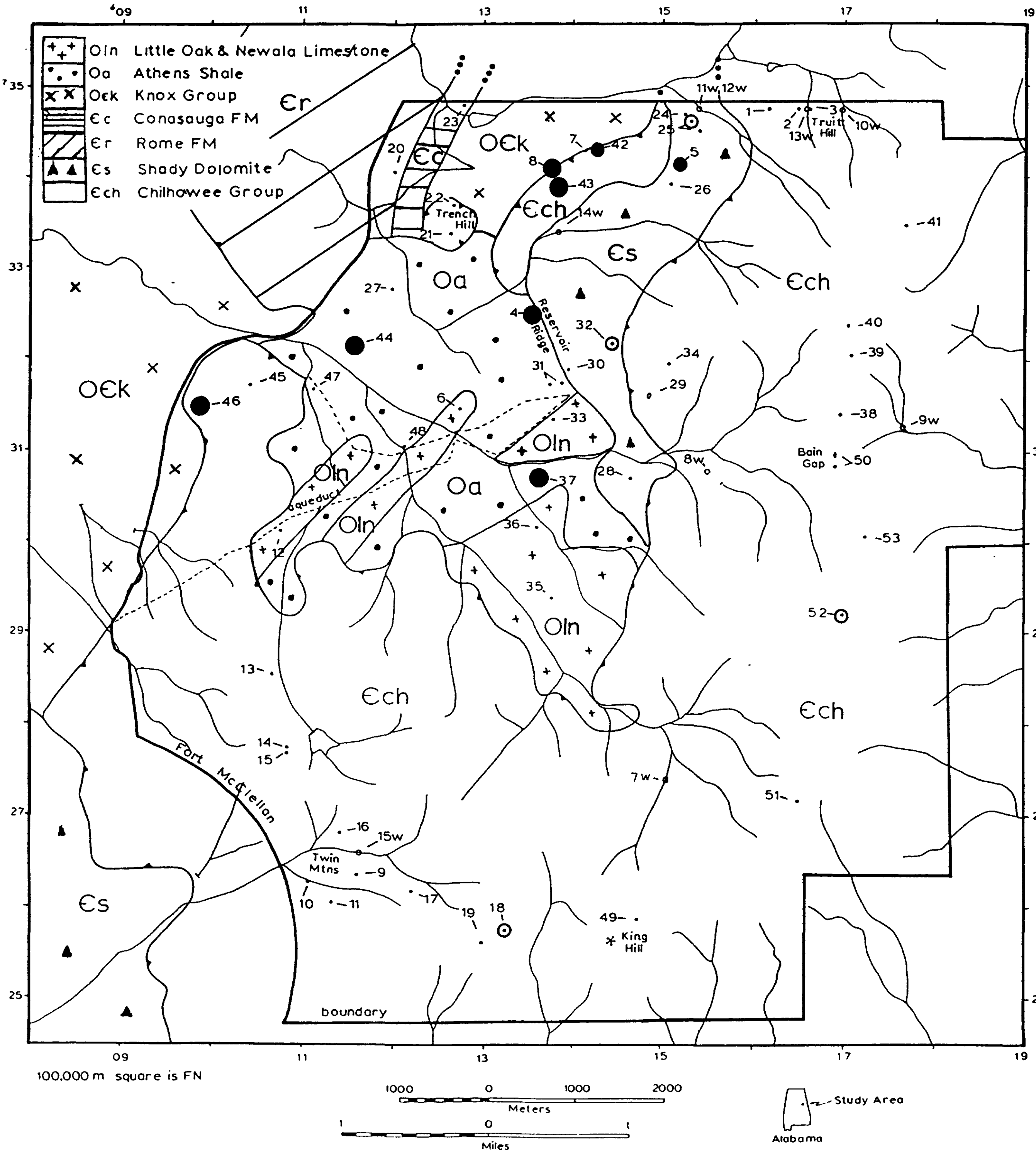

Figure 19. Distribution of elevated Cu concentrations in soil samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Cu in ppm

● ≥ 50

● 30

• 10-20

○ ≤ 7

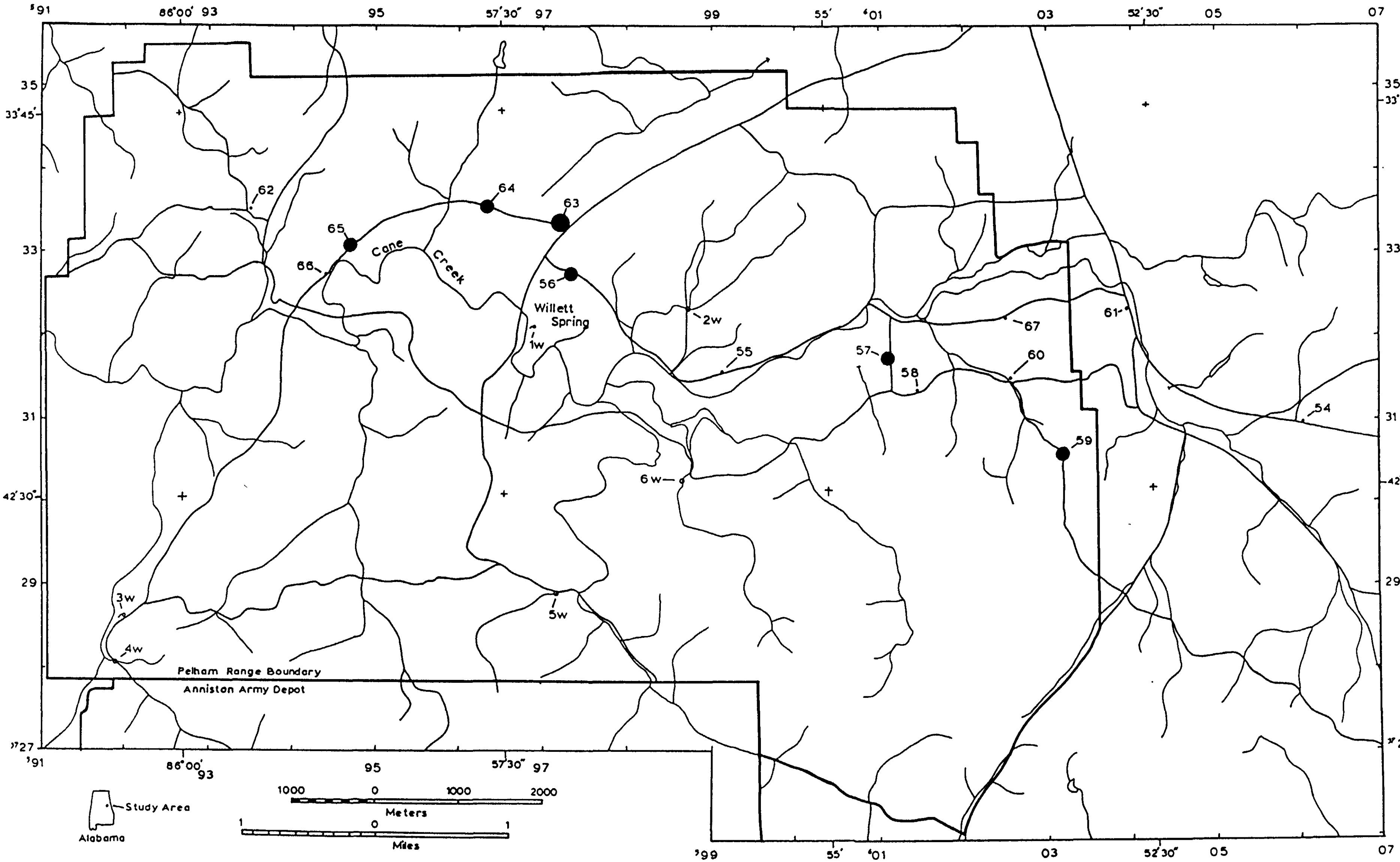

Figure 20. Distribution of elevated Cu concentrations in soil samples from the Pelham Range study area, Fort McClellan, AL.

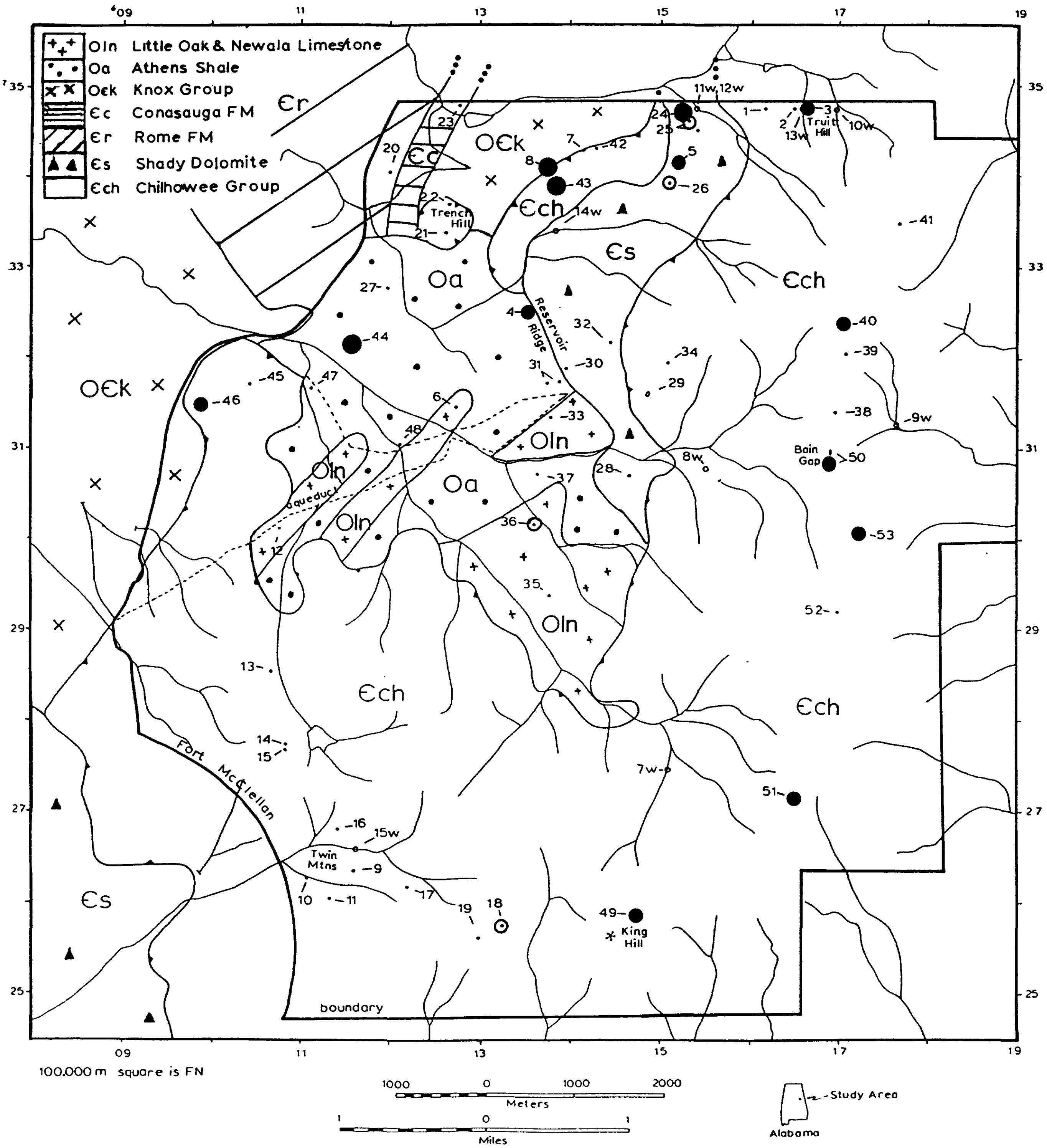

Figure 21. Distribution of elevated Pb concentrations in soil samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Pb in ppm

