Distribution of Selected Elements in Stream Sediments, Stream Hydrogeochemistry, and Geology of the Oconee River Basin, Georgia

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ABSTRACT

Water quality management plans which are being developed for the 16 major river basins within Georgia will evaluate the hydrogeochemistry of the surface water and provide for the maintenance of water quality within those river basins. This report documents the natural background geochemistry and hydrogeochemistry of the Oconee River Basin as an aid to developing the water quality management plan for that basin. Primary databases used in this study are the stream sediment and stream hydrogeochemical data generated by the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program, which was conducted in the late 1970's. These databases provide the most extensive geochemical sample coverage for the state. Because the NURE data are from stream sediments and water, that data may be directly related to the water quality of streams. The NURE data are also an important geochemical baseline with which to evaluate environmental changes which may have occurred since the NURE program. The present study involves extensive use of a computer-based Geographical Information System (GIS) to map, analyze, and relate the data to other geographical and geological databases.

Differences in regional geology from the northern to the southern end of the Oconee River Basin are reflected in the stream sediment geochemistry and stream hydrogeochemistry. Approximately 60 percent of the basin is underlain by crystalline rocks of the southeastern Piedmont province and the remainder is underlain by sedimentary strata of the Coastal Plain province. The northern Inner Piedmont terrane of the Piedmont province contains predominantly metagranitic rocks and metasedimentary rocks in the form of gneiss and schists of intermediate to felsic composition and moderate to high metamorphic grade. The southern Carolina terrane contains crystalline igneous rocks of mafic to felsic composition. These include metavolcanic and metavolcaniclastic rocks, as well as gabbroic to granitic intrusions. Metamorphic grade is generally low to intermediate. The Coastal Plain sediments in the southern half of the basin include sandy, clayey and calcareous formations.

Differences in pH, conductivity, and alkalinity of stream waters between each of these major regions indicate a fundamental geological influence on the water hydrogeochemistry. These geological effects can be related to such basic differences as rock geochemistry, porosity and permeability of the rocks, and organic matter in the streams. Differences in stream chemistry will have important consequences concerning dissolution or precipitation of metals. The effect of rock geochemistry on stream hydrogeochemistry also has important consequences regarding buffering effects on natural and anthropogenic contamination.

Metals in stream sediments that are examined in this study are limited to those available in the NURE databases for Georgia. These include aluminum, beryllium, chromium, cobalt, copper, lead, nickel, zinc, iron, magnesium, manganese, titanium and vanadium. Several metals, including iron, magnesium, manganese, titanium and vanadium, are examined because of their influence on the availability of other metals to stream water or their potential use in interpreting the distribution of the other metals. Distribution of anomalously higher concentrations of most of these metals can be related to either the regional geology or to more localized geology such as individual rock units or structural trends. A relatively small proportion of samples with anomalously higher concentrations of one or more of these metals may be related to sites of human activity noted in the NURE databases.

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INTRODUCTION

The Oconee River Basin (ORB) is located in east-central Georgia (Figure 1, p. 2). Several other river basins, which include the Savannah River and Ocmulgee River basins, are located to the east and west of the ORB. The Chattahoochee River Basin is located north of the ORB. The ORB averages about 60 km in width, is 270 km in length, and covers 13,820 km^2. This basin extends from Gwinnett and Hall counties, directly northeast of the Atlanta metropolitan area, to Wheeler and Montgomery counties (Figure 1) where the Oconee River and the Ocmulgee River join to form the Altamaha River. The ORB includes parts or all of 27 counties. The three largest cities within the ORB are Athens, Milledgeville, and Dublin. Other cities within the ORB include: Winder, Eatonton, Greensboro, and Monticello.

The ORB is one of sixteen major river basins within Georgia which require a river basin management plan. Documentation of the background geochemistry of a river basin provides an important platform with which to evaluate surface water hydrogeochemistry and from that, the maintenance of water quality. The ORB is the first river basin to be systematically documented with respect to its background geochemistry.

The geochemistry and geology of a river basin provide an important and relatively stable framework with which to evaluate the hydrogeochemistry of that river basin. Stream sediment geochemistry represents the average composition of rocks within each drainage from which the sediments are derived. Stream sediment geochemistry is a more consistent database than stream hydrogeochemistry because of temporal changes in Eh-pH conditions related to variations in landscape type and precipitation. Variation in concentration of metals due to changes in precipitation and runoff also affect stream hydrogeochemistry on a temporal basis. The natural hydrogeochemistry of streams and rivers is principally derived from rocks and sediments through which the water flows. Stream sediment geochemistry can be used to quantify natural geochemical baselines and anthropogenic effects. Natural element enrichments caused by mineralization, host-rock sources and landscape type can be distinguished from anthropogenic effects in stream sediments (Birke and Rauch, 1993; Simpson et al., 1993; and Xie and Ren, 1993). Soil contamination that is related to atmospheric deposition also may be reflected in the drainage.

This investigation focussed on the following trace elements which are regarded as primary pollutants in Water Quality Standards or Drinking Water Standards: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Data are lacking, however, for antimony, cadmium, mercury, selenium, and thallium.

Stream sediments within the ORB affect stream flow and stream hydrogeochemistry. Extensive erosion caused by agricultural practices during the 1800's and early 1900's contributed a vast quantity of sediment into stream valleys of the headwaters of the ORB, choking the streams and raising the streams' base level. Stream discharge through these sediments rather than above the sediments increases the availability of metals to be remobilized into the water. As conservation practices stabilized erosion, streams began to reestablish grade and cut into the thick accumulations of sediments (Trimble, 1969), remobilizing them into the major rivers and eventually into reservoirs. Because more than 90 percent of the transport of most primary pollutant metals in river systems is as a solid phase (Horowitz, 1991), concentration of these metals into primary water supplies is of concern.

Mapping of surficial geochemical data for states, provinces, and countries during the past decade has provided an overview of relative geochemical abundances, regional geochemical trends, and anomalous distribution patterns (Koch et al., 1979; Koch, 1988; Darnley, 1990; Bolviken et al., 1990; McMillan et al., 1990; Kerr and Davenport, 1990; Reid, 1993; Birke and Rauch, 1993; Davenport et al., 1993; Simpson et al., 1993; and Xie and Ren, 1993). Surficial geochemical data are important for mineral resource and geological problems, agricultural, forestry, and waste disposal siting issues, as well as health and environmental studies.

Since the production of the Geochemical Atlas of Georgia (Koch, 1988), significant advances in computer technology permit rapid manipulation of geochemical data, incorporation of other data, and further interpretation of the various data sets relative to each other. This report emphasizes the databases produced by the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) Program in the late 1970's that were also used by Koch (1988). The NURE Program was designed to assess the uranium potential of the United States. These geochemical and hydrochemical databases are the largest and most extensive databases for Georgia. Data are mainly from stream sediments, streams, and ground water. This report expands on the maps produced by Koch (1988) by examining, in detail, the stream sediment and stream geochemistry of a specific geographic area (i.e. the Oconee River Basin) in Georgia within the context of the state's geology particularly in regards to the water quality of that river basin. This report may serve as a guide for other government agencies as that report described by Simpson et al. (1993) for the United Kingdom.

Simpson et al. (1993) described a program that consisted of the systematic geochemical mapping of the United Kingdom which has confirmed relationships between regional geochemical data and the known distribution of agricultural disorders and has indicated further suspect areas requiring detailed investigations. That geochemical mapping highlighted the principal mineralized areas and disclosed extensive areas with contaminated agricultural soils. These geochemical maps provide a unique source of multi-element data for detailed agricultural and health studies and have been used to assist siting of water monitoring stations and have indicated suspect elements for inclusion in water quality monitoring programs (Simpson et al., 1993). Regional geochemical data have been used to define metal-rich drainage inputs to estuaries used for shellfish culture and to guide area selection for many aspects of ecological and environmental research (Simpson et al., 1993).

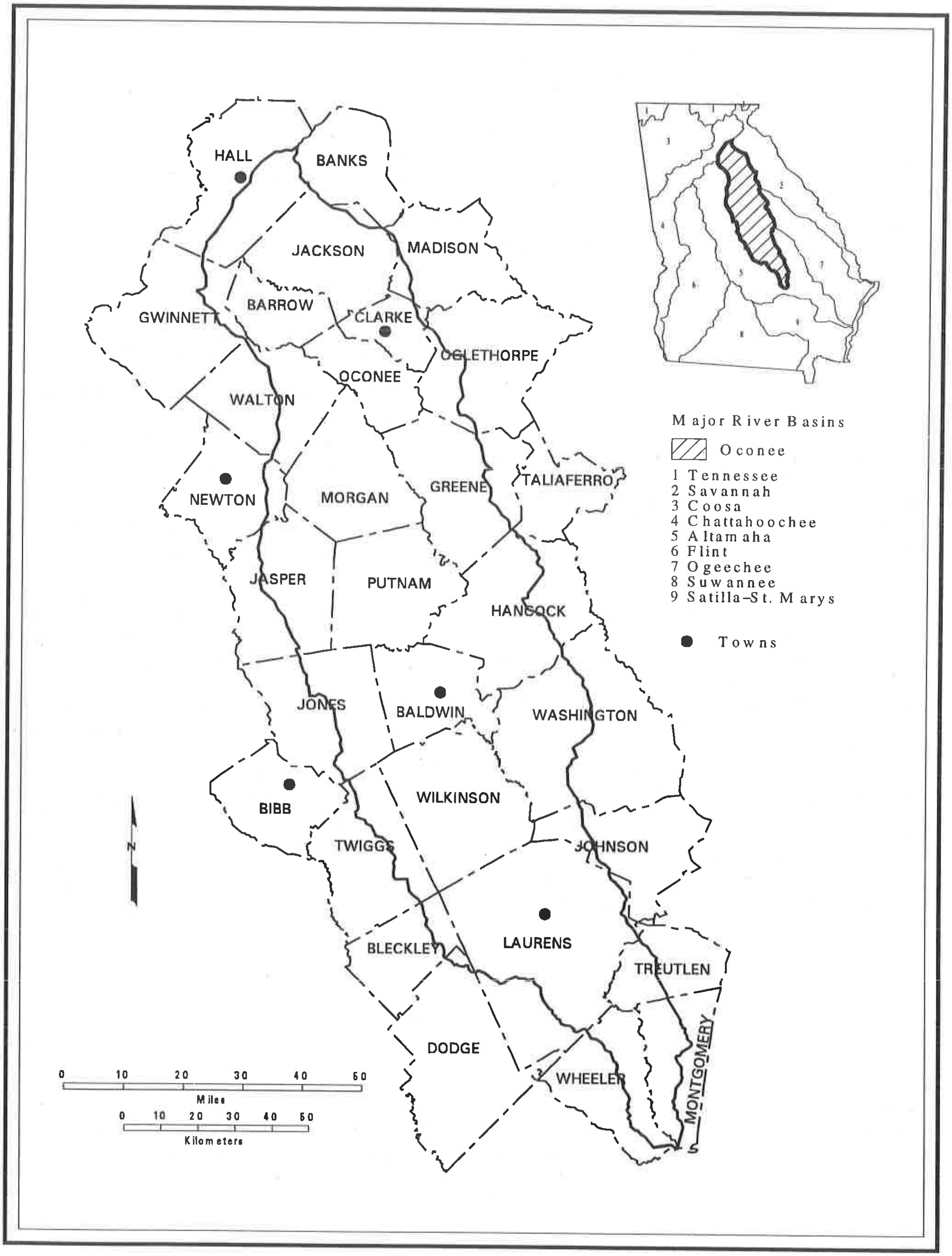

Figure 1. Location of the Oconee River Basin.

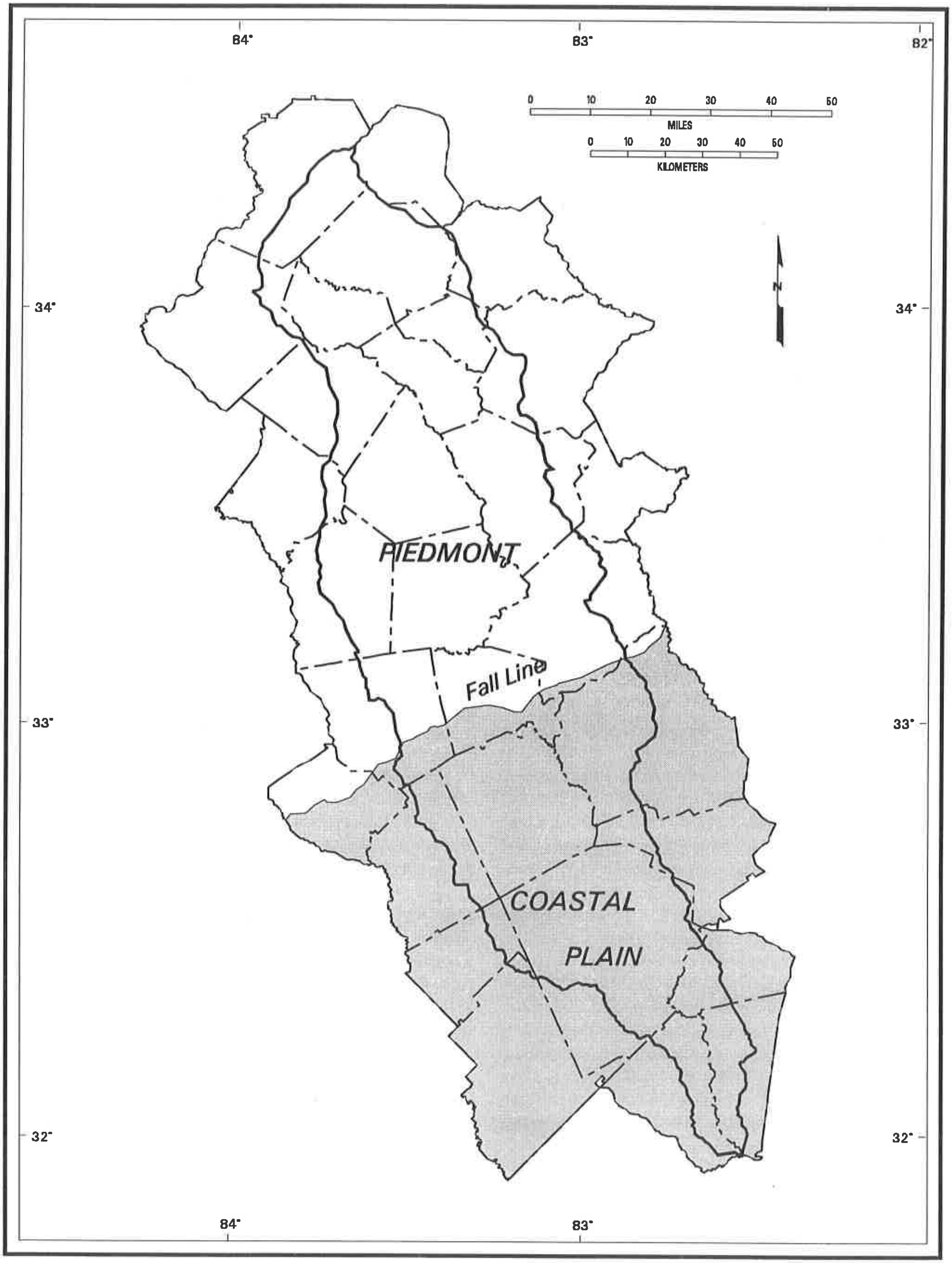

Figure 2. Physiographic Provinces.

Table 1. Lithologic Map Units within the Oconee River Basin.

Map Unit	Lithologies	Map Unit	Lithologies
fg1	biotite gneiss/feldspathic biotite gneiss	pa2b	sillimanite schist/gneiss/amphibolite
fg1a	biotite granite gneiss/feldspathic biotite gneiss/amphibolite-hornblende gneiss	pm2	metagraywacke/mica schist
		pms1	mica schist
fg2	biotite gneiss undifferentiated	pms3a	mica schist/gneiss/amphibolite
fg3	biotitic gneiss/mica schist/amphibolite	pms4	mica schist/quartzite/gneiss/amphibolite
fg4	biotitic gneiss/amphibolite	pms6a	sericite schist/amphibolite
bg1	biotite gneiss	pms6e	sericite schist/hornblende schist/biotite gneiss
bg2	biotite gneiss/amphibolite		
gg1	granite gneiss undifferentiated	pms7	button mica schist
gg4	granite gneiss/amphibolite	q1a	quartzite/mica schist
gg6	granite gneiss/granite	v4	undifferentiated metavolcanics/sericite phyllite/metargillite/quartz mica schist
gr1	granite undifferentiated		
gr1b	porphyritic granite	um	ultramafic rocks undifferentiated
gr2a	granite/gneissic biotite granite	mp2	gabbro
mm1	amphibolite	c1	mylonite and ultramylonite
mm3	hornblende gneiss/amphibolite	TKu	Tertiary - Cretaceous undifferentiated (sands and clays)
mm4	hornblende gneiss/amphibolite/granite gneiss	Ei	Eocene - Irwinton Sand
mm6	hornblende gneiss/granite gneiss/biotite gneiss	Etw	Eocene - Twiggs Clay
		Eo	Eocene - Ocala Limestone
mm9	amphibolite/mica schist/biotitic gneiss	Os	Oligocene - Suwanee Limestone
pa2	sillimanite schist	Qal	Quaternary - stream alluvium and stream terrace deposits
pa2a	sillimanite schist/gneiss		

GEOGRAPHIC INFORMATION SYSTEMS AND MAPS

A Geographic Information System (GIS) was used in this study to perform spatial operations on the geochemical and geological data and to link data from various databases using location as a common linkage. A GIS identifed and extracted from those databases specific items such as drainage basin boundaries, rock units, different types of samples, and unique geochemical values or ranges of geochemical values. The GIS was used to select single or multi-element data for a river basin and areas adjacent to that basin, and display that data with geographical or geologic information.

Geographical, geochemical, and geological databases used in this project are derived from a variety of sources, have different geographical extent, are at different scales and projections, and contain different types of data such as points, arcs, and polygons. Examples of point data include: stream sediment sample points, wells, rock samples, water samples, and mines. Arcs include stream segments and roads. Polygons include such data as: geologic units, hydrologic units, soil types, and political units.

Databases from the Georgia Geologic Survey's GIS that were used in this project include: hydrography, hydrounits, county boundaries, geology, major lakes, major roads, soils, physiography, and land use data. Hydrography databases include streams and rivers. Hydrounit databases are the U.S. Geological Survey defined units for drainage basins and smaller divisions within those drainage basins. Additional databases utilized for this project for the GIS include: NURE (National Uranium Resource Evaluation) geochemical and hydrogeochemical data, Georgia Environmental Protection Division hydrochemical data, mines and prospects, and various databases based on published and unpublished Georgia Geologic Survey (GGS) geochemical data, published U.S. Geological Survey (USGS) geochemical data, and geochemical data from student theses.

Maps contained in this report are sized to fit the format of the report and are thus at a scale of 1:1,469,266. Geochemical data were interpreted from 1:500,000 scale versions of the maps. These maps are at the same scale as other statewide maps of Georgia published by the Georgia Geologic Survey. Copies of 1:500,000 scale maps used in this study are in open-files of the GGS.

Maps depicting various types of rock units in the ORB were created by selecting a particular rock type or groups of rock types (Table 1) from the GIS coverage developed from the Geologic Map of Georgia (GGS, 1976). Tectonic terranes were labeled based on Williams (1978) and are depicted in Figure 3 (p. 7). Similar types of rock units were grouped together and displayed in Figures 4 through 9 (p. 12-15, 17, and 18) . A coverage which included the major structures (i.e. faults) was also developed from the Geologic Map of Georgia (GGS, 1976).

The map showing the metal, kaolin, and pegmatite mines (Figure 10, p. 23) is a composite of several coverages. The kaolin mines coverage was developed from USGS 1:24,000 scale topographic maps which cover the Coastal Plain kaolin belt and from a map showing the distribution of kaolin and fuller's earth mines (Shrum, 1970). The metal deposits coverage was also developed from mine locations shown on USGS 1:24,000 scale topographic maps and on geologic maps contained in student theses. Locations of pegmatites and pegmatite mines were derived from field work on pegmatites in the Georgia Piedmont (Cocker, 1992a, 1992b, 1995b, and unpublished data).

Geochemical maps were developed through a series of steps using a GIS. Sample point coverages were created from latitude and longitude data in the NURE databases. NURE databases were joined to the sample point coverages. Contoured geochemical maps were developed through the use of Environmental Systems Research Institute's (ESRI) Arc/Info version 6.02. A triangular integrated network (TIN) was generated from sample points within the NURE geochemical coverages. From that TIN, a lattice was created such that each cell in the lattice was assigned a geochemical value relative to that of two or more nearby sample points. Contours were then created by linking lattice cells with equal geochemical values. Because the ORB is located within four 1°x2° National Topographic Map Series (NTMS) quadrangles, these four databases were considered as one single coverage to be contoured. After this large coverage was contoured, the outline of the ORB was used to clip (include) only those contours which are within the ORB. This method was used to eliminate or reduce edge effects created by the contouring software. Edge effects are created where data and data points are absent, and the software creates contours relative to non-existent data. Unavoidable edge effects appear as elongated contours on some of the geochemical maps.

GENERAL GEOLOGY

INTRODUCTION

The geology discussed in this report is based primarily on the Geologic Map of Georgia (GGS, 1976) and augmented with descriptions in later references. Rock units on the Geologic Map of Georgia are defined principally by the dominant lithology and secondarily by less abundant lithologies. Specific rock units and groups of rock units having similar lithologic classifications were selected by use of the GIS and are depicted in Figures 3 through 9. Additional ultramafic occurrences documented by Prowell (1972) were used to create an additional coverage to augment the Geologic Map of Georgia GIS coverage.

The ORB is located within two physiographic provinces: the Piedmont and the Coastal Plain provinces (Figure 2) which are described in the section on geomorphology. The ORB trends approximately N30°W across the Piedmont and the Coastal Plain physiographic provinces. The Piedmont province, which constitutes approximately 60 percent of the ORB, is underlain by crystalline metamorphic and igneous rocks. The remaining portion of the basin consists of the Coastal Plain province which is underlain by sedimentary strata. Because of significant differences in chemical composition, porosity, permeability, and origin of the different rock units within the Piedmont and Coastal Plain, these rock units and the stream sediments derived from these rock units significantly influence differences in the stream hydrogeochemistry.

From the geologic coverage of the ORB, the GIS calculated that 57% of the exposed rocks consist of several types of gneiss (Figures 4-6). Biotite gneisses cover 29%, granitic gneisses cover 14%, and amphibolite gneisses cover 5% of the ORB. Granites (Figure 5) occupy 4% of the basin. Metasedimentary rocks (Figure 7) such as metagraywackes, quartzites, and schists cover 4% of the ORB. Less than 0.1% of the ORB is occupied by ultramafic and mafic rock units (Figure 4). Although the overall ratio of felsic (biotite gneisses plus granitic gneisses plus granites plus metasedimentary rocks) to mafic (amphibolite gneisses plus ultramafic and mafic rocks) lithologic units within the Piedmont is approximately 7:1, this ratio may not be significant. Mafic lithologies (e.g. amphibolites) may be important constituents of the felsic units (Table 1, p. 4) shown on the Geologic Map of Georgia (GGS, 1976).

Coastal Plain sediments are present over 40% of the ORB (Figures 8 and 9). Lithologic map units which occur within the ORB are listed in Table 1. Approximately 85% of the Coastal Plain sediments are sandy and clayey sediments. The rest include calcareous sediments and Quaternary alluvium. More recent geologic mapping and stratigraphic analyses of the Georgia Coastal Plain by Huddleston (1988, 1993), Hetrick and Fridell (1990), and Hetrick (1990, 1992) have redefined the stratigraphy and distribution of sedimentary formations. This recent geologic mapping is gradually being incorporated into the Geologic Survey's GIS, but such coverages are discontinuous, have not undergone quality control checks, are not ready for general use at this time, and have not been included in this report. Recent mapping does not affect interpretations reached in this report.

CRYSTALLINE ROCKS OF THE PIEDMONT

STRUCTURAL GEOLOGY

Within the ORB, the Piedmont physiographic province is composed of two tectonostratigraphic terranes: the Inner Piedmont terrane and the Carolina terrane (Figure 3). Tectonostratigraphic terranes are "fault-bounded packages of rocks of regional extent characterized by a geologic history which differs from that of neighboring terranes" (Horton and Zullo, 1991). The Inner Piedmont terrane is separated from the Carolina terrane in the ORB by the Towaliga Fault Zone (Figure 3) (Williams, 1978). The Lowndesville Shear Zone is projected as the division between the Inner Piedmont and Carolina terranes east of the

ORB (Allard and Whitney, 1994). Along the northern edge of the ORB, the Brevard Fault Zone (Figure 3) separates the Inner Piedmont from the Blue Ridge terrane to the north of the basin. The southern edge of the Carolina terrane is covered by Coastal Plain sediments. Tectonostratigraphic terranes, most crystalline rock units, and major faults in the Georgia Piedmont as depicted on the Geologic Map of Georgia (GGS, 1976), strike approximately N45°E and define the regional tectonic fabric. A series of smaller faults, Mesozoic mafic igneous dikes, and a few post tectonic granitic intrusions cut across the main regional fabric in a northwest to southeast direction.

The Inner Piedmont terrane consists mainly of migmatitic granitic and biotite (intermediate) gneisses with smaller volumes of schists, amphibolites, and ultramafic bodies (Figure 4). Source rocks or protoliths for these Inner Piedmont rocks were primarily sedimentary and perhaps felsic to intermediate igneous rocks (Horton and McConnell, 1991). The middle part of the ORB contains several lithologic belts, the Carolina slate belt, and the Charlotte belt, which have been grouped together as the Carolina terrane. The Carolina slate belt contains generally lower grade metamorphic rocks than the Charlotte belt. The Carolina terrane includes predominantly intermediate to mafic metavolcanic or metasedimentary rocks derived from intermediate to mafic volcanic rocks.

The Inner Piedmont terrane and the Carolina terrane in the vicinity of the ORB may be divided into at least two thrust sheets each (Nelson et al., 1987; Horton and McConnell, 1991). Recent regional geologic mapping within the Piedmont of Georgia and adjacent states suggest that distinctive rock assemblages may represent allochthonous thrust sheets emplaced one above another as a result of tectonic transport to the west during formation of the Appalachian Mountains (Cook et al., 1979; Nelson et al., 1987; Higgins et al., 1988; Nelson, 1988; Nelson et al., 1990). Boundaries between these thrust sheets are either poorly defined or are concealed (Nelson et al., 1987). Although effects of these thrust sheets are presently difficult to define, the two major tectonostratigraphic terranes have a pronounced influence on the geochemistry of the ORB.

Major geologic structures may influence the geology and geochemistry of a river basin. Faults may juxtapose rocks with different geochemical signatures and result in significant differences in stream chemistry over a short distance or between adjacent drainage basins. Faults and folds may structurally repeat or remove rock types which have a unique geochemical signature. Although the above mentioned major faults are generally not mineralized, secondary structures related to these faults may be important hosts to metal mineralization.

Within the ORB, traces of the major faults (Figure 3) that cut across the basin (the Brevard Fault Zone, the Towaliga Fault Zone, the Middleton-Lowndesville Fault and the Modoc Fault Zone) are marked by intensely sheared cataclastic rocks. High concentrations of nickel (discussed later) may be related to ultramafic rock units that occur within the Brevard Fault Zone. Slices of ultramafic oceanic crust or mantle rocks may be included in the cataclastic zones of major faults.

The Towaliga Fault Zone appears to have the most important influence on the geology and geochemistry of the crystalline rocks of ORB. This fault zone is the boundary between high-grade metasedimentary and felsic to intermediate igneous rocks of the Inner Piedmont terrane to the north and lower grade mafic metavolcanic and metavolcaniclastic rocks of the Carolina terrane to the south. Stream pH, conductivity, and alkalinity are characteristically different in the Carolina and Inner Piedmont terranes. Differences in metal concentrations occur in stream sediments on either side of the Towaliga Fault Zone. These changes in metal concentrations in the stream sediments and the stream hydrogeochemistry are discussed below.

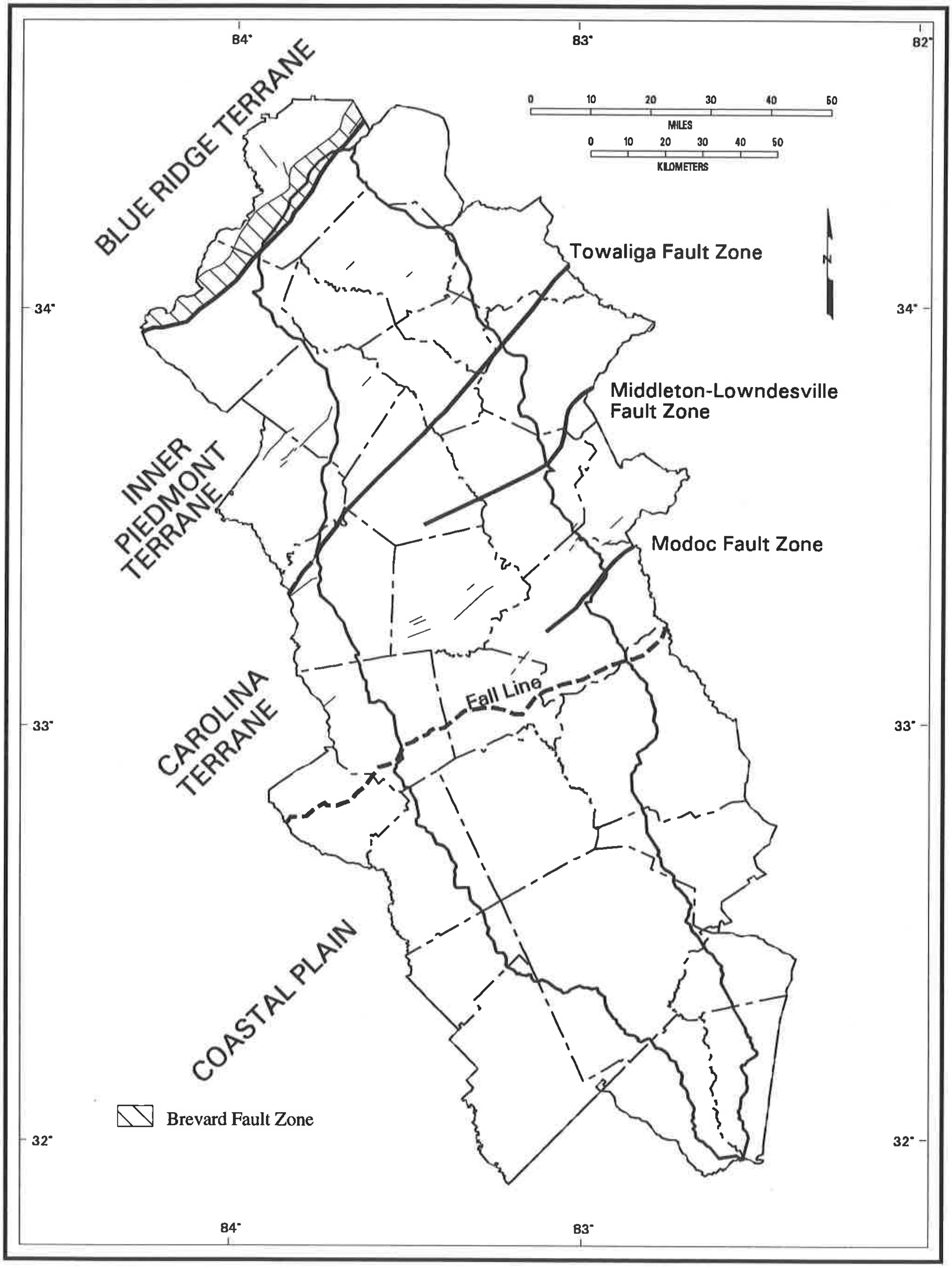

Figure 3. Tectonic Terranes and Major Structures.

INNER PIEDMONT TERRANE

Mafic and Ultramafic Rocks

A variety of mafic and ultramafic rock units (um, mm11, and mp2 in Table 1 and on the Geologic Map of Georgia [GGS, 1976]) and are shown in Figure 4. These rock units occur within northeast trending linear belts that extend across the ORB. Mafic rock units may consist of amphibolites, amphibolitic gneisses and gabbroic intrusions. Ultramafic rocks may be metaperidotites, serpentinites, or metadunites. Most of these rock units are small in size. These rock units may be igneous intrusions or remnants of oceanic crust tectonically emplaced along crustal sutures.

Mineralogy of these rock units is quite similar. Gabbroic rocks generally consist of hornblende or actinolite, plagioclase feldspar, epidote, quartz, and magnetite with traces of chlorite and apatite (Libby, 1971). Ultramafic rock units generally consist of serpentine, talc, actinolite, carbonates, magnetite, chromite, and sulfides (Prowell, 1972). These rocks are susceptible to chemical weathering and may release locally significant amounts of chromium, nickel, copper, zinc, lead, iron, titanium, manganese, magnesium, arsenic, and antimony.

Diabase Intrusions

Diabase dikes are scattered throughout the Georgia Piedmont and the ORB. More persistent dikes are depicted on the Geologic Map of Georgia (GGS, 1976). These dikes are not shown on the maps in this report, because the dikes were not digitized in the Geologic Map GIS coverage.

Most dikes are on the order of one to several meters in width, but may be up to several tens of meters in width and extend for tens of kilometers in a northwest-southeast direction. Because of their limited areal extent, diabase dikes probably have contributed little to the stream sediment load and probably do not significantly affect the stream hydrogeochemistry. Diabase dikes described from Putnam (Libby, 1971) and Clarke counties (Woolsey, 1973) are composed mainly of plagioclase feldspar, olivine, augite, hypersthene, magnetite with minor chlorite, titanomaghemite, chalcopyrite, sphalerite, idaite, serpentine, chlorite, and calcite.

Granitic Gneisses

Granitic gneisses, rock units fg1a, gg1, gg4, and gg6 in Table 1, are highlighted in Figure 4. These rock units may include metamorphosed granodiorites, granodiorite gneisses, two-mica gneisses, and migmatites as well as minor amphibolitic gneisses. Metamorphosed granodiorites may contain quartz, plagioclase, potassium feldspar, muscovite, and biotite with minor garnet and tourmaline, and trace amounts of zircon, apatite, epidote, sphene, magnetite, carbonate, chlorite, and scapolite (Grant, 1958; Klett, 1969). Biotite-granite gneiss is a distinctly banded, resistant rock which contains microcline, plagioclase, quartz, and biotite with minor amounts of muscovite, garnet, magnetite, and calcite (Reade, 1960).

Intermediate (Biotite) Gneisses

Intermediate or biotite gneisses are principally represented by rock units fg1, fg1a, fg2, fg3, fg4, bg1, and bg2 in Table 1 and on the Geologic Map of Georgia (GGS, 1976). These rock units are grouped together in Figure 6. Within the ORB, biotite gneisses are volumetrically more abundant within the Inner Piedmont than the Carolina terrane. Biotite gneisses within the Inner Piedmont terrane are generally interpreted as being derived from sedimentary sources.