● ≥ 100
● 50-70
• 20-30
○ ≤ 10

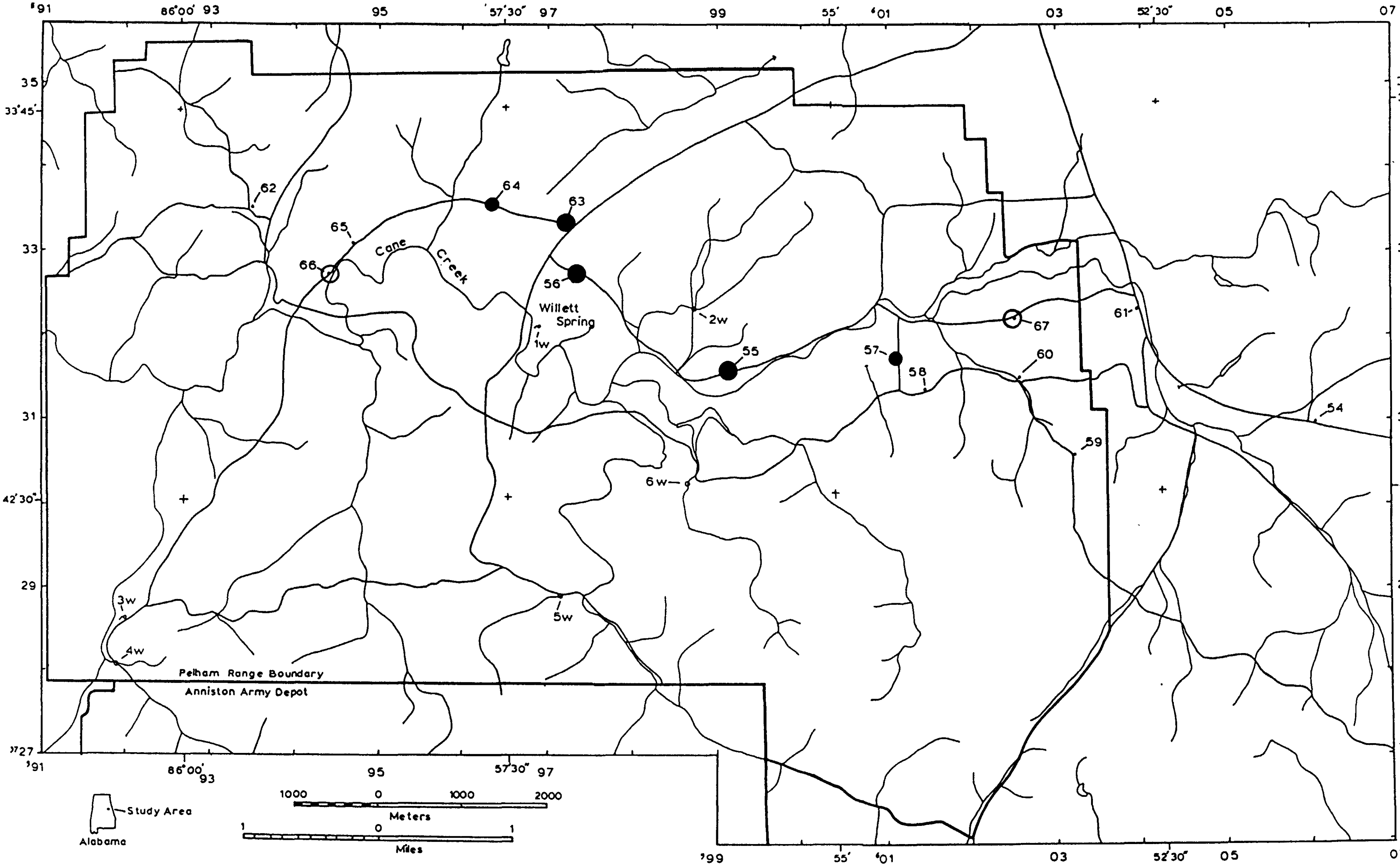

Figure 22. Distribution of elevated Pb concentrations in soil samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Pb in ppm

● ≥ 100
● 50-70
• 20-30
○ ≤ 10

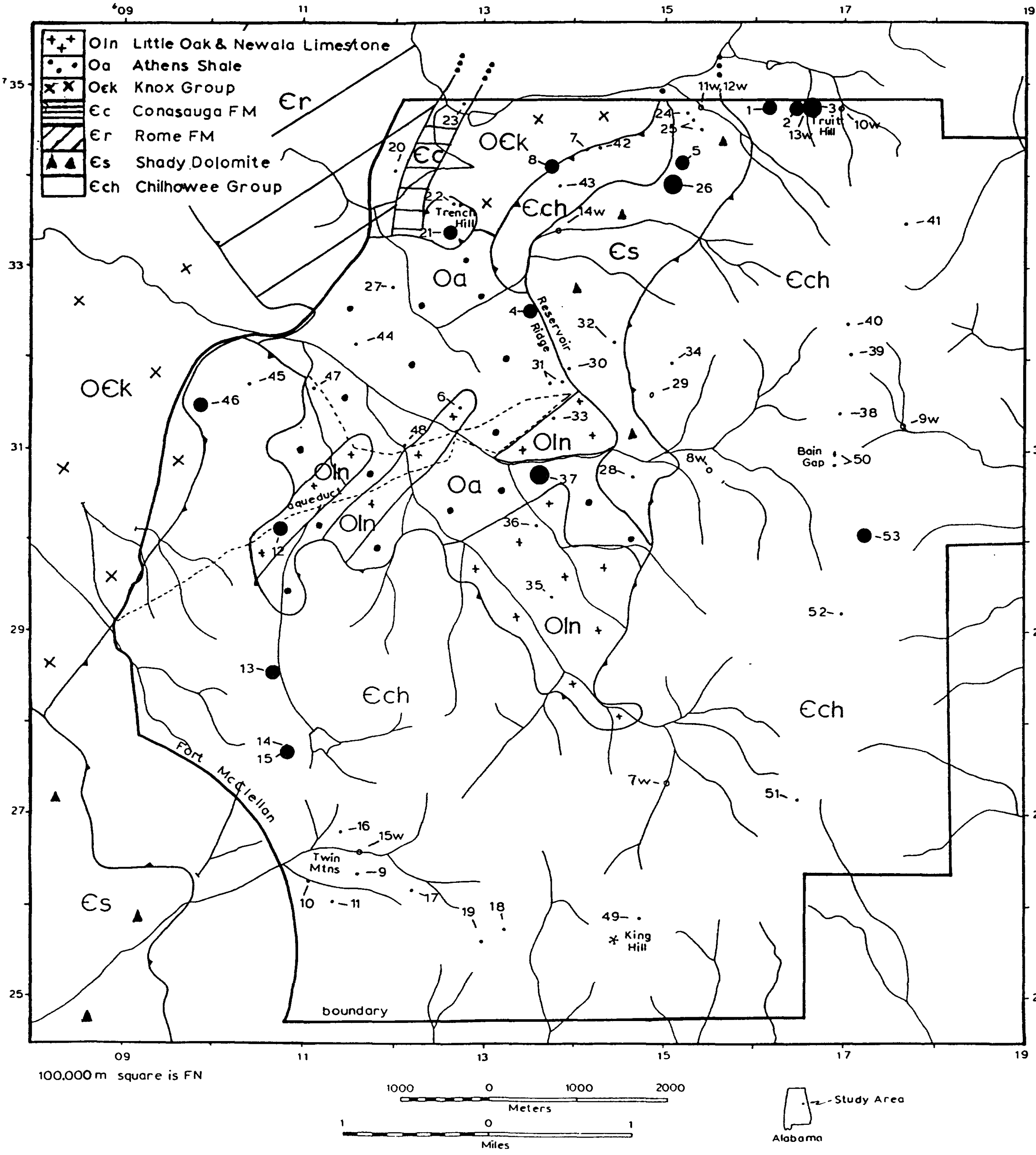

Figure 23. Distribution of elevated Au concentrations in soil samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Au in ppb

● ≥ 5

● 2-4

• ≤ 1

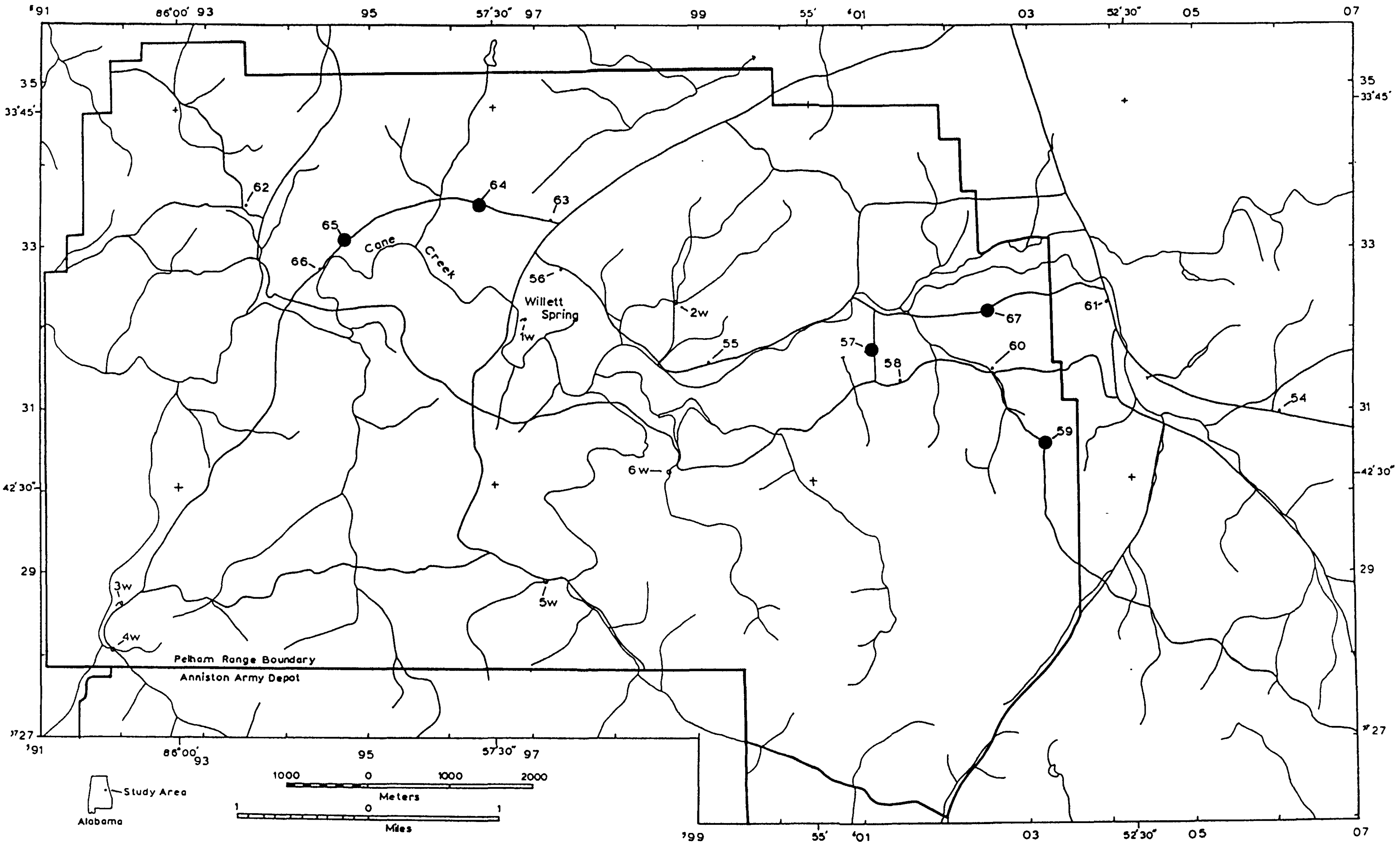

Figure 24. Distribution of elevated Au concentrations in soil samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Au in ppb

● ≥ 5
● 2-4
• ≤ 1

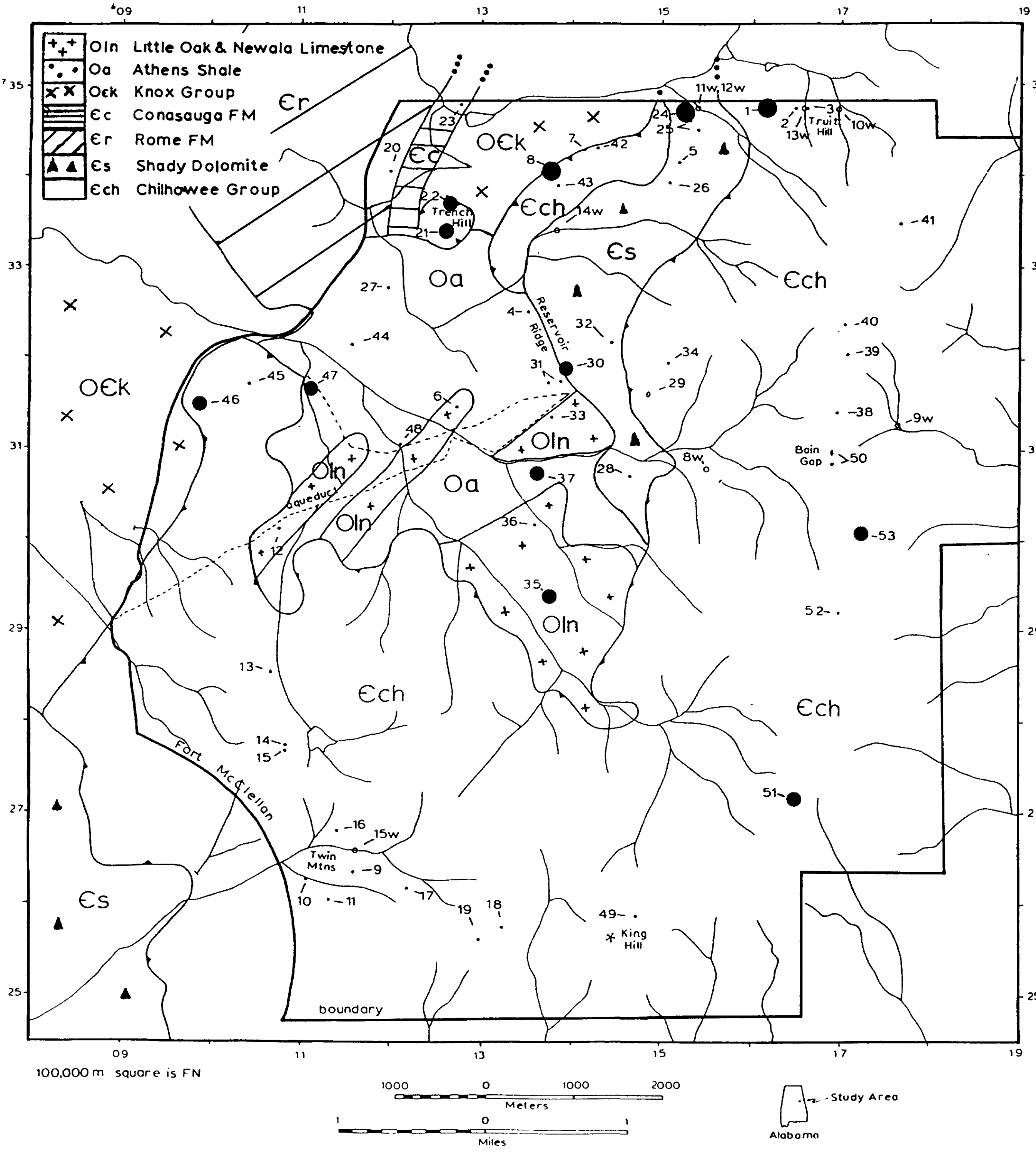

Figure 25. Distribution of elevated Mn concentrations in soil samples from the Fort McClellan study area, Fort McClellan, AL.

Explanation

Mn in ppm

- ● ≥ 1000
- ● 500-700
- • ≤ 300

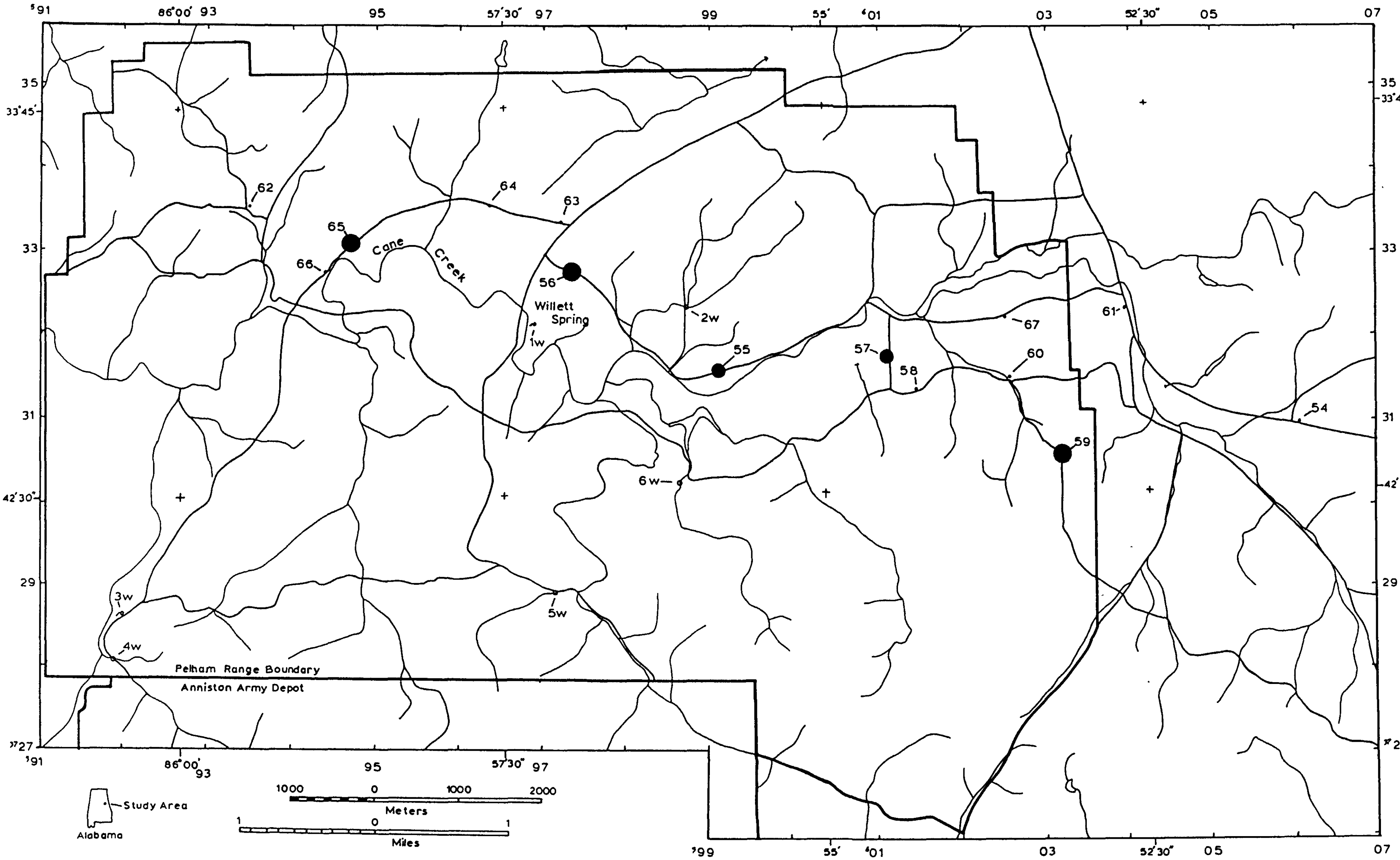

Figure 26. Distribution of elevated Mn concentrations in soil samples from the Pelham Range study area, Fort McClellan, AL.