Biotite gneisses are described from Clarke (Woolsey, 1973), Hart (Grant, 1958), Newton, Walton (Reade, 1960), and Morgan (Lawton, 1969) counties. These gneisses are generally composed of alternating layers of quartz, plagioclase, and microcline feldspar and layers of biotite and graphite. Minor constituents may include hornblende, garnet, muscovite, zircon, apatite, cordierite, sphene, magnetite, and sulfides. Pyrrhotite is one of the sulfides disseminated throughout the gneiss. Many of the biotite gneisses have well-developed mineralogic banding, and many can be classified as migmatites and paragneisses. Heavy minerals, such as monazite and xenotime, in stream sediments in Clarke County may be derived from the migmatite with which they are spatially associated (Woolsey, 1973).

Amphibolites and Amphibolite Gneisses

Amphibolites and amphibolitic gneisses are represented by units mm1, mm3, mm4, mm6, and mm9 in Table 1 and on the Geologic Map of Georgia (GGS, 1976). These rock units are grouped together in Figure 4. Amphibolites are also present in other units such as fg4 and bg2 (Table 1). Amphibolitic rocks are generally less abundant in the Inner Piedmont than in the Carolina terrane. Amphibolitic rocks are commonly interpreted to be metamorphosed mafic volcanic rocks, but many in the Inner Piedmont may be metasedimentary.

Feldspathic amphibolite gneiss, amphibolites, and hornblende gneisses are described from Hart (Grant, 1958), Clarke (Woolsey, 1973), Morgan, Hall, Jackson (Klett, 1969), Newton, and Walton (Reade, 1960) counties. Feldspathic amphibolite gneiss is described as a unit dominated by feldspathic amphibolite gneiss with lesser amounts of biotite plagioclase gneiss, granitic layers, and biotite bearing amphibolite gneiss. These lithologic units generally contain hornblende and plagioclase feldspar with lesser amounts of epidote, quartz, biotite, garnet, diopside, chlorite and calcite. Minor amounts of sphene, magnetite/ilmenite, rutile, apatite, and pyrite are usually present (Grant, 1958; Woolsey, 1973; Klett, 1969; Reade, 1960). Antigorite, cordierite, and orthoclase are also reported (Reade, 1960).

Metasedimentary/Metavolcanic Rocks

Metasedimentary rock units shown on the Geologic Map of Georgia (GGS, 1976) include aluminous schists, mica schists, metagraywackes, and quartzites, and are highlighted in Figure 7. Recent studies (Conway, 1986; Dunnagan, 1986; Allard and Whitney, 1994) indicate that many of these rock units may be metavolcanic. If these metavolcanic rocks are metal-bearing, their weathering and erosion can affect metal concentrations in stream sediments and stream hydrogeochemistry.

Aluminous schists include the rock units pa2, pa2a, and pa2b in Table 1. These schists may contain staurolite-mica schist, sillimanite-mica schist, and sillimanite-graphite schist. These rocks are composed of quartz, muscovite and biotite with either staurolite, sillimanite, or graphite. Trace or minor amounts of tourmaline, zircon, garnet, and iron oxide may be present (Grant, 1958; Reade, 1960). Several units of sillimanite-mica schist extend through Clarke County (Woolsey, 1973). Aluminous schists are commonly interpreted as strongly hydrothermally altered metavolcanic rocks.

Mica schists, which include the rock units pms1, pms3a, pms4, pms6a, pms6e, and pms7 in Table 1, are interpreted to be less hydrothermally altered metavolcanic rocks. Within the Inner Piedmont, biotite schist and muscovite-biotite-tourmaline schist usually contain muscovite, quartz, plagioclase, chlorite, and garnet. Biotite schist contains biotite and quartz, with minor muscovite and garnet (Woolsey, 1973). Muscovite-biotite-tourmaline schist in Hall and Jackson counties consists of sillimanite schist, quartz-muscovite schist, purple quartzites, and mica schist. Minerals include muscovite, quartz, plagioclase, chlorite, garnet, tourmaline, and biotite (Klett, 1969).

Rock unit pm2 in Table 1 is the only rock unit within the ORB listed as a metagraywacke. Although no description of this particular rock unit is available, a quartz-muscovite schist noted in Jackson and Hall counties (Klett, 1969) and a biotite gneiss in Hart County (Grant, 1958) are interpreted as metagraywackes.

Quartzites are represented by the rock unit q1a and to a certain extent pms4 in Table 1. Within the ORB amphibole-plagioclase quartzite, garnet-plagioclase quartzite, and feldspar quartzite are present (Woolsey, 1973); sillimanite-garnet quartzite in Newton and Walton counties (Reade, 1960); and massive quartzite in Hall and Jackson counties (Klett, 1969). These quartzites may contain hornblende, plagioclase and microcline feldspar, quartz, sillimanite, muscovite, manganese garnet, with lesser amounts of calcite, sphene, sericite, biotite, and diopside. Minor amounts of apatite, graphite, tourmaline, zircon, clinozoisite, sulfides, and magnetite may be present (Reade, 1960; Klett, 1969; Woolsey, 1973). Quartzites may be metamorphosed sandstones or silicified hydrothermal alteration zones which are usually associated with volcanic activity. Metallic mineralization may be associated with either original source rock.

CAROLINA TERRANE

Granites

Elberton Granite. The Elberton Granite (gr2a on the Geologic Map of Georgia, GGS, 1976) is a major rock unit which extends from the Savannah River into the northeastern part of the ORB within Oglethorpe and Greene counties (Figure 5). The Elberton Granite is an extremely homogeneous, fine-grained, equigranular granite composed mainly of equal parts of quartz, microcline, and plagioclase feldspar with a minor component of biotite, muscovite, allanite, sphene, and several iron-titanium oxides. Although the Elberton Granite is mineralogically homogeneous, variations in trace element chemistry suggest subtle magmatic zoning in the pluton (Allard and Whitney, 1994).

The Elberton Granite commonly forms granite pavements with thin, poorly developed soil. The presently exposed surface of the Elberton Granite may be near its original uppermost intrusive contact (Allard and Whitney, 1994). Because of its resistance to weathering and its relatively recent exposure to surface weathering and erosion, the Elberton Granite has contributed little to the stream sediment load except in the immediate vicinity of its outcrop.

Siloam Granite. The Siloam Granite (gr1b on the Geologic Map of Georgia, GGS, 1976) lies principally within the ORB in Greene County (porphyritic granite in Figure 5). Minor portions of this granite are located beyond the edge of the ORB. The Siloam Granite is a composite intrusion composed principally of several phases of a porphyritic biotite granite. Minor phases include several fine to coarse-grained equigranular biotite granites (Vincent, 1984). The characteristic microcline feldspar phenocrysts in the saprolitized porphyritic biotite granite (Humphrey and Radcliffe, 1972) are currently mined. The Siloam Granite and the Sparta Granite, described below, appear to be more deeply weathered than the Elberton granite and may contribute more sediment to nearby streams.

Sparta Granite. The Sparta Granite, which extends into the central part of Hancock County (Figure 5), is described as a multiphase quartz monzonite intrusion with granodioritic and aplitic phases (Henry, 1983). Principal minerals include microcline, plagioclase, quartz, and biotite with minor amounts of sphene, magnetite-ilmenite, epidote, allanite, and trace amounts of zircon and apatite. An earlier study of the Sparta Granite describes several phases which consist of a pink biotite granite, a gray biotite granite, and a leucocratic adamellite (Humphrey and Radcliffe, 1971). The distribution of sodium and potassium in stream sediments tends to support the location of map units mapped by Humphrey and Radcliffe (1971), but not necessarily the composition of those map units. For the purposes of this basin study, differences in mapping and petrographic descriptions are not critical.

Other Granites. Additional unnamed and undocumented (not described in the literature) granitic rocks within the ORB are depicted in Figure 5 and the State Geologic Map (1976). No metal enrichment or hydrothermal activity is known to be associated with either the better known or these poorly known granitic intrusions. The lack of any spatial association with high concentrations of metals in the NURE databases tends to support this observation.

Mafic and Ultramafic Rocks

A variety of mafic and ultramafic rock units (um, mm11, and mp2 in Table 1) occur within northeast trending linear belts extending across the ORB (Figure 4). Most occurrences are generally small in size. These rock units may be igneous intrusions or remnants of oceanic crust or mantle tectonically emplaced along crustal sutures. Mafic and ultramafic rock units which occur within the ORB portion of the Carolina terrane include gabbros, pyroxenites, and tonalites. The largest of the mafic rock units, the

Gladesville Norite (mm11 on the Geologic Map of Georgia, GGS, 1976), extends for a short distance into the ORB in Jasper County. Descriptions of these lithologies are given by Libby (1971) and Hooper (1986). Pyroxenite, gabbro, and tonalite form small elongate plutons aligned in a belt that extends across the northwestern half of Putnam County. Other gabbroic intrusions located to the northeast (Conway, 1986; Dunnagan, 1986; Davidson, 1979) continue this trend further in the Carolina terrane. Granophyric gabbroic plutons are located in a second belt in the southeastern part of Putnam County (Libby, 1971). Additional gabbroic intrusions in Taliaferro (Conway, 1986) and Wilkes counties (Dunnagan, 1986; Allard and Whitney, 1994) extend this belt further along the Carolina terrane in Georgia. Many of these gabbroic intrusions are not depicted on the Geologic Map of Georgia (GGS, 1976).

The mineralogy of these rock units is quite similar. Gabbroic rocks may consist of hornblende or actinolite, plagioclase feldspar, epidote, quartz, and magnetite with traces of chlorite and apatite. A compositionally different gabbroic intrusion consists of plagioclase, augite, hypersthene, hornblende, and ilmenite. Pyroxenites may consist of augite, hypersthene, hornblende, and plagioclase with minor amounts of pyrrhotite and pentlandite. Meta-pyroxenites contain actinolite, anthophyllite, hornblende, chlorite, and traces of magnetite. Tonalitic intrusions contain hornblende, plagioclase, quartz, and epidote with minor amounts of microcline, apatite, and allanite. Granophyric gabbroic intrusions contain plagioclase, augite, hypersthene, quartz and orthoclase feldspar intergrowths, magnetite, chlorite, biotite, and talc with minor calcite (Libby, 1971).

These rock units may contain disseminated or massive metallic sulfides and oxides. These sulfides and oxides may contain chromium, nickel, copper, zinc, lead, iron, titanium, manganese, arsenic, and antimony. Mafic silicates may also contain iron, manganese, magnesium, chromium, nickel, copper, and zinc.

Metavolcanic Rocks

Moderate to high grade metamorphism of basaltic to rhyolitic volcanic rocks will form amphibolites to granitic gneisses, respectively. Metamorphism of hydrothermally altered volcanic rocks may form chloritic schists, biotite gneisses, mica schists, aluminous mica schists, and quartzites depending on the composition of the source rock and the type of hydrothermal alteration. Basaltic rocks generally contain higher concentrations of chromium, cobalt, nickel, zinc, and copper than rhyolitic rocks (Rose et al., 1979). Local enrichment of these metals may result from magmatic differentiation. More rhyolitic volcanic rocks may contain higher concentrations of lithium and fluorine than other less felsic volcanic rocks. Most of the metavolcanic rocks within the Carolina terrane of Georgia and South Carolina are believed to have originally formed under submarine conditions (Allard and Whitney, 1994). The physical and chemical environment of submarine volcanism is conducive for development of hydrothermal systems which may be enriched in trace metals. Local high concentrations of copper, lead, zinc, gold, arsenic, antimony, mercury, barium, manganese, and fluorine in the metavolcanic rocks in Georgia and South Carolina may be related to submarine hydrothermal systems (Clark et al., 1993; Tockman and Cherrywell, 1993; Maddry et al., 1993; Allard and Whitney, 1994).

Mafic volcanic rocks generally contain higher amounts of iron, magnesium, and calcium than felsic volcanic rocks. Submarine volcanic rocks may acquire sodium from seawater and become more enriched in sodium than subaerial volcanic rocks. At low to moderate grades of metamorphism, primary calcium, magnesium, and iron-bearing silicates (e.g. plagioclase and amphiboles) are commonly replaced by secondary calcium, magnesium, and iron carbonates (e.g. calcite, dolomite, and siderite). Abundant intermediate to mafic metavolcanic and metavolcaniclastic rocks in the Carolina terrane may have an important effect on the stream sediment geochemistry and stream hydrogeochemistry. Weathering and hydrolysis of iron, magnesium, calcium, and sodium silicates and carbonates can affect the pH, conductivity, and alkalinity of surface and ground water that flows through the volcanic rocks and metasedimentary rocks derived from volcanic activity.

Granitic Gneisses

Granitic gneisses may include: metamorphosed granodiorite, granodiorite gneiss, two mica gneisses, and migmatite. In Figure 5, large masses of granitic gneiss (gg4 in Table 1 and on the Geologic Map of Georgia [GGS, 1976]) may be similar to the Jackson Crossroads granite, located northeast of the ORB and within the Carolina terrane. That metagranite consists of quartz, plagioclase, and potassium-feldspar, with minor to trace amounts of epidote, muscovite, biotite, chlorite, sphene, garnet, and zircon (Hutto, 1986; Young, 1985).

The Woodville granite, which has recently been delineated along the southern margin of the Elberton Granite, is mineralogically similar to the Jackson Crossroads granite but may also have a significant component of biotite (Allard and Whitney, 1994). In contrast to the Elberton Granite, the Woodville granite is commonly strongly weathered with a saprolite from 10 to 17 meters thick. The Woodville granite is not depicted as a separate rock unit on the Geologic Map of Georgia (GGS, 1976).

Intermediate (Biotite) Gneisses

Intermediate or biotite gneisses are highlighted in Figure 2 and include the rock units fg1, fg1a, fg2, fg3, fg4, bg1, and bg2 in Table 1 and on the Geologic Map of Georgia (GGS, 1976). Biotite gneisses are generally interpreted as being derived from volcanic rocks.

An extensive area within Greene, Hancock, and Taliaferro counties is underlain by a porphyroblastic (or porphyroclastic) biotite gneiss. This gneiss consists of microcline and plagioclase feldspar, quartz, and biotite with minor amounts of epidote and muscovite and trace amounts of opaque minerals and sphene (Humphrey and Radcliffe, 1972; Conway, 1986), and the original rocks are interpreted to be porphyritic intermediate to felsic volcanic flows (Conway, 1986). Other biotite gneisses within the Carolina terrane may consist of layers of biotite gneiss and hornblende gneiss. Biotite gneiss consists of quartz, plagioclase, biotite, and microcline with lesser amounts of muscovite and garnet, and trace amounts of sillimanite, opaque minerals, epidote, and zircon (Humphrey and Radcliffe, 1972; Conway, 1986). Some of the biotite gneisses are interpreted to be metamorphosed graywackes derived from volcanic sources. Hornblende gneiss consists of hornblende and plagioclase with accessory magnetite and ilmenite (Humphrey and Radcliffe, 1972).

Amphibolites and Amphibolite Gneisses

Amphibolites and amphibolitic gneisses are mainly represented by rock units mm1, mm3, mm4, mm6, and mm9 on the Geologic Map of Georgia (GGS, 1976) but are present in other units such as fg4 and bg2 (Table 1). Amphibolitic rocks are volumetrically more abundant in the Carolina terrane than in the Inner Piedmont (Figure 4). Amphibolitic rocks have been interpreted to be metamorphosed mafic volcaniclastics, sediments derived from basalts and gabbros (Conway, 1986).

Hornblende gneiss, amphibolites, and amphibolite gneisses located in Hancock County (Humphrey and Radcliffe, 1971) and Greene and Taliaferro counties (Conway, 1986) generally consist of hornblende, plagioclase feldspar, biotite, epidote, sphene, and opaque minerals. The opaque minerals may include pyrite and copper sulfides which include chalcopyrite, chalcocite, and covellite (Conway, 1986), as well as magnetite and ilmentite (Humphrey and Radcliffe, 1971).

Metasedimentary/Metavolcanic Rocks

Metasedimentary rock units highlighted in Figure 7 include many rock units which are actually metavolcanic rocks (Conway, 1986; Dunnagan, 1986; Allard and Whitney, 1994). The origin of these rock units can be important in their effect on trace metals in stream sediments and hydrogeochemistry of surface and ground water.

Aluminous schists include mainly the rock units pa2, pa2a, and pa2b on the Geologic Map of Georgia (GGS, 1976). In Greene and Taliaferro counties, muscovite-sillimanite-quartz schist is considered to be a metamorphosed, intensely hydrothermally altered felsic volcaniclastic rock. Extreme hydrothermal alteration may have leached the original volcanic rock leaving it enriched in alumina and silica. In addition to quartz, sillimanite, and muscovite, pyrite and rutile are also present. This rock unit is related to the War Hill felsic intrusive center and the Stoney Ridge gold mine in Wilkes County (Conway, 1986; Dunnagan, 1986).

Mica schists include the rock units pms1, pms3a, pms4, pms6a, pms6e, and pms7 (Table 1) on the Geologic Map of Georgia (GGS, 1976). Quartz muscovite schists generally consist of quartz and muscovite with minor amounts of biotite and epidote and accessory pyrite and magnetite. Gneissic biotite schists consist of quartz, biotite, plagioclase, and potassium feldspar with minor pyrite. Narrow bands of amphibolite may be interlayered with the schist (Humphrey and Radcliffe, 1971; Conway, 1986). These rocks are interpreted as metamorphosed felsic lithic crystal tuffs and metamorphosed sedimentary rocks derived from an iron-rich volcanic exhalite (Conway, 1986).

Only one rock unit (pm2) within the ORB is listed as a metagraywacke on the Geologic Map of Georgia (GGS, 1976). Although a description of this particular rock unit has not been located in this study, a quartz-muscovite schist noted in the Talmo area is interpreted as a metagraywacke by Klett (1969).

Quartzites may be metamorphosed sandstones or silicified alteration zones usually associated with volcanic terranes. Metallic mineralization may be associated with either source rock. Rock units listed as or containing quartzites on the Geologic Map of Georgia (GGS, 1976) include q1a and to a certain extent pms4. Although lithologic descriptions are lacking for quartzites in the Carolina terrane, the quartzites should, in general, be similar to those described for the Inner Piedmont. Higher grade minerals such as sillimanite are generally absent.

A small lens of chlorite schist in Hancock County that consists of chlorite, plagioclase feldspar, quartz, magnetite, and talc with minor garnet and epidote (Humphrey and Radcliffe, 1971), is spatially associated with a high concentration of chromium in stream sediments and may be an altered ultramafic rock unit. The large size of the chromium anomaly suggests that other unrecognized ultramafic rocks may be located nearby.

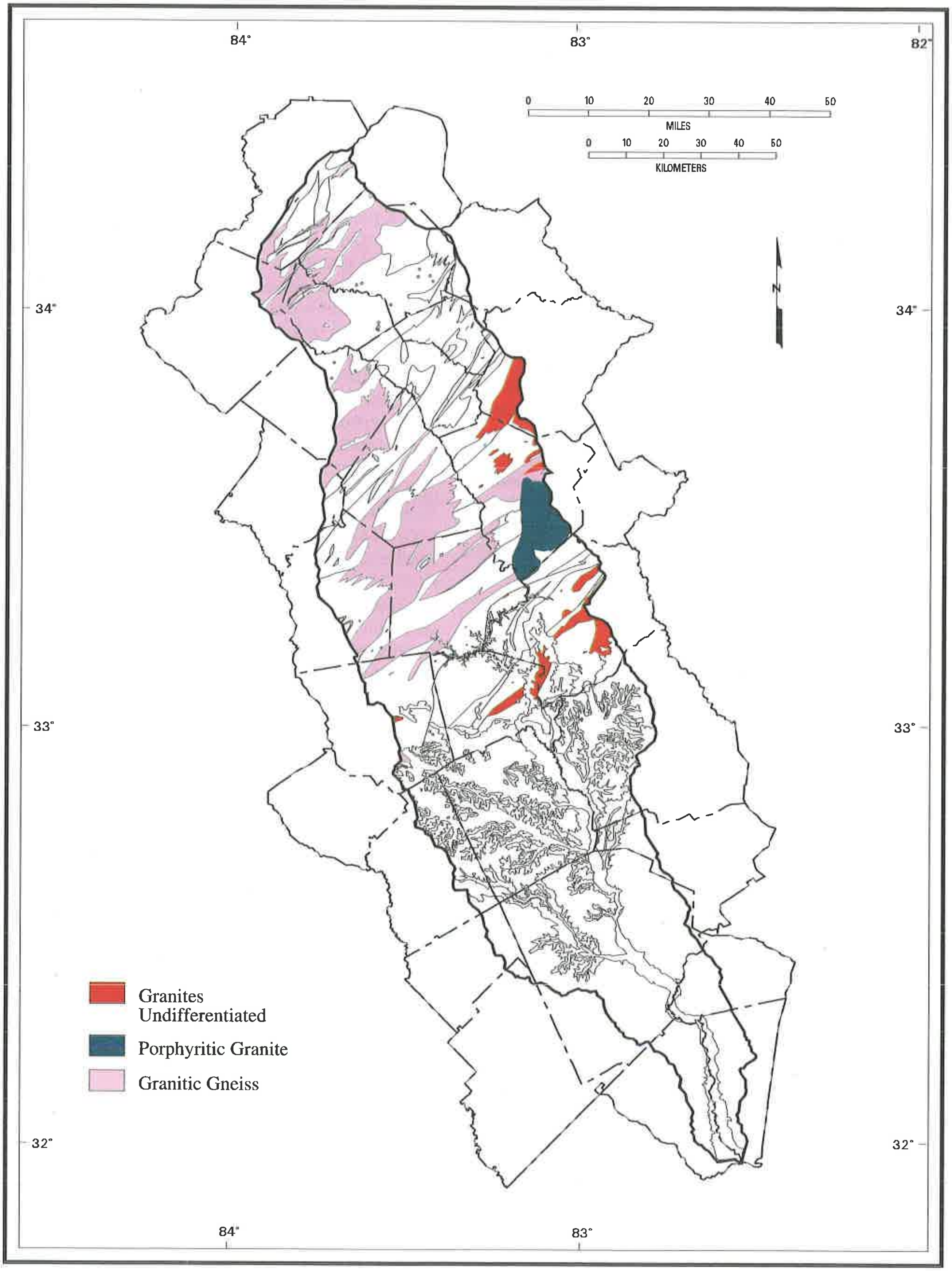

Figure 4. Granites and Granitic Gneisses.

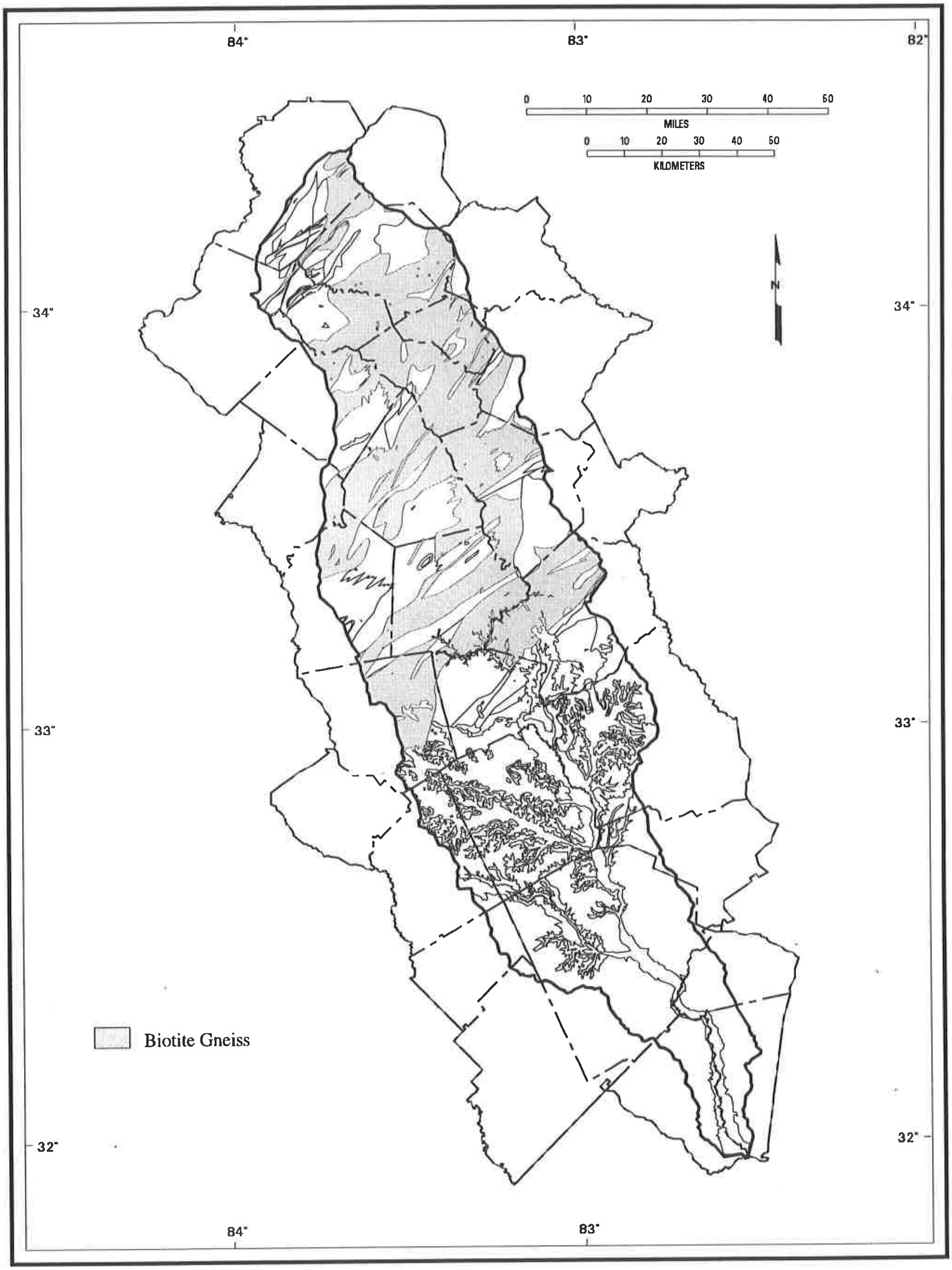

Figure 5. Biotite Gneiss.

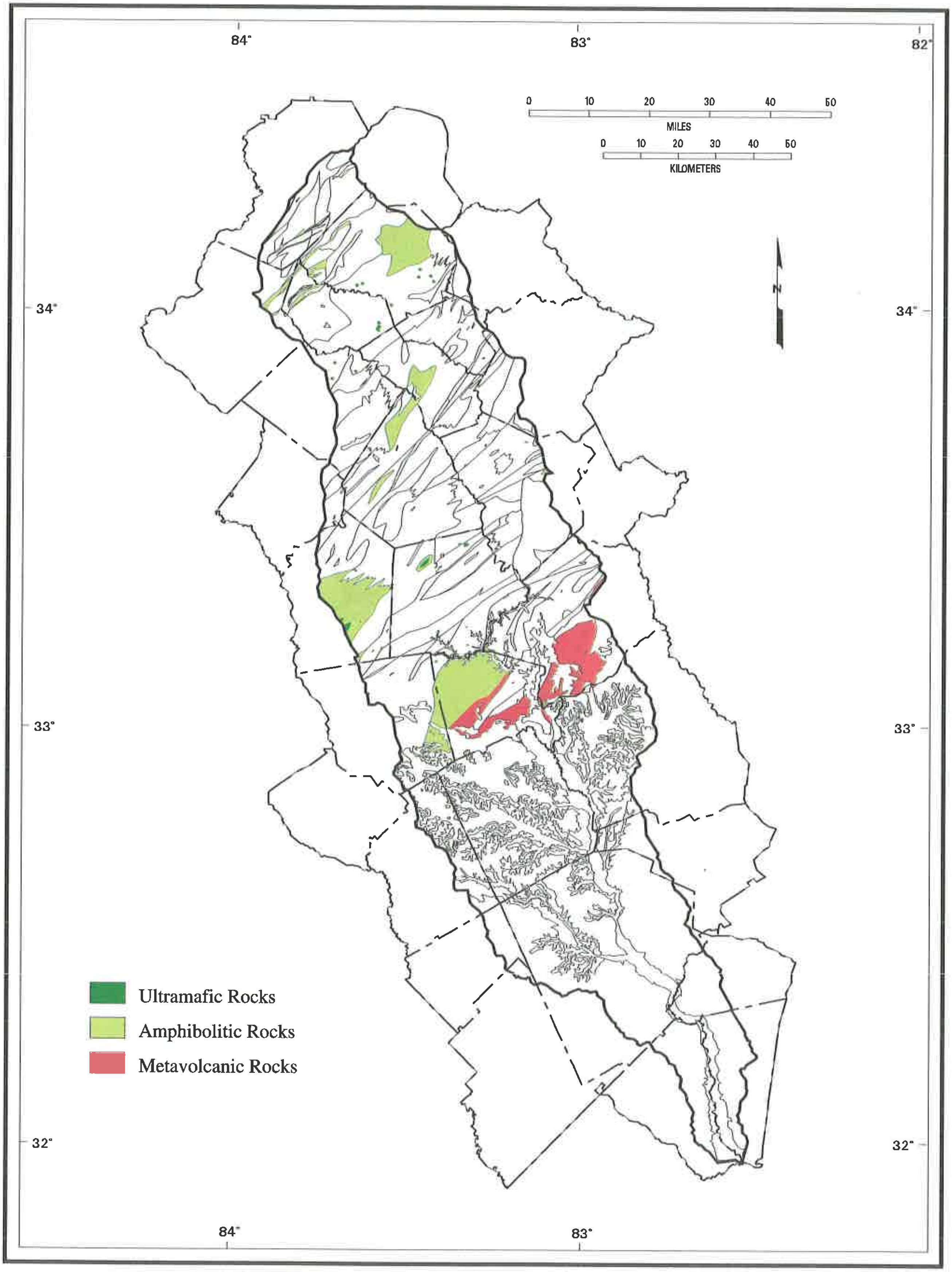

Figure 6. Amphibolitic, Ultramafic and Metavolcanic Rocks.

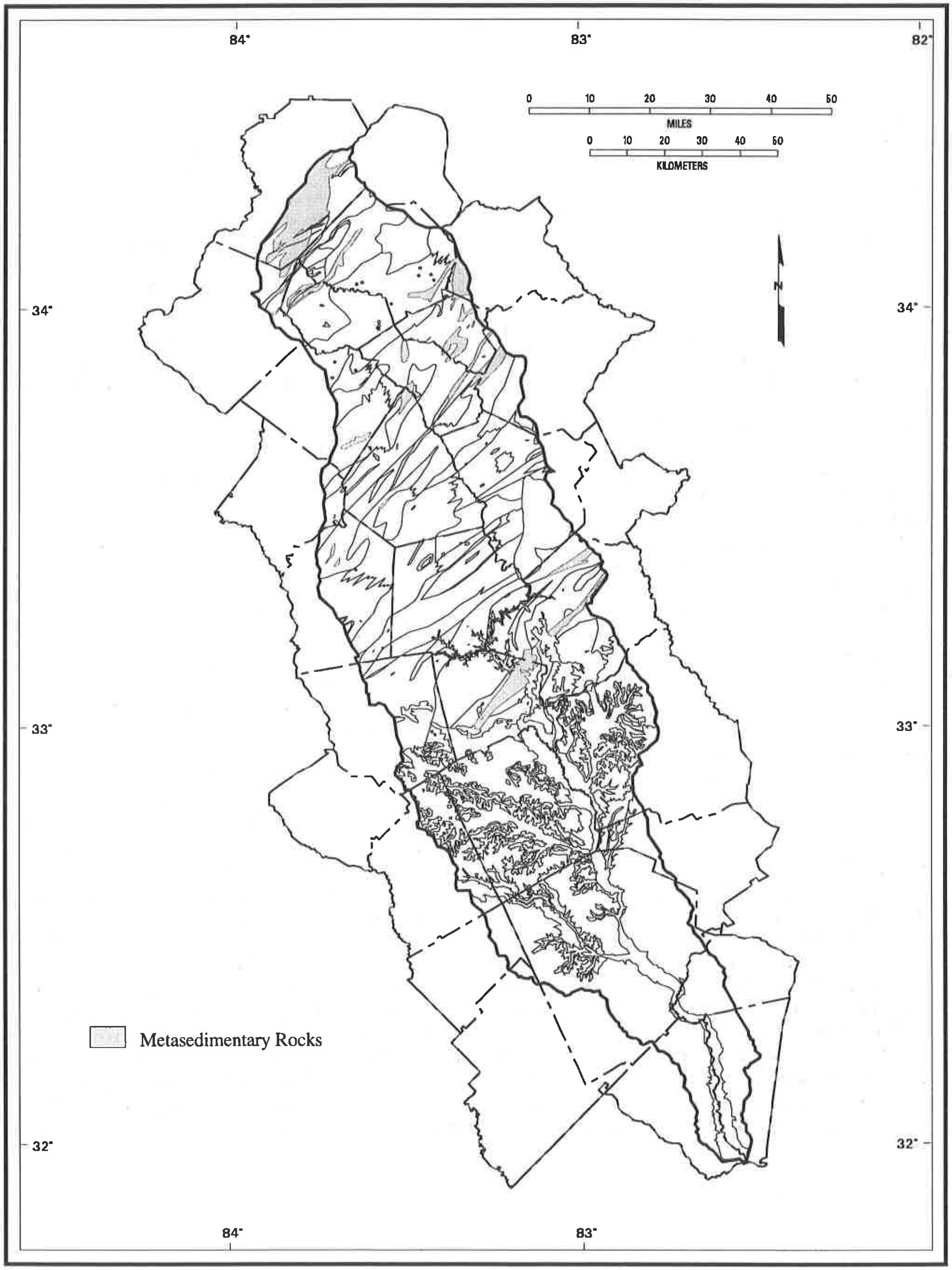

Figure 7. Metasedimentary Rocks.

COASTAL PLAIN STRATA

The Coastal Plain within the ORB contains Late Cretaceous to Miocene strata as well as Quaternary alluvium. The Geologic Map of Georgia (GGS, 1976) shows the distribution of six rock units. Figures 8 and 9 highlight calcareous rock units and sandy and clayey rock units in the Coastal Plain.

Coastal Plain stratigraphy from the Upper Eocene to the Holocene has been redefined by Huddlestun and Hetrick (1986) and Huddlestun (1988, 1993) since the publication of the Geologic Map of Georgia (GGS, 1976). In addition, Hetrick and Friddell (1990) and Hetrick (1990, 1992) have remapped the stratigraphy of the Coastal Plain in the vicinity of the Fall Line. Brief lithologic descriptions of the stratigraphy are included below, but the reader is referred to these publications for revisions in the stratigraphy and distribution of the mapped units.

TERTIARY-CRETACEOUS UNDIFFERENTIATED

The rock unit shown as Tertiary-Cretaceous undifferentiated sands and clays (TKu) on the Geologic Map of Georgia (GGS, 1976) has been called the Oconee Group of Upper Cretaceous to middle Eocene age (Hetrick and Friddell, 1990). This group is divided into the Cretaceous Gaillard Formation and the Tertiary Huber Formation. The Gaillard Formation consists of kaolin and micaceous kaolinitic sand. The Huber Formation consists of generally poorly sorted, kaolinitic sand, kaolin, clay clasts, and pebbly sand. Local concentrations of heavy minerals occur in the Huber Formation (Hetrick and Friddell, 1990).