Explanation

Mn in ppm

- ● ≥ 1000
- ● 500-700
- • ≤ 300

c. Waters

Samples from three springs and eleven small streams were collected in July of 1994. Samples 11 and 12 were collected from the same site. Figures 1 and 2 show the sample localities on Fort McClellan and Pelham Range respectively. It had rained heavily several days prior to the water sampling and the creeks were running high. Some dilution of the normal concentration of dissolved constituents is expected.

The concentrations of Ca, Mg, and alkalinity (HCO3) show good correlation with each other (Table 4). The highest concentrations of these three constituents occur on Pelham Range at Willett Spring, an unnamed spring and a nearby small creek.

The unnamed spring has the lowest water temperature and the highest Ca and Mg concentrations suggesting a high residence time in the underground reservoir system, probably in contact with carbonate rocks at some point along the flow line.

The concentration of dissolved Sr ranges from 4.6 to 22 ppb. The highest Sr values occur in the waters with high Ca and Mg. This reflects a carbonate source rock.

The concentration of Fe varies from less than 10 to 80 ppb. The Fe concentrations are low throughout the study area. However, sites with high Fe generally drain areas noted for high alteration or mineralization in the recharge area (e.g. sites 7, 8 and 13). The high Fe concentration in sites 2 and 5 may reflect the weathering of minerals similar to those near sites 7, 8, and 13; however, no samples were collected from the recharge areas.

The occurrence of elevated concentrations of Cu, Pb, Zn, or Mo in waters is often a good indicator of mineralization within the drainage system and a low pH within the waters. The concentration of dissolved Cu ranges from less than 0.6 to 6.1 ppb; but, only four samples have concentrations greater than 2 ppb. Sample 8 has the highest Cu concentration at 6.1 ppb. All but two samples with detectable Cu occur on Pelham Range.

The concentration of dissolved Pb ranges from less than 0.5 to 16 ppb. Only samples 5, 8, and 14 have detectable Pb. Zinc concentrations are generally low, ranging from less than 3 to 9 ppb. The highest concentrations occur in samples from Pelham Range.

Molybdenum is found in samples 1,3, and 4 at concentrations of 0.5, 0.3 and 0.5 ppb respectively. These concentrations are just above the detection limit of the analytical method.

Manganese concentrations range from less than 0.4 to 75 ppb. The highest concentrations occur in samples 4 and 13. Sample 13 comes from a small basin west of Truitt Hill (site 3) that contains elevated concentrations of base and precious metals. Sample 4 has a similar hydrogeochemical signature as sample 13 and may reflect weathering of mineralized areas.

The concentration of dissolved K varies from 0.3 to 1.9 ppm. The highest concentrations come from sites draining the mountains surrounding Fort McClellan. These rocks show definite signs of alteration and minor mineralization.

The concentration range of dissolved Rb varies from 0.4 to 2.3 ppb. There is a good correlation between elevated K and Rb. Potassium and Rb often concentrate in late-stage hydrothermal fluids due to their ionic size and charge. The high concentrations of K and Rb may reflect the weathering of fluid inclusions or minerals genetically related to the alteration of the Chilhowee Group sandstones. The Chilhowee Group sandstones contain a low abundance of potassium-containing minerals such as orthoclase, further supporting the idea that an alteration mineral assemblage contributes solutes to these ground waters.

The elements Y and Ce and other rare earth elements generally concentrate in late stage hydrothermal fluids due in part to low crustal abundance and large size.

Upon precipitation from solution, these elements form minerals with complex chemical compositions. The presence of these elements may reflect the weathering of these late-stage hydrothermal minerals. The concentrations of these elements in the waters is generally low, but their occurrence is a possible subtle indicator of alteration and mineralization in the drainage recharge area.

The anions Cl, F, SO4, or NO3 can also reflect the geochemical environment through which the waters flow. For example, high NO3 often reflects anthropogenic sources such as fertilizers or animal waste runoff; Cl with Na or Ca can show the effects of salting roads; SO4 can show the weathering of sulfide minerals.

The analyses show that no samples had detectable F. Only sample 1 had detectable NO3 at 1.1 ppm. The concentrations of Cl and SO4 are generally low and have a small range. Chloride concentrations range from 0.76 to 1.6 ppm. Sulfate concentrations range from 0.99 to 3.4 ppm. The highest Cl value occurs in sample 1, collected at Willet Spring.

Sample 10 has the highest SO4 value at 3.4 ppm. This drainage area east of Truitt Hill contains rocks that are highly altered and mineralized. The next highest SO4 values occur in samples 5 and 7 with 3.1 ppm and samples 6 and 9 at 2.9 and 2.8 ppm respectively. These springs or brooks drain areas with high metal concentrations in the rocks and soils. Most of the mineralized areas now contain iron oxide minerals at the surface. At depth, sulfide minerals occur or would be expected. The sulfides observed are encased in an iron oxide rind which slows further oxidation. These observations help explain the relatively low SO4 concentrations found in the waters. It should be noted that the SO4 concentrations approach the assumed concentrations for HCO3 (7 ppm), which suggests that naturally occurring carbonic acid in rainwater is not the only agent of weathering or complexing metals from the rocks in the study area

d. Monitoring Wells

Table 5 gives the data from five monitoring wells located near an old sanitary landfill that is referred to as Landfill 4 (figure 27). The data comes from the on going monitoring program of the sanitary landfill in conjunction with the Alabama Deptartment of Environmental Management program. Wells 1-4 are monitoring wells around Landfill 4 and well 5 is located up gradient, to serve as a control and to provide background values. The concentrations of Ca, Mg, K, and alkalinity (HCO3) are not available. These four constituents, along with the determined constituents Na, Cl, and SO4, figure significantly in determining the hydrogeochemical nature of nearly all natural waters. Without this full suite of major cations and anions a charge balance cannot be completed or computer based speciation programs cannot be utilized. A charge balance is an excellent method of checking the accuracy of the analysis. Computer based speciation programs calculate metal - anion speciation based on thermodynamic data, which gives some idea on how the metals are migrating. Stabilities of certain minerals are also evaluated.

Dissolved Pb in the waters is a major environmental concern. The Pb values from wells 1, 3, and 5 are within the 15 ppb standard. Wells 2 and 4 have Pb values above the published standard (see Table 5). Notable fluctuations in Pb concentrations occur in samples from wells 2 and 4. The most probable complexing anions for Pb are Cl followed by CO3. (Lead forms insoluble salts with Cl, CO3, and SO4 but will form soluble charged complexes with several anions). There is no correlation between the concentrations of Pb and Cl in either of the wells and alkalinity concentrations are not determined.

Barium shows high concentration fluctuations in samples from wells 3 and 4. There is no correlation between Ba and either Cl or SO4 concentrations. Sodium shows wide

Table 5. Summary of inorganic constituents from five monitoring well around Sanitary Landfill 4, Fort McClellan, AL.

MONITOR WELL 1-94, FORT MCCLELLAN LANDFILL 4

PARAM	Mar-94	Apr-94	May-94	Jun-94	Sep-94	Mar-95	MCL
pH	6.1	5.6	5.6	5.8	5.6	5.2	**
SP COND	200	100	100	100	100	100	**
Pb ug/l	26	11.0	bdl	5.0	8.0	11	15
Fe mg/l	21	20	17	17	18	15	0.3
Na mg/l	17	21	20	28	14	14	**
Mn mg/l	5.2	2.7	3.4	3.6	4.1	3.5	50
Ba ug/l	160	150	120	100	100	150	2000
Cl mg/l	19	12	22	20	20	21	250
SO4 mg/l	5.2	4.8	3.0	2.4	1.1	2.5	500
NO3 mg/l	bdl	0.04	bdl	bdl	bdl	bdl	10

MONITOR WELL 2-94, FORT MCCLELLAN LANDFILL 4

PARAM	Mar-94	Apr-94	May-94	Jun-94	Sep-94	Mar-95	MCL
pH	6.9	6.1	6.0	6.8	6.3	5.9	**
SP COND	400	200	200	200	300	300	**
Pb ug/l	23	67	170	67	210	85	15
Fe mg/l	80	62	64.0	69	70	55	0.3
Na mg/l	15	20	75	11	4.3	7.8	**
Mn mg/l	0.88	0.80	0.80	0.90	0.91	0.92	50
Ba ug/l	430	400	730	540	740	440	2000
Cl mg/l	7.9	6.4	8.0	7.1	7.1	6.6	250
SO4 mg/l	8.4	16	9.9	11	11	15	500
NO3 mg/l	bdl	bdl	bdl	bdl	bdl	bdl	10

MONITOR WELL 3-94, FORT MCCLELLAN LANDFILL 4

PARAM	Mar-94	Apr-94	May-94	Jun-94	Sep-94	Mar-95	MCL
pH	5.7	5.2	5.4	5.2	5.4	7.0	**
SP COND	200	100	100	100	100	100	**
Pb ug/l	bdl	bdl	bdl	bdl	bdl	bdl	15
Fe mg/l	2.7	8.9	9.1	10	2.7	3.4	0.3
Na mg/l	20	16	29	32	15	14	**
Mn mg/l	0.34	0.46	0.63	0.66	0.53	0.23	50
Ba ug/l	80	520	190	1700	90	110	2000
Cl mg/l	10	11	12	12	13	15	250
SO4 mg/l	25	39	49	46	27	14	500
NO3 mg/l	0.08	bdl	0.09	0.08	bdl	0.06	10

MONITOR WELL 4-94, FORT MCCLELLAN LANDFILL 4

PARAM	Mar-94	Apr-94	May-94	Jun-94	Sep-94	Mar-95	MCL
pH	6.9	6.4	6.3	6.3	6.2	8.0	**
SP COND	1500	900	800	1100	1500	900	**
Pb ug/l	19	7.0	91	bdl	61	70	15
Fe mg/l	1.7	2.1	5.0	10	3.5	29	0.3
Na mg/l	46	47	67	32	89	62	**
Mn mg/l	2.1	1.8	2.0	0.66	1.9	0.67	50
Ba ug/l	420	830	1300	150	720	520	2000
Cl mg/l	480	200	240	310	350	170	250
SO4 mg/l	13	11	11	15	16	19	500
NO3 mg/l	0.15	0.18	0.19	bdl	bdl	bdl	10

MONITOR WELL 5-94, FORT MCCLELLAN LANDFILL 4

PARAM	Mar-94	Apr-94	May-94	Jun-94	Sep-94	Mar-95	MCL
pH	5.9	6.1	6.7	6.0	5.2	6.4	**
SP COND	bdl	bdl	bdl	bdl	bdl	bdl	**
Pb ug/l	bdl	bdl	bdl	bdl	bdl	bdl	15
Fe mg/l	0.83	0.14	0.09	bdl	0.09	1.4	0.3
Na mg/l	3.3	86	1.6	15	1.7	11	**
Mn mg/l	0.18	0.13	0.1	0.11	0.060	0.10	50
Ba ug/l	60	60	90	bdl	bdl	70	2000
Cl mg/l	2.7	1.6	1.2	1.6	3.6	9.8	250
SO4 mg/l	4.5	1.7	0.72	0.50	0.070	bdl	500
NO3 mg/l	bdl	bdl	bdl	bdl	bdl	bdl	0.09

All values rounded to two significant figures only.

MCL is Maximum Contaminant Level ** Indicates no standard published

bdl indicates constituent fell below detection limit

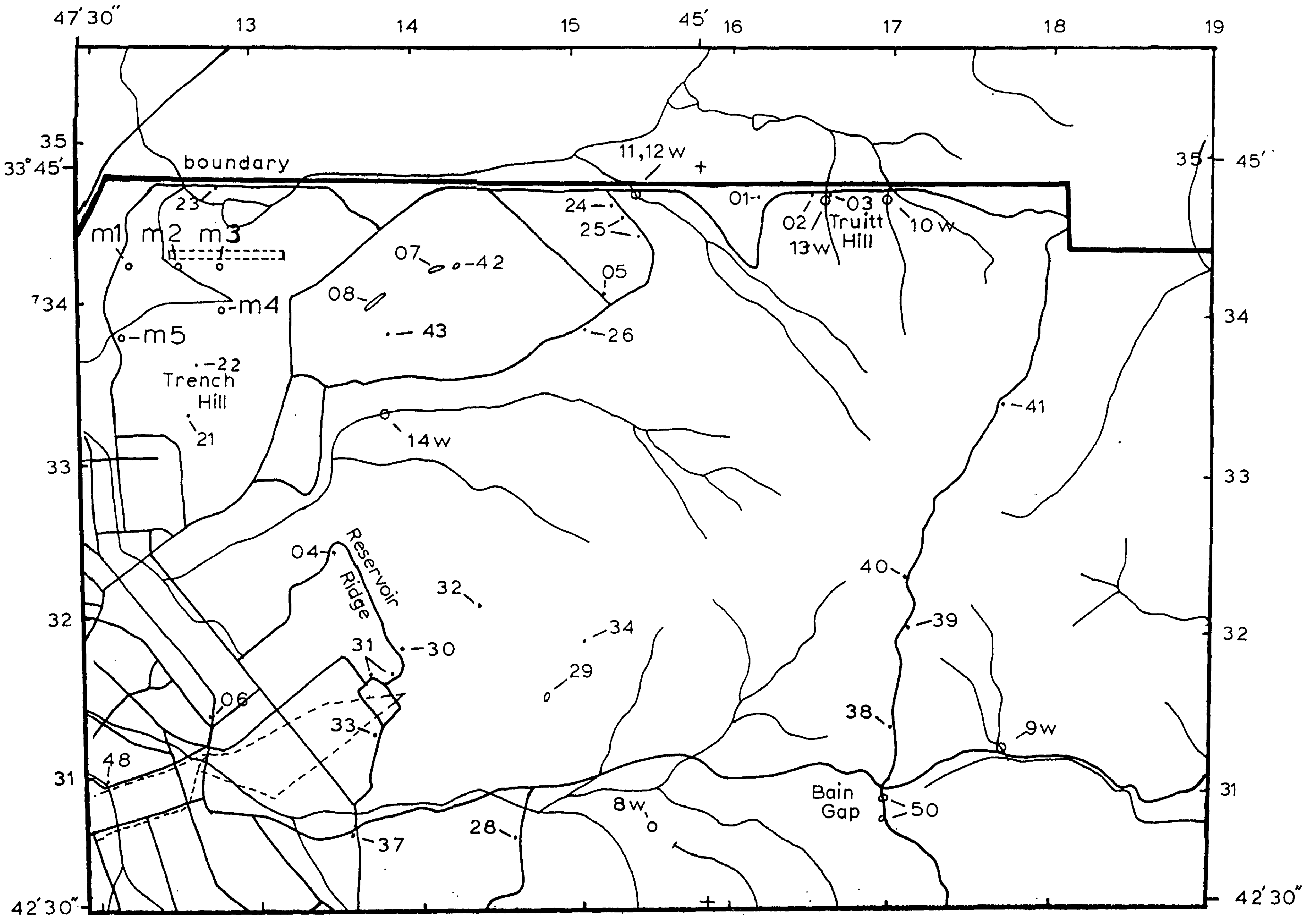

Figure 27. Site locations for five monitoring wells around Sanitary Landfill 4, Fort McClellan, AL.

concentration fluctuations in samples from wells 2 and 5. There is no similar change in either Cl or SO4. The concentrations of Mg and Ca must also be changing to keep the solution electrically neutral.

The constituent ions dissolved in a water depends on the soil and rocks through which the water percolates and to some degree on the microflora within the system (Baross and Deming, 1983, Kushner, 1978; Kuznetsov, 1963; Miller and others, 1982; Simpson and others, 1993; Tucker and others, 1984). The sanitary landfill cap material was taken from the highly mineralized soil and rocks of Trench Hill. Dissolution of Pb and Ba- containing minerals from the soil cap or buried materials sould account for the high Pb and Ba concentrations in the water from wells 2 and 4. The months with low values seem to reflect a possible precipitation of Pb minerals in the immediate vicinity, thus lowering the dissolved Pb concentrations (or dilution of Pb ion by an influx of dilute surface waters). It is curious that other wells do not show the same geochemistry.

Fluctuations in major constituent ions (e.g. Ca, Mg, Na, Cl, SO4, HCO3) generally reflect changes in basal flow. An influx of diluted waters, such as rain or snow melt, will immediately dilute the major and trace elements in streams and generally affects springs some time later. A reduction in the basal flow will generally show a rise of major and minor constituents. If the individual wells down slope from wells 2 and 4 were in an open system, a flux or surge showing metals enrichment should occur in wells 1 and 3 that would coincide or follow shortly after the highs observed in wells 2 and 4. The seemingly isolated major and trace metal fluctuations in the wells may reflect dilution and concentration of the metals within a restricted reservoir zone around each well.

A good example of this possible concentrating mechanism occurs in wells 2 and 4 over the Apr-May-Jun sampling period. Sodium, Pb, and Ba show marked concentration increases in May compared to Apr values. In June, these concentrations nearly drop back to the Apr concentrations. However, it is curious that the anions do not show a similar change in concentrations to keep the charge balance equal. Many of the hydrogeochemical characteristics of the wells are not fully understood.

Discussion

a. Historical mining and mineral use.

Jemison (1959) discusses some of the mineral deposits and resources found in and around Talladega County. Of particular interest is the occurrence of several gold deposits located to the south and east of the study area. The Abacoochee Mine was probably the largest, producing up to 20 tons of ore per day in 1888. Along with gold, copper salts and sulfide ores and galena were mined from a few sites in Talladega County during the Civil War.

The Talladega area was a significant producer of iron and steel for many years, particularly during the Civil War. The Talladega Iron and Steel Co. based its production capabilities on approximately 2000 acres of ironstone deposits, ranging in size from 20 to 640 acres (Jemison, 1959). These ironstone ores are undoubtedly the weathered remains of large, predominantly pyrite deposits.

Within the study area there were several ironworks. One of the longest producing works was located on Cane Creek (vic 94 32) on what is now Pelham Range. These works began producing iron in 1840 and stopped during the Civil War (Joseph and others, 1992). The ironstone source was local, with some deposits within 600 yds of the mill.
The works reported producing 6000 lbs of iron a day (Joseph and others, 1992).

In 1872, the ironmasters Alfred Tyler and Samuel Noble formed the Woodstock Iron Company to make iron for rebuilding the South. They built a "model industrial city" called Anniston (Joseph and others, 1992) because there was abundant iron ore and timber resources close at hand. The works produced iron until 1893. The brecciated, iron rich zones on Twin Mountains may have been mined at this time.

b. Comparing the rock and soil data

The rock and soil data complement each other very well in defining the geochemical signature of the mineralized areas identified during this study. Elevated concentrations of Fe, Pb, Cu, and Au are the major elements that define the geochemical signature of the mineralization. Elevated concentrations of Ag, Mo, Be, and Zn occur at many sites, which further defines the mineralization suite. The mineralization cross cuts all rock types.

Table 6 compares the rock and soil data from samples at 27 sites for six elements. These sites were chosen because the soils were collected either directly above or very near the rock sample.

Gold concentrations in the rock subset range from less than 1 to 50 ppb. Soils show a Au concentration range from less than 1 to 5 ppb. However, at 10 sites, Au shows a slight concentration in the soil compared to the value detected in the rock. Due to the availability of outcrop and a larger concentration range, rocks are a better sampling media in this area for defining the extent of Au anomalies accurately.

Lead concentrations in the rock subset range from not detected to 100 ppm. Soils show a lead concentration range from 10 to 500 ppm. Nine rock samples show a higher Pb concentration than in the soils. There is a general tendency for the soils to have a similar concentration as the rocks or to concentrate Pb. Site 43 is a good example of the soils showing a higher concentration than the rocks; however, the rock is mapped as an overthrust. The borrow pits on the north side of the hill at sites 7 and 8 show intense alteration and mineralization. The high lead concentrations in the soil reflects the mineralization and not the overthrust rock sheet. The soil Pb is undoubtedly collecting in resistate minerals such as carbonates or sulfates. Soils are a slightly better media for depicting lead anomalies, particularly in light of the environmental problems associated with elevated Pb concentrations.

Barium concentrations in the rock subset range from 30 to 1000 ppm. Soils show a concentration range from 15 to 1000 ppm. Eighteen sites show soil Ba concentrations that are equal to or slightly higher than the rocks. There is a slight tendency for the soils to concentrate Ba minerals, probably barite, from the weathering rocks. In this study area either sample media would be useful in defining Ba anomalies.