EOCENE

Upper Eocene strata in central and eastern Georgia consist of the Barnwell Group overlain by the Ocala Group. The Barnwell Group consists of three formations: the Clinchfield Formation, the Dry Branch Formation, and the Tobacco Road Sand. The Clinchfield Formation contains the Riggins Mill and Treadwell Members. The Dry Branch Formation consists of three interfingering and intergradational lithofacies: the Twiggs Clay, the Irwinton Sand, and Griffins Landing Members (Huddlestun and Hetrick, 1986). The Irwinton Sand and Twiggs Clay are shown on the Geologic Map of Georgia (GGS, 1976) as Ei and Etw. The Tobacco Road Sand contains the Sandersville Limestone Member at it base.

The Clinchfield Formation consists of generally unconsolidated, fine to medium, well-sorted, calcareous, quartz sand. The Twiggs Clay consists predominantly of montmorillonitic clay. The Irwinton Sand consists of fine to medium, well-sorted, almost pure quartz sand. The Griffins Landing Member is generally found east of the Ogeechee River and will not be discussed here. The Tobacco Road Sand is a poorly sorted, medium to coarse, pebbly weathered sand with local concentrations of clays, chert, calcite, limestone, heavy minerals, mica, glauconite, and wad. The Sandersville Limestone Member is a fairly pure limestone with local concentrations of quartz sand, montmorillonite clay, disseminated pyrite, manganese oxide, and glauconite (Huddlestun and Hetrick, 1986).

The Ocala Group consists of the lower Tivola Limestone and the upper Ocmulgee Formation separated by the Twiggs Clay Member of the Dry Branch Formation (Huddlestun and Hetrick, 1986). The Ocala Limestone is shown on the Geologic Map of Georgia (GGS, 1976) as Eo. The Tivola Limestone is generally a fine to coarse, bioclastic limestone with subordinate montmorillonite, kaolinite, illite, glauconite, disseminated pyrite, and quartz sand. The Tivola Limestone is only found west of the Oconee River. The Ocmulgee Formation ranges in composition from a very calcareous, glauconitic clay to an argillaceous, glauconitic, granular limestone (Huddlestun and Hetrick, 1986).

OLIGOCENE

The rock unit shown as the Oligocene age Suwanee Limestone (Os) on the Geologic Map of Georgia (GGS, 1976) was not mapped by Hetrick and Friddell (1990). Huddlestun (1993) does not show the Suwanee Limestone within the ORB. This unit is described as a soft to indurated pelletoidal limestone. Stream hydrogeochemistry, discussed later, indicates that a limey unit corresponding to the Suwannee Limestone shown on the Geologic Map of Georgia (GGS, 1976) does exist in the ORB.

NEOGENE UNDIFFERENTIATED

The rock unit depicted as Neogene undifferentiated (Nu) on the Geologic Map of Georgia (GGS, 1976) is the Miocene age Altamaha Formation. This formation consists of poorly sorted, pebbly, argillaceous, micaceous sands, sandy clays, and minor amounts of angular pebbles (Hetrick and Friddell, 1990).

QUATERNARY

Stream alluvium and stream terrace deposits are depicted as Quaternary in age (Qal) on the Geologic Map of Georgia (GGS, 1976) although some of these deposits may be Tertiary (Hetrick and Friddell, 1990). The alluvium consists of poorly sorted sand, clayey sand, and gravel. Iron oxide cement is reported in the older deposits of alluvium (Hetrick and Friddell, 1990).

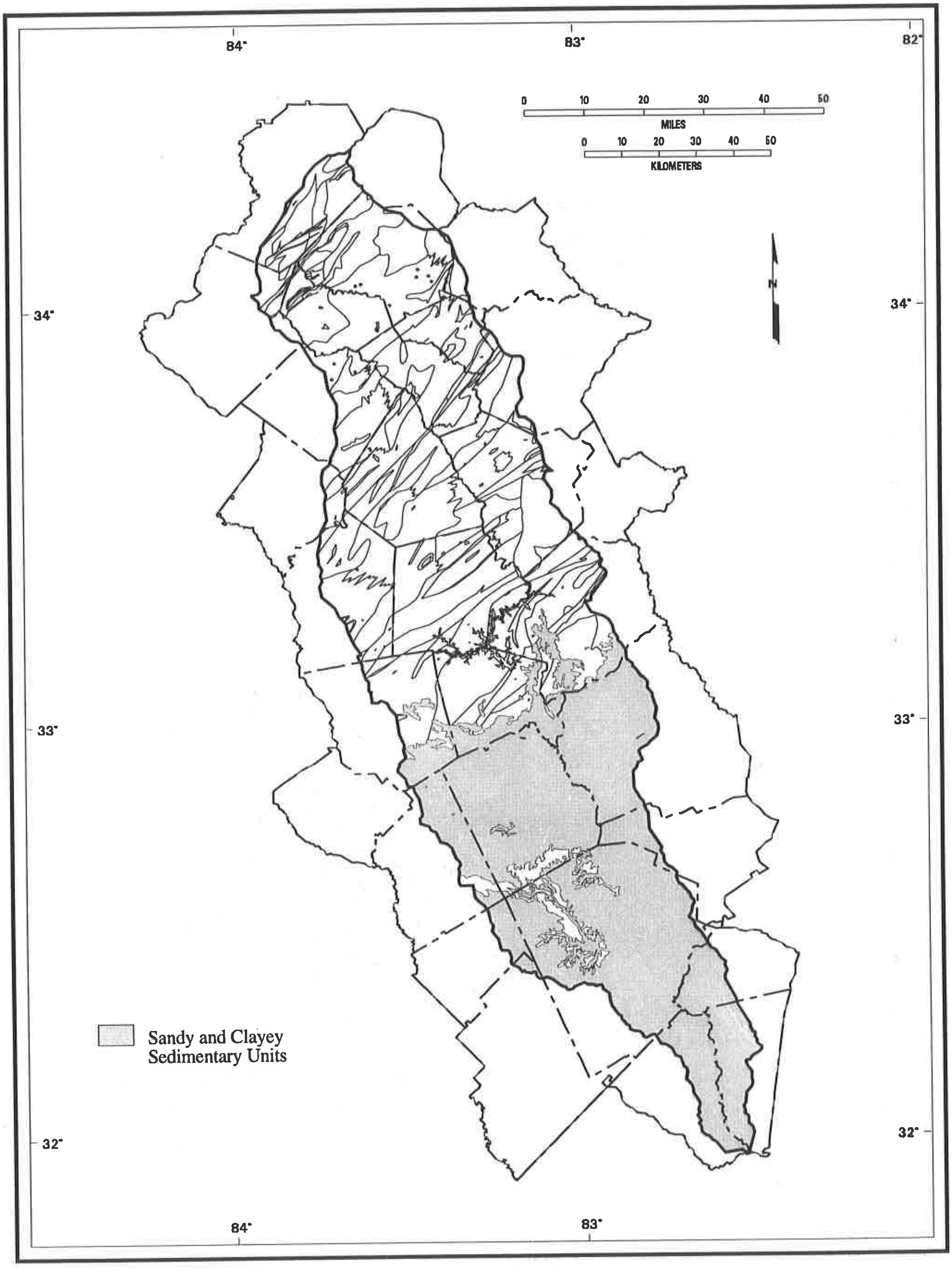

Figure 8. Coastal Plain Sandy and Clayey Sedimentary Units.

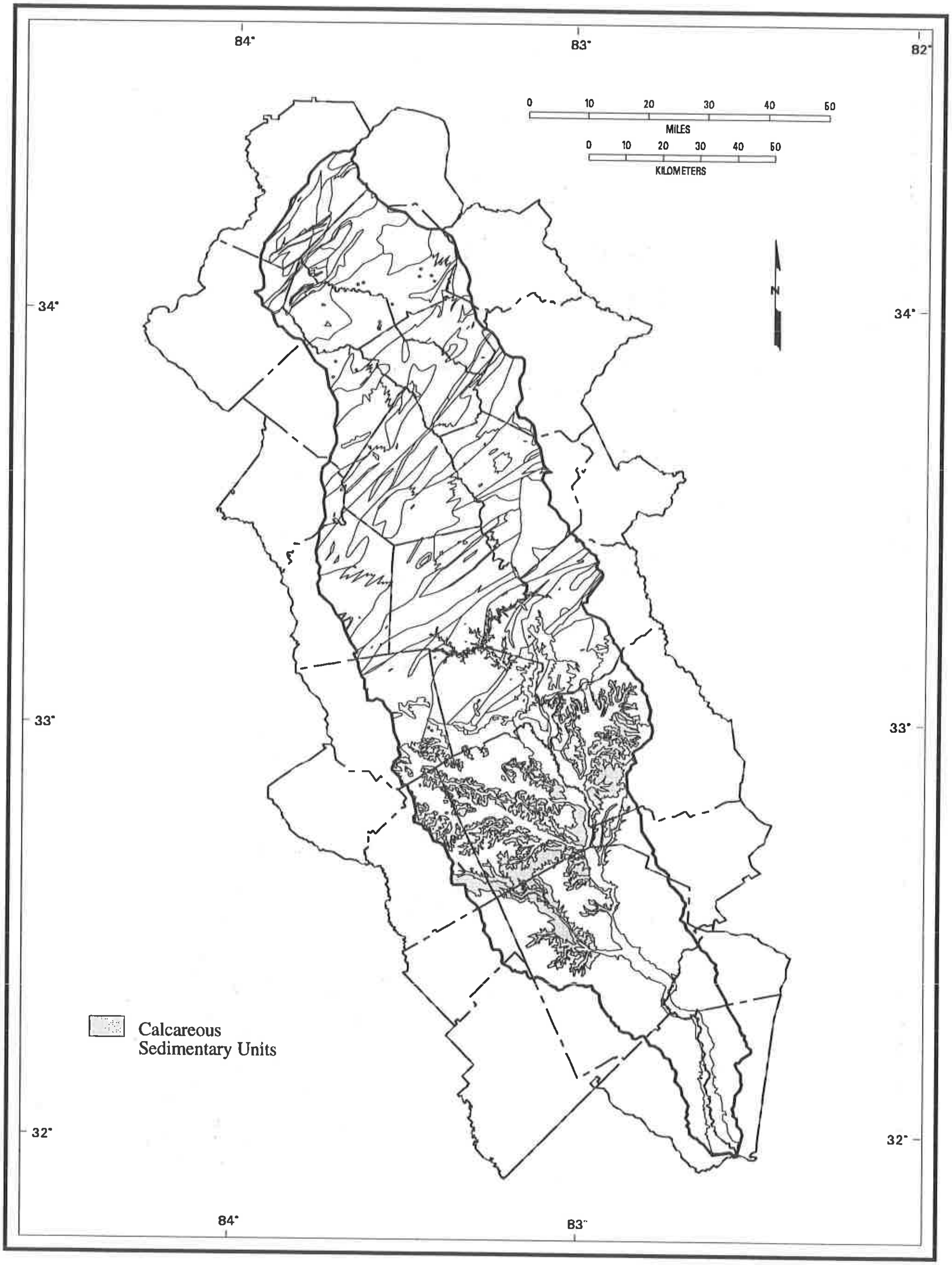

Figure 9. Coastal Plain Calcareous Sedimentary Units.

SURFICIAL GEOLOGY

PRECIPITATION

The amount of precipitation has a significant effect on the surficial geology, i.e. the weathering and erosion of rocks and soils, within Georgia. Annual precipitation can vary significantly in different parts of the ORB and from year to year. Precipitation may range from 30 to 40 inches up to 60 to 70 inches per year within the ORB (Kennedy, 1964). Average annual precipitation is about 45 inches in the southern part of the ORB, and that increases to 55 inches near the northern end of the ORB (Hodler and Schretter, 1986). Average pH of precipitation in Georgia has declined from 5.6 in 1955 to 4.5 in 1980 (Hodler and Schretter, 1986).

GEOMORPHOLOGY

As noted earlier, the Piedmont and Coastal Plain physiographic provinces cross and divide the ORB nearly in half. The Piedmont is characterized by broadly undulating topography. This surface is broken by low knobs or ridges and by valleys 17 to 100 meters deep (Thornbury, 1965). The Piedmont has been exposed to deep weathering over a long period. The boundary between the Piedmont and Coastal Plain is a conspicuous topographic break referred to as the Fall Line or Fall Zone. Within the ORB, the Coastal Plain is characterized by deeply dissected hilly terrain near the Fall Line in Washington, Wilkes, and Twiggs counties. The terrain becomes more gentle in the southern end of the ORB.

River basin geomorphology affects the residence time of water in the ground, the rate at which water moves through the basin, and the type of geological material through which water may acquire its chemical characteristics. Geomorphology of the ORB is controlled by rock composition, structural development, precipitation, weathering, and erosional history. Geomorphological studies of the ORB or surrounding areas are generally limited to the Piedmont. Studies of the Coastal Plain province are generally oriented toward paleo-shoreline development in that part of the Coastal Plain that lies beyond the extent of the ORB.

Piedmont geomorphology may be locally controlled by lithology and structure. More resistant lithologies such as granites, granitic gneisses and quartzites generally form hillier terrain with broad interfluvial areas and greater relief than do less resistant rocks such as amphibolites, schists and mafic rocks, which commonly form valleys or depressions, and have lower relief and narrower interfluvial areas. Rocks that are more intensely jointed, foliated, or strongly sheared, are less resistant to weathering and erosion and will have lower relief than other rocks of similar composition (Grant, 1968). The broad, generally flat surface of the Piedmont may be viewed as a former erosion surface or as the result of regionally uniform weathering, erosion, and uplift (Soller and Mills, 1991). Relief in the interfluvial areas is generally low, and increases with increasing proximity to major streams. Down-cutting by major streams in the Piedmont indicates a geologically recent lowering of stream baselevel. The Fall Line or Fall Zone is a sharp break in topography or stream gradient representing the transition from relatively resistant Piedmont rocks to less resistant Coastal Plain rocks (Figure 1).

Major rivers and streams in the ORB generally flow southeastward across the Piedmont and the Coastal Plain. Dominantly dendritic patterns in both provinces suggest that superposition of southeast-flowing master streams on the Piedmont during the Cretaceous Period may have controlled some present major drainage patterns (Staheli, 1976). The southeast pattern is also parallel to many of the brittle faults, fracture zones, and jointing in the Piedmont. Locally abrupt, right-angle bends in the drainage patterns within the Piedmont are caused by joints and changes in lithology.

The Coastal Plain may be divided into four topographic divisions:

1) Fall Line Hills
2) Louisville Plateau/Dougherty Plain
3) Tifton Upland
4) Coastal Terraces (LaForge et al., 1925).

The Coastal Terrace division lies beyond the extent of the ORB and will not be discussed here. The Tifton Upland is characterized by a gently rolling terrain with topographic relief generally about 30 meters. The Louisville Plateau and the Dougherty Plain extend eastward and westward from the same stretch of the Oconee River. The Louisville Plateau is characterized by red sandy soil and broad, gentle divides. The Dougherty Plain is similar in topography to the Louisville Plateau and is characterized by black loamy soil derived from limestone. Relief in these two areas is about 30 meters. The Fall Line Hills are characterized by steep slopes and narrow ridges. Sandy and clayey sedimentary units in this part of the stratigraphic section have been deeply dissected (LaForge et al., 1925).

SAPROLITE

Saprolite is weathered bedrock formed by intense chemical weathering that has removed as much as 60 percent of the rock mass with essentially no loss in volume (Soller and Mills, 1991). Average saprolite thickness in the Piedmont rarely exceeds 20 meters but the thickness can vary widely within a short distance. A considerable amount of ground water flows through the saprolite and recharges streams in the Piedmont. Saprolite will increase the storage and residence time of water in a basin. Ground water in saprolite may transport large amounts of dissolved metals. Saprolite is easily eroded when covering vegetation and soil are removed.

SURFICIAL DEPOSITS

TRANSPORTED REGOLITH

Colluvium deposits, perhaps of Pleistocene age, are best developed in the Inner Piedmont and are along valley sides and heads. Colluvium, which developed during slope failure of saprolite and overlying soils, generally consists of massive, poorly sorted, firm sandy clay, or clayey sand (Soller and Mills, 1991).

High-level alluvial terrace deposits are scattered along the sides of the principal drainages and occasionally on the divides throughout the Piedmont. These terraces may be pre-Quaternary in age. Terrace deposits that are found along the Coastal Plain drainages apparently were developed at the same time as the Quaternary barrier island complexes (Soller and Mills, 1991). Within the Coastal Plain, alluvial deposits (Qal in Table 1 and on the Geologic Map of Georgia, GGS, 1976) associated with the rivers draining the Piedmont are more voluminous and contain less mature minerals than alluvial deposits associated with streams and rivers that drain the Coastal Plain sediments and sedimentary rocks (Soller and Mills, 1991).

SOILS

Prolonged, intense weathering in Georgia forms clayey to sandy soils. Predominant soil types in the Piedmont are sandy loam clay to fine sandy loam. When covering vegetation is removed, soils are easily eroded and no longer protect the underlying saprolite from erosion. Directly south of the Fall Line, soils are loamy sand, sandy loam, and sand. Sandy loam and clay to sand soils cover the rest of the Coastal Plain sediments within the ORB (Kennedy, 1964). Erosion of soils produces sediment carried by streams and rivers. Clay and silt-sized particles are generally carried as suspended load. Sand-sized particles generally move as bedload, except during periods of high stream bedload capacity.

RECENT STREAM SEDIMENTATION

Erosion and sedimentation are major factors controlling stream sediment geochemistry and related hydrogeochemistry of streams within the ORB. Before the 1940's, severe erosion of agricultural land caused rapid deposition of sediments in headwater streams. Mobilization of this sediment into the main tributaries and reservoirs may have an impact on the water quality of the ORB.

Factors that contribute to erosion in the ORB include: heavy rainfall; high erosion susceptibility of deeply weathered Piedmont soils and underlying saprolite; increased cultivation of steep, more easily erodible slopes; and increased acreage of row crops and decreased acreage of forest land. The last two factors increase erosion at a geometric rate (Trimble, 1969). Severe erosion and stream sedimentation within the Georgia Piedmont during the 1800's to about 1940 are major factors that controlled composition of stream sediments in the ORB. Erosion of agricultural land and rapid sedimentation in formerly fertile stream valleys was initially noted in 1850 and documented by subsequent studies that began in the 1890's. This erosion and sedimentation affected the nature of the stream sediments, stream discharge, and stream bedload capacity (Trimble, 1969). During that period, row crops, particularly cotton and corn, were planted initially on the flatter upland surfaces and progressively on steeper slopes. By 1919, 40 percent of the land was under cultivation for cotton and corn (Trimble, 1969).

During this period of intense cultivation, the northern counties (Hall and Jackson) experienced the most severe erosion. Gwinnett, Clark, Oconee, Walton, and Jasper experienced moderately severe erosion, and the other counties of the ORB within the Georgia Piedmont experienced moderate erosion (Trimble, 1969). Besides the erosion, many stream valleys in Hall, Jackson, Gwinnett, Barrow, Walton, Oconee, Greene, and Morgan counties experienced very severe sedimentation. Clarke, Oglethorpe, Jasper, Newton, Jones, and Baldwin counties contain areas of severe sedimentation, while sections of Putnam, Green, and Oglethorpe counties experienced moderate sedimentation (Trimble, 1969). Very severe sedimentation is defined as filled stream channels, extensive overbank deposition, and extensive wet areas formed along streams. Moderate sedimentation is defined as extensive, but not continuous channel filling and overbank deposition, and occasional wet or damp areas along streams.

Filling of stream channels with sandy sediment caused much of the stream discharge to flow through the sand beneath the surface of the channel (Trimble, 1969). Rock-water reactions in sediments may be an important factor for determining stream hydrogeochemistry. Reduction in surface discharge decreased the stream's sediment load capacity and further increased deposition of sediment. When normal flow was too impeded by channel filling or blockage by debris, streams flowed onto the adjacent flood plain and into distributary channels (Trimble, 1969). This led to scouring of fertile topsoil and deposition of more sand on the flood plains. As streams left their normal channels, larger and heavier sediment was deposited adjacent to the stream channels as overbank deposits. The resulting development of natural levees led to ponding of water in adjacent flood plains as ponds and swamps. (Trimble, 1969). Lower order streams suffered greater sedimentation than higher order streams, as the sediment load capacity of the lower order streams is lower. Lower order streams are those with the fewest tributaries. Higher order streams are fed by numerous tributaries. Stream valleys are filled with one to several meters of sand and gravel (Woolsey, 1973; Trimble, 1969).

Beginning in the 1920's, a variety of factors led to stabilization of the land surface. Rapid decrease in row crops during the 1920's and 1930's was caused by devastation of cotton crops by the cotton boll weevil and a decrease in arable, fertile land caused by erosion and sedimentation. During the 1930's, soil conservation measures were implemented. Pasture and forested land gradually increased, so that by 1966, approximately 80 percent of the Piedmont within the ORB was in pasture or forest (Trimble, 1969).

Because of the raising of base level in sedimented, lower order streams relative to higher order streams, the lower order streams are re-establishing grade. As a result, stream gradients have increased, sediment load capacity has increased, and streams have incised into the stream valley fill. Sediments deposited in the upper reaches of the streams have been mobilized and are moving downstream to new depositional sites (Trimble, 1969). Principal depositional sites are major stream valleys and eventually major reservoirs in the ORB.

Although Trimble completed his study in 1969, the data are principally derived from observations during the 1800's and early 1900's. More recently, in 1958, concentrations of suspended sediment in the Oconee River near Greensboro ranged from 14 to 115 ppm, and at Milledgeville, concentrations ranged from 17 to 102 ppm (Kennedy, 1964). At Slash Creek, near McIntyre, concentrations of suspended sediment that ranged from 165 to 5300 ppm were attributed to clay processing plants in Gordon (Kennedy, 1964). In Commissioner Creek near Toomsboro, 32 to 62 ppm suspended sediment was linked to clay-processing plants and to discharge from Slash Creek, a tributary of Commissioner Creek. Suspended sediment concentration in the Oconee River near Mt.Vernon ranged from 28 to 62 ppm in 1958 and 1959 (Kennedy, 1964). Kennedy's data suggest that streams below dams carry less sediment because of deposition of that sediment in the ponds or reservoirs behind the dams. More suspended sediment is carried in Piedmont streams than in Coastal Plain streams because of factors that may include: more development and less vegetation in the Piedmont; higher energy streams in the Piedmont; and deposition of sediment behind dams in the Piedmont. Discharge does not appear to affect the amount of suspended sediment in Coastal Plain streams (Kennedy, 1964).

GEOCHEMISTRY

METALS IN STREAM SEDIMENTS

NATURAL SOURCES

Metals in stream sediments may be derived from a variety of sources and along a variety of paths. Erosion and transportation of metal-rich soils, gossans, or other metal-bearing weathering products associated with ore deposits may account for some metals in stream sediments. Weathering of rocks that are not associated with ore deposits may contain concentrations of metals in greater amounts than normal mean crustal abundances (Table 2). Other metals may be derived from mobilization of clastic sediments in hydromorphic anomalies associated with springs or seeps. Metals may also be directly deposited from solution onto the stream sediments.

A variety of mineral deposits are found within or in areas adjacent to the ORB. The principal mineral deposits within the ORB are nonmetallic and include: crushed stone, gravel, clay, dimension stone, feldspar, and mica. Olivine, asbestos, corundum, talc, vermiculite, kyanite, sillimanite, and various heavy minerals have been prospected or have undergone minor production. Metal deposits have been prospected or mined principally in areas adjacent to the ORB (Figure 10), but metal deposits may occur within the ORB.

Mineral deposits are commonly concentrated in elongate bands or "belts", which, in general, extend through the ORB and adjacent areas from southwest to northeast. These belts are generally associated with specific lithologies or groups of rock units. The principal mineral belts include: the Piedmont Monazite Belt, several strings of mafic and ultramafic intrusive igneous rocks, pegmatite districts, crushed and dimension stone granitic rock, the Carolina slate belt, and the Coastal Plain kaolin belt.

The Piedmont Monazite Belt contains heavy minerals that include phosphates, oxides, and silicates of thorium, uranium, cerium, dysprosium, europium, hafnium, lanthanum, lutetium, samarium, titanium, ytterbium, and zirconium. These minerals occur principally within granitic and intermediate/biotitic gneisses and migmatitic rocks north of the Towaliga Fault Zone. In Clarke County, an association of monazite and xenotime in stream sediments with a migmatite is suggested (Kennedy, 1973).

Mafic and ultramafic rocks generally contain disseminated metallic sulfides and oxides and may contain massive metallic sulfide and oxide deposits. This mineralization may contain copper, lead, zinc, nickel, iron, manganese, chromium, and cobalt, as well as sulfur, antimony, and arsenic. These rocks may be an important source of metals to local stream sediments, and they may also be natural sources of asbestos or asbestos-like material. Chemical weathering may concentrate copper, chromium, nickel, titanium, lead, zinc, iron, magnesium, and manganese. These metals are generally in greater concentrations in silicates in the ultramafic and mafic rock types than in more felsic rock types.

The large, sulfide-bearing Gladesville Norite and other poorly exposed intrusions that may be similar in character to the Gladesville Norite are found in Jasper and Putnam counties. Stream sediments in and near the Gladesville Norite contain anomalous concentrations of nickel (131 to 385 ppm), copper (96 to 227 ppm), and zinc (140 to 510 ppm) (Carpenter and Hughes, 1970). A core hole drilled within the northern end of the Gladesville Norite contained extensive intervals of disseminated sulfides. Segments of this core analyzed in 1970 contain 10 to 2020 ppm copper, 20 to 122 ppm zinc, and 25 to 1980 ppm nickel (unpublished GGS data). Reanalysis of this core confirms the high metal concentrations (Cocker, 1995a). Because nickel and copper concentrations in the stream sediments are comparable to nickel and copper concentrations in the drill core, the Gladesville Norite is likely to be an important source of those metals in the stream sediments. An area that contains high concentrations of zinc extends over much of the western part of the Carolina terrane in the ORB. The distribution of zinc is discussed in more detail later in this report. The extent of the high zinc area and the relatively low concentration of zinc in the drill core suggests that the source of the zinc in the stream sediments may not be the Gladesville Norite, but rather the mafic rocks (amphibolites or metabasalts) which are abundant in that part of the ORB.

Base- and precious-metal sulfide mineralization in the volcanic rocks of the Carolina slate belt within the Carolina terrane contains the following principal metals: gold, copper, lead, zinc, iron, manganese, and barium. Other metals that are generally associated with the type of mineralization in the Carolina slate belt include: arsenic, bismuth, cadmium, chromium, mercury, thallium, molybdenum, antimony, tellurium, vanadium, and silver (Tockman and Cherrywell, 1993; Maddry et al., 1993; Clark et al., 1993). The locations of known mineral deposits and high concentrations of base metals in the Carolina slate belt in eastern Georgia and southwestern South Carolina suggest mineralization may be found at the intersection of northeast-trending favorable lithologic horizons and northwest-trending structural elements. This pattern continues along strike of these northeast-trending favorable lithologic horizons into the ORB. (Maps for copper, nickel, zinc, iron, and manganese are included later in this report.)

Aluminous mica schists and quartzites may be metamorphosed alteration zones or mineralized zones associated with the volcanogenic sulfide deposits. These lithologies may contain gold, copper, lead, zinc, iron, manganese, barium, arsenic, bismuth, cadmium, chromium, mercury, thallium, molybdenum, antimony, tellurium, vanadium, and silver. The Carolina terrane contains many of these lithologies in the metavolcanic rock units (Figure 4).

During their formation, some lithologies may become enriched in metals. Examples of metal enrichment found in the ORB include heavy minerals and aluminum-rich kaolin. Heavy minerals that may contain thorium, uranium, cerium, dysprosium, europium, hafnium, lanthanum, lutetium, samarium, titanium, ytterbium, and zirconium are concentrated in apparent metasedimentary units in the Inner Piedmont. Mobilization of some of these minerals and their deposition resulted in their concentration in Cretaceous and Eocene sandy sediments south of the Fall Line. Repeated erosion, transportation, concentration and deposition of these heavy minerals also occurred in sandy beaches along the Georgia coast and on the continental shelf. Concentration of kaolinite, a product of extreme weathering in the Georgia Piedmont, resulted in the deposits of kaolin in the Cretaceous and Eocene sedimentary strata south of the Fall Line (Figure 10).

MODE OF OCCURRENCE

Naturally derived metals may occur in stream sediments in the following forms (Rose et al., 1979):

1) Primary ore minerals that are generally resistant to weathering and are dense enough to occur within the heavy mineral fraction of the stream sediment.

2) Eroded secondary minerals such as oxides and carbonates of heavy metals. Most of these are friable and become dispersed as suspended load.

3) Precipitated minerals such as iron and manganese oxides, carbonates, and silica that contain heavy metals incorporated into their structures.

4) Heavy metals may be adsorbed onto iron and manganese oxides, clay minerals, or organic matter.

5) Organic matter that incorporated the metals during growth.

Table 2. Median concentrations of elements in rocks.

Element	Ultramafic Rocks	Mafic Rocks	Granitic Rocks	Limestones	Sandstones	Shales	Average Crustal Rocks
Be[1,3]	0.x	0.x	3	0.x	0.x	3	2
Cr[1]	2,980	170	4.1	11	35	90	100
Co[1]	110	48	1	0.1	0.33	19	25
Cu[1]	42	72	12	5	10	42	50
Fe[1]	94,300	86,500	14,200	3,800	9,800	47,000	46,500
Pb[1]	1	4	18	5	10	25	10
Mg[3]	340,200	63,400	5,200	20,000	7,000	15,000	17,000
Mn[1,3]	1,040	1,500	390	1,100	170	850	1,000
Ni[1]	2,000	130	4.5	20	2	68	75
Na[1,3]	0.x	8,300	42,000	2,700	10,700	26,600	25,000
K[1]	34	830	42,000	2,700	10,700	26,600	25,000
Zn[1]	58	94	51	21	40	100	80
Th[1]	0.004	2.7	20	1.7	5.5	12	10
Ti[2,3]	3,000	9,000	2,300	400	0.x	4,600	4,400
U[1]	0.03	0.53	3.9	2.2	1.7	3.7	2.5
V[1]	40	250	44	20	20	130	150
As[1]	1.0	1.5	2.1	1.1	1.2	12	2

[1]Rose et al., 1979; [2]Levinson, 1974; [3]Wedepohl, 1978. Notes: Average crustal rocks are averages of granitic and mafic rocks (Rose et al., 1979). 0.x represents a range of values from 0.1 to 0.9 ppm.

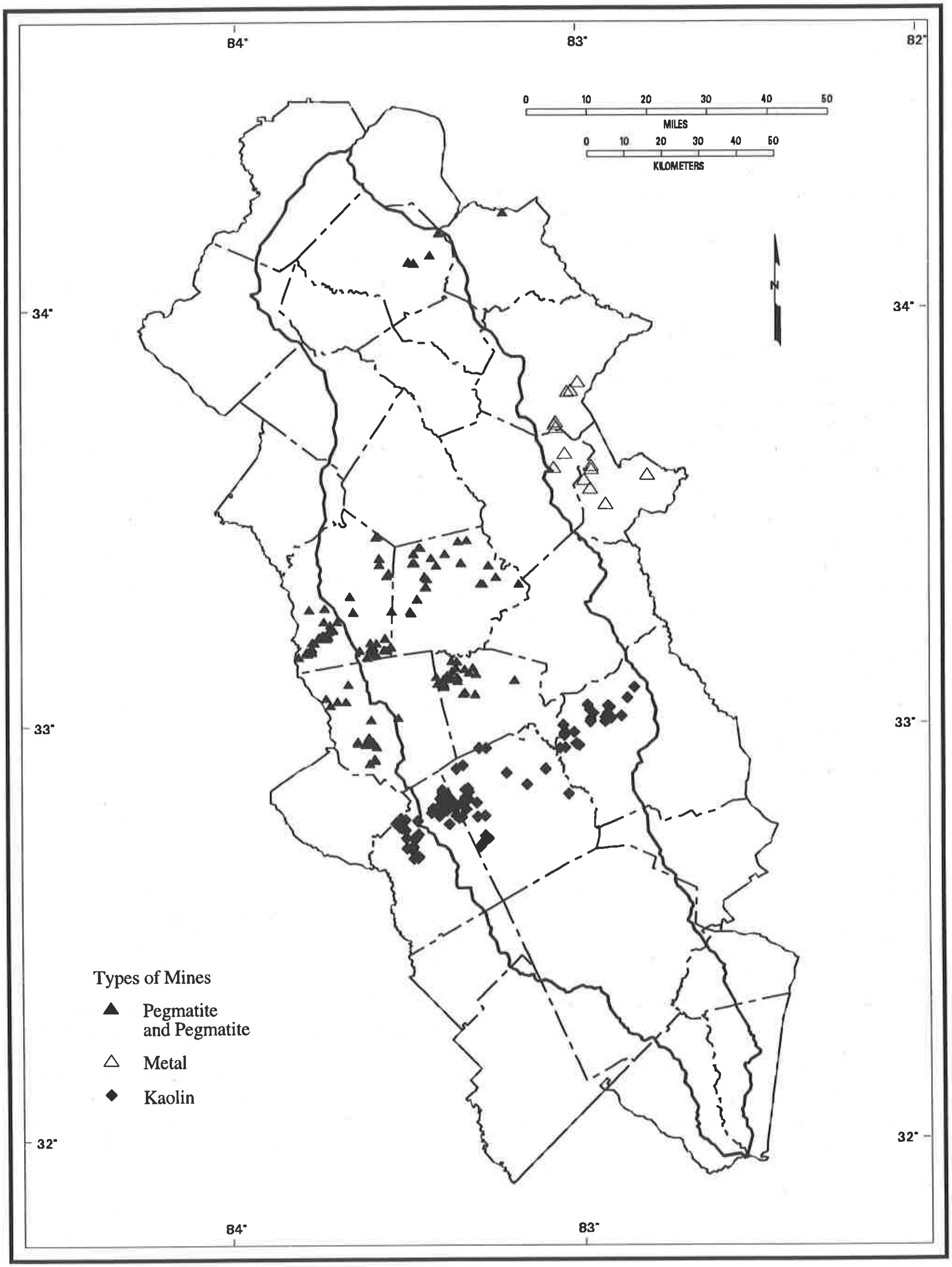

Figure 10. Mineralization and Mining Activity.

GEOCHEMICAL DATABASES FOR GEORGIA

Geochemical databases that exist for the ORB are quite varied in their scope, quality, size, and type of sample. Stream sediments, stream water, spring water, ground water, soils, saprolite, and rocks within the ORB have principally been analyzed within the last 40 years. Various types of state and federal geochemical surveys are best in overall quality, inclusiveness, and size. Other studies, including those associated with student theses and contract studies performed by universities or "independent" individuals, are generally focussed on petrologic or economic problems. These studies are generally limited in scope and of variable quality.

By far the most inclusive, largest, and best in quality of the geochemical databases for Georgia are those generated by the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) Program. Stream sediments, water wells, and streams were sampled for an area that includes the entire ORB. To a more limited extent, rock, soil, and saprolite samples were collected for the Athens 1°x2° quadrangle that crosses the middle of the ORB. One important aspect of the NURE databases is that the samples were collected within a short period (1976 to 1978), and thus provides a critical baseline for comparative studies during subsequent times. In addition, the samples were analyzed by the same laboratory, and by the same analytical procedures.