Copper concentrations in this rock subset range from not detected to 70 ppm. Soils show a Cu concentration range from 5 to 50 ppm. Over half of the rock samples show higher Cu concentrations than the corresponding soils. There are nine soils that have higher Cu concentrations than the rocks. What is noticeable is the Cu concentrations tend to level out at between 10 -30 ppm, regardless of the starting Cu concentration in the rock. This indicates that the soils have a capacity to hold a certain amount of Cu regardless of the initial concentration in the rocks. This geochemical characteristic was also observed in the Virgin Islands over mineralized and nonmineralized rocks (Tucker, 1987). Both areas are highly vegetated and have similar annual rainfall. Due to the widespread availability of outcrop and a larger concentration range, rocks would be the preferred sampling media in this area for accurately defining Cu anomalies.

Table 6. Comparison of rock and soil concentrations for 6 elements from 27 sites in the Fort McClellan-Pelham Range study area, Fort McClellan, AL

sample	Rx Au ppb	S Au ppb	Rx Pb ppm	S Pb ppm	Rx Ba ppm	S Ba ppm	Rx Cu ppm	S Cu ppm	Rx Fe %	S Fe %	Rx Mn ppm	S Mn ppm
FM 03R1	50	5	100	15	30	15	50	15	G20	3	100	10
FM 12R1	1	2	50	20	150	300	30	15	7	0.7	100	300
FM 13R1	0.5	2	30	30	70	150	10	10	3	1	50	70
FM 15R1	0.5	2	N10	30	100	200	N5	15	0.7	1.5	10	70
FM 18R1	1	L1	30	10	150	300	10	5	10	1.5	70	100
FM 22R2	1	1	100	20	700	300	70	20	7	3	5000	700
FM 23R1	1	1	70	30	150	150	70	20	7	2	100	300
FM 24R1	0.5	1	70	150	300	300	50	20	3	3	700	1000
FM 26R1	0.5	5	N10	10	100	300	L5	10	0.3	2	20	70
FM 28R2	1	L1	30	15	200	500	30	10	5	1.5	70	70
FM 30R1	0.5	L1	N10	15	700	300	20	15	1	1.5	500	300
FM 31R1	1	1	30	20	1000	500	70	30	7	3	50	70
FM 32R1	1	L1	30	15	700	300	50	7	3	1.5	70	300
FM 34R1	0.5	L1	N10	30	70	300	N5	15	0.2	1.5	10	100
FM 35R1	0.5	1	N10	20	70	300	L5	20	0.7	2	300	700
FM 40R1	0.5	1	N10	50	100	300	N5	20	0.7	2	100	70
FM 41R1	1	1	20	30	300	150	30	20	7	2	300	70
FM 42R1	0.5	1	30	30	150	500	20	30	7	3	100	300
FM 43R1	0.5	L1	N10	500	70	300	N5	50	0.5	0.7	500	300
FM 44R1	2	1	30	100	700	500	50	50	5	5	300	100
FM 49R1	1	1	20	50	1000	700	10	10	1	2	10	200
FM 50R2	2	1	50	50	200	200	30	20	20	2	50	70
FM 51R1	1	L1	50	70	700	1000	30	20	5	2	100	300
FM 52R1	1	L1	N10	20	70	500	5	5	1	1.5	30	150
FM 53R1	0.5	2	30	50	500	1000	5	15	15	3	100	700
FM 55R1	0.5	L1	N10	150	100	300	7	20	1	1.5	70	700
FM 57R1	0.5	2	70	50	100	150	70	30	G20	3	1500	500

Iron concentrations in the rock subset range from 0.2 to greater than 20%. Soils show iron concentrations ranging from 0.7 to 5%. The concentration of iron in the soils appears to stabilize at about 1.5 to 3% regardless of the starting concentration in the rocks. This geochemical characteristic is similar to Cu. Due to the widespread availability of outcrop and a larger concentration range, rocks would be the preferred sampling media in this area for defining areas of metal enrichment with Fe veins or anomalies.

Manganese concentrations in the rock subset range form 10 to 5000 ppm. Soils show a range from 10 to 1000 ppm. Nineteen sites show soil Mn concentrations that are equal to or slightly higher than in the rocks. The soils have a tendency to concentrate Mn, probably with the iron oxides. This follows the geochemical association of Mn and Fe in hydrothermal fluids and mineralization processes. The distribution of Mn between the rocks and the soils does not show any distinct trends. For example, site 22 shows an almost order of magnitude decrease from the rock to the soil; however, site 49 shows the opposite trend. Within this subset the rocks show a slight advantage as a sampling media, due to an increased concentration range.

c. Water constituents and weathering

The high water level in the study area during the sampling undoubtedly diluted the constituent concentrations but an overall hydrogeochemical pattern still emerges. The dissolved constituents reflect three rather general suites. One suite of constituents suggests the weathering of carbonate rocks, with elevated concentrations of Ca, Mg, Sr, and alkalinity. Samples 1,3, and 4 represent this group of waters.

The second suite of constituents reflects the weathering of the sandstones of the Chilhowee Group. Samples 9, 10, 11, 12, and 15 are examples of a normal weathering of sandstones with the exception of elevated K and Rb in a few samples (Table 4). These two ions may reflect the weathering of feldspars, or a variety of minerals or fluid inclusions related to deposition from circulating hydrothermal solutions in the host rock.

The third suite of constituents reflects the weathering of base metal mineralization and/or a rather intense hydrothermal alteration in the recharge area. This group includes samples 2, 4, 5, 6, 7, 8, 13, and 14. Sample 8 has the highest concentrations of Fe, SiO2, Cu, Pb, Rb, and Sb and has high K as well.

Sample 8 comes from a drainage basin that includes Bain Gap and sites along the ridge line road that contain elevated concentrations of Cu, Pb, Au, Fe, Mn, and Ba. This site is on a small arms rifle range. The weathering of ball ammunition would be an obvious explanation for the lead and copper ions in the water. However, the rock and soil geochemical data clearly indicates a natural source for these metals. The plants growing in the spring outflows appear to have adapted to life in this rather metal rich environment The Pb concentrations in this spring are above the generally accepted limit for "clean water" but it may be that the plants in this area are here due to the heavy metals and "clean water" is hazardous to their survival. Many plants are indeed adapted to or can withstand high metal concentrations in their environment (Brooks, 1972; Dunn, 1993).

It should be noted here that ball ammunition does not appear to contribute significantly to the overall soil metal load or to the hydrological cycle. The bullets appear to react rather quickly to the surficial weathering environment by forming an oxidation coating. The coatings, once formed, are very stable in the surficial weathering environment and effectively seal the underlying metals from further chemical attack. Bullets collected from a small arms range abandoned at least 20 years ago near site 8 illustrate this point.

The bullets have a greenish coating, probably a copper carbonate or other complex mineral. The bullet's form and vertical ribbing are still sharply defined. There is a white crusty mineral over the lead center of the bullet. Upon scraping the coatings, shiny metals emerge. Brass casing form a dull dark brown to blackish coating. Casings manufactured in the 1940s (and possibly expended in that time era) have survived quite well in the woods for as much as fifty years.

Sample 14 shows a similar hydrogeochemical signature to sample 8. Rock samples from along the ridge contain elevated concentrations of Cu, Ba, and Mn. Although none of these samples are within the direct recharge area of sample 14, the geochemical evidence strongly suggests that mineralization could occur within the recharge basin. The water sample constituents certainly support this hypothesis.

Sample 4 contains high concentrations of Fe, Cu, Zn, Mo, and Mn. This sample also shows a hydrogeochemical signature of weathering carbonates. There are no rock or soil samples from the recharge basin but the constituent suite of ions in the sample strongly suggest base metal mineralization occurs within the recharge basin.

The presence of elevated Mn, Y, Ce, and possibly Ni concentrations may reflect the weathering of hydrothermally emplaced minerals associated with the base and precious metal mineralization process. For example, sample 13 drains the highly mineralized area west of Truitt Hill (French Hill) where site 3 is located. The mineralization here shows a definite hydrothermal component with thick layers of banded iron oxides that are metal rich. The water contains elevated concentrations of Fe, Mn, Ni, Y, and Ce. Sample 2 show a similar hydrogeochemical signature with Cu, Zn, Mn, Y, and Ce. It is interesting to note that these samples do not generally contain elevated concentrations of K or Rb which would be expected with hydrothermal fluids. The geochemistry of the solutions is not well understood given the limited scope of this study.

The hydrogeochemistry of the water samples readily supports the rock and soil geochemical data, indicating the presence of mineralization and alteration within the host rocks and on a rather wide scale. An expanded sampling program during a drier time of the year that would catch the basal flow could further define the extent of the mineralization and the impact the metals have on the environment.

d. Origins of the mineralization

The mineralized areas show two distinct forms or characteristics in outcrop. One mineralization sequence shows a close relationship to sulfide minerals and the subsequent weathering in the surficial environment. The other mineralization sequence shows pervasive hydrothermal fluid alteration and mineralization characteristics in the host rocks. The two mineralization sequences possess similar geochemical signatures in the rocks and are undoubtedly related both in time and metals source(s).

The Trench Hill vicinity is an example of the sulfide mineralization sequence. A large suite of elements which includes elevated concentrations of Fe, Au, Pb, Cu, Mo, Zn, Ag, and Be occur in samples from this area. This area has deep red soil and contains pebble to fist-sized gossan nodules. Gossan is associated with the weathering of pyrite and other iron-containing sulfide ores (Ryall and Taylor, 1981; 3. __, 1971). Other areas with similar characteristics are presumed to have their origins from sulfide-rich bodies as well. Areas that show a similar geochemical suite and the surficial physical characteristics of Trench Hill include sites 2, 5, and 46 on Fort McClellan and the area near sites 56 and 63, 57, 59, and 67 on Pelham Range. The spatial relationships of the mineralized areas that may contain sulfide minerals at depth (or are related to the weathering of sulfide minerals) are shown in figures 28 and 29.

The other mineralization sequence is associated with a very similar geochemical suite of elements but shows a genetic relationship to a more oxidized hydrothermal component. The outcrop observations and the presence of certain elements in the rocks suggest the hydrothermal event was pervasive in extent, the solutions more oxidized, and perhaps cooler. For example, some iron-rich veins show complex banding and swirling, suggesting the hydrothermal solutions were more oxidized; Fe precipitated as an oxide and not as a sulfide. Higher concentrations of Ba occur in these areas, suggesting the presence of barite. This further supports an oxidized environment because sulfate was the predominant sulfur species. The best examples of this sequence occur in the vicinity of site 3 and Bain Gap.

The best model to describe the observed mineralization sequences in the study area requires a mineralization process with multiple, small scale but highly metal rich sources precipitating metals, with or without sulfide, into an aqueous environment. This is similar to the mineralizing environment discovered by explorations of the deep sea vents (Ballard and Grassel, 1979; Lutz and Haymon, 1994). The formation of the sulfide mineralization sequences identified in this study area are analogous to the "black smokers" environment, where the metal-rich vents discharge considerable quantities of sulfide minerals over a restricted area in a short period of time. Changes in the plumbing system and/or the source of the metals or sulfide occur, which halts the metal sulfide outpourings. Changes in the plumbing system and/or in the metals or sulfide source area permit a new vent to begin in a nearby area. A "black smoker" model is given in figure 30.

Some of the hydrothermal vents described by Lutz and Haymon (1994) indicate intense hydrothermal activity occurs but without sulfide mineralization. These hydrothermal solutions are altering the surrounding rocks. Intense alteration occurs in the rocks in the Chilhowee Group throughout the study area. Hydrothermal solutions can also carry metals but without sulfide as the predominant sulfur species. Thus, deposition from metal-rich fluids in a host rock would occur without the need to form sulfide minerals. Some of the best exposures of iron rich-veins with associated metals occur west of Truitt Hill, Bain Gap, and Twin Peaks. Some of the best exposures of intense alteration with the deposition of iron rich veins are visible in the road cuts on the way to Yahoo Lake.

A "black smoker"- like hot springs formational model has not previously been applied to mineralization events for this vicinity. This type of a formational relationship ties the observed mineralization with the dominant structural environment along the Jacksonville Fault. The mineralization identified in the study area undoubtedly ties into the regional trends that extend from Talladega through the gold fields near Dahlonega, GA (to include Ducktown, TN) and into South Carolina (1. __Gold Maps of Alabama and South Carolina, 1983 and 2. __Gold Map of Georgia, 1983).

The "black smoker" mineralization environment shares many characteristics with a mineral-rich porphyry environment in that metal rich hydrothermal fluids release from a zone of concentration and migrate upwards. In a metal-rich porphyry system, the metal rich hydrothermal fluids deposit the metals within a complex network of veins in the host rock above (or peripheral to) the central mineralized intrusive (Alminas and others, 1994; Cunningham and Steven, 1979; Wallace and others, 1978). In the "black smoker" environment, the metal rich fluids migrate up through a system of cracks above a differentiating melt. Upon reaching the surface, immediate precipitation of metals occurs due to the dramatic change in fluid conditions at the seawater-hydrothermal fluid interface. There are undoubtedly some metals precipitating in the plumbing system also.

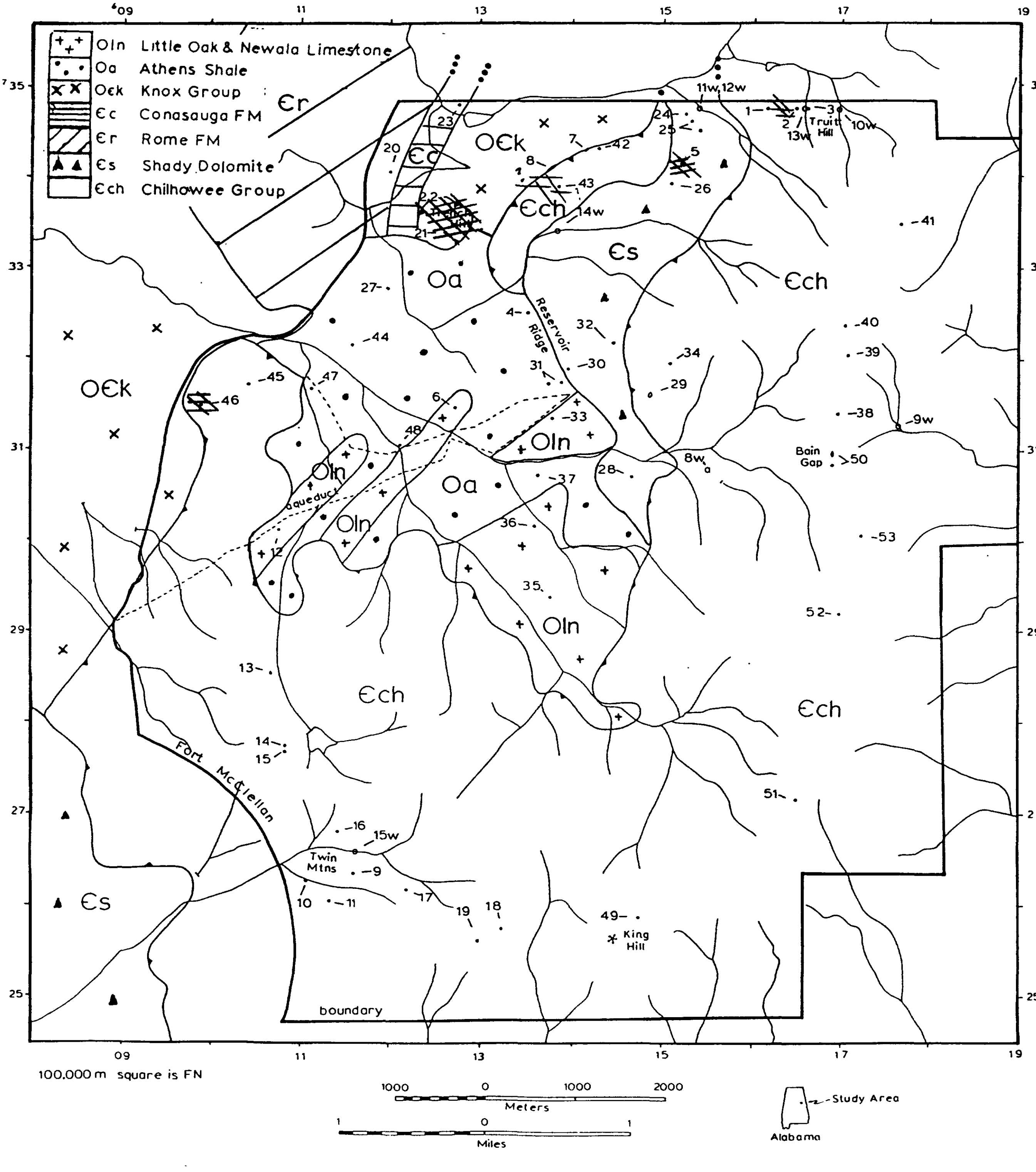

Figure 28. Distribution of sites where sulfide minerals appear to have been implace in the Fort McClellan study area, Fort McClellan, AL.

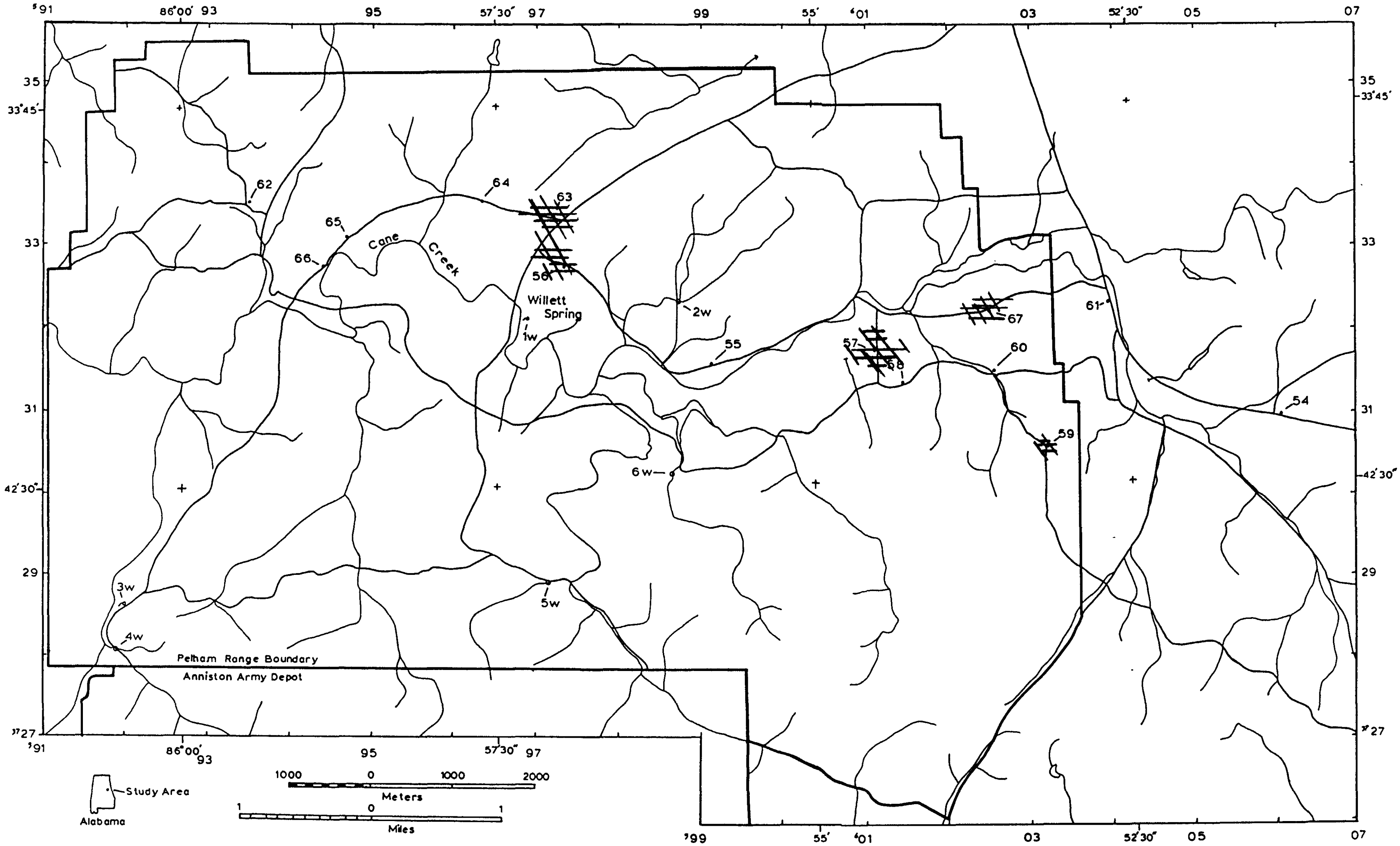

Figure 29. Distribution of sites where sulfide mineral appear to have been implaced in the Pelham Range study area, Fort McClellan, AL.