Other studies are limited in the number of sample sites, the size of the areas sampled, and the number of elements analyzed. Within the ORB other chemical data includes analyses of: three soil samples collected by the Environmental Protection Division (J. German, personal communication); water samples from 14 water quality monitoring stations of which 10 have some chemical data, and one has heavy metal analysis (Arnsdorff et al., 1991); and two soil samples collected by the USGS (Boerngen and Shacklette, 1981).

The USGS study of surficial materials in the United States was conducted between 1961 and 1975 and includes more than 1200 sites of which 33 are in Georgia. Data includes analyses for 46 elements. The analytical techniques are semiquantitative for some elements and quantitative for other elements in that survey (Boerngen and Shacklette, 1981).

NURE DATABASES FOR GEORGIA

The National Uranium Resource Evaluation (NURE) Program was established to evaluate domestic uranium resources in the continental United States and to identify areas favorable for uranium exploration. NURE geochemical data for the conterminous United States is presently available on CD-ROM from the U.S. Geological Survey (Hoffman and Buttleman, 1994). Files on that CD-ROM contain technical information concerning the various types of data collected in the field and obtained by laboratory analysis.

The program for 30 eastern states that included Georgia was directed by the U.S. Department of Energy's Savannah River Laboratory (SRL). The SRL contracted sample collection and trained the samplers in the sample collection and field analytical procedures. The SRL had the responsibility for the actual laboratory chemical analyses. Information regarding sample collection, preparation and analysis is briefly summarized in the following sections.

The NURE program consisted of five parts:

1) Hydrogeochemical and stream sediment reconnaissance survey,
2) Aerial radiometric survey,
3) Surface geologic investigations,
4) Drilling for geologic information, and
5) Geophysical technology.

NURE data are organized by individual 1°x2° National Topographic Map Series (NTMS) quadrangles. The ORB includes parts of the Greenville, Athens, Macon, and Waycross NTMS quadrangles.

SAMPLE COLLECTION AND FIELD MEASUREMENTS

Stream sediment and ground water samples were collected within Georgia during the period 1976 to 1978. Most samples were collected during July, August, and September of 1976. The next highest number of samples was collected during April 1978. The fewest number of samples was collected during April 1977. Rocks, saprolite, soil, drill cuttings, and drill core samples were collected in the Athens NTMS quadrangle from January to November 1978 (Lee, 1980). Sampling methods for the latter samples are not described by Lee (1980).

A minimum of five sediment sub-samples was composited from each stream site. Approximately 400 grams of sediment passing a 420 micrometer (U.S. Std. 40-mesh) screen were collected. A sample of one liter of filtered water was usually collected at each ground water site. Dissolved ions in individual water samples were concentrated on ion exchange resin for analysis (Ferguson, 1978).

Sample locations were marked on compilation maps, which were returned to SRL for determination of geographic coordinates. An electronic digitizer was used to measure, verify, and enter latitude and longitude data for each site into the SRL-NURE data base. These data were recorded to four decimal places, but are considered reliable to only three decimal places. Two to five percent of the sampled sites were routinely checked by SRL personnel or by a subcontractor to assure that reported field locations were accurate. More than 98 percent of the sampled sites were judged to be located as accurately as they could be plotted on county road maps. Most sites that were mapped incorrectly were within 300 meters of their correct locations (Ferguson, 1978).

Location data in the computerized NURE databases were used to generate point coverages of stream sediment sample sites and ground water sample sites for each NTMS quadrangle. Locations of the stream sediment samples are shown with respect to the stream hydrography (Figure 11). Correlation of the locations of most of the stream sediment sample locations with the streams in the hydrography database shows that the locations have been reasonably determined. Those samples that do not correspond with a stream segment on the hydrography database may be on a stream segment that is not included on that database. Locations of the ground water (well and spring) sample sites are displayed in Figure 12. Locations of the samples described by Lee (1980) are not documented except on maps in that publication. Sample locations to create a database and coverage for that study were scanned from those maps.

Nominal stream sediment sampling density in rural areas was one site per 13 square kilometers, for a total of 1413 sites per NTMS quadrangle. A total of 792 NURE stream sediment sample sites is within the ORB. With a total area of 13,820 km^2, this number of samples represents a ratio of one stream sediment sample site per 17 km^2. Nominal ground water sampling density was one site per 25 square kilometers, for a total of 731 sites. The number of ground water samples is 619. Sampling density for ground water samples is one site per 22 km^2 for the ORB. Distribution of stream sediment and ground water samples (Figures 11 and 12) should provide a representative picture of the ORB geochemistry.

ANALYTICAL METHODS

All analyses were done by automated neutron activation techniques (NAA). Sediment samples were dried at 105° C, sieved to <149 micrometers, blended, coned, and quartered. Half gram aliquots of the <149 micrometer material were packed in ultrapure polyethylene capsules for NAA analysis. The encapsulated samples were loaded into the NAA pneumatic system in batches of 25 that included one standard and one blank (Ferguson, 1978).

Each groundwater sample was treated with a 10-gram portion of ultrapure mixed cation-anion exchange resin that collected all dissolved ions from the water. The volumes of water ranged from 50 to 1000 milliliters depending upon sample conductivity. Resin samples were dried at 105°C and packed in ultrapure polyethylene capsules for analysis. Encapsulated samples, including one blank, were loaded in batches of 25 into the NAA pneumatic system. Standards were included in every fifth batch (Ferguson, 1978).

Analytical values were calculated using the measured neutron fluxes, irradiation times, decay times, counting times, published values for activation cross-section, decay constants and spectra for each element. Spectral lines that were least likely to interfere with each other were used to determine elemental concentrations. An internal calibration was based on strong gamma-ray peaks for key elements that were present in all the stream sediments. Standard reference materials and blanks were included in the analyses for periodic checks on the analyses. Standards included blanks, a Savannah River Laboratory sediment standard, Department of Energy intersite comparison materials, and external reference materials such as USGS and Spectroscopy Society of Canada standard rocks, and National Bureau of Standards (Ferguson, 1978).

Uranium was determined by counting neutrons emitted by induced fission products of U^{235} in the sample. Other elements were determined by computer reduction of gamma-ray spectra collected at intervals from a few seconds to about 10 days after irradiation (Ferguson, 1978).

Initial analyses of the stream sediment samples included a suite of elements (Table 3) for all the sample sites for which there was a sample. Conductivity, pH, alkalinity, and temperature were measured from water samples collected at each site. Analyses of the samples from many sample sites were conducted for a second suite of elements. For the ORB, this resulted in a "complete" set of stream sediment data for the Greenville and Athens quadrangles and an incomplete data set for the Macon and Waycross quadrangles (Table 3). Stream and ground-water hydrogeochemistry is "complete" for all four quadrangles. The term complete is relative, because some sample sites have no analyses or measurements, and a few elements are not included in any of the NURE data sets for Georgia. Extensive rock, as well as some soil and saprolite geochemical data are available only for the Athens quadrangle (Lee, 1980).

The GIS was used to identify each sample point that was geographically within each rock unit in Table 1. The number of sample sites was totaled for each rock unit and is included in Table 4. Percentages represented by each rock unit of the total number of sample sites for the ORB were also calculated (Table 4). Summary statistics were calculated for each element for the entire ORB (Table 5) and for the total number of samples within each rock unit (Table 6). Samples which were not analyzed for a particular element (e.g. Cu) were not included in the calculations of statistics for that element.

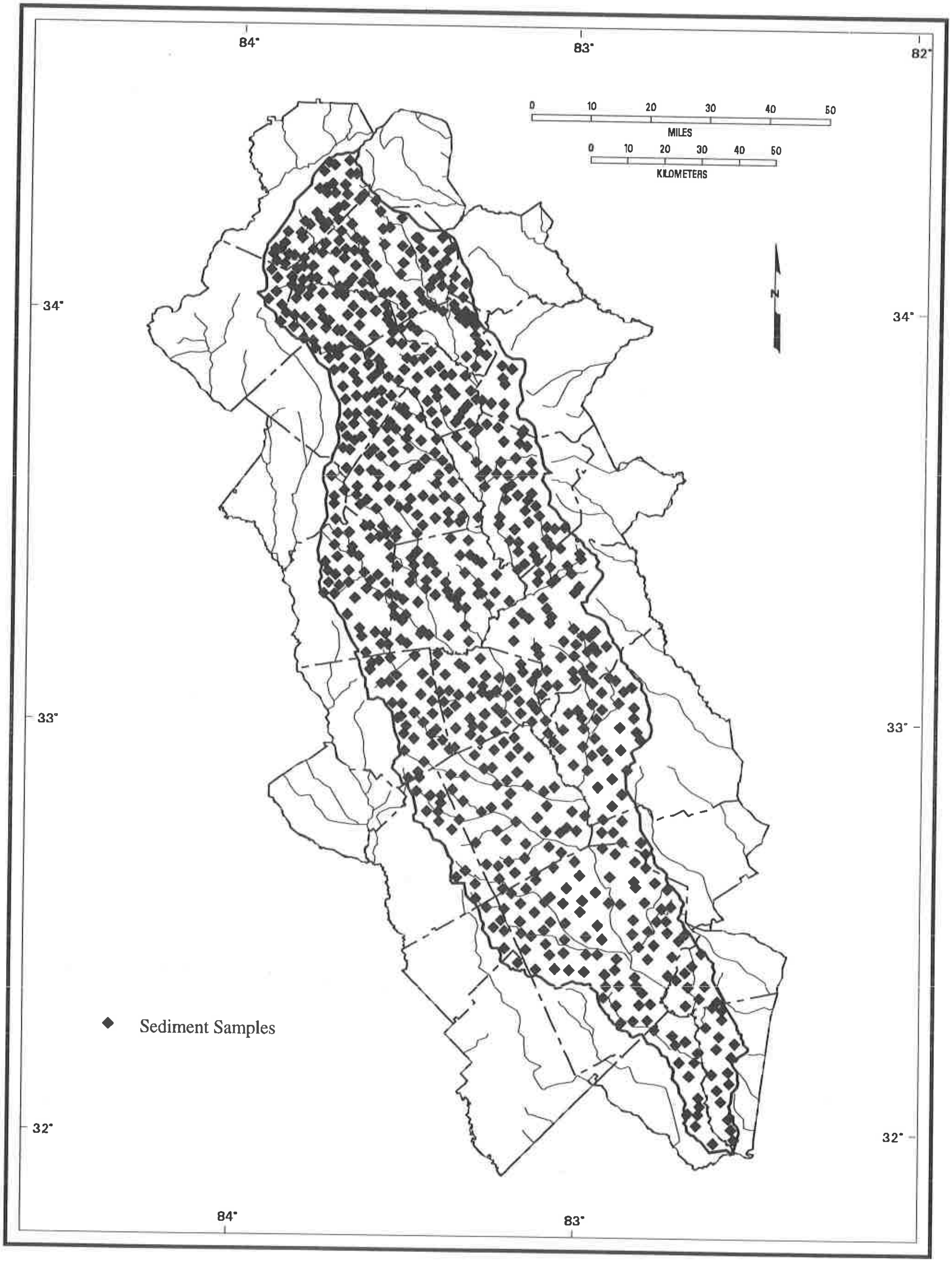

Figure 11. Stream Sediment Sample Locations.

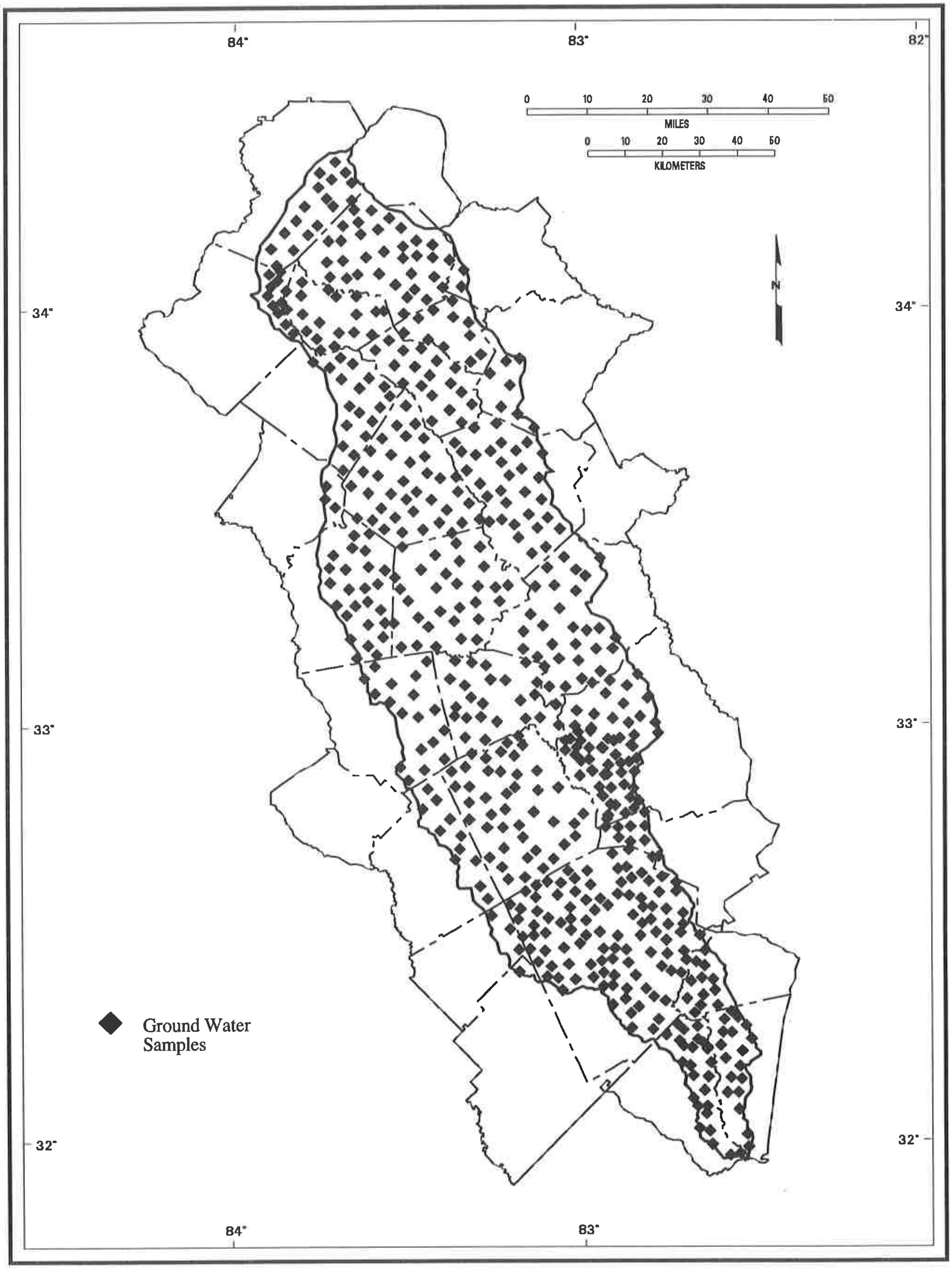

Figure 12. Ground Water Sample Locations.

Table 3. Elements analyzed in NURE stream sediment samples.

Analyzed in all databases	Not analyzed in Macon and Waycross databases
Al	Ag
Ce	Be
Dy	Co
Du	Cr
Fe	Cu
Hf	K
La	Li
Lu	Mg
Mn	Mo
Na	Nb
Sc	Ni
Th	P
Ti	Pb
U	Sn
V	Sr
Yb	W

Table 4. Number of stream sediment sample sites per rock unit.

Map Unit	Sample Sites	Percentage	Map Unit	Sample Sites	Percentage
fg1	70	8.9	pa2b	2	0.2
fg1a	72	9.2	pm2	3	0.4
fg2	6	0.8	pms1	2	0.2
fg3	93	11.8	pms3a	4	0.5
fg4	5	0.6	pms4	7	0.9
bg1	1	0.1	pms6a	3	0.4
bg2	5	0.6	pms6e	2	0.2
gg1	70	8.9	pms7	2	0.2
gg4	74	9.4	q1a	6	0.8
gg6	2	0.2	v4	22	2.8
gr1	5	0.6	um	1	0.1
gr1b	16	2.0	mp2	1	0.1
gr2a	11	1.4	c1	3	0.4
mm1	5	0.6	Tku	72	9.2
mm3	20	2.5	Ei	8	1.2
mm4	1	0.1	Etw	35	4.4
mm6	20	2.5	Eo	1	0.1
mm9	5	0.6	Os	8	1.0
pa2	3	0.4	Nu	110	14.0
pa2a	3	0.4	Qal	8	1.0

Table 5. Summary statistics for each element within the Oconee River Basin.

	Mean	Std. Deviation	Minimum[1]	Maximum
Water temp.(°C)	22	2.6	13.0	29.0
pH	6.8	0.8	4.3	10.7
Alkalinity (meq/L)	0.3	0.3	0.02	4.17
Conductivity (micromhos/cm)	58	39	13	750
Al (ppm)	39,151	29970	1,600	279,000
Be (ppm)	0.7	0.6	0.25	4.0
Co (ppm)	6	8	2.5	113
Cr (ppm)	3	5	2.5	75
Cu (ppm)	5	5	1	38
Fe (ppm)	35,816	38,861	2,500	443,000
Mg (ppm)	1,298	1,035	100	7,700
Mn (ppm)	1,083	1,381	20	13,550
Ni (ppm)	5	6	2.5	63
Pb (ppm)	8	23	5	525
Ti (ppm)	10,039	10,947	200	82,700
V (ppm)	80	95	10	970
Zn (ppm)	17	23	2.5	230

[1] Values of 2.5 ppm are half of detection limit of 5 ppm.

Table 6. Summary of rock unit geochemistry.

Rock	pH	Alkalinity	Conduct.	Al	Be	Co	Cr	Cu	Ni	Pb	Zn
Qal	6.7	0.23	49.00	19714	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nu	6.0	0.17	42.32	19053	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Os	6.7	0.27	47.88	13562	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Etw	6.8	0.32	70.31	10803	0.6	4.6	2.5	1.2	2.5	5.0	8.3
Eo	6.8	0.24	40.00	4600	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ei	6.3	0.17	34.71	729412	0.2	3.3	2.5	1.0	2.5	6.7	6.7
Tku	6.6	0.29	51.93	31694	0.7	7.0	2.7	2.2	4.9	8.1	15.8
gr1	7.3	0.46	61.50	31300	0.8	5.5	2.7	3.6	4.9	10.4	8.8
gr1b	7.4	0.59	63.69	71714	1.5	4.4	3.1	1.8	3.3	10.0	8.9
gr2a	7.1	0.26	49.27	41254	1.0	5.0	6.2	3.4	15.0	12.3	19.4
c1	7.0	0.35	89.33	45667	1.5	4.3	2.5	5.7	4.0	5.0	18.3
q1a	7.7	0.32	68.00	40180	0.9	6.8	3.8	8.5	6.8	95.0	41.2
pa2	6.9	0.20	35.67	45900	0.8	3.3	4.5	6.3	4.0	9.0	16.0
pa2a	7.2	0.20	36.67	57700	0.6	8.0	2.5	3.7	2.5	5.0	17.7
pa2b	7.0	0.35	49.00	35400	0.6	2.5	2.5	3.0	3.8	7.5	9.5
pms1	6.7	0.25	45.00	43550	1.0	15.0	5.0	7.0	6.8	18.5	53.0
pms3a	6.8	0.25	50.50	41225	0.6	5.8	2.5	8.2	4.6	7.5	17.2
pms4	6.9	0.23	51.86	33628	0.6	4.0	4.6	5.3	4.4	5.0	14.7
pms6a	7.1	0.25	48.33	31700	0.8	2.5	12.5	7.0	3.3	5.0	13.7
pms6e	7.5	0.79	104.50	47600	0.8	6.0	2.5	4.5	3.8	5.0	7.5
pms7	6.1	0.16	36.00	44550	2.5	2.5	2.5	4.5	2.5	5.0	12.5
pm2	7.2	0.36	68.33	46167	1.0	3.3	22.7	9.3	5.2	6.7	21.0
v4	8.0	0.29	52.95	21859	0.6	3.5	5.9	2.2	5.8	6.8	8.4
gg1	6.8	0.28	50.37	51038	1.0	5.3	3.7	6.0	5.5	8.8	24.5
gg4	7.4	0.54	83.26	42687	0.9	9.9	4.3	7.2	6.3	10.3	29.6
gg6	7.0	0.66	93.00	41450	0.5	2.5	2.5	5.0	5.0	5.0	23.0
fg1	7.1	0.32	53.10	59151	1.0	8.5	4.3	7.0	6.9	10.8	23.3
fg1a	7.4	0.56	80.33	54403	1.0	11.8	3.3	7.8	7.4	12.1	30.8
fg2	8.2	0.37	55.50	33640	0.9	7.2	2.5	5.5	8.3	7.8	20.7
fg3	7.0	0.26	50.16	49209	1.1	6.5	6.0	7.6	5.7	9.9	22.0
fg4	7.7	0.49	82.80	35900	1.1	8.6	3.0	6.2	6.3	8.4	20.6
bg1	7.5	0.40	68.00	70400	1.5	9.0	2.5	9.0	14.0	5.0	25.0
bg2	6.8	0.28	50.00	52300	1.6	6.2	2.5	5.4	4.4	7.0	18.2
mm1	7.1	0.17	46.00	34520	1.2	3.0	7.1	4.6	3.0	5.0	10.8
mm3	7.0	0.37	62.55	72310	1.6	14.8	2.8	9.2	7.8	12.2	38.6
mm4	7.4	0.36	49.00	49900	1.0	8.0	6.0	9.0	14.0	17.0	44.0
mm6	7.9	0.41	84.70	51260	1.2	10.5	2.7	7.4	14.8	11.8	42.7
mm9	7.2	0.21	43.60	33300	0.8	8.5	2.5	6.2	8.2	8.0	18.8
mp2	7.0	0.66	89.00	37500	0.5	11.0	2.5	8.0	6.0	5.0	23.0
um	7.2	0.96	112.00	55400	1.5	18.0	7.0	18.0	28.0	5.0	40.0

IDENTIFICATION OF DATA GAPS

A better analysis of the background geochemistry of the ORB could be made if some important data were available. Important data gaps in the NURE stream sediment data base include: lack of analyses for some primary pollutant metals in all samples, lack of a complete suite of metal analyses for certain quadrangles, lack of background geochemical analyses for rocks within the basin, no distinction between total metal versus extractable metals in the analyses, no data on sediment grain-size distributions, and no data on size-fraction chemical analysis.

Analyses for several primary pollutant metals are lacking for all the NURE stream sediment samples. Databases for the Greenville, Athens, Macon and Waycross 1°x2° quadrangles do not include arsenic, antimony, barium, thallium, and mercury.

Databases of the NURE stream sediment samples for the Macon and Waycross 1°x2° quadrangles do not include silver, beryllium, cobalt, chromium, copper, lithium, molybdenum, nickel, phosphorous, lead, and zinc. Because these elements are only included in the Greenville and Athens databases, a complete basin analysis is not possible for these metals.

Metal content of most rocks within the ORB is undocumented. High metal concentrations in some stream sediment analyses suggest that unknown sources for these metals exist within the ORB. The sources of these metals should be identified.

Stream sediments were only analyzed for total metal content. No distinction between immobile elements versus mobile and semi-mobile elements was made during analysis by the SRL or other laboratories. Cold extraction analytical techniques used with total metal analyses may indicate the potential mobility of the metals.

The NURE databases do not contain information regarding grain-size distributions, nor does it contain size-fraction chemical analyses. Differences in these factors between samples may strongly influence chemical analysis (Horowitz, 1991). This information was beyond the scope of the NURE program, but should be a consideration for further stream sediment geochemical programs.

STREAM HYDROGEOCHEMISTRY

Field analyses of stream water in the NURE database provide measurements of pH, conductivity, alkalinity, and water temperature. A knowledge of the basic parameters of stream hydrogeochemistry is important to understanding the results and effectiveness of a water sampling program.

Within the ORB, regional trends in relief, stream pH, stream sediment iron and manganese, as well as organic-rich environments are important factors that will affect the water chemistry. Along with its generally humid climate, regions in the ORB with moderate to strong relief and low pH will provide the most favorable conditions for water sampling (Rose et al., 1979). Streams in regions with alkaline, calcareous, ferruginous, and organic-rich environments reduce the effectiveness of water sampling (Rose et al., 1979).

ACIDITY (pH)

An earlier study of water quality, which included 25 measurements from 11 stations within the ORB, showed that the pH range was 6.2 to 7.0 (Cherry, 1961). Differences in the pH of stream water were noted for the Piedmont, Upper Coastal Plain, and Lower Coastal Plain rocks in the ORB (Cherry, 1961).

NURE hydrochemical data provide more detailed information of stream pH. Although the mean pH (6.8) of the 792 stream samples in the ORB is slightly acidic, pH varies considerably within different areas of the Piedmont and within the Coastal Plain (Figure 13). These differences can generally be directly attributed to the principal type of host rock in which the stream pH was measured. The ORB cuts across five zones in which the pH changes from acidic to alkaline. Two of these zones roughly divide the Piedmont in half. These changes may be related directly to differences in tectonostratigraphic/lithologic terranes. The other three may be related to progressively younger sediments in the Coastal Plain.

Two groups of streams or zones within the Coastal Plain (Figure 13) have the lowest pH (4.4 to 5.6) in the basin. One zone of low pH streams extends along the northwestern edge of Wilkinson, Twiggs, and Washington counties, and the other is located in Laurens, Treutlen, Wheeler, and Montgomery counties. These two zones are underlain by sands, clays, and gravels of Cretaceous to Eocene age rocks and the Miocene age Altamaha Formation respectively. Coastal Plain rock units in the GIS geology database (Table 1) include those with the lowest mean pH (Table 6):

Nu (6.0)	Ei (6.3)	TKu (6.6)	Os (6.7)
Qal (6.7)	Etw (6.8)	Eo (6.8).	

A group of streams with low pH (5.6 to 6.8) is found in the northern half of the Inner Piedmont terrane (Figure 13) principally in Gwinnett, Barrow, and Clarke counties. Ground water, which has a pH of 4.6 to 5.6 in that area, may influence the stream samples. This area is underlain principally by granitic and biotitic gneisses, but the low pH in the surface and ground water cannot be directly related to a particular rock unit or to known mineralization in that area. Granitic gneisses in this area are not distinguishable from other granitic gneisses in other parts of the ORB where the waters are more neutral.

Within the Coastal Plain, a zone (Figure 13) of more alkaline streams separates the two zones of more acidic streams. Stream pH measurements range from 6.7 to 8.1 in a band approximately 25 km wide which runs along the border between Wilkinson and Laurens counties and into Johnson County. This area is underlain by carbonates of the Suwanee Limestone and the Ocala Limestone and calcareous clays of the Twiggs Clay. The carbonate minerals in these units appear to buffer the stream water.

A broad zone of neutral to alkaline streams, which is found in Morgan, Oglethorpe, and Greene counties and south to Jones, Baldwin, and Hancock counties, is underlain by metavolcanics and metavolcaniclastic rocks of the Carolina terrane. The neutral to alkaline nature of the water may be caused by weathering of carbonates in the rocks and/or by hydrolysis of iron-magnesium silicate minerals.

Several groups of more alkaline streams (pH >8) in Morgan, Baldwin, and Hancock counties (Figure 13) occur along the northern and southern edge of this zone of neutral to alkaline streams. A map of pH in eastern Georgia and adjacent areas of South Carolina (unpublished GGS map) shows that these more alkaline streams are clustered around the periphery of the area of neutral to alkaline streams within the Carolina terrane.

Highest pH measurements (9.2 to 10.7) are recorded for streams in southeastern Baldwin county and adjacent parts of southwestern Hancock County. NURE ground water data for Baldwin County shows a minimum pH of 7.8. Wells with pH values of 8.7 to 9.4 are spatially related to a band of streams with pH's greater than 8 that trends northeasterly across this county. The underlying rock unit, mm6 (Table 1), consists predominantly of hornblende gneiss (Figure 6).

Rock units (Table 1) which contain streams with the lowest mean pH (Table 6) include:

Nu (6.0)   pms7 (6.1)   Ei (6.3)
TKu (6.6)   Os (6.7)   pms1 (6.7)
Qal (6.7)   Etw (6.8)   Eo (6.8)
bg2 (6.8)   gg1 (6.8)   pms3a (6.8)
pa2 (6.9)   fg3 (7.0)   mm3 (7.0).

These rock units are primarily Coastal Plain sandy sediments, granitic gneiss, and muscovite schists (Table 1). Rock units which contain streams with the highest mean pH include: fg2 (8.2), v4 (8.0), and mm6 (8.0). These rock units contain undifferentiated biotite gneiss and mafic metavolcanic rocks (Table 1).

Water samples collected near anthropogenic activities that might contaminate the samples do not exhibit any apparent trend in pH. Although most of the other pH measurements were near 7, a pH of 9.2 was recorded near a waste disposal site where a stream sediment sample contained 525 ppm lead and 125 ppm zinc. The high pH may prevent solution of lead, zinc, and other heavy metals in those stream sediments.

CONDUCTIVITY

Conductivity is a measure of the ability of water to conduct an electrical current and is measured in micromhos/cm. Water will conduct more electricity if it contains more ions to carry an electrical charge. The concentration of dissolved ions in the water controls the conductivity of water. The dissolved ion concentrations may be estimated by multiplying conductivity by a factor of 0.55 to 0.75 (Driscoll, 1986). Water with a high specific conductivity will have a high electrochemical activity. High electrochemical activity facilitates the dissolution of iron-bearing materials such as naturally occurring silicates, oxides, sulfides, and man-made metallic objects.

Conductivities vary from 16 to 750 micromhos/cm within different areas of the Piedmont and within the Coastal Plain of the ORB (Figures 3 and 14). The ORB cuts across five regions in which the conductivities are markedly different. Two regions roughly divide the Piedmont in half, and they may be related directly to different tectonostratigraphic/ lithologic terranes. The other three regions are related to sedimentary units in the Coastal Plain. These regions are generally similar in extent to the regions of different pH. Some differences in the size and extent of these regions may be due to actual physiochemical differences, measurement of different hydrogeochemical parameters, or an artifact in the selection of the contour levels.

Within much of the northern third of the ORB (Figure 14), conductivities are between 20 and 50 micromhos/cm. Smaller groups of streams within this region have higher conductivities of 50 to 119 micromhos/cm. The largest of these groups is part of an irregular band that extends from Johnson, Hall, and Banks counties northeastward into South Carolina. This region of stream conductivity extends as far to the northwest as the Brevard Fault Zone and to the southeast as far as the Towaliga Fault Zone, and is generally coincident with a band of streams with a pH of 7 to 8.

Streams in the Piedmont south of the Towaliga Fault Zone (Figures 3 and 14) have high conductivities (>50 micromhos/cm). Streams within this region also have a high pH. The region of high pH streams extends about 20 km to the north of the region of high conductivity streams. Streams with pH greater than 8 that are found along the northern edge of the high pH region are located north of this region of high conductivity. Smaller groups of streams with higher conductivity (>100 micromhos/cm) are located within this region of high conductivity streams.

These smaller groups of streams with higher conductivity lie along two northeast-trending bands (Figure 14). One band that extends from Jasper and Monroe counties on the southwest through Putnam, Greene, and Taliaferro continues into Wilkes and Lincoln counties. A less prominent band extends from Bibb County through Jones and Baldwin counties and may continue into Warren, McDuffie, Columbia, and Richmond counties. These bands of higher conductivity occur in a variety of rock types as depicted on the Geologic Map of Georgia (GGS, 1976). While the northern bands do not correlate with streams with a pH greater than 8, the southern bands do show a spatial correlation to those areas on the map of pH (Figure 13). The northern bands generally correlate with mafic rocks such as amphibolites and pyroxenites. Further to the northeast and outside the ORB, the smaller areas of higher conductivity are spatially correlative with mafic rocks such as gabbros and diorites as depicted on the Geologic Map of Georgia (GGS, 1976) and on the geologic map of Allard and Whitney (1994). These correlations suggest that the zones of higher conductivity reflect a greater degree of dissolved solids from mafic rocks such as gabbro and diorite.

This region (Figure 14) of high conductivity streams (>50 micromhos/cm) is spatially coincident with the Carolina terrane (Figure 3). Rocks within the Carolina terrane are generally less resistant to weathering because of their lower metamorphic grade and volcanic-derived composition than high-grade, metasedimentary rocks within the Inner Piedmont. Streams within the Carolina terrane will thus contain higher concentrations of dissolved material, and stream conductivities will be higher. This region of higher conductivity streams corresponds to a region containing stream sediments with high iron and sodium content. Elements such as sodium, calcium, magnesium, and potassium often contribute to the conductivity.

Streams in the northern and southern part of the Coastal Plain with conductivities of 19 to 49 micromhos/cm are separated by a group of streams with conductivities greater than 50 micromhos/cm. The northern and southern streams are roughly coincident with sandy sediments and clays and generally correspond to the groups of low pH streams noted earlier in this report. Most conductivities were between 50 and 100 micromhos/cm with a few as high as 140 micromhos/cm in Twiggs, Wilkinson, Laurens, Johnson, and Washington counties. This group of streams is roughly coincident with calcareous clays and limestones and an irregular group of streams with a pH of 7 to 8.1. An exceptionally high conductivity of 750 micromhos/cm was measured in west central Washington County near Sandersville (Figure 14) may be anthropogenic.

Rock units (Table 1) which contain streams with the lowest mean conductivities (micromhos/cm) (Table 6) include:

Ei (35) pa2 (36) pms7 (36) pa2a (37).

The rock unit with the lowest conductivity is a Coastal Plain sandy sediment. Other rock units are high metamorphic grade sillimanite schists that may be relatively stable under chemical weathering conditions. Rock units which contain streams with the highest mean conductivity (micromhos/cm) include:

um (112) pms6e (104) gg6 (93)
c1 (89) mp2 (89).

These rock units are only represented by one to three samples. The next highest group includes:

mm6 (85) gg4 (83) fg4 (83) fg1a (80).

These rock units are represented by 20, 74, 5, and 72 samples, respectively. Rock units which contain streams with the higher conductivities are predominantly ultramafic and mafic rocks, and biotite gneisses with amphibolites.

Conductivities of streams near several anthropogenic activities suggest possible contamination. The stream near the urban site at Milledgeville had a conductivity of 173 micromhos/cm. Seven streams near waste disposal sites had conductivities between 64 and 180 micromhos/cm. Streams near two mining sites in the Piedmont had conductivities of 95 and 102 micromhos/cm. The mean conductivity is 58 micromhos/cm for streams near farming activities and is 55 micromhos/cm for streams near no recorded activity.

ALKALINITY

Alkalinity is a measure of the acid neutralizing capacity of water; units are in terms of milliequivalents of acid per liter (meq/L). Alkalinities in the ORB generally show a positive correlation with pH up to a pH of about 7.7, and a general lack of correlation above a pH of 7.7 (Figure 15). A good correlation with pH may indicate that carbonates may have a stronger influence than silicate hydrolysis on alkalinity values below a pH of about 7.7. The reaction of carbonates with acidic water proceeds at a faster rate than that of silicates. The lack of correlation above pH of about 7.7 may reflect a greater influence of silicate hydrolysis on pH as the silicate reactions are slower.

As with pH and conductivity, the ORB cuts across five general regions of different stream alkalinities (Figure 16). These regions of different alkalinities are generally similar to those described for pH and conductivity.

In the northern third of the ORB, corresponding to the area underlain by the Inner Piedmont, conductivities are generally less than 0.3 meq/L. Small areas with alkalinities greater than 0.3 meq/L are scattered within Gwinnett, Hall, Jackson, Oconee, Walton, and Morgan counties and are coincident with areas of conductivity greater than 50 micromhos/cm.

A broad band of streams with alkalinities greater than 0.3 meq/L extends across the ORB from Jasper, Morgan, Greene, and Oglethorpe counties on the north to Jones, Baldwin, and Hancock counties on the south (Figure 16). The broad band of higher alkalinity streams is coincident with the metavolcanic rocks of the Carolina terrane. Within this band of higher alkalinity are several smaller groups of streams with conductivities exceeding 0.9 meq/L. These groups of streams are very similar in extent to the areas noted above where conductivities exceed 0.5 micromhos/cm. Streams with the highest alkalinities, up to 4.17 meq/L, are in central Greene County and in the northern end of the Siloam Granite (Figure 5). The smaller group of streams with higher alkalinity are generally coincident with mafic rocks such as gabbros and diorites. These geological-geochemical relationships are also observed to the northeast in other parts of the Carolina terrane.

In the Coastal Plain, a band of streams with alkalinities greater than 0.3 meq/L extends through Twiggs, Wilkinson, Laurens, Johnson, and Washington counties and separates two groups of streams with alkalinities generally less than 0.3 meq/L (Figure 16). This band of high alkalinity streams is spatially coincident with a band of high conductivity streams (Figure 14) and is believed to be related to the calcareous clays and limestones (Figure 9) which occur in this region. A small group of streams with alkalinities up to 0.92 meq/L in central Washington County is coincident with the 750 micromhos/cm conductivity near Sandersville. The other parts of the Coastal Plain within the ORB with low alkalinities are spatially coincident with sandy sediments and clays of undifferentiated Cretaceous and Tertiary sediments in the northern part of the Coastal Plain and Neogene undifferentiated (actually Miocene) sediments in the southern portion of the Coastal Plain (Figure 8).

Rock units (Table 1) which contain streams with the lowest mean alkalinity (meq/L) (Table 6) include:

pms7 (0.16) Ei (0.17) mm1 (0.17)
Nu (0.17) pa2 (0.20) pa2a (0.20).

Except for Nu, these rock units are the same as those with the lowest conductivities. The Nu rock unit consists of sandy sediments in the southernmost part of the ORB. Rock units which contain streams with the highest mean alkalinity include:

um (0.96) pms6e (0.79) mp2 (0.66) gg6 (0.66).

This group is only represented by one or two samples per rock type. The next highest group includes:

gr1b (0.59) fg1a (0.56) gg4 (0.54),

which are represented by 16, 72, and 74 samples, respectively. These rock units are ultramafic and mafic lithologies or gneisses with a component of amphibolites.

Alkalinities of some streams may be affected by nearby anthropogenic activities. Mean alkalinities of streams near farming activities and no perceptible anthropogenic activities are about 0.29 meq/L and 0.34 meq/L, respectively. Mean alkalinity values of samples collected near "other industrial" activities, waste disposal sites and sewage activity are 0.18 meq/L and 0.44 meq/L, respectively.

WATER TEMPERATURE

Recorded temperatures of stream water during sample collection range from 13° to 29° C with most of the temperatures in the range 16° to 25°C. The percentage of samples in the 13° to 15° range is 7.9, and in the 26° to 29° range it is 7.7. Mean temperature is 21.5°C.

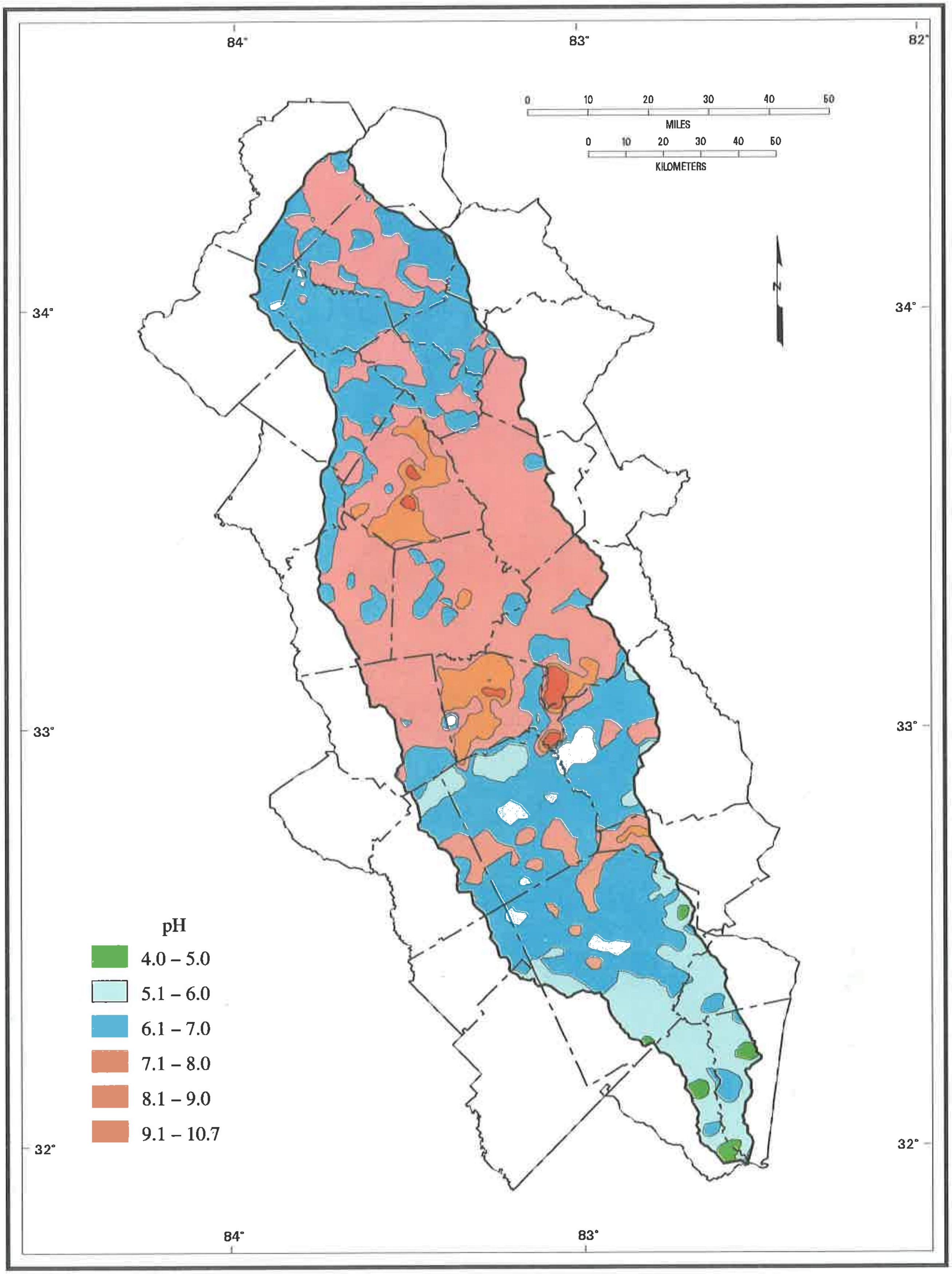

Figure 13. pH of Stream Water.

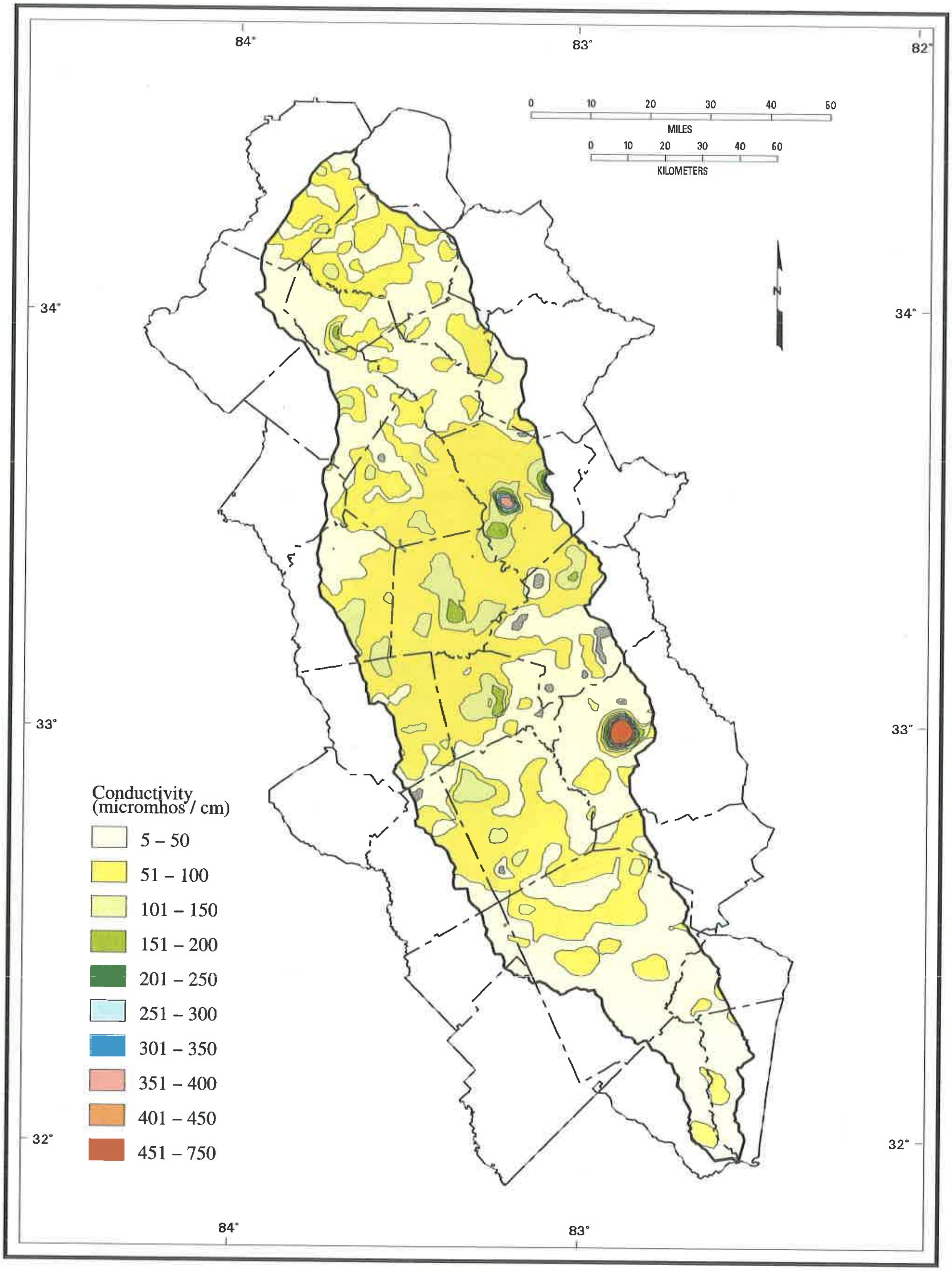

Figure 14. Conductivity of Stream Water.

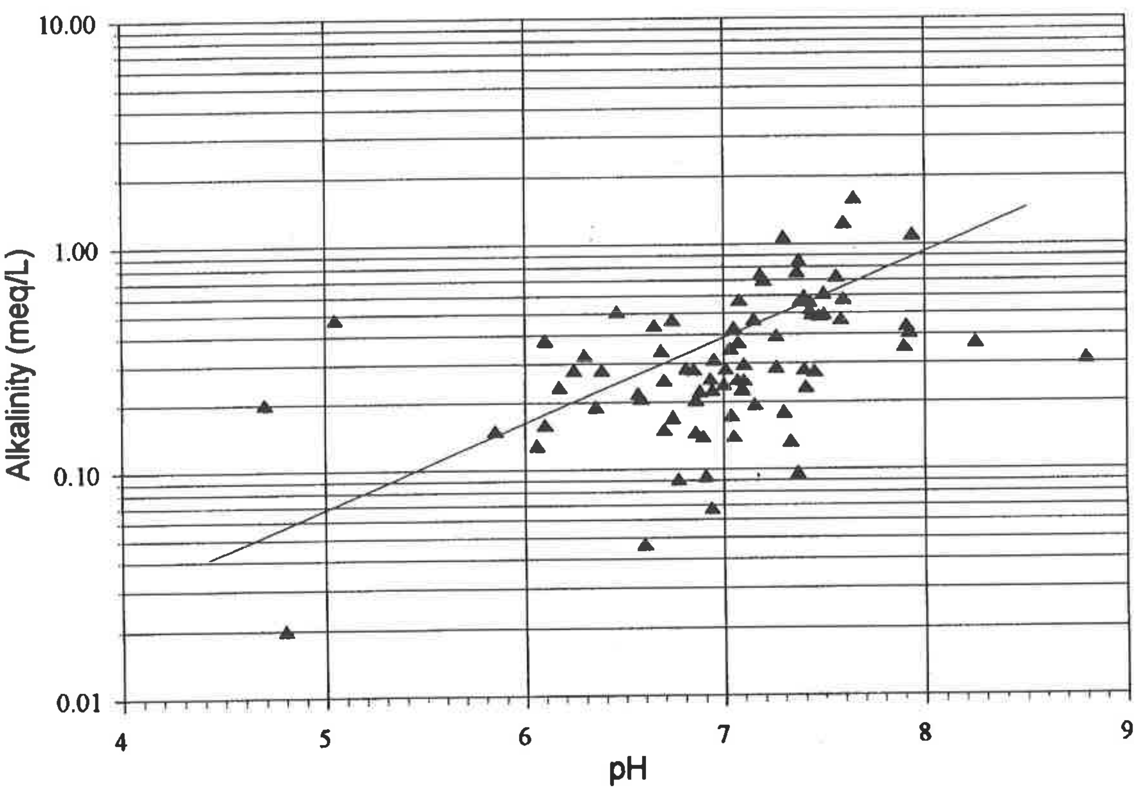

Figure 15. Scatter plot of pH versus Alkalinity.

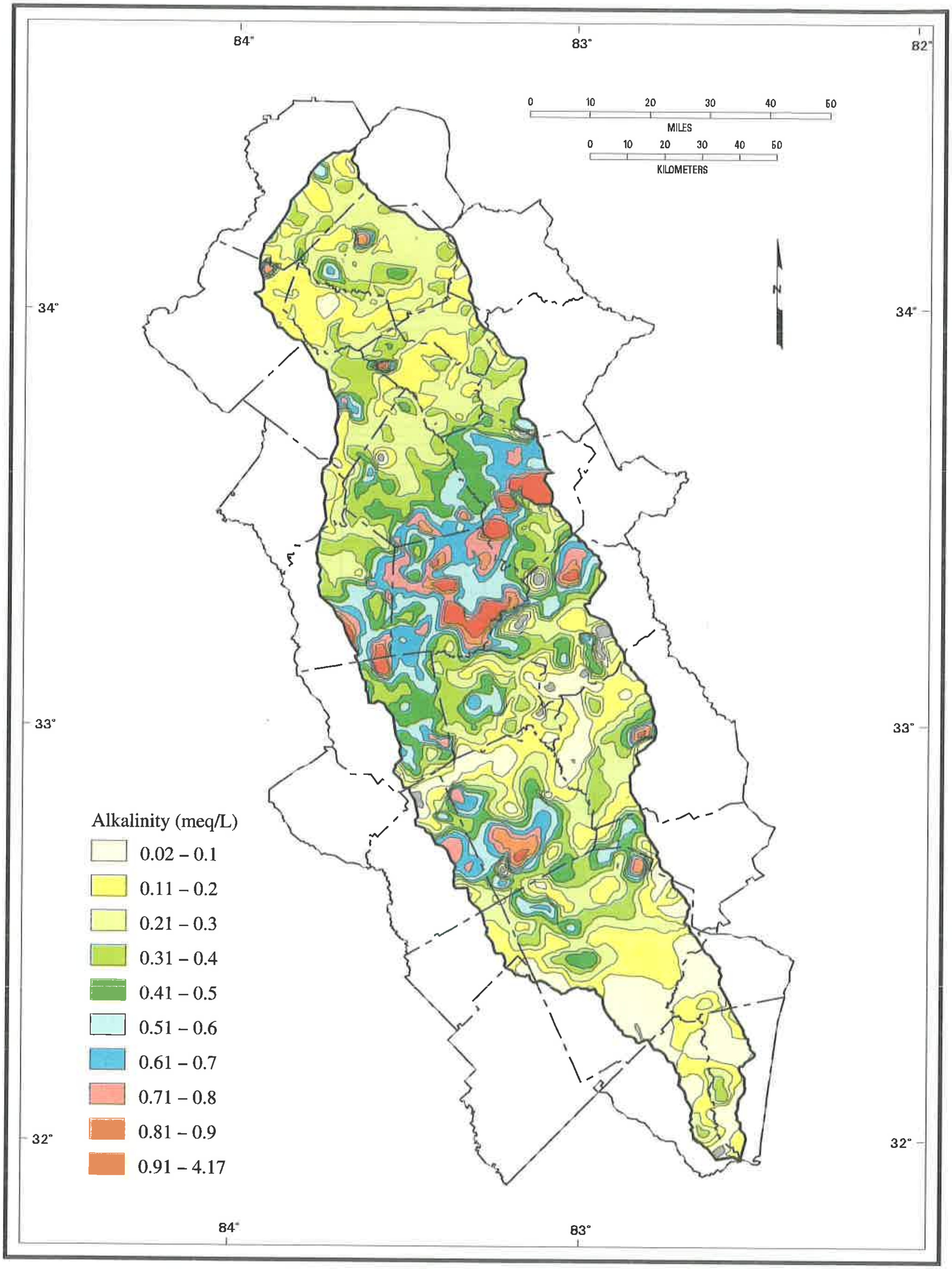

Figure 16. Alkalinity of Stream Water.

DISCUSSION OF STREAM HYDROGEOCHEMISTRY

The ORB cuts across five regions that differ in pH, conductivity and alkalinity. Two regions of higher pH (>7), higher conductivity (> 50 micromhos/cm), and higher alkalinity (> 0.3 meq/L) are coincident with each other and separate regions of lower pH, lower conductivity, and lower alkalinity (Figures 13, 14, and 16). These regions are generally correlative with regional geologic and related geochemical trends. The regions of higher conductivity and higher alkalinity display a much closer relationship to the regional geologic and geochemical trends than does pH.

Acidity of ground water and surface water, as measured by its pH, is strongly influenced by: the composition of rocks and sediments with which the water is in contact, the permeability of the rock or sediments, the amount of organic activity, the flow rate of the ground water or surface water, temperature, and precipitation. Weathering of sulfides will cause a decrease in pH while weathering of carbonates and silicates will increase the pH. Carbonates and silicates buffer the naturally weak acidity of rain water. Also, certain types of contamination may also influence the pH.

The composition of rocks and sediments influences the pH of water during chemical weathering. Major factors that facilitate chemical weathering include: solution, hydration, oxidation, and hydrolysis. Solution and hydrolysis of carbonates and hydrolysis of silicates may be the principal factors controlling the pH of surface waters in the ORB. Reaction of carbonic acid (H_2CO_3) with carbonates produces bicarbonate (HCO_3^-). Hydrolysis of carbonates and silicates involves a reaction with water to form HCO_3^- or H_4SiO_4, which are weaker acids than water. Hydrolysis of silicates may involve carbonic acid besides water. The solution or hydrolysis of carbonates and hydrolysis of silicates produces a solution that is more basic than it was before these reactions. Continued reaction of the solution with the silicates or carbonates eventually results in an alkaline solution.

Carbonate-bearing rocks such as limestones significantly reduce the acidity of water. Carbonates generally react with acidic solutions at a faster rate than silicates. Carbonate minerals may be abundant in silicate rocks because of low-grade metamorphism or hydrothermal alteration. Hydrolysis of mafic silicates such as olivine, amphiboles, pyroxenes, epidote, calcium-bearing feldspars, and biotite occurs at a faster rate than hydrolysis of felsic silicates such as quartz and sodium- or potassium-bearing feldspars. Water in contact with rocks or sediments with a higher proportion of mafic silicates will become alkaline at a faster rate than water in contact with felsic silicates. Thus, silicate rocks that may be expected to increase the alkaline nature of water at the greatest rate include amphibolites, metavolcanics, ultramafic rocks, gabbroic rocks, hornblende, and biotite gneisses.

In an analogous study, LeGrand (1958) described two characteristic types of ground water in North Carolina are derived from crystalline bedrock. A soft, slightly acidic water that is low in dissolved mineral constituents occurs with and is derived from granitic rock types. Median pH of this type of water was 6.5, and hardness, as $CaCO_3$, was 25 (LeGrand, 1958). Silica content in the granitic waters was as much as 30 to 50 percent of the total dissolved solids because of the lower amount of the other dissolved constituents. Ground water from granitic rocks contained 5 ppm calcium, 35 ppm bicarbonate, and 75 ppm dissolved solids and is thus classified as siliceous. In terms of major element composition, the granitic rocks include granite, granite gneiss, mica schist, slate, and rhyolitic volcanic and volcaniclastic rocks. A hard, slightly alkaline water that is relatively high in dissolved material occurs in and is derived from dioritic type rocks. Median pH of this water was 7.1, and hardness as, $CaCO_3$, was 172. Ground water from dioritic rocks contain 49 ppm calcium, 137 ppm bicarbonate, and 269 ppm dissolved solids (LeGrand, 1958). The dioritic waters may be classified as bicarbonate. The dioritic type of rocks generally resemble diorite in composition and include diorite, gabbro, hornblende gneiss, and andesitic volcanic and volcaniclastic rocks.

Within the ORB, carbonate-rich rocks occur on the Coastal Plain. Bands or layers of carbonate and disseminated secondary carbonate minerals also are present in the metavolcanics and metavolcaniclastic rocks of the Carolina terrane. The amount of carbonate contained in the silicate rocks in the ORB is difficult to assess because of the lack of documentation and the lack of fresh, unweathered rock. Drill core in ultramafic rocks of Columbia County contained carbonates below a depth of 13 meters (Cocker, 1991). Ground water in the Carolina slate belt (Carolina terrane) of South Carolina was saturated with respect to carbonates, including dolomite (Clark and Stone, 1993). Ground water within that part of the Carolina slate belt had higher concentrations of calcium, magnesium, sodium, bicarbonate (HCO_3^{-1}) and chloride as compared to the other Piedmont geologic belts. Microcrystalline carbonates, such as calcite and dolomite, were noted in saprolite by Clark and Stone (1989). Carbonate-poor silicate rocks are prevalent in the Inner Piedmont and over much of the Coastal Plain within the ORB.

Because of relatively slow reaction rates, water will become more alkaline or acidic the longer the water is in contact with the rocks. Relatively impermeable rocks such as massive granites or gneisses or well cemented sedimentary or metasedimentary rocks will be the least likely to alter the pH of the water. Highly permeable rocks such as the poorly cemented quartzose sands on the Coastal Plain, allow a relatively rapid flow of water and would not be likely to greatly affect the pH. Rocks that are moderately permeable may retain the water and be more likely to affect the pH. The pH of water in contact with impermeable or highly permeable rocks and sediments would be expected to be acidic like rain water.

Slow flowing streams in the southernmost part of the ORB are high in organic matter. Decaying organic matter tends to increase the acidity of the water. Carbonate and bicarbonate ions in ground water generally originate in soils from respiring organisms and decaying vegetation and from the dissolution of carbonate rocks (Driscoll, 1976). Higher organic activity will increase the amount of carbon available to form carbonic acid and increase the acidity of water. Rapidly decaying vegetation will also increase the acidity of water. Temperature affects pH by controlling the amount of CO_2 dissolved in water. At low temperatures, relatively large amounts of CO_2 are dissolved in water generating more carbonic acid and decreasing pH. The relatively small differences in water temperature that were recorded during sampling probably have not greatly affected pH in this ORB study. Acidity of water may increase near springs due to a higher content of CO_2 in ground water. In these instances, relatively lower temperature of ground water will tend to increase the amount of dissolved CO_2.

The rate of water flow through or over rocks and sediments will determine how much time the water can react with rocks or sediments. A high flow rate will result in rocks and sediments having little effect on the water. Generally this will result in pH remaining about the same as rain water. Flow rates will also affect how much decaying vegetation that might remain in contact with the water. In sluggish streams or marshes, decaying vegetation will remain in place and increase the acidity of water. This may account for low pH values in the Coastal Plain near the southern end of the ORB.

Increased amounts of precipitation will increase the amount of water relative to the rock that can react with the water and will increase the flow rate. This will have a diluting effect on pH and cause a relative decrease in pH toward that of rain water. In areas of low flow rates and high organic matter content, higher precipitation may have the opposite effect and raise pH.

Chemical weathering of various minerals will contribute dissolved solids to the stream water and influence conductivity. Water from mafic rocks have a high content of dissolved solids due to the greater solubility of the iron-bearing mafic minerals (Price and Ragland, 1972). Water from quartzose and granitic rocks is lower in dissolved solids because of the lower susceptibility of felsic minerals to weathering.

Spatial correlation of conductivity with pH coincides with a plot of conductivity versus pH (Figure 17). Conductivity correlates with pH up to a pH of about 7.7. Above a pH of about 7.7, lack of correlation may be related to a greater influence of silicate hydrolysis on stream pH than carbonate dissolution. Because of slower silicate reactions, less material is dissolved and the conductivity is lower. With increasing pH, dissociation of adsorbed water causes an increase in OH^- and an increase in the negative charge on manganese oxides. The increased negative charge with increasing pH causes an increase in the adsorption of cations on manganese oxides. Increased adsorption of cations should cause a decrease in the number of cations in solution and a decrease in the conductivity of the water. This effect may be what is observed above a pH of about 7.7. The conductivities may be reflecting the concentrations of cations, such as Ca^{+2} and Mg^{+2}, which have the lowest affinity for adsorption on manganese oxides (Rose, et al., 1979).

Ground water from granitic rocks and dioritic rocks in North Carolina suggests that significantly higher conductivities should be expected for dioritic rocks (LeGrand, 1958). In that study, water in dioritic rocks contained a total of 269 ppm dissolved solids versus 75 ppm dissolved solids for water in granitic rocks. The major cations in the dioritic waters are calcium (49 ppm), magnesium (12 ppm), sodium + potassium (14 ppm), and in the granitic water, the major cations are calcium (5 ppm), magnesium (2 ppm), and sodium + potassium (7 ppm). Median pH is 7.1 for dioritic water and 6.5 for granitic water (LeGrand, 1958).

Streams with higher alkalinity, conductivity, and pH are essentially located south of the Towaliga Fault Zone and generally correlate with the metavolcanic and metavolcaniclastic rocks of the Carolina terrane. Streams within the generally metasedimentary rocks of the Inner Piedmont terrane have lower pH, conductivity, and alkalinity. Streams within the Inner Piedmont that have higher pH, conductivity, and alkalinity are found along the strike of the Inner Piedmont and may have some local lithologic control. Within the Inner Piedmont, correlation with particular rock units is more difficult because of the general ambiguity of the Geologic Map of Georgia (GGS, 1976). Within the Carolina terrane, the streams with the highest alkalinity, conductivity, and pH generally correlate with ultramafic and mafic rocks such as serpentinites, norites, gabbros, and diorites.

In the Coastal Plain, streams with higher alkalinity, conductivity, and pH correlate with the extent of calcareous sediments of the Suwanee Limestone, the Ocala Limestone and the Twiggs Formation (Figure 9). Streams with low pH, conductivity, and alkalinity occur with sandy sediments and clays of Cretaceous, Eocene, and Miocene formations (Figure 8).

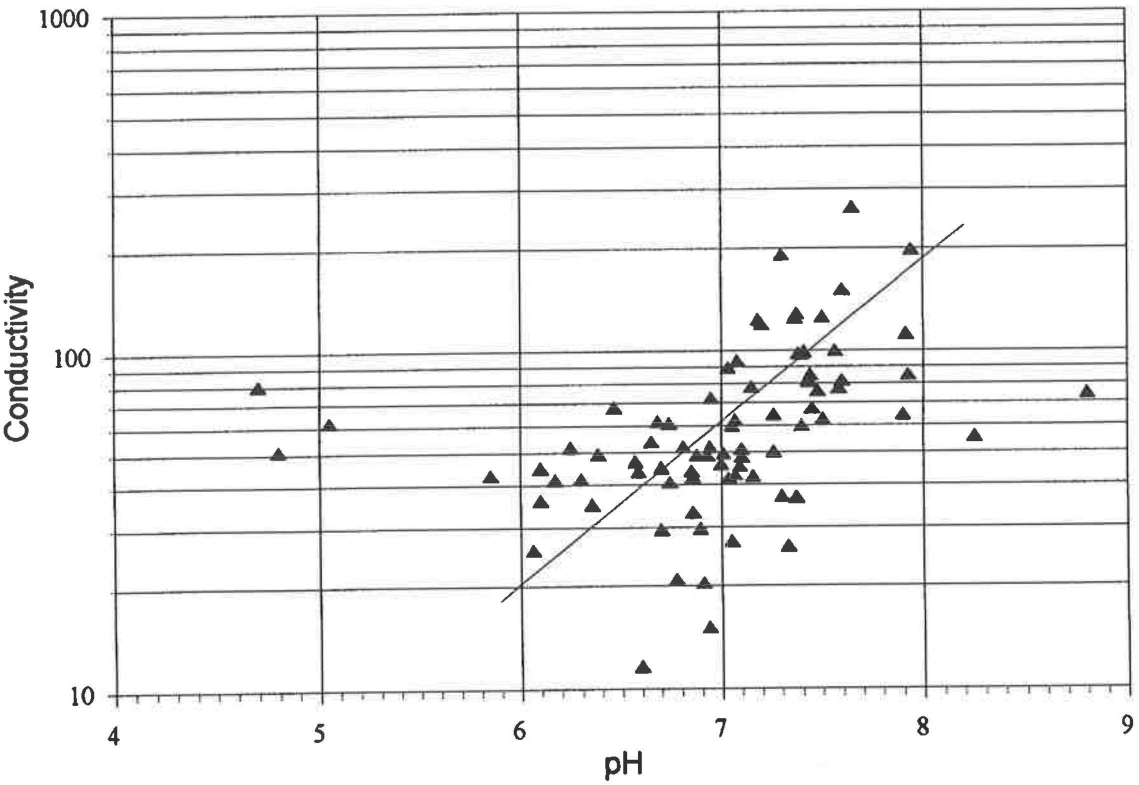

Figure 17. Scatter plot of pH versus Conductivity.

STREAM SEDIMENT GEOCHEMISTRY

The following discussion focusses on those heavy metals which were included in the NURE databases, several metals in which Georgia's Environmental Protection Division is interested (e.g., aluminum), and several other metals (e.g., iron, manganese) which are not defined as heavy metals. These other metals were included because they may influence the distribution of heavy metals in the sediments and water.

ALUMINUM (Al)

Stream sediments in the Coastal Plain are distinctly different in aluminum content from sediments in the Piedmont (Figure 18). The concentration of aluminum in most Coastal Plain stream sediments is less than 20,000 ppm, and in the Piedmont it is generally greater than 30,000 ppm. Rock units (Table 1) with the lowest mean aluminum (Table 6) include:

Eo (4600 ppm)
Etw (10,800 ppm)
Os (13,560 ppm)
Nu (19,050 ppm)
Qal (19,710 ppm)
v4 (21,860 ppm).

Except for the v4 unit, these are all Coastal Plain sedimentary formations. The v4 unit contains phyllites, meta-argillites, and quartz-mica schists (Table 1) that may be metavolcanic or metasedimentary.

Early Tertiary-Cretaceous undifferentiated sediments contain the highest mean aluminum concentration (31,690 ppm) and the highest single analysis (169,000 ppm) among the other Coastal Plain samples. The highest aluminum concentrations in the Coastal Plain stream sediments occur in Twiggs, Wilkinson, and Washington counties (Figure 18). Some samples with high concentrations of aluminum occur near kaolin mining activity. The present geochemical data can not distinguish between the effects of kaolin mining on the aluminum concentraions in stream sediments and the high, natural background concentrations of aluminum associated with kaolin deposits.

Within the Piedmont, the highest concentration of aluminum in stream sediments is located south of the Towaliga Fault Zone in the Carolina terrane (Figure 3). Rock units (Table 1) with the highest mean aluminum (Table 6) include:

mm3 (72,310 ppm)
gr1b (71,710 ppm)
bg1 (70,400 ppm).

The highest mean aluminum (72,310 ppm) and highest single point (209,000 ppm) correlate with a mm3 unit (hornblende gneiss/amphibolite in Table 1) in Jasper County. In that part of the ORB, most amphibolite gneisses contain 13 to 20 wt. percent Al_2O_3, but one sample contained nearly 26 wt. percent Al_2O_3 (Hooper, 1986). Layered biotite gneisses contain 10 to 16 wt. percent Al_2O_3 (Hooper, 1976). Gabbroic rocks other than the Gladesville Norite contain 12 to 27 wt. percent Al_2O_3 and may also be a source of aluminum in the sediments in this area. Large, feldspar-rich pegmatites of the Jasper County pegmatite district may be a source for the aluminum-rich sediments. Another source may be corundum (Al_2O_3) which occurs with ultramafic and mafic rocks in the Piedmont.

Differences in the composition of the Siloam granite, located in southern Greene and northeastern counties, (porphyritic granite in Figure 5) are apparent from the NURE data. The southern lobe of this granite contributes a large amount of aluminum (>100,000 ppm) to the stream sediments (Figure 18). The northern lobe contributes 37,600 to 72,200 ppm aluminum to the sediments. The mean for stream sediments associated with the Siloam granite is 71,700 ppm aluminum. Lithogeochemical data shows that the Al_2O_3 content of this granite ranges from 11.6 to 16.8 weight percent (Humphrey and Radcliffe, 1972), and no major differences are apparent between the northern and southern lobes. Sediments associated with the Siloam granite are more aluminum-rich than sediments related to the Elberton granite that generally contain 50,000 to 80,700 ppm aluminum.

Aluminum shows a relatively good correlation regarding iron, vanadium, copper, magnesium, manganese, titanium, and sodium (Tables 7 through 10). The association with sodium may indicate the presence of sodic plagioclase, and the other associations may be related to the overall composition of the Carolina terrane.

BERYLLIUM (Be)

Primary sources for beryllium in stream sediments in the Georgia Piedmont are probably granites (Table 2) and pegmatites which may contain the mineral beryl, a beryllium-bearing silicate. The beryllium content of stream sediments in the ORB ranges from below the detection limit of 0.5 ppm to 4.0 ppm. Five areas within the ORB contain greater than 3 ppm beryllium in stream sediments. These areas are found in Barrow, Jackson, Oconee, Oglethorpe, and Greene counties (Figure 19). Regional trends in the contoured data are not immediately apparent on the map of the ORB. Spatial correlation with granitic rocks in addition to correlation with potassium in stream sediments suggests that the primary sources for beryllium are granitic rocks and pegmatites.

The largest area containing greater than 3 ppm beryllium is found in Jackson County (Figure 19) and generally correlates with the southern end of a hornblende gneiss (Figure 6), rock unit mm3 on the Geologic Map of Georgia (GGS, 1976). The 4 ppm sample in Oconee County is in a biotite gneiss (fg1). Stream sediments with more than 3 ppm beryllium in Oglethorpe County are spatially associated with the Elberton Granite, and these sediments contain more beryllium than other sediments associated with the granite. High beryllium concentrations in Greene County are spatially related to the Siloam Granite. Because other samples in the Siloam Granite are in the 1.5 to 2.5 ppm range, the Siloam Granite may contain anomalously high beryllium. Although beryl-bearing pegmatites are not reported for the Siloam and Elberton Granites, small beryl-bearing pegmatitic segregations may be present. Sediments with high beryllium in Barrow County may be associated with a group of rocks including a granite gneiss (gg4), button mica schist (pms7), and a hornblende gneiss (mm4). Beryllium anomalies in Barrow, Jackson, and Oconee counties may be related to various beryl-bearing pegmatites in the Inner Piedmont.

Rock units (Table 1) with the lowest mean beryllium (Table 6) include:

Ei (0.25 ppm) gg6 (0.50 ppm)
mp2 (0.50 ppm) Etw (0.55 ppm)
pms4 (0.57 ppm) pa2a (0.58 ppm).

Rock units (Table 1) with the highest mean beryllium (Table 6) include:

pms7 (2.50 ppm) bg2 (1.60 ppm)
mm3 (1.58 ppm) um (1.50 ppm)
bg1 (1.50 ppm) c1 (1.50 ppm)
gr1b (1.47 ppm).

Because the average concentration of beryllium (3 ppm) in granitic rocks and shale is higher than in other rock types (Table 2), the Siloam Granite (gr1b) may be expected to be contain higher amounts of beryllium. Relatively high beryllium associated with the ultramafic, amphibolitic rock units as well as the biotite gneisses may be related to beryl-bearing pegmatites in or near those rock units. Beryllium exhibits a relatively good correlation with potassium (Correlation coefficients in Tables 7 through 10 and Figure 20). This association may indicate the presence of potassic feldspar and beryl in the sediments.

CHROMIUM (Cr)

Ultramafic rocks and, to a lesser extent, amphibolites and shales commonly have a high chromium content with median concentrations of 2980 ppm, 170 ppm, and 90 ppm, respectively (Rose et al., 1979). Lithogeochemical data from Jasper County (Hooper, 1986) shows the concentration of chromium ranges from below detection limits up to 484 ppm for amphibolites, from 4 to 30 ppm for biotite gneisses, from 305 to 786 ppm for amygdaloidal amphibolites, 115 to 2613 ppm for ultramafic rocks, 8 to 499 ppm for various small gabbroic intrusions, and 78 to 577 ppm for the Gladesville Gabbro (Norite).

Ultramafic rocks are commonly located in or near major crustal sutures or faults that join major crustal lithospheric plates. These are zones of weakness where igneous intrusions may ascend from deeper crustal levels or slices of underlying mantle or slivers of oceanic crust may be tectonically emplaced. These intrusions or slivers may be up to several tens of kilometers in length, but in Georgia they are generally small - approximately a few tens to hundreds of meters in length. The ultramafic lens-shaped masses are subject to low-grade metamorphism and are highly susceptible to weathering. Outcrops are rare, and direct evidence of their presence may be lacking. Rock units that cover larger areas than the ultramafic rocks may contribute a greater amount of chromium to the sediments than do the ultramafic rocks.

Most stream sediments in the ORB contain less chromium than the detection limit of 5 ppm and are plotted as 2.5 ppm (Figure 21). Stream sediments that contain 6 ppm or more chromium lie along five NE-trending linears that extend across the ORB. Several of these linears with 6 ppm or more chromium correlate with trends in known ultramafic rock occurrences (Figure 4). Other anomalies may correlate with occurrences of ultramafic rocks that have not been identified or defined by mapping.

A large cluster of stream sediments with greater than 6 ppm chromium covers the northern half of Hall County (Figure 21) and is the largest chromium anomaly in the Greenville and Athens quadrangles. This anomaly is one of several that sit astride the northeast trending Brevard Fault Zone (Figure 3). This fault zone is a major zone of sheared, cataclastic rocks that may contain unrecognized, strongly deformed chromium-bearing ultramafic rocks.

A second trend extends from Gwinnett and Walton counties through Barrow, Clarke, Jackson, and Madison counties and into South Carolina (unpublished GGS maps). Many ultramafic rock units are found along this trend (Hopkins, 1914; Prowell, 1972).

Several weak chromium anomalies extend to the northeast along the southern edge of the Towaliga Fault Zone (Figure 3) from Jasper County through Morgan, Greene, Oconee, Oglethorpe, and Madison counties (Figure 21), and Elbert County and into South Carolina (unpublished GGS maps). A few scattered ultramafic rocks or magnesium-rich rocks are found along this trend (Hopkins, 1914).

Clusters of stream sediments with greater than 6 ppm chromium form a trend from Monroe through Jasper, Jones, Putnam, Hancock (Figure 21), Warren, McDuffie, and Columbia counties (unpublished GGS maps) and into South Carolina. This trend is spatially correlative with known ultramafic and mafic rocks in the western end of that trend and to numerous occurrences of ultramafic rocks in Columbia County (GGS, 1976; Sacks, 1989; Cocker, 1991). This trend lies immediately south of the trace of the Modoc Fault Zone.

A fifth trend of anomalous chromium may extend from Baldwin and Hancock counties into Warren, McDuffie, and Columbia counties (Figure 21). The highest concentration of chromium (75 ppm) in the ORB occurs in Hancock County along this trend. Major structures or ultramafic rocks have not been identified along this trend (Figure 3 and 4).

Only a few Coastal Plain stream sediments in the ORB were analyzed for chromium because samples from the Macon and Waycross quadrangles were not analyzed. A comparison may be made with stream sediments further to the east where the Athens Quadrangle intersects the Coastal Plain (unpublished GGS maps). Anomalous chromium occurs in irregular clusters that may parallel the strike of the sedimentary formations. These samples may contain chromium related to heavy mineral deposits in Cretaceous to Eocene sedimentary formations.

Rock units (Table 1) with mean values below the detection limit of 5 ppm chromium (Table 6) include:

pms6e bg2 pms3a Etw gr1 bg1
mp2 mm9 fg2 pa2a c1 gg6
Ei pa2b pms7.

Rock units (Table 1) with the highest mean chromium

(Table 6) include:

pm2 (23 ppm)	pms6a (12 ppm)
mm (7 ppm)	um (7 ppm).

The amphibolite (mm1) and the ultramafic rock (um) are expected to contain relatively high chromium (Table 2). High amounts of chromium in the metagraywacke/mica schist (pm2) and the sericite schist/amphibolite (pms6a) are unusual. The source of the chromium may be a nearby unidentified ultramafic rock unit or a chromium-rich mica in the schist.

COBALT (Co)

Natural sources of high concentrations of cobalt, like chromium, are commonly ultramafic rocks and, to a lesser extent, amphibolites and shales (Table 2) with median concentrations of 110 ppm, 48 ppm, and 19 ppm, respectively (Rose et al., 1979). As with chromium, large regionally extensive rock units with low to medium levels of cobalt may contribute a larger volume of cobalt to stream sediments than small, scattered, cobalt-rich ultramafic rock units. In the ORB, cobalt in stream sediments ranges from less than the detection limit of 5 ppm to 113 ppm. Most of the stream sediments in the Inner Piedmont contain 5 ppm or less cobalt. Concentrations of cobalt in stream sediments from the Carolina terrane are commonly greater than 10 ppm and may indicate an overall tectonostratigraphic control on cobalt content.

Two principal trends in anomalous cobalt extend through the ORB (Figure 22). The strongest trend extends from Jasper and Jones counties through Putnam, Morgan, and Greene counties and into Oglethorpe, Elbert, and Wilkes counties. This trend continues into South Carolina. A second trend extends from Jones County through Baldwin, Putnam, Hancock, Taliaferro, Wilkes, and Lincoln counties into South Carolina (unpublished GGS maps). These trends correlate with two series of ultramafic and gabbroic intrusions and the pH, conductivity, and alkalinity trends in the Carolina terrane which were discussed earlier. Concentrations of cobalt in stream sediments are generally higher west of the Oconee River in the Carolina terrane.

A large, elongate anomaly, with up to 55 ppm cobalt, extends northeastward from Jackson County (Figure 22). This area (Figure 6) is underlain, in part, by hornblende gneisses (rock unit mm3 in Table 1).

Stream sediments in the Coastal Plain generally contain less than 5 ppm cobalt. A few scattered anomalous samples within the ORB contain up to 18 ppm cobalt, and in adjacent areas of the Coastal Plain outside the ORB, concentrations as high as 59 ppm were found.

Rock units (Table 1) with mean cobalt concentrations below the detection limit of 5 ppm (Table 6) include:

pa2b pms6a pms7 gg6.

Rock units mm1, pm2, pa2, Ei, and v4 also have low mean cobalt content (3 ppm). The highest mean cobalt concentrations are in rock units:

um (18 ppm)	pms1 (15 ppm)
mm3 (15)	fg1a (12 ppm)
mp2 (11 ppm)	mm6 (10 ppm).

This group includes ultramafic rocks (um), hornblende gneisses (mm3 and mm6), and gabbro (mp2) (Table 1) which are expected to contain higher cobalt (Table 2). The gabbro is the Gladesville Norite intrusion that contains up to 71 ppm cobalt in a drill core sample (Cocker, 1995a). Other rock units that contain unusually high concentrations of cobalt lie along the trends of ultramafic and gabbroic intrusions discussed earlier and the high cobalt may be related to an adjacent or undefined ultramafic or mafic rock unit.

Cobalt shows a relatively good correlation with zinc, copper, manganese, aluminum, vanadium, magnesium, titanium, nickel, and alkalinity (Tables 7 through 10). The association of zinc, copper, nickel, and cobalt may indicate the presence of base metal sulfides in those stream sediments. The association with aluminum, vanadium, magnesium, and titanium (Tables 9 and 10) strengthens the observation of tectonostratigraphic control on cobalt.

COPPER (Cu)

High concentrations of copper (Table 2) in ultramafic rocks (42 ppm), in mafic rocks (72 ppm) and in shales (42 ppm) (Rose et al., 1979) indicate that these rock types or their metamorphic equivalents may be important sources of copper in stream sediments. Within the ORB, stream sediments generally contain less than 10 ppm copper. Stream sediments containing more than 10 ppm copper are isolated occurrences or are in elongate clusters (Figure 23). Clusters of stream sediments with greater than 10 ppm copper are larger and more abundant in the Carolina terrane than in the Inner Piedmont. Stream sediments in the Coastal Plain contain very little copper, and concentrations are generally below 5 ppm.

Stream sediments with a high copper content occur along the northeast trace of the Brevard Fault Zone and (Figure 23 and unpublished GGS maps). High copper in the sediments may be related to sheared ultramafic masses suggested by the large chromium anomaly in Hall County.

Copper shows a good correlation with zinc (Figure 24), nickel and cobalt (Tables 7 through 10) which suggests the presence of base-metal sulfides in the stream sediments. Disseminated chalcopyrite, a copper-bearing iron sulfide, occurs within the Gladesville Norite and in amphibolitic gneisses in Greene County (Conway, 1986). A stream sediment sampling program in and adjacent to the Gladesville Norite identified concentrations of up to 227 ppm copper (Carpenter and Hughes, 1970). Chalcopyrite is present in drill core from the Gladesville Norite with concentrations up to 1300 ppm (Cocker, 1995a). The correlation with aluminum (Tables 9 and 10) may be related to copper mineralization in aluminous schists that may be metamorphosed hydrothermal alteration zones.

Rock units (Table 1) with the lowest copper content (Table 6) include:

Ei (1 ppm)	Etw (1 ppm)	
gr1b (2 ppm)	v4 (2 ppm)	TKu (2 ppm).

The Coastal Plain rock units Ei, Etw, and TKu (Table 1) would be expected to have low concentrations of copper, in part due to the low pH in many Coastal Plain streams (Figure 13). Stream sediments in Greene County with a low copper content are associated with the Siloam granite (gr1b, the porphyritic granite in Figure 5), which apparently contains little copper. Rock units with the highest copper content (Table 6) include:

um (18 ppm) pm2 (9 ppm) mm3 (9 ppm)
mm4 (9 ppm) bg1 (9 ppm).

High concentrations of copper in the ultramafic rocks (um) and the amphibolitic gneisses (mm3 and mm4) may be expected from the high copper content (Table 2) of these rocks (Rose et al., 1979). The source of the high concentrations of copper in the metagraywacke (pm2) and biotite gneiss (bg1) is not known.

High copper concentrations of 31 ppm and 38 ppm in stream sediments nearwaste disposal sites near Eatonton in Putnam County and Milledgeville in Baldwin County may be related to human activity. The sample near Milledgeville also contains high lead and zinc.

LEAD (Pb)

Anomalous lead in stream sediments may be derived from granitic rocks, shales, or sandstones that have median concentrations 18 ppm, 25 ppm, and 10 ppm (Rose et al., 1979). Some anomalous lead in these rocks may be in potassium feldspars. Within the ORB, lead in stream sediments ranges from below the detection limit of 10 ppm to a high of 525 ppm.

Higher lead concentrations within the ORB occur as isolated sites (Figure 25). These singular points appear to be near population centers. Because these lead anomalies may not be spatially related to natural sources, the high lead in the sediments may be anthropogenic. The highest concentration of lead (525 ppm) occurs near a waste disposal site and urban activity near Milledgeville in Baldwin County.

Rock units (Table 1) with a mean lead content less than 10 ppm (the detection limit of lead) include:

c1 pms6a pms6e
pms4 pms7 mp2um
gg6 pa2a Etw
bg1 mm1.

Rock units with the highest mean lead include:

q1a (95 ppm) pms1 (18 ppm) mm4 (17 ppm).

Because lead concentrations are low in most of the stream sediments within the ORB, and the possibility of contamination associated with the higher values, high mean lead concentrations in these rock units may not be statistically or geologically significant. Relatively high median lead in sandstones (Table 2) may indicate a source for the high lead in the rock unit q1a (a quartzite).

NICKEL (Ni)

Natural sources of nickel are commonly ultramafic rocks and, to a lesser extent, amphibolites and shales with median concentrations of 2000 ppm, 130 ppm, and 68 ppm, respectively (Table 2 and Rose et al., 1979). Concentrations of nickel in stream sediments within the ORB are generally less than 10 ppm, and most of those samples contain less than the detection limit of 5 ppm. Distribution of nickel may be related to rock composition, with higher values correlative with the distribution of ultramafic and mafic rock units (Figure 4).

Stream sediments in the Carolina terrane south of the Towaliga Fault Zone and in particular west of the Oconee River (Figure 26) commonly contain 6 ppm or greater nickel. This concentration of nickel correlates with a general increase in the abundance of amphibolites (metabasalts?) in this part of the Carolina terrane. In general, the nickel-bearing sediments follow the trend of high pH (Figure 13) that extends around the western edge of the Carolina terrane in Georgia. The most anomalous stream sediment samples (those containing greater than 20 ppm and up to 58 ppm nickel) are associated with amphibolites, the Gladesville Norite, and perhaps scattered smaller gabbroic intrusions in Putnam, Jones, and Jasper counties. The stronger northeast trending anomalies in Baldwin County may be related to more nickel-rich metabasalts (amphibolites).

Stream sediments in the Inner Piedmont terrane with high nickel (Figure 26) may be related to the small ultramafic intrusions or limited occurrences of metabasaltic rocks in this area (Figure 4). Most occurrences of high nickel in the Inner Piedmont are small and only one contains more than 20 ppm nickel.

Strongest correlations for nickel are with copper, zinc, and cobalt (Tables 7 through 10) and may suggest the presence of base-metal sulfides. High nickel concentrations are spatially coincident with some high chromium concentrations (Figure 21), particularly the single point sites. The association of chromium with nickel in ultramafic rocks suggests that those samples that contain both chromium and nickel may be derived from ultramafic rocks.

Although most samples from the Coastal Plain sediments in the ORB were not analyzed for nickel, a comparison may be made with those further to the east where the Athens Quadrangle intersects the Coastal Plain (unpublished GGS maps). As with the chromium anomalies, anomalous nickel samples may be related to heavy mineral deposits in the Cretaceous and Eocene sandy sediments. One unusual stream sediment sample east of the ORB contains 59 ppm nickel.

Rock units (Table 1) with less than the detection limit of 5 ppm nickel (Table 6) include:

Etw (2 ppm) pa2a (2 ppm) pms7 (2 ppm)
Ei (2 ppm) mm1(3 ppm) gr1b (3 ppm)
pms6a (3 ppm) pa2b (4 ppm) pms6e(4ppm).

Rock units with the highest mean nickel content include:

um (28 ppm) gr2a (15 ppm) mm6(15ppm)
mm4 (14 ppm) bg1 (14 ppm).

The ultramafic rocks (um) and amphibolites (mm4 and mm6) may be expected to contain higher nickel (Table 2). High nickel values for the Elberton granite (gr2a) and the biotite gneiss (bg1) are unusual and not yet explained.

Some higher nickel values may be related to human activity as noted in the section on contamination. Because rock units that may contribute nickel to the sediments are near possible sources of contamination, defining the precise source of the nickel may not be feasible without additional data.

ZINC (Zn)

Mafic rocks and shales may be important sources of zinc in stream sediments as suggested by concentrations of 94 ppm and 100 ppm, respectively (Rose et al., 1979). Within the ORB, zinc ranges from less than the detection limit of 5 ppm up to 230 ppm. The spatial correlation of anomalous zinc values with mafic rocks suggests important lithologic controls on the distribution of zinc.

Stream sediments from Rockdale County in the northwest through Newton, Jasper, Putnam, and Baldwin counties (Figure 27) contain anomalous zinc on the order of 30 to 253 ppm. Regionally high values extend westward into Monroe and Henry counties. The high zinc concentrations may be related to an apparent increase in the volume of amphibolitic rocks in the western end of the Carolina terrane as indicated on the Geologic Map of Georgia (GGS, 1976) and through investigations by Hooper (1986).

High amounts of zinc from single sample or multisample sites in other parts of the ORB appear to lie along more narrow, but regionally extensive trends (Figure 27 and unpublished GGS maps). These trends lie along E-W, N70°E, to N50°E directions and are on the order of many tens to hundreds of kilometers in length. Other less well-defined trends appear to crosscut these longer trends and lie along a N-S to N30°W orientation (unpublished GGS maps). Some of these trends may be related to regional structures. Stream sediments near known base-metal mineralization in Wilkes and Lincoln counties contain less zinc, up to 115 ppm, and do not form large anomalies.

A sediment sample from Jackson County containing 230 ppm zinc (Figure 27) is spatial correlative with the location of a mica schist (pms3a). The source of zinc in this area is unknown.

As equally intriguing as the high zinc sediments are the stream sediments in Greene and Hancock counties that are unusually low in zinc (Figure 27). These areas are underlain by the Siloam and Sparta granites (Figure 5) and by rock unit v4, which consists of undifferentiated metavolcanic rocks.

Rock units (Table 1) with the lowest zinc content (Table 6) include:

Ei (7 ppm)
pms6e (8 ppm) Etw (8 ppm) v4 (8 ppm)
gr1 (9 ppm) gr1b (9 ppm)
pa2b (10 ppm).

As with copper, the low zinc values in the Coastal Plain rock units (Ei and Etw) may be expected because of the acidic nature of the streams and leaching of zinc from the source rocks and the sediments derived from those source rocks. Low values of zinc in the granitic rocks (gr1 and gr1b) suggest that those rocks contain no zinc mineralization. Aluminous mica schists and undifferentiated metavolcanics (pms6e, pa2b, and v4) appear to contain very little zinc while a similar lithology, a mica schist (pms1a), contains a significant amount of zinc. Reasons for these differences cannot be identified with the present data. Rock units with the highest zinc content include:

pms1 (53 ppm) mm4 (44 ppm)
mm6 (43 ppm) q1a (41 ppm)
um (40 ppm) mm3 (39 ppm).

High zinc in the amphibolitic gneisses (mm3, mm4, and mm6) and the ultramafic rocks (um) may be expected by the higher concentration of zinc that is common in these rock types (Table 2).

Strongest correlations of zinc are with copper, cobalt, and nickel (Tables 7 through 10). As discussed earlier, these associations suggest the presence of base-metal sulfides in those sediments.

Some high zinc concentrations in the ORB may be related to contamination from nearby anthropogenic activities. As noted in the section on contamination, high zinc analyses are reported for some sites near waste disposal sites, and other industrial, sewage, and urban sites. Because of the abundance of samples with apparently naturally high concentrations of zinc near some of these sites, identifying the sources of the zinc from the present data are not possible.

IRON (Fe)

Iron has an important influence on water quality and provides important information regarding the effects of lithology on water quality, particularly within the ORB. The direct effect of iron on water quality is its tendency to form iron oxide or iron hydroxide crusts that may cause the precipitation or absorption of heavy metals. Iron is soluble under acidic and reducing conditions and insoluble under alkaline and oxidizing conditions. Increased oxidation may change the iron from dissolved ferrous iron to semisolid ferric iron which commonly results in precipitation of iron coatings. Precipitation of iron bicarbonate will also form coatings. Precipitation of iron will cause the coprecipitation of other metals.

Iron bacteria such as Crenothrix, Gallionella, and Leptothrix may precipitate ferric iron or create gel-like slimes which may clog pipes and screens (Driscoll, 1986). Growth of these bacteria may be facilitated in iron-bearing water.

Iron in stream sediments is an indication of the abundance of iron-bearing minerals. The iron compounds are quantitatively probably the most important inorganic reducing agents. Organic-free waters lose their oxidizing character by reaction with silicates containing ferrous iron, such as biotite, chlorite, amphiboles, and pyroxenes, or by contact with sulfides or ferrous iron-containing carbonates. As pH rises due to silicate hydrolysis, the environment becomes alkaline as well as reducing. In environments containing organic matter, biochemical reactions quickly remove oxygen, commonly with a marked increase in CO_2, and with production of hydrogen sulfide. The influence of bacteria is paramount, and deoxygenation may be accompanied by pH lowering as CO_2 and H_2S are generated (Garrels and Christ, 1965). A relationship between iron and pH is suggested by the spatial correlation of high iron in stream sediments (Figure 28) and high pH of stream water (Figure 13) in the Carolina terrane. A plot of iron versus pH shows a positive correlation of iron with pH (Figure 29), although correlation coefficients in Tables 7 and 8 suggest a weak correlation. A lack of correlation at pH values above about 9 suggests that iron-bearing silicates may not be an important control on pH under more alkaline conditions. Under low pH conditions, much of the iron may be in solution.

Rock units (Table 1) with the lowest iron content (Table 6) include:

Eo (12,900 ppm) Nu (13,300 ppm)
Qal (13,600 ppm) Os (14,100 ppm)
Etw (14,400 ppm) c1 (16,400 ppm)
pms4 (17,300) Ei (17,300 ppm)
TKu (18,400 ppm) pm2 (19,000 ppm).

All of the Coastal Plain stream sediments contain the lowest amount of iron. At low stream pH (<7), iron in stream sediment samples is below 50,000 ppm with most samples below 35,000 ppm. Where stream pH is equal to or greater than 7, iron content is generally higher with a range of 18,000 to 110,000 ppm. These relationships may indicate leaching of iron from stream sediments and source materials by acidic waters, particularly in the Coastal Plain. Rock units (Table 1) with the highest iron content include:

pms6e (110,000 ppm) mp2 (98,200 ppm)
um (93,200 ppm) mm3 (71,200 ppm)
q1a (67,700) gg4 (63,800 ppm)
mm6 (61,300 ppm).

Except for q1a, a quartzite/mica schist unit, each of these rock units has an important component of amphibolite or hornblende gneiss or is a gabbro or ultramafic rock. Massive magnetite/martite is associated with a quartzite unit in the ORB (Figure 4) and may account for the high iron content of the stream sediments (Figure 28). Relative concentrations of iron in stream sediments spatially associated with these rock units correlate with the concentrations of iron in similar rocks (Table 6).

High median concentrations of iron in ultramafic rocks (94,300 ppm) and in mafic rocks (86,500 ppm) should be reflected in stream sediments derived from these rocks. Moderate median concentrations of iron (Table 2) in shales (47,000 ppm) and in granitic rocks (14,200 ppm) should distinguish stream sediments derived from these rocks from the more mafic rocks and stream sediments derived from limestones (3800 ppm) and sandstones (9800 ppm) (Rose et al., 1979).

Strongest correlations for iron are with titanium, vanadium, manganese, magnesium, and sodium (Tables 7 through 10 and Figures 30, 31, 32, and 35). These associations may indicate the presence of vanadium-bearing iron-titanium oxides such as magnetite, hematite, and ilmenite. Moderately good correlations are with aluminum, alkalinity, and conductivity. The iron-magnesium association may indicate the presence of iron-magnesium silicates, possibly derived from ultramafic rocks and amphibolitic rocks (metabasalts). The iron-titanium-vanadium-manganese-magnesium-sodium-aluminum-alkalinity-conductivity association is characteristic of the metavolcanic rocks of the Carolina terrane as shown on the geochemical maps.

MAGNESIUM (Mg)

Primary sources of magnesium are ultramafic and mafic rocks and, to a lesser extent, carbonates and shales (Table 2). These sources are evident in the ORB with the highest magnesium in the stream sediments related to rock units:

um (5250 ppm) pms6e (3080 ppm)
mm4 (3000 ppm) mm6 (2940 ppm)
q1a (2600 ppm).

High magnesium in the ultramafic rocks and the amphibolites is attributed to the abundant iron-magnesium silicates of those rock units. Rock units (Table 1) with the lowest mean magnesium (Table 6) include:

Etw (630 ppm) Ei (630 ppm)
pms1 (880 ppm) TKu (970 ppm).

All the Coastal Plain units contain little magnesium.

Strongest correlations for magnesium are with iron, vanadium, aluminum, manganese, titanium, sodium, and alkalinity (Tables 7 through 10). These relations can be observed by the distribution of magnesium in stream sediments and that for iron, manganese, vanadium, and alkalinity (Figures 16, 28, 33, and 34 and unpublished GGS maps).

MANGANESE (Mn)

The distribution of manganese can strongly affect the distribution and concentration of other metals, particularly the heavy metals. Manganese oxide is a major factor controlling the content of cobalt, nickel, copper and zinc in soils and waters (Jenne, 1968). Colloidal manganese oxides generally adsorb cations to a greater degree than do iron oxides. Colloidal iron oxides have a positive charge up to a pH of about 8.5, while manganese oxides are negatively charged above a pH of about 3. Metal enrichment by adsorption is thus generally greater for manganese oxides than for iron oxides. Excess manganese in water can clog pipes and screens and stain clothes. Manganese is present as soluble manganese bicarbonate that will precipitate when CO_2 is liberated from solution. Manganese bicarbonate may change to manganese hydroxide with increased oxidation.

Correlation coefficients (Tables 7 and 8) show a relatively good correlation of manganese with pH and alkalinity. A plot of manganese versus pH shows that the manganese content of stream sediments is generally less than 1200 ppm where stream pH is less than 7. The manganese content is generally greater than 2000 ppm, when stream pH is greater than or equal to 7. These relations suggest that manganese may be in solution under low pH conditions and as manganese oxides under high pH conditions.

Distribution of manganese in stream sediments (Figure 34) is similar to that for iron (Figure 28), titanium, and vanadium (unpublished GGS maps), with the highest concentrations of manganese in the Carolina terrane and the lowest in the Coastal Plain. Correlation coefficients also show a strong positive correlation with iron (Figure 35), titanium, vanadium, aluminum, magnesium, alkalinity, and conductivity (Tables 7 through 10).

Rock units (Table 1) with the lowest manganese content (Table 6) include:

Nu (210 ppm) Os (216 ppm)
Eo (440 ppm) pms4 (510 ppm)
pms2 (520 ppm) gg6 (530 ppm)
Etw (540) Ei (570 ppm)
v4 (570 ppm) Qal (570 ppm)
TKu (660 ppm) pms6a (680 ppm).

Many of these rock units (Table 1) are Coastal Plain sedimentary strata. Rock units (Table 1) with the highest manganese include:

pms6e (3300 ppm) mp2 (3020 ppm)
pms1 (2740 ppm) mm3 (2590 ppm)
gr1b (2410 ppm) gg4 (2280 ppm)
um 2160 ppm) bg2 (2060 ppm)
fg1a (1960 ppm).

Many of these rock units are amphibolites, contain amphibolites or are ultramafic rocks. Higher concentrations of manganese (Table 2) in mafic rocks (1500 ppm) and ultramafic rocks (1040 ppm) generally supports the relationships in the ORB stream sediments.

TITANIUM (Ti)

Rock units (Table 1) with the lowest titanium content include:

c1 (3000 ppm) pms4 (3740 ppm)
bg1 (5500 ppm) Nu (5670 ppm).

Rock units (Table 1) with the highest titanium content include:

um (36,600 ppm) mp2 (28,800 ppm)
pms6e (24,850 ppm) bg2 (24,460 ppm).

A plot of titanium versus iron (Figure 30) also shows a strong positive correlation of titanium with iron (Tables 7 through 10). The titanium may be present as iron-titanium oxides such as ilmenite, hematite, or magnetite. Correlation of high concentrations of titanium, iron, and vandium in stream sediments associated with ultramafic rocks may indicate a similarity to the iron-titanium oxide mineralization in the Burks Mountain ultramafic complex (Cocker, 1991).

Median concentrations of titanium (Table 2) are 3000 ppm in ultramafic rocks, 9000 ppm in basalt, 8000 ppm in granodiorite, and 2300 ppm in granitic rocks. Median concentrations are 400 ppm in limestones and 4600 ppm in shales (Levinson, 1974).

VANADIUM (V)

Rock units (Table 1) with the lowest vanadium include:

Eo (30 ppm) Nu (32 ppm) Os (34 ppm)
Qal (36 ppm) Etw (37 ppm).

Rock units (Table 1) with the highest vanadium include:

mp2 (350 ppm) um (310 ppm) pms6e (185 ppm).

High concentrations of vanadium in sediments that are associated with ultramafic rocks may be similar to the vanadium associated with ilmenite mineralization in the Burks Mountain ultramafic complex (Cocker, 1991). The vanadium-iron-titanium-manganese association (Tables 7 through 10), which has been discussed earlier, is supported by a plot of vanadium versus iron and a similar distribution of titanium and iron (Figures 16, 28, 31, and unpublished alkalinity maps).

The median concentration of vanadium (Table 2) is significantly higher in mafic rocks (250 ppm) and shales (130 ppm) (Rose et al., 1979) than in other rock types. This relation may help identify sediments derived from mafic rocks and shales.

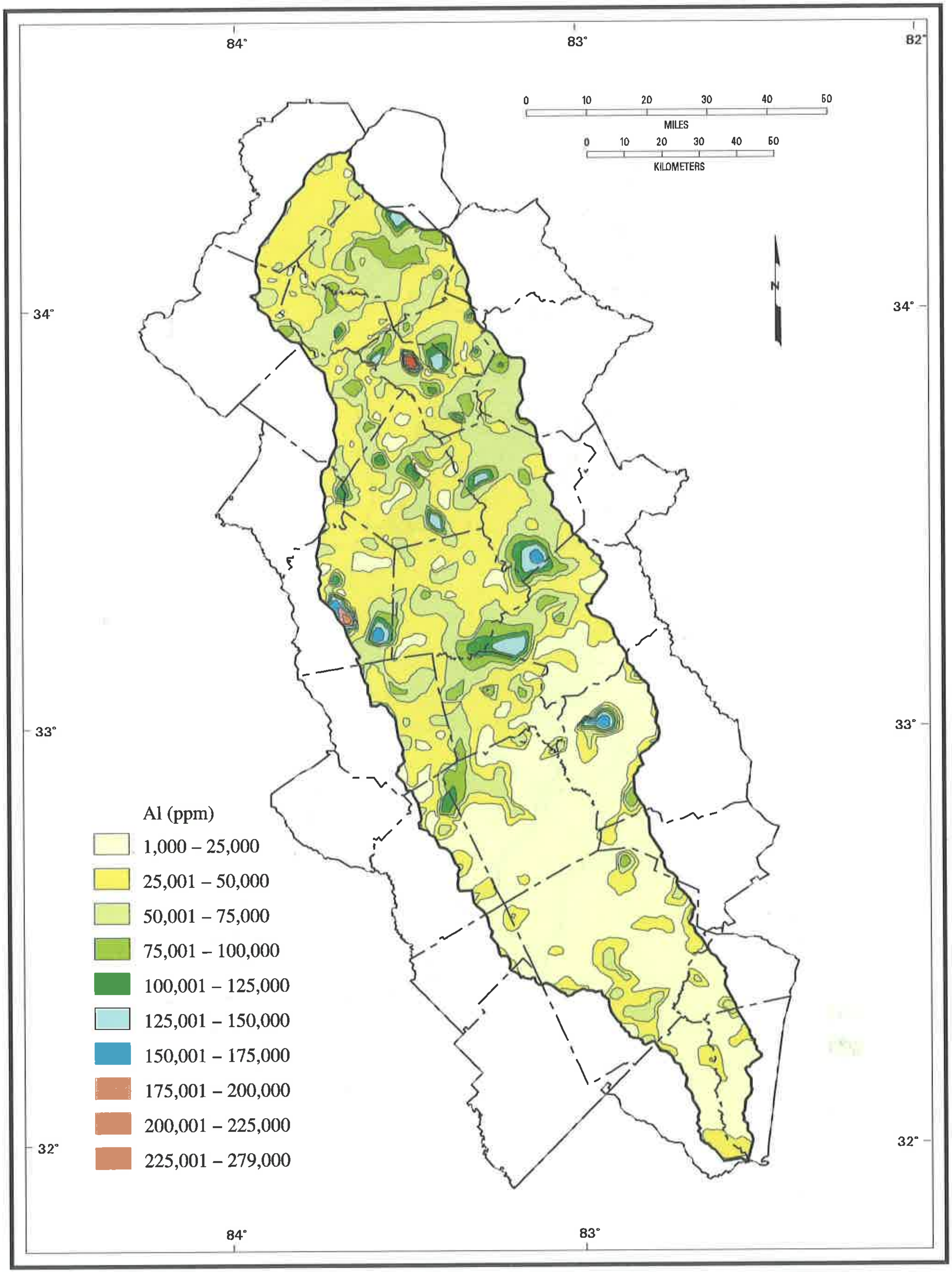

Figure 17. Aluminum in Stream Sediments.

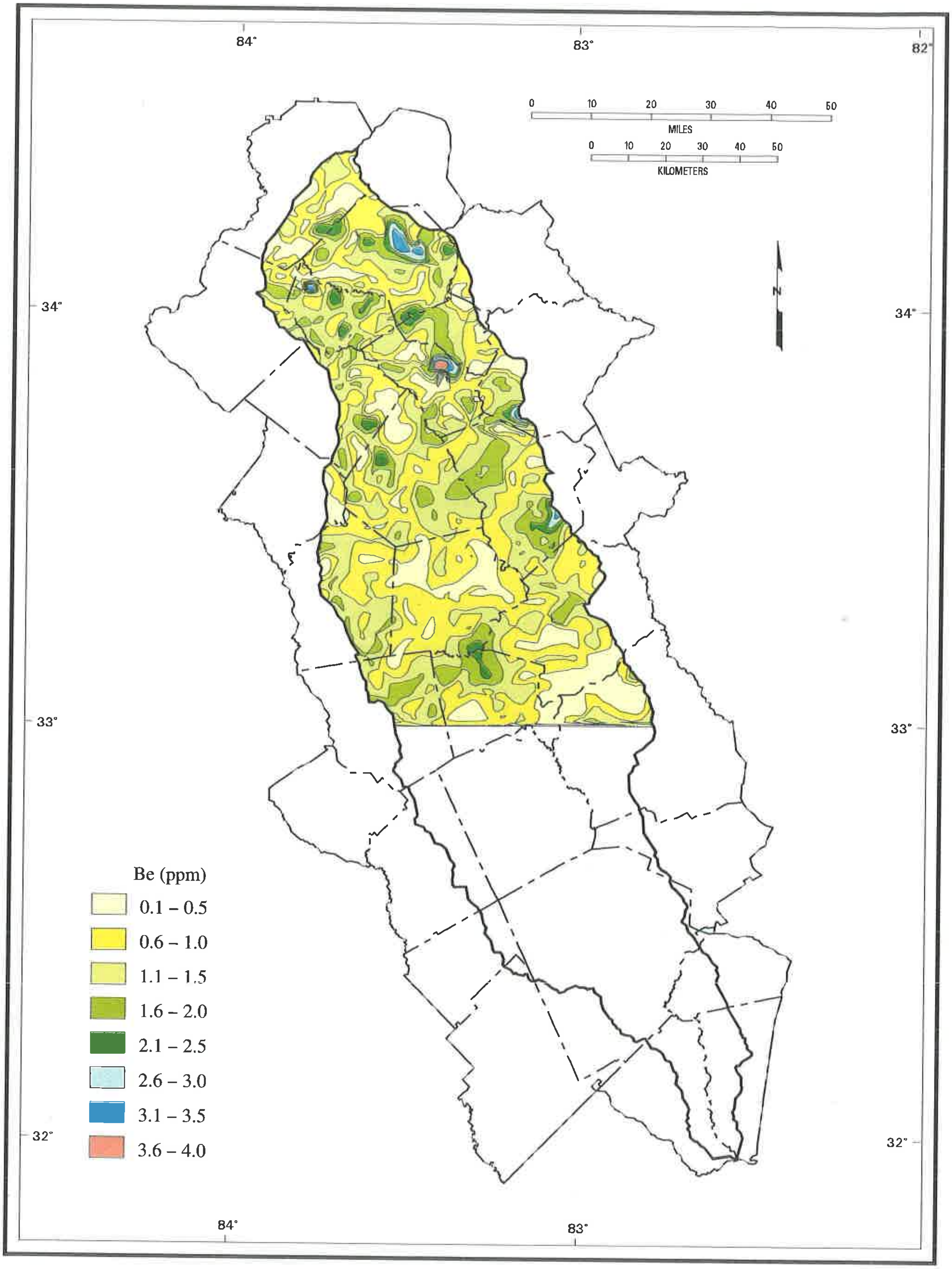

Figure 19. Beryllium in Stream Sediments.

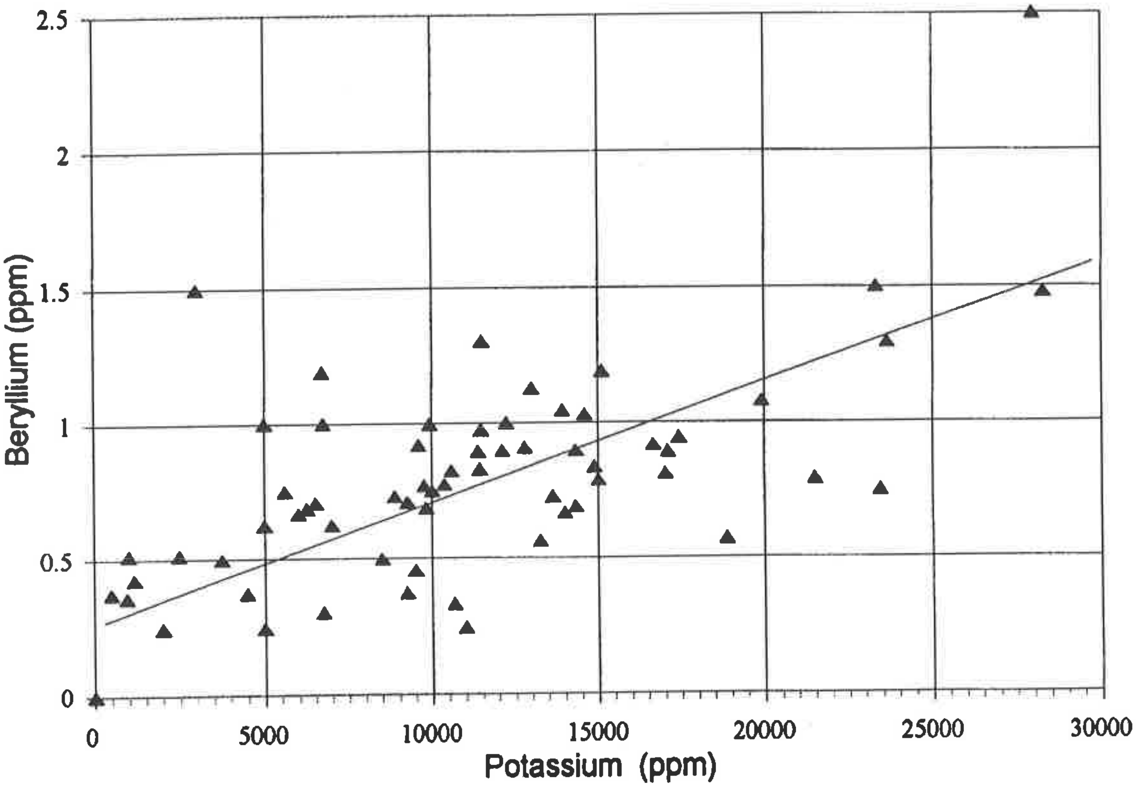

Figure 20. Scatter plot of Beryllium versus Potassium.

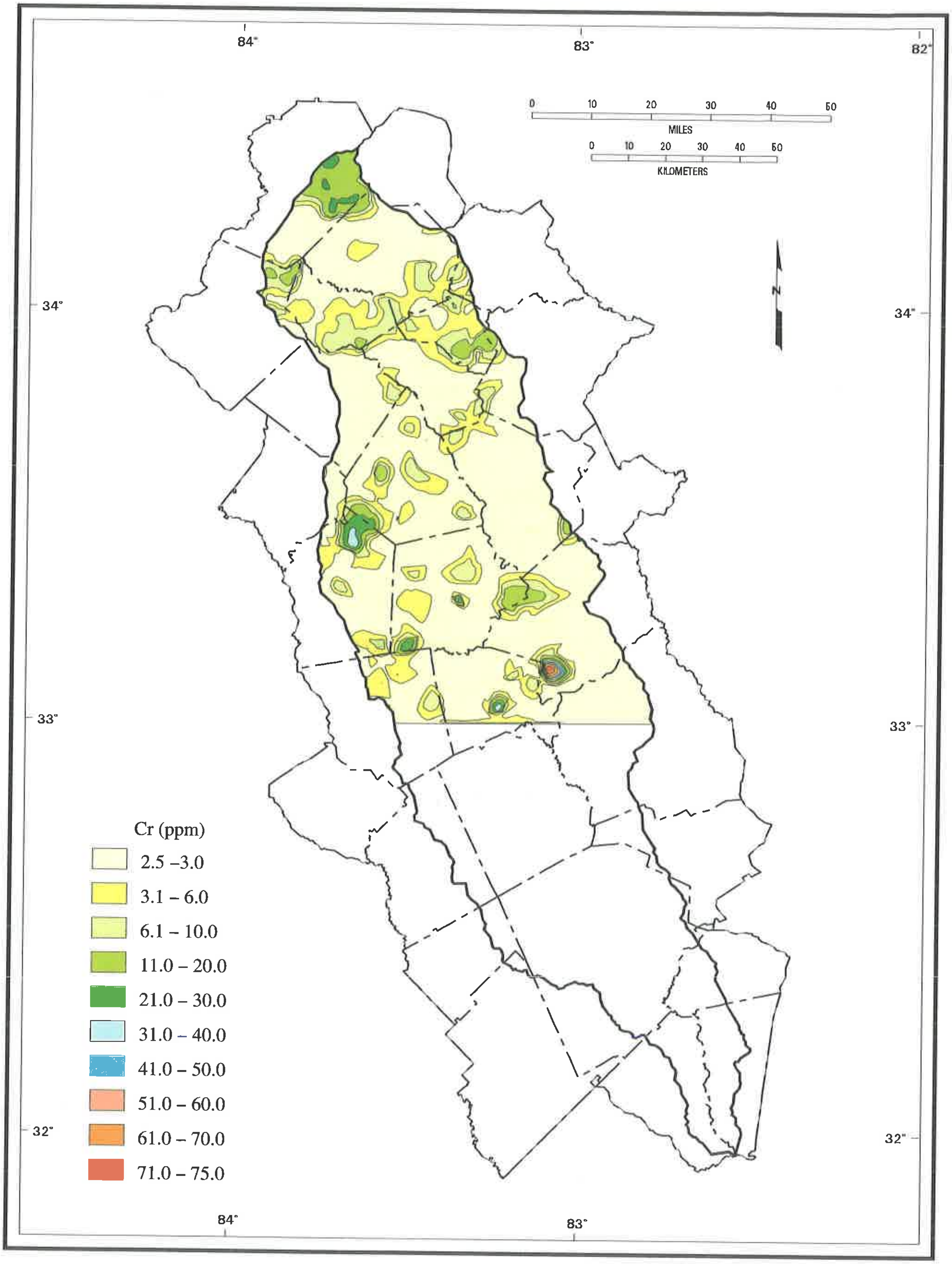

Figure 21. Chromium in Stream Sediments.

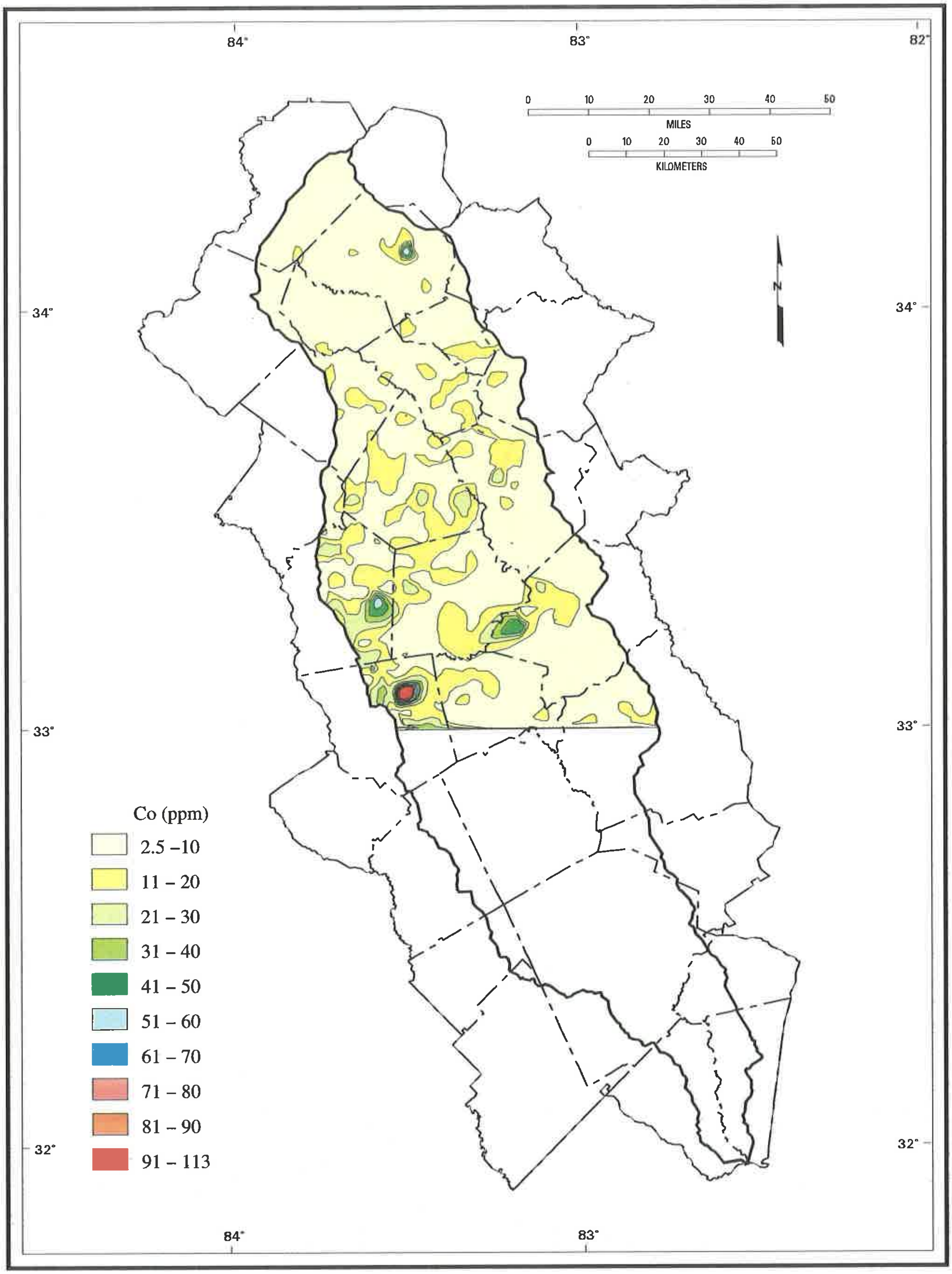

Figure 22. Cobalt in Stream Sediments.

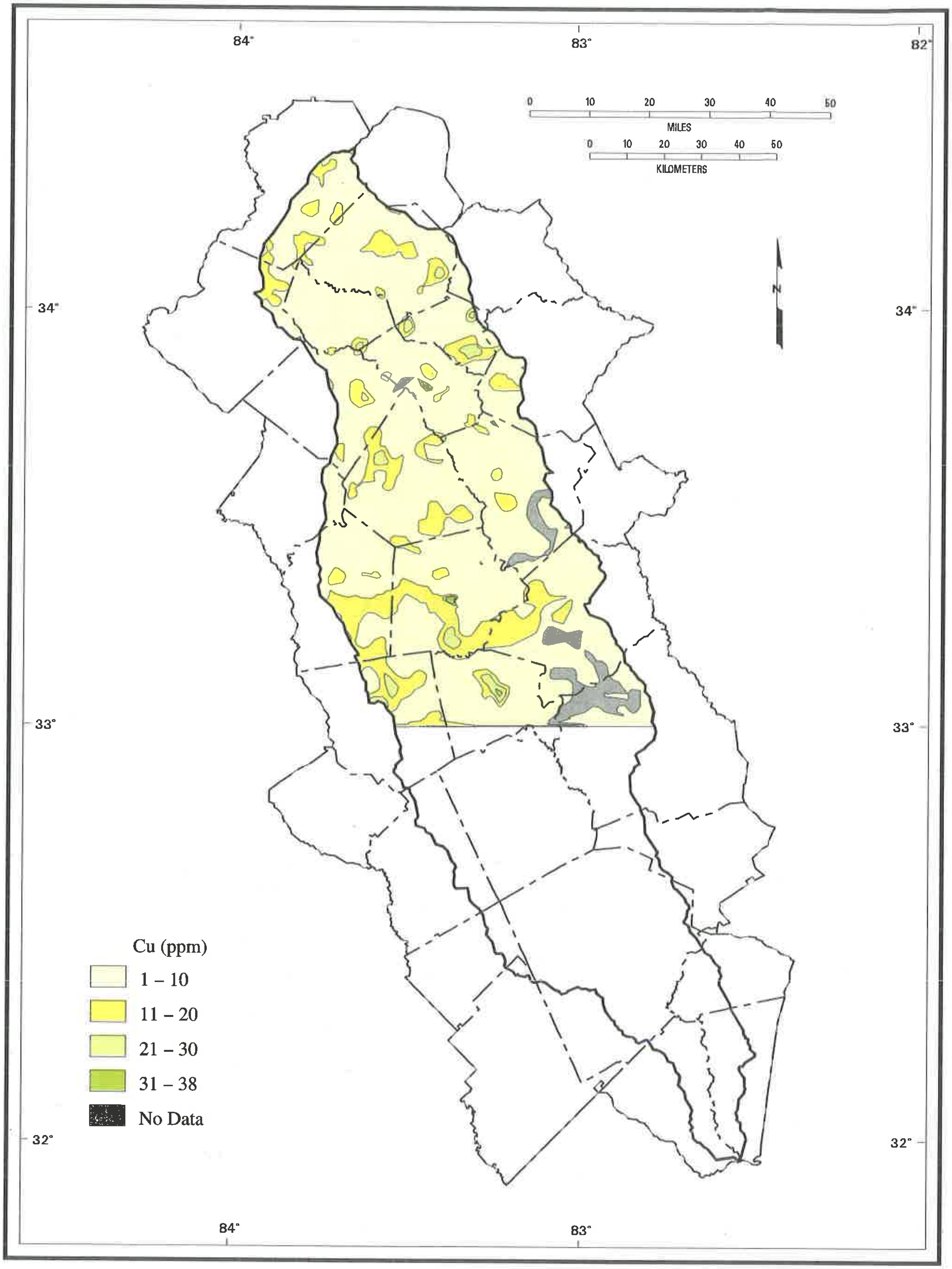

Figure 23. Copper in Stream Sediments.

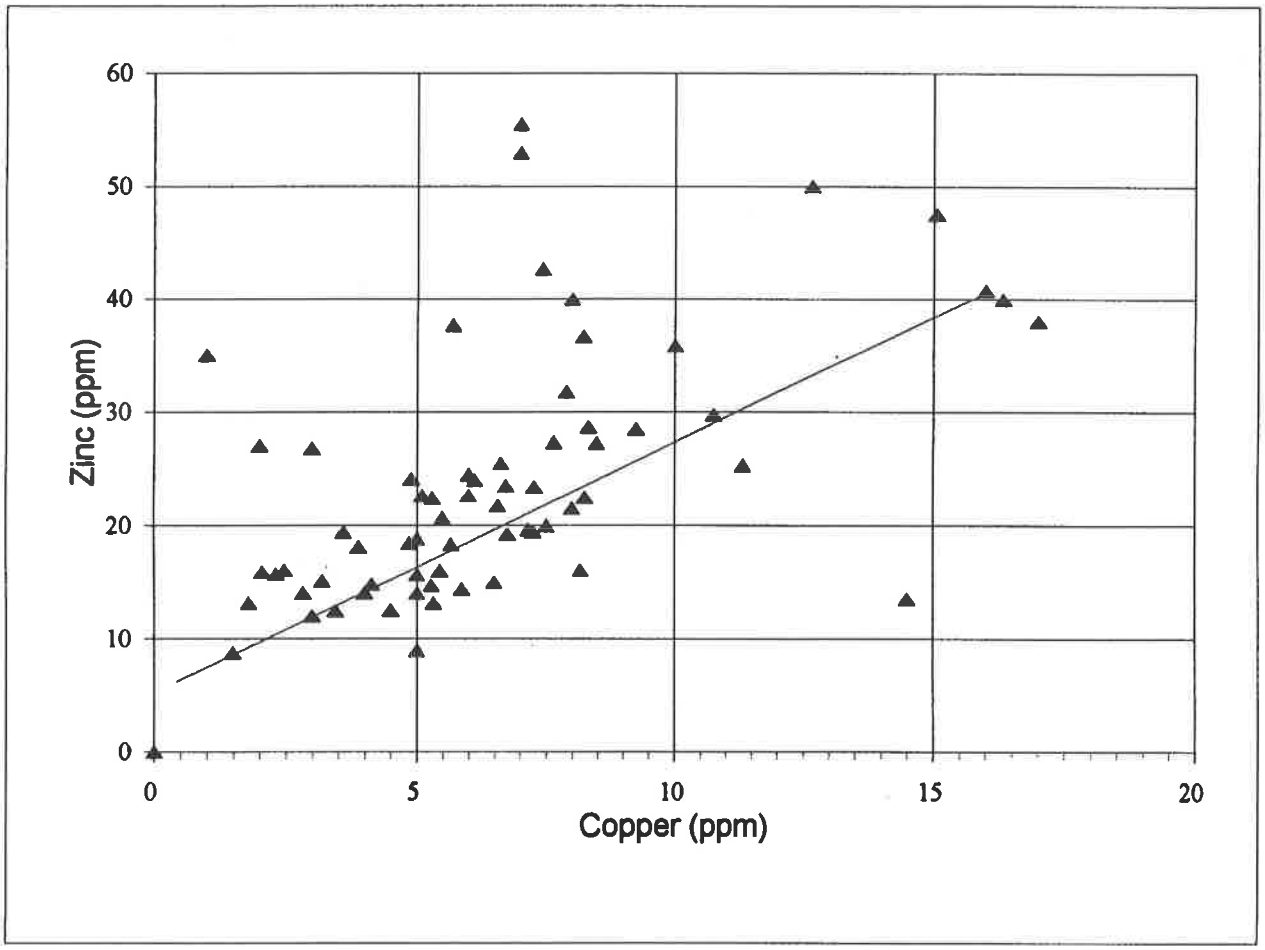

Figure 24. Scatter plot of Copper versus Zinc.

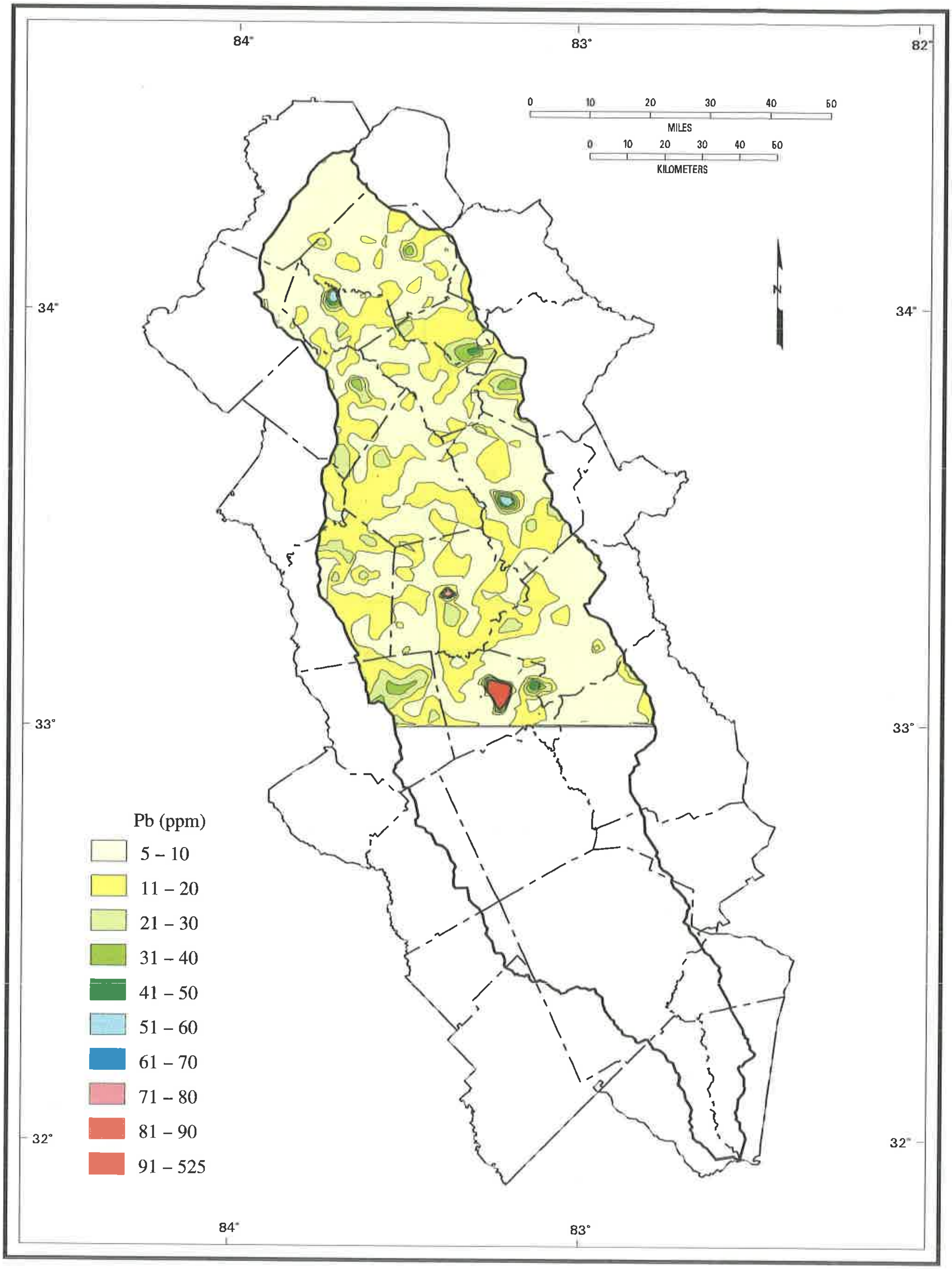

Figure 25. Lead in Stream Sediments.

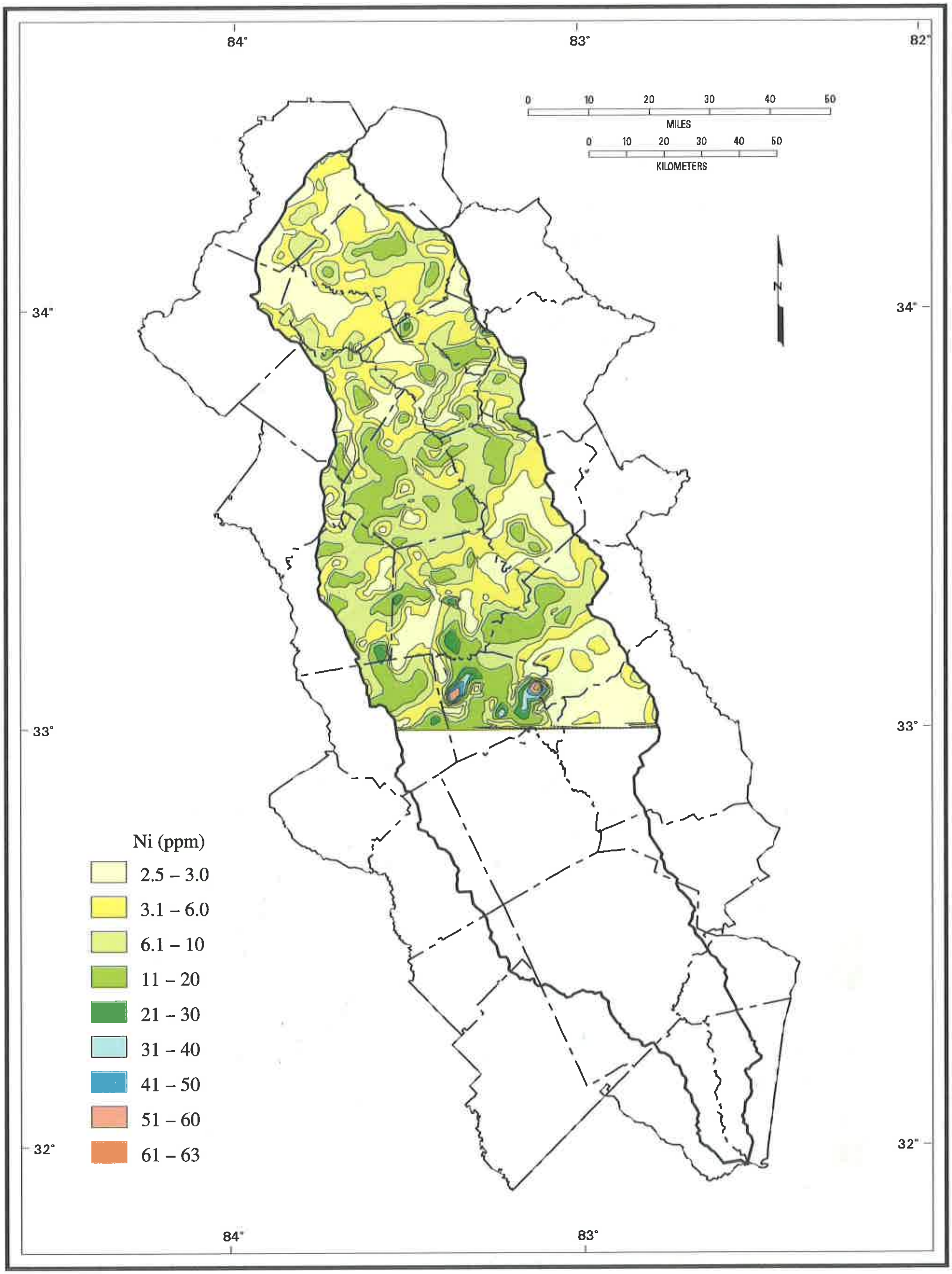

Figure 26. Nickel in Stream Sediments.

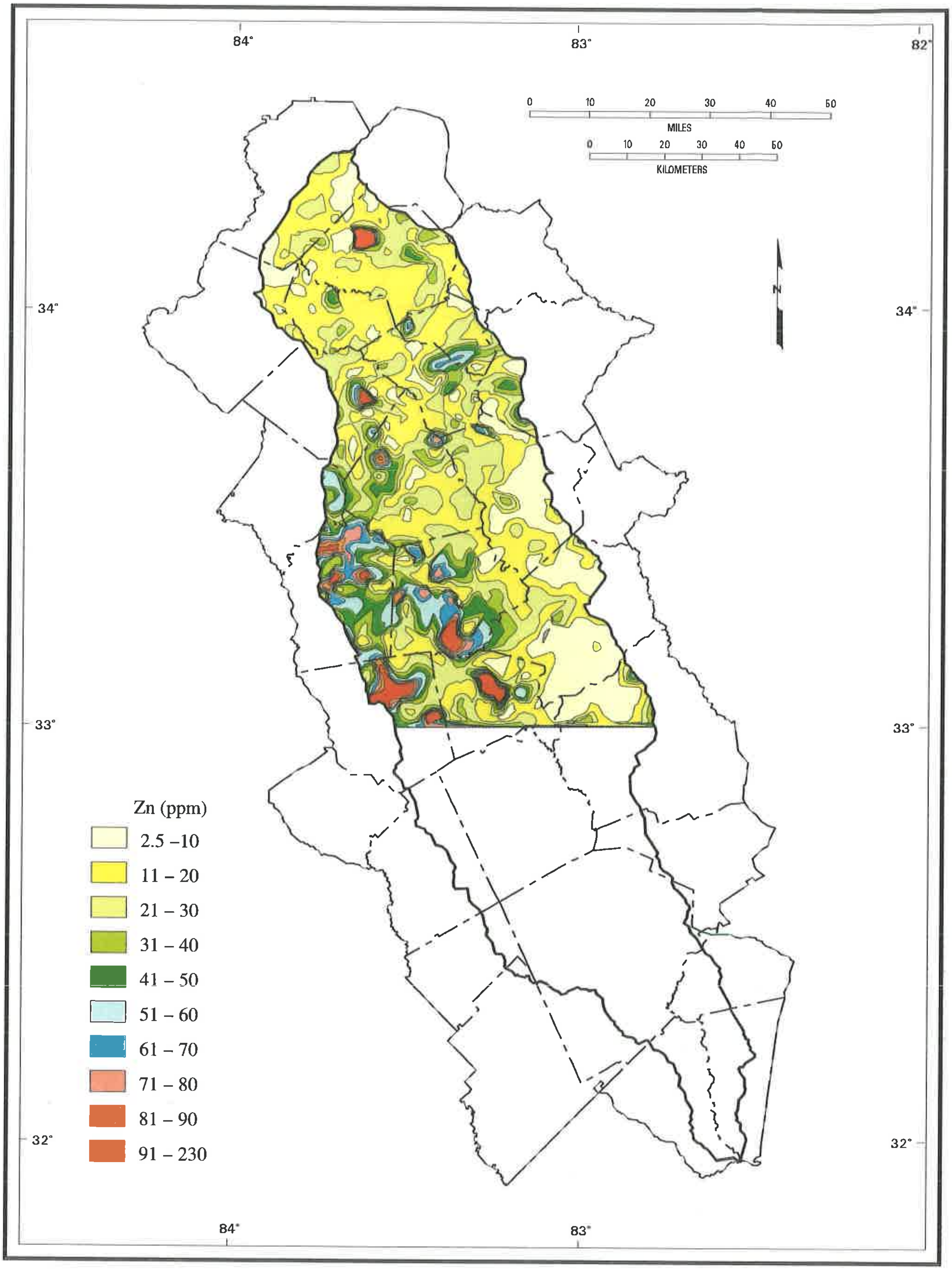

Figure 27. Zinc in Stream Sediments.

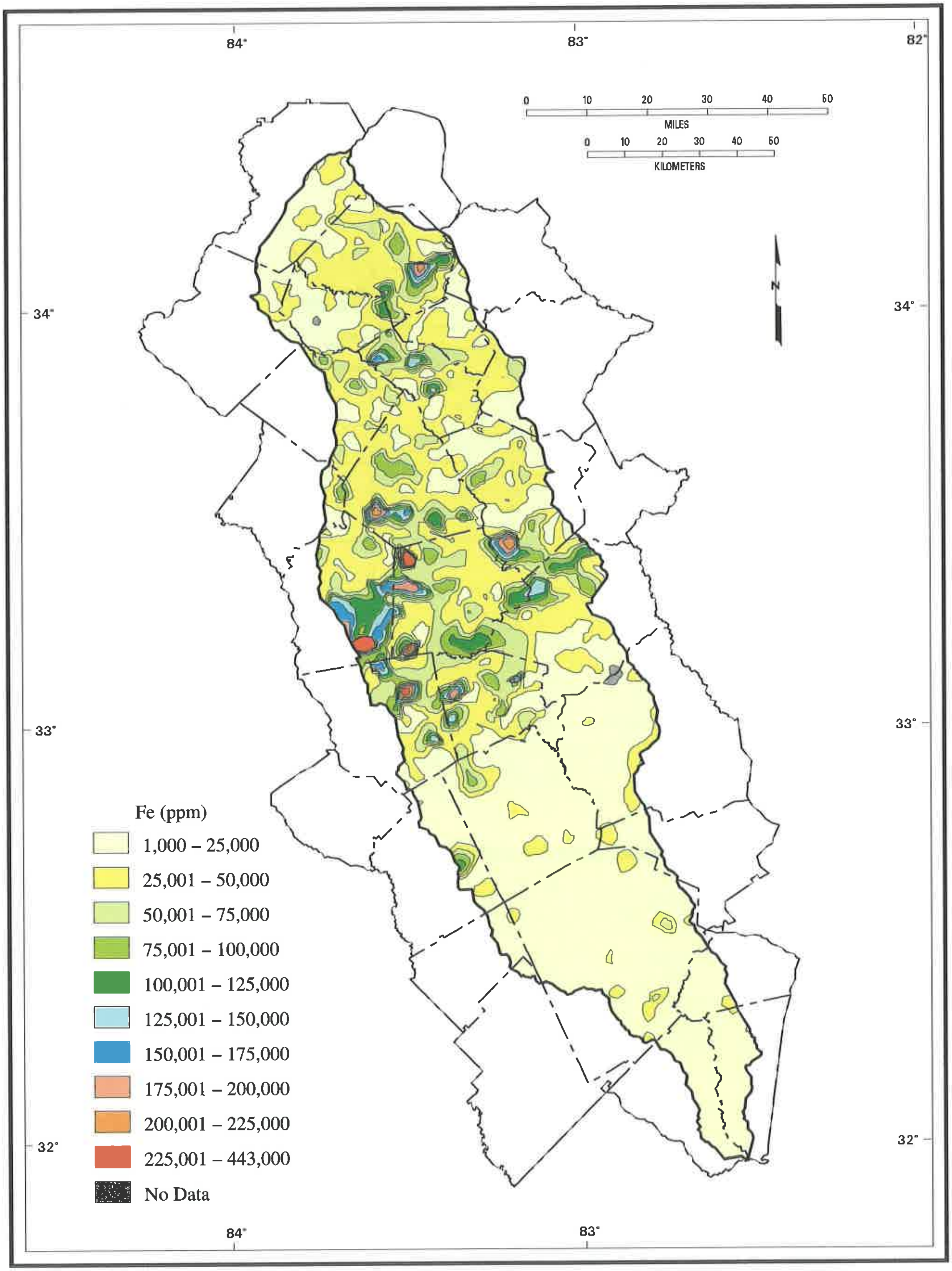

Figure 28. Iron in Stream Sediments.

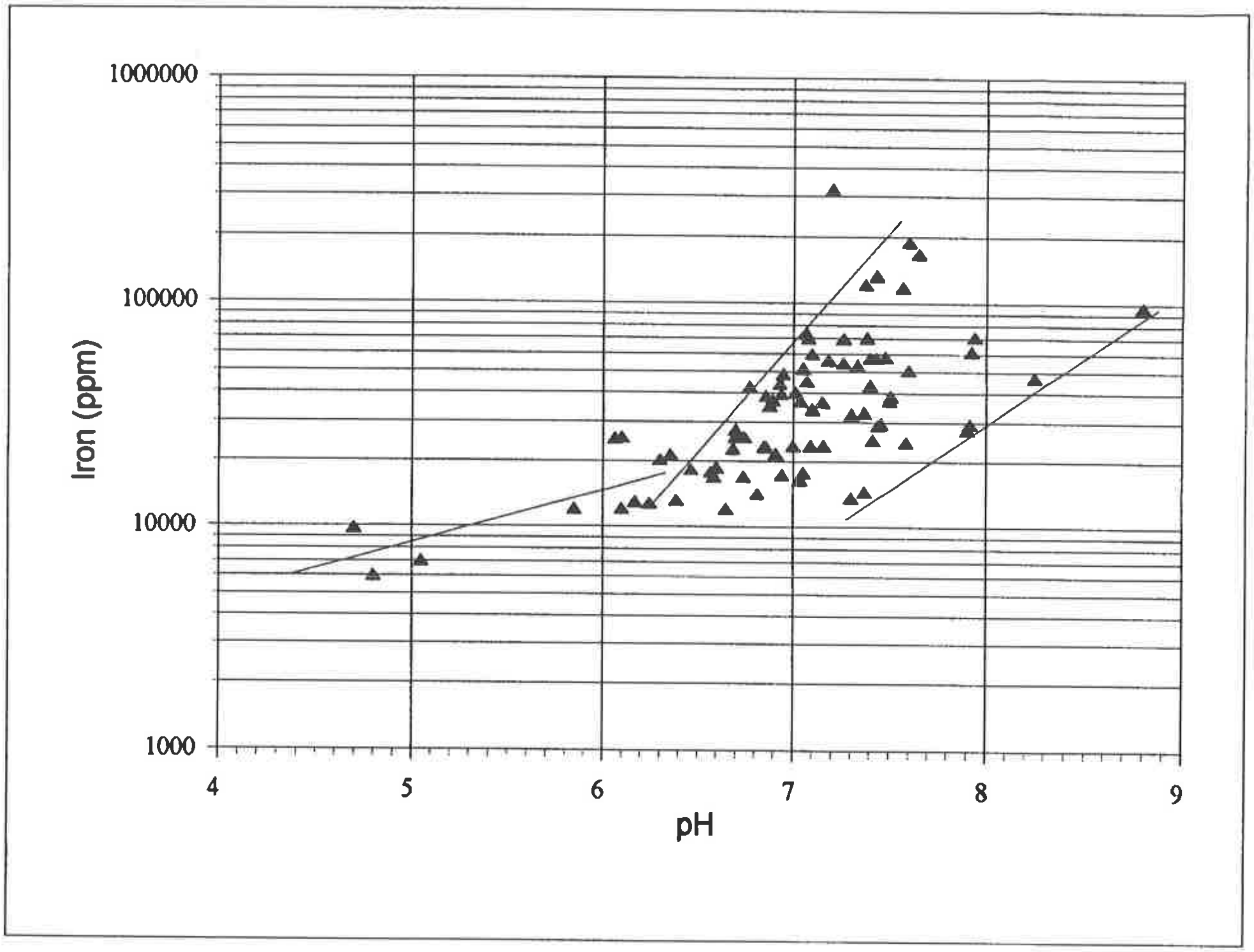

Figure 29. Scatter plot of pH versus Iron.

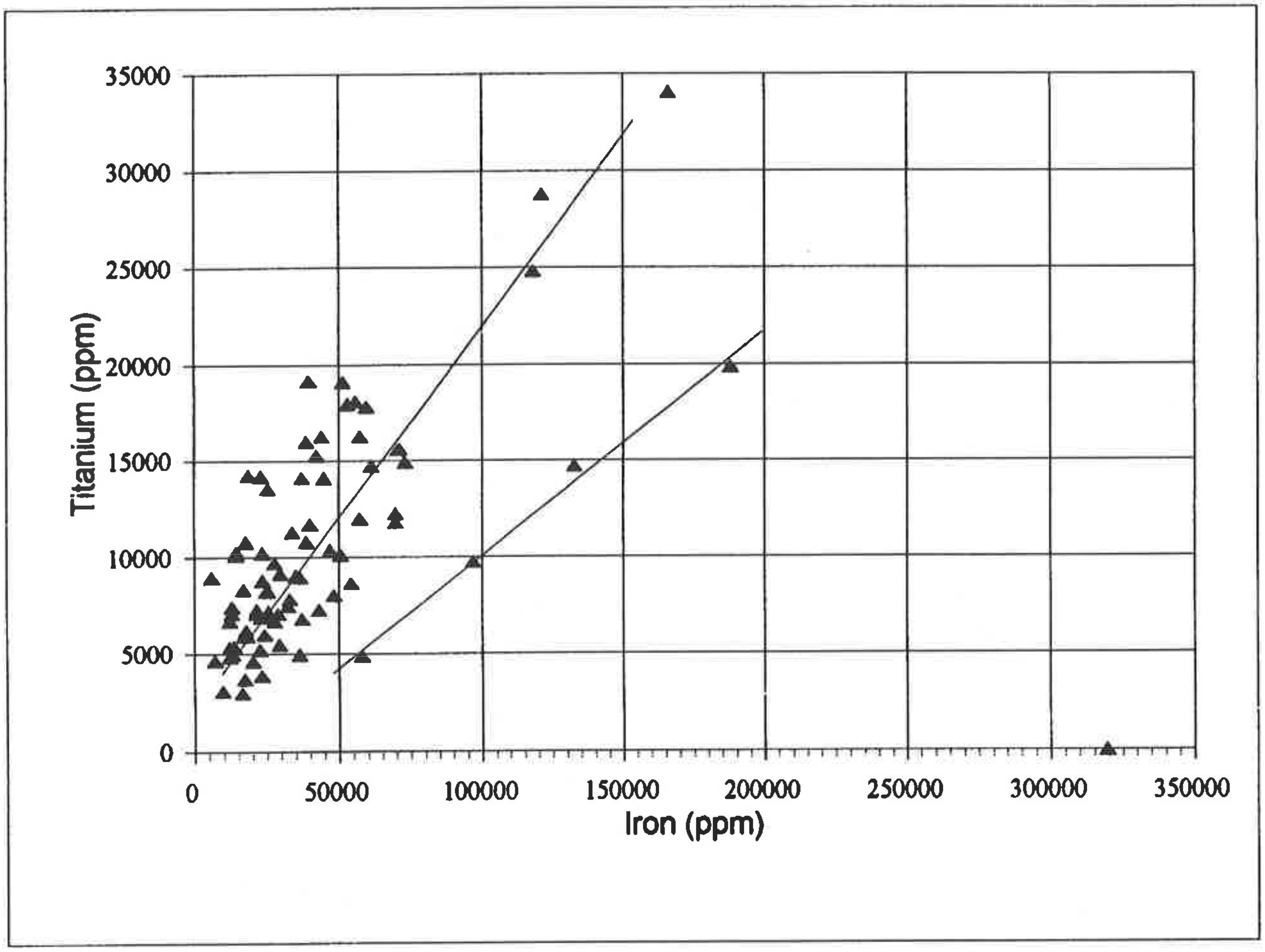

Figure 30. Scatter plot of Titanium versus Iron.

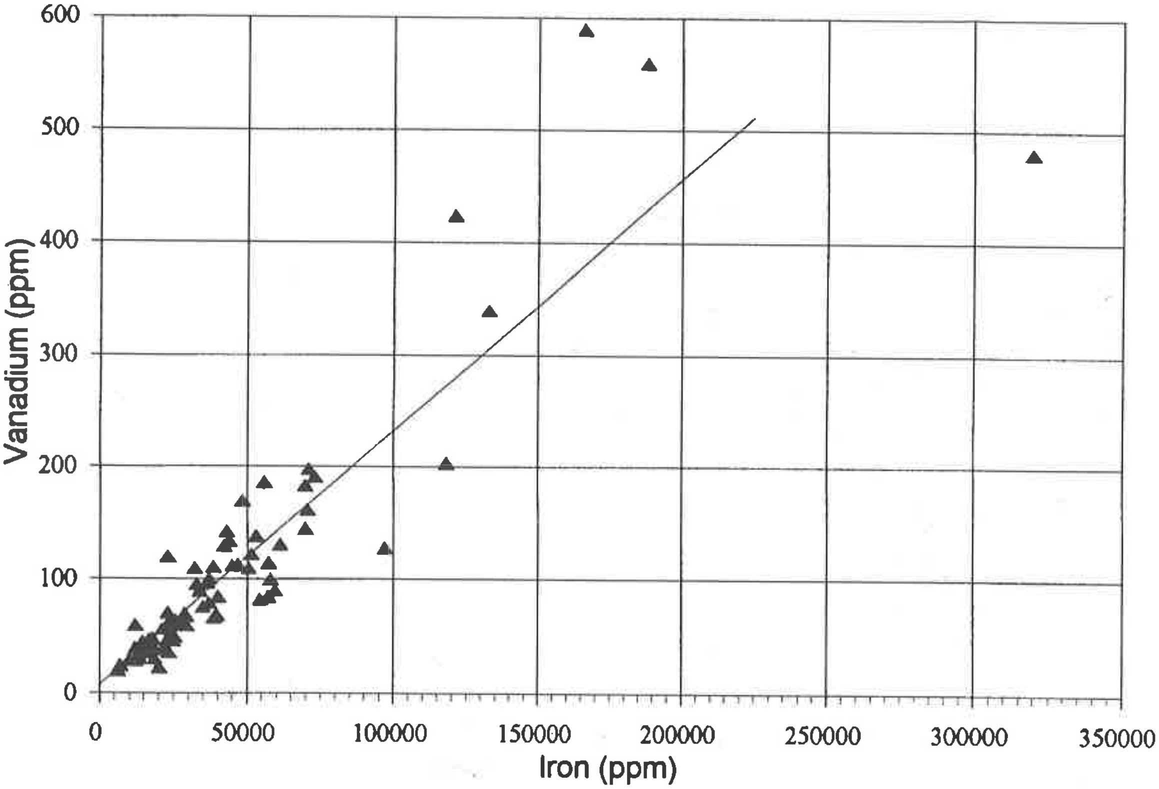

Figure 31. Scatter plot of Vanadium versus Iron.

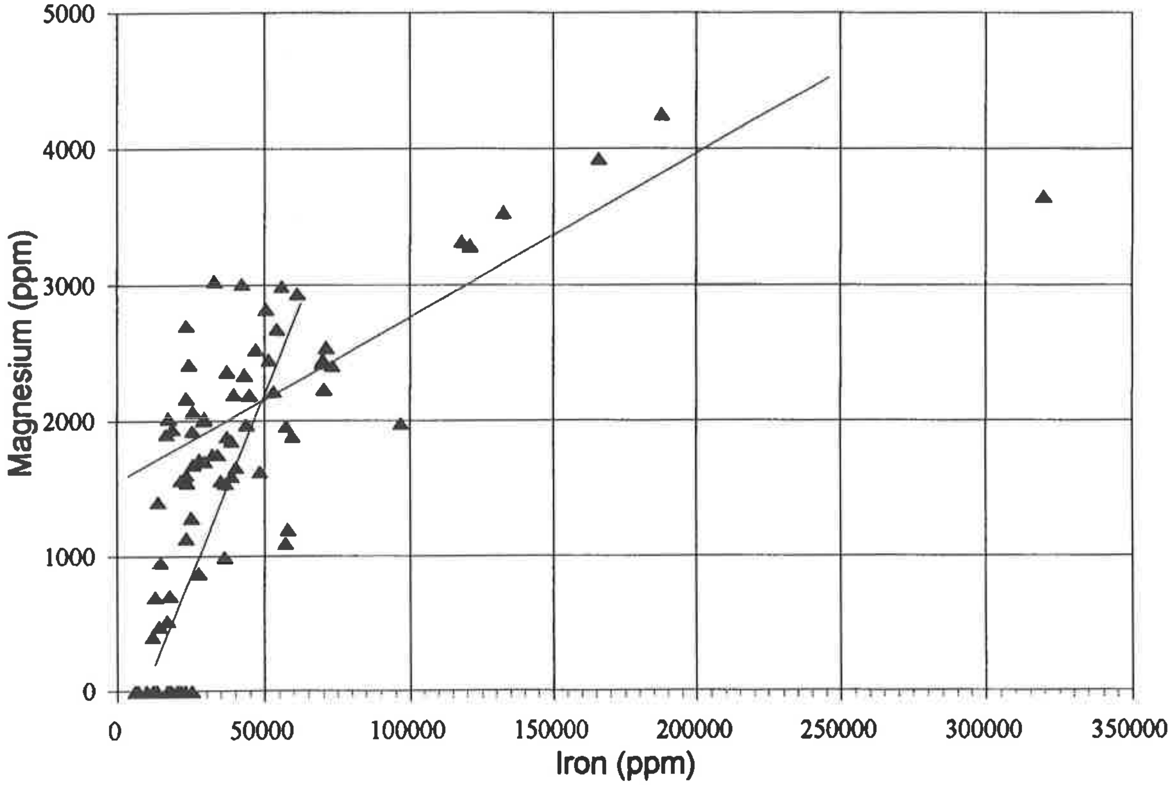

Figure 32. Scatter plot of Magnesium versus Iron.

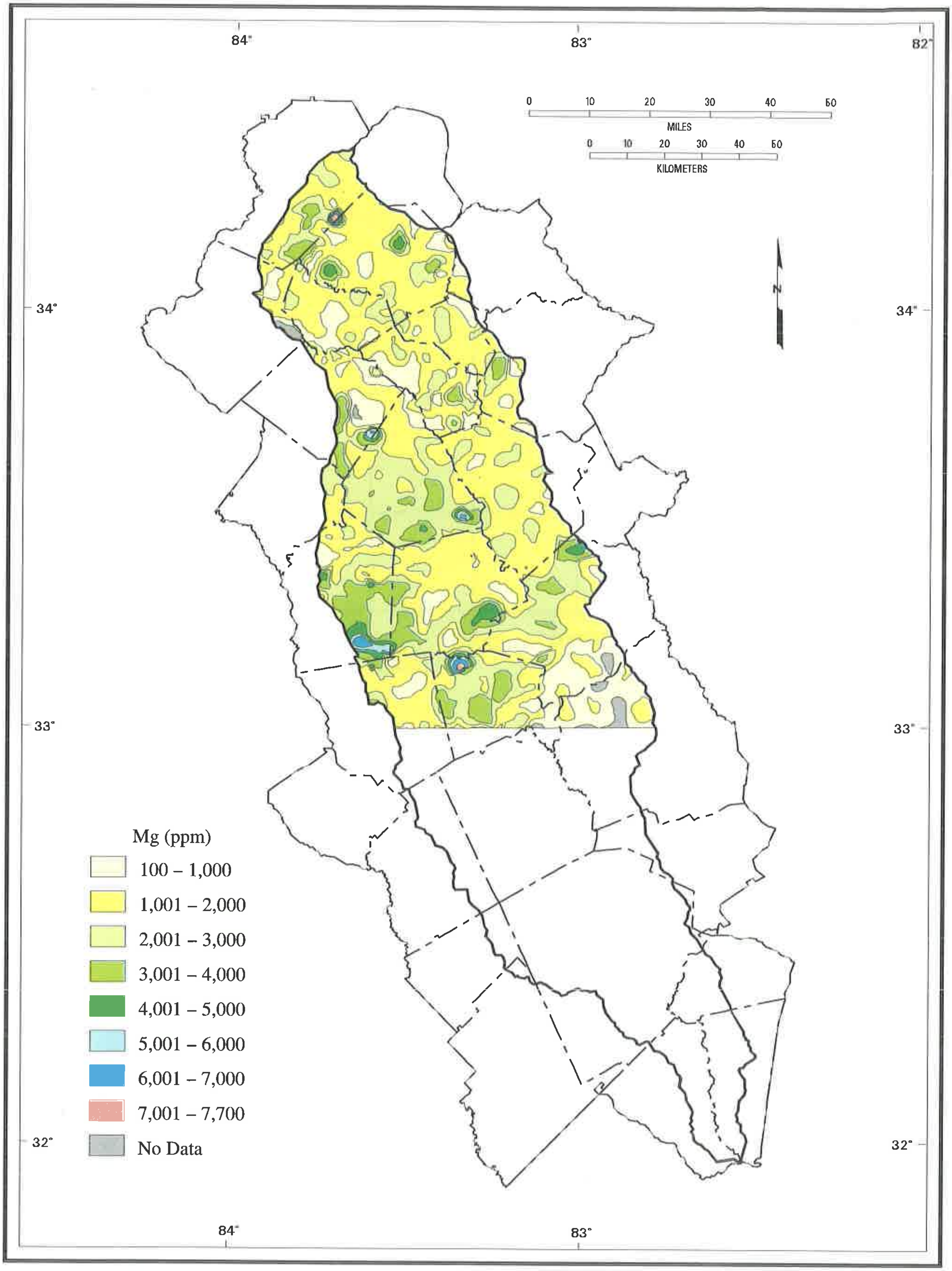

Figure 33. Magnesium in Stream Sediments.

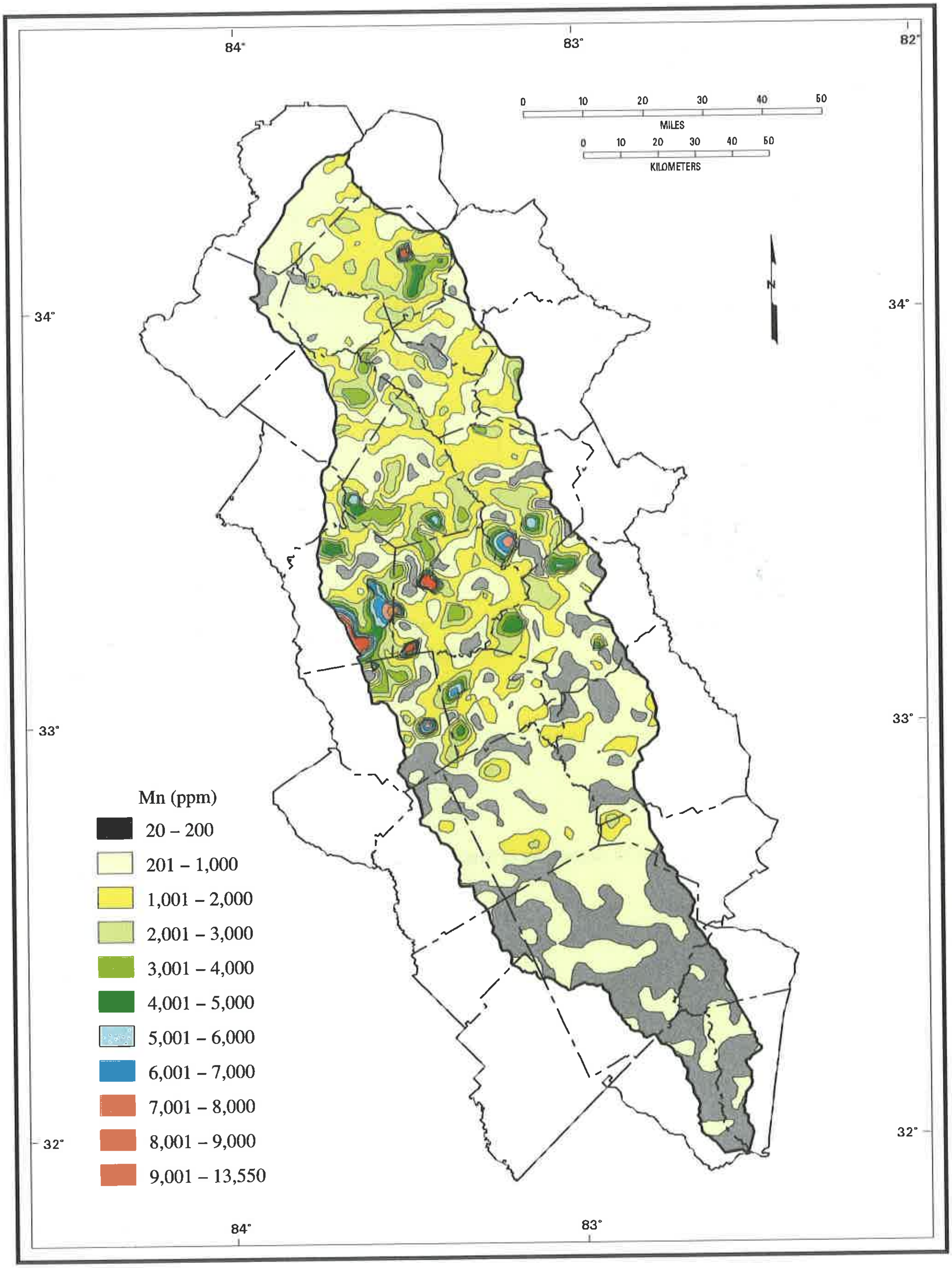

Figure 34. Manganese in Stream Sediments.

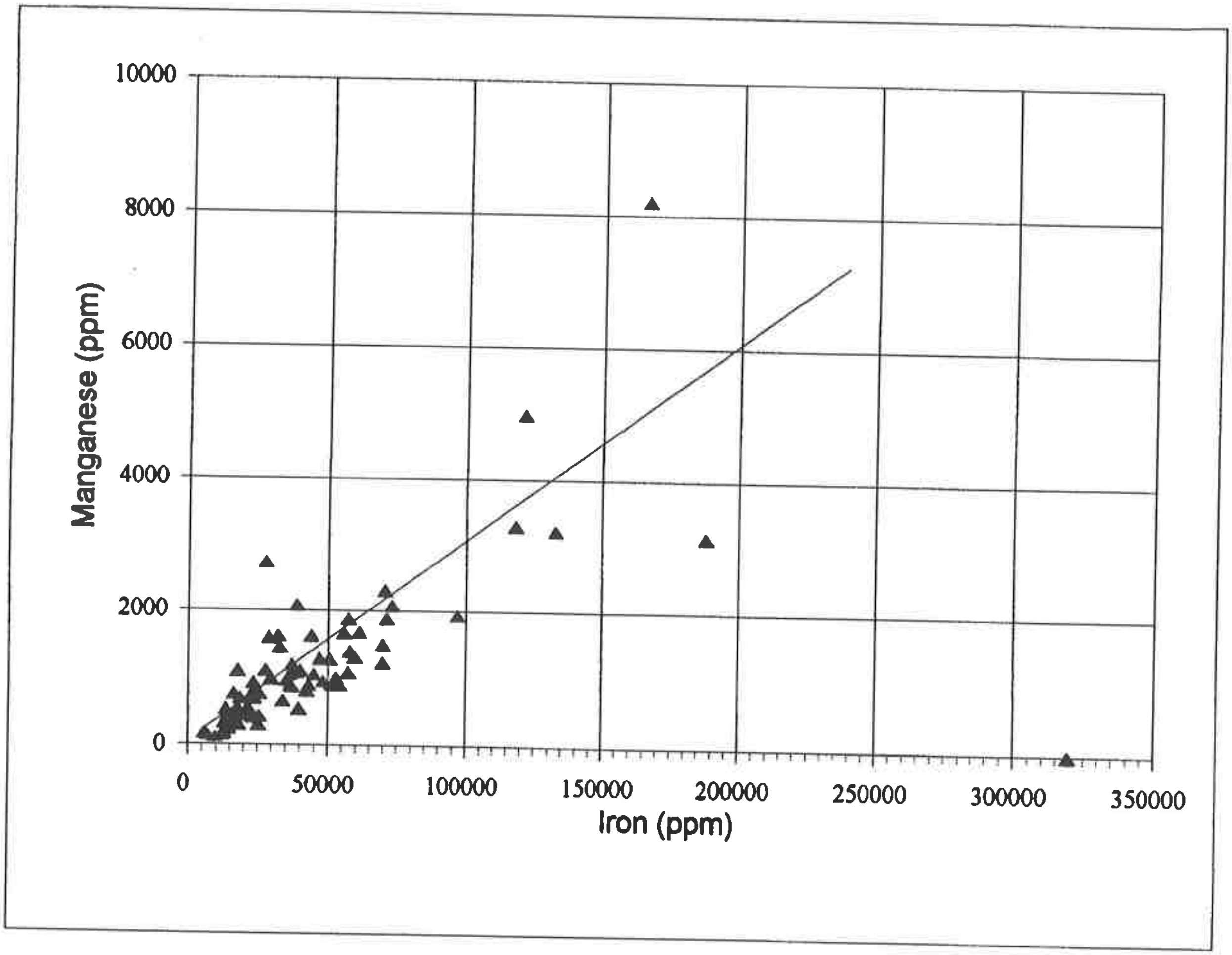

Figure 35. Scatter plot of Manganese versus Iron.

LITHOGEOCHEMISTRY

ARSENIC (As)

Although none of the stream sediments were analyzed for arsenic, 38 samples of rock, soil and saprolite in the Athens 1°x2° quadrangle were analyzed (Lee, 1980). Summary statistics are not included for arsenic in this report, because these arsenic analyses may not be directly comparable with other analyses of stream sediments. Analyses are from different materials, and rock, soil, and saprolite samples are not from the same sample sites as stream sediments. The number of arsenic analyses (38) is small relative to the 792 stream sediment sample analyses.

Of these 38 samples, 80 percent contained greater than 100 ppm arsenic and 13 samples contained 250 to 825 ppm arsenic. Wide distribution of high arsenic values (Figure 36), high concentrations of arsenic, and the high percentage of samples with high arsenic content may indicate that arsenic may affect water quality of streams in that area.

The source of arsenic is unknown, but may be related to metal mineralization or agricultural use. The arsenic may be related to base-metals in rock, soil, and saprolite analyses in that area. Arsenic-bearing pyrite may occur in shales, schists, or metallic vein deposits. High median concentration (Table 2) of arsenic (12 ppm) (Rose et al., 1979) in shales may be reflected in stream sediments derived from shales or their metamorphosed equivalent rock type. Metamorphosed shales may be mica or aluminous mica schists. Weathering of arsenic-bearing pyrite may result in increased acidity and dissolution of arsenic into stream water rather than concentration in stream sediments.

Arsenic in the ORB may be a residue from pesticides used on cotton crops earlier in this century. Widespread distribution of high arsenic values in the Athens 1°x2° quadrangle may suggest an agricultural source. Extensive erosion of cotton fields noted earlier, may have mobilized arsenic into ground water, surface water, and stream sediments.

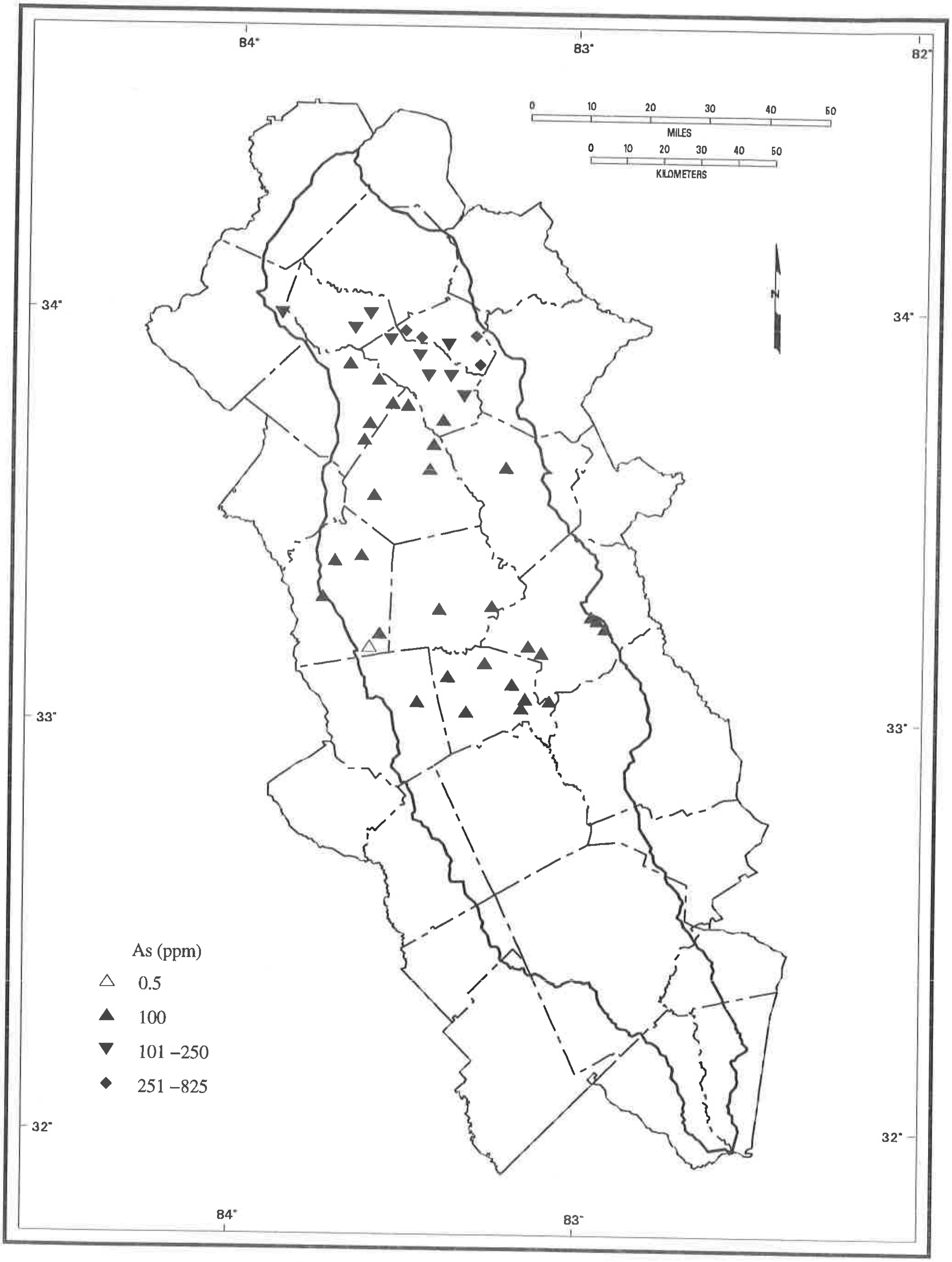

Figure 36. Arsenic in Rocks, Soils and Saprolite.

GEOCHEMICAL STATISTICS

A large geochemical database such as the NURE stream sediment database can be analyzed in a variety of ways to determine the natural background geochemistry of an area such as the ORB. The simplest method is to compute basic statistics for each element for all samples in the ORB. A more sophisticated method is to calculate the basic statistics for subdivisions within the larger area to determine if variations in geochemistry can be attributed to those subdivisions. This study focussed on the statistics of various rock units. Stream sediments are derived from various rock units, and the stream hydrogeochemistry is strongly influenced by reaction with the mineralogy of those rock units with which the water is in contact.

The GIS identified each stream sediment sample site that occurred within each rock unit by overlaying the State Geologic Map coverage and the sample sites in the NURE geochemical coverage. Errors are created because of the differences in locational detail. The accuracy of a location for a rock unit on the 1:500,000 scale of the geologic map is less than that described in the section on sample collection and field measurements for the stream sediment sample sites. The GIS used all of the polygons (separate bodies) of each rock unit. This treats samples from several distinctly separate bodies of a particular rock unit as being in the same body of rock. Table 4 shows the number of sample sites that the GIS counted per rock unit. Because not all of the samples were analyzed for each metal, the number of samples per rock unit may be different for different metals. Table 4 also shows the percentage of sample sites that are found within each rock unit in the ORB. Rock units that had no sample sites are not included in Table 4. Besides providing an indication of the relative influence of a particular rock unit to the overall geochemistry of the ORB, Table 4 also suggests the relative reliability to assign to metal concentrations in each rock unit. A greater degree of confidence may be expected in the geochemistry for the various gneissic units (e.g., fg1, fg1a, fg3, gg1, and gg4 in Table 1) than for units such as pa2, pa2a, pa2b, pm2, and pms1 (Table 1). Generalizations of rock type and lithologic contacts on the Geologic Map of Georgia GIS coverage precludes a rigorous treatment of the data. Mean values were calculated for all sample sites that are within each rock unit.

Average concentrations of the various metals in the more common rock types in the earth's crust (Table 2) provide a standard for comparison with NURE stream sediment geochemistry of the rock units within the ORB. Data in Table 2 shows that ultramafic and mafic rock units commonly contain higher concentrations of heavy metals than more felsic rocks such as granites. Shales also may be expected to be a source of heavy metals. Differences in concentrations between the data in Table 2 and stream sediment geochemical data are to be expected, due in part to the degree of weathering.

Correlation coefficients were calculated to provide a basin-wide picture of the more prominent geochemical relations and are shown in Table 7. Positive numbers may range from 0.0000, meaning no correlation, to 1.0000, meaning a perfect correlation. Negative numbers show an inverse correlation. Although some strong positive correlations are evident in Table 7, some small correlation coefficients may be misleading and suggest very little correlation. The great diversity of source materials, the mixing of stream sediments and stream waters from different sources, and potentially different weathering environments may create considerable noise and modify otherwise strong correlation coefficients. Variations in mineralogy may generate a low correlation coefficient between metals derived from the same source rock.

Correlation coefficients were also calculated for samples grouped by rock unit. This intra-group correlation matrix (Table 9) differs for the total correlation matrix in two ways. In