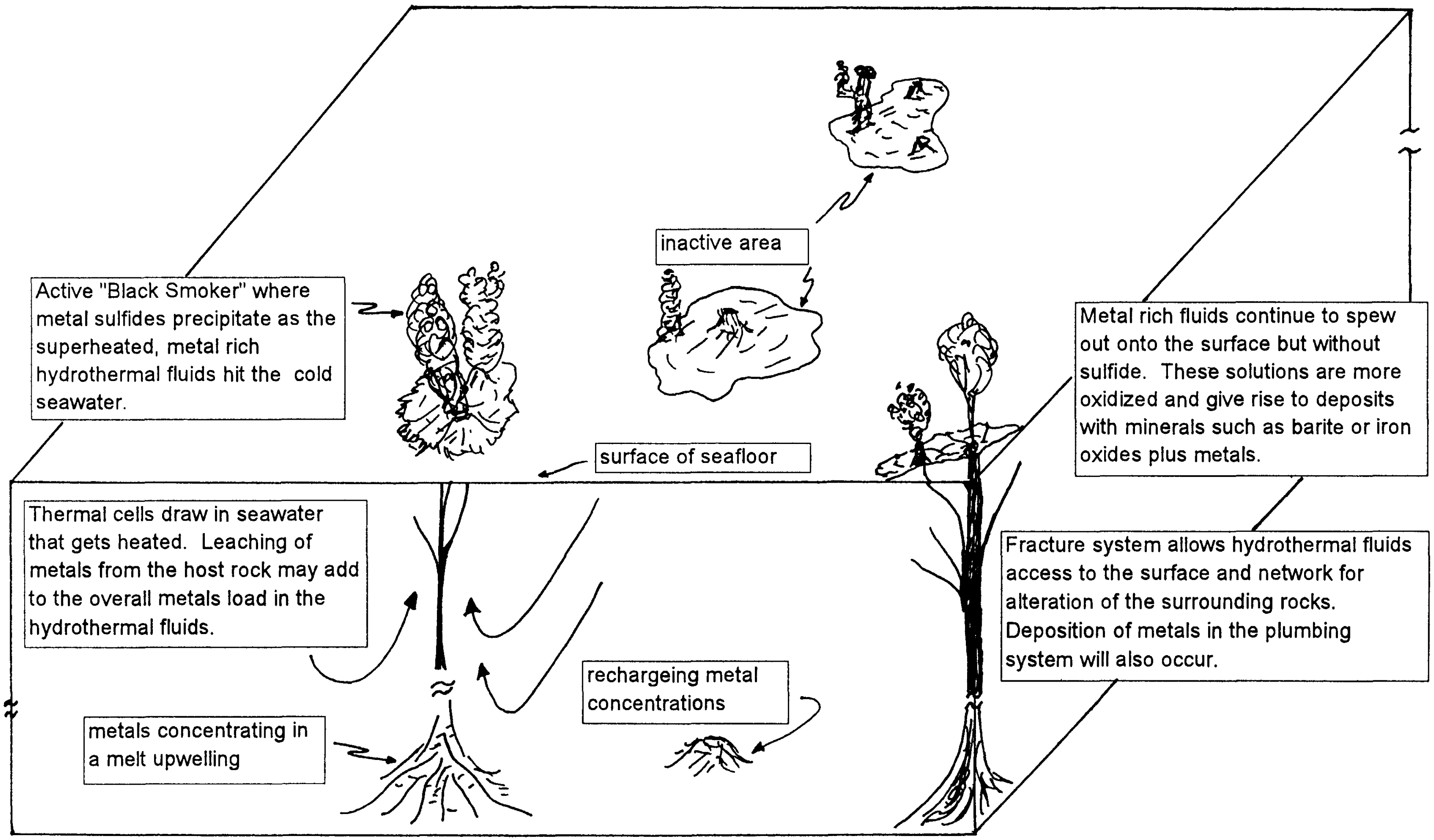

Figure 30. "Black Smokers" and the formation of mineralized areas in the Fort McClellan-Pelham Range study area, Fort McClellan, AL.

The significant difference in these two processes is that the "black smokers" produce a high volume of metal sulfides over a horizontal area rather than entrapped within a veining network in a host rock.

Environmental Concerns

Geologic recognition and geochemical characterization of the mineralized areas will impact three broad topics.

a. Compliance with environmental laws and regulations.

The presence of naturally occurring heavy and precious metals in both rocks and soils can complicate environmental monitoring programs. The discharge and disposal of these metals are often regulated through state and federal statutes. Monitoring is initiated to measure the discharge or accumulation of these contaminants from suspected sources such as landfills, CERCLA sites or operational facilities. The underlying assumption in most monitoring programs is that suspected contaminants originate from the monitored operation. While this may be a valid assumption at most locations, the presence of elevated metals in soils and rocks on Fort McClellan could constitute an additional nonanthropogenic source of contaminants. To accurately monitor and assess the impact of past and present military operations on the environment, this variable must be considered in analyzing suspected environmental problems.

Existing contaminant monitoring programs in the Trench Hill area provide an indication of possible mineralization influences on sampling results. This area is known to contain sulfide mineralization. Recent groundwater monitoring from wells around Landfill 4, show elevated lead levels downgradient of Landfill 4. The underlying assumption is that this contaminant originated from the material deposited in the active landfill. While this possibility exists, the location of wells within a highly mineralized area may also influence the dissolved constituents in the waters.

Another example involves monitoring programs at a nearby chemical decontamination training facility located just west of Trench Hill. Soils at this location contained up to 31 ppm total Pb. A source of Pb in the soils at this facility could not be found from the anthropogenic sources tested. The high Pb results may well be the product of natural mineralized rocks and soils under the site. The existence of highly mineralized rocks and soils on Fort McClellan indicates the need to consider this source of "contamination" in designing future environmental monitoring programs.

b. Endangered Species

Mineralization and geological strata can also be expected to affect the presence and distribution of flora and fauna on the installation. While these geologic and chemical processes may prevent the establishment of some species, others adapt through evolution to tolerate extremes in pH or elevated mineral concentrations. This is often an adaptive ability that eliminates the need to compete with more aggressive organisms that are found on less altered rocks and soils. Species unable to successfully compete with others for a niche in the community develop this tolerance as a mechanism to survive. Resulting endemic and restrictive biotic communities represent a rare and uncommon element of the ecosystem. These communities are particularly valuable in contributing to regional biodiversity.

Most rare flora and fauna on Fort McClellan can be found in and along springs and seepages. These water medium habitats are particularly influenced by the chemical composition of associated rocks and soils. For example, Tennessee yellow-eyed grass (Xyris tennesseensis) is a federally endangered species that is restricted to thin calcareous soils and bedrock. It can be found adjacent to two springs on Pelham Range. Another plant, Mohr's barbara buttons (Marshallia mohrii) is federally listed as threatened and can be found within spring seeps along shallow shale-bedded ephemeral streams within the large impact area. This plant is totally restricted to alkaline seasonally wet soils. Both plants represent unique biota that have adapted to specific environmental substrates dependent on geologic processes. A number of additional rare plants and insects are known from springs and seepages on the installation. While the environmental parameters governing habitat requirements is poorly understood, there is a strong possibility that extremes in geologic and soil parameters may influence the presence and distribution of the plants. A comprehensive understanding of these physical and chemical processes on Fort McClellan could prove invaluable in locating and managing rare biotic communities on the installation.

c. Future research.

This initial study identified areas containing precious and base metals. More detailed rock and soil geochemical and hydrogeochemical studies on Fort McClellan and Pelham Range would further delineate and characterize the mineralized areas. Geochemical and hydrogeochemical studies should extend onto the Anniston Army Depot and into the outlying area to further delineate mineralized areas and the related environmental concerns. (Highly altered and presumably mineralized areas were observed on Anniston Army Depot and in the surrounding area).

A detailed mineralogical study of the minerals in the rocks and soils would be beneficial to the overall understanding of the mineralization. This would include panned concentrates from streams and soils. Examining the weathering characteristics of bullets would also be beneficial.

There is a need to examine the relationships between the geology and geochemistry of the area and the plant and animal distributions found on Fort McClellan. The presence of some of the rare and endangered plant species on Fort McClellan and Pelham Range may be there due to the presence of specific metal tolerances or requirements in these plants.

CONCLUSIONS

A multifaceted study of Fort McClellan and Pelham Range was conducted to characterize the geochemical signature of mineralized and highly altered rocks observed throughout the study areas. The data show that several areas contain elevated concentrations of base and precious metals. The hydrogeochemical data support the rock and soil geochemical data. The water data further suggests that some basins that do not have rock and soil coverage also may contain base and precious metals mineralization.

The mineralization occurs in two distinct modes. Sulfide minerals form one mode of occurrence in the study area. The second mode of mineralization is associated with a rather pronounced hydrothermal fluid emplacement and alteration of the host rock. Both modes of mineralization contain varying amounts of base and precious metals.

The surficial expression of the sulfide containing mineralization shows a thick sequence of deep red soils reaching depths of at least 4 m in several locations with pebble to cobble-sized gossan nodules on the surface or within the soil.

The hydrothermal mineralization grades from hard, silica-rich rocks to clay-like iron-rich veins of varying thickness. Some of the veins show distinct banding; alteration of the surrounding host rock is common. Some of the outcrop occurrences suggest the hydrothermal fluids were highly oxidized because iron oxides and possible sulfate minerals predominate.

The water samples fall into three general hydrogeochemical suites. One constituent suite shows the weathering of carbonate rocks. A second suite reflects the weathering of the sandstones of the Chilhowee Group rocks. The presence of K and Rb may reflect the possible input from feldspars, fluid inclusions or minerals deposited from circulating hydrothermal fluids. The third suite contains ions reflecting base metal mineralization and alteration. The three groups do show considerable overlap in some samples.

Some of the mineralization is interpreted as representing the weathering remnants of metal-sulfide deposits located at several locations within the study area. These mineralized areas are generally less than a 1000 m in diameter or in length and are surrounded by areas showing varying degrees of hydrothermal mineralization and alteration of the host rock. A proposed genetic model based on the "black smoker" mineralizing sequence provides the best fit for the field observations. The Jacksonville Fault is the zone of weakness within which the mineralization and alteration occurred. Applying this model to the mineralization opens a whole area of research and geological interpretation.

There are environmental concerns about the concentration of heavy metals in the monitoring wells, vehicle wash racks, and surficial waters throughout the study area. The significant impact of this study is the identification of natural sources for the heavy metals. Although there is suspected anthropogenic contributions to the overall metal load by far the greatest contributor is the natural environment.

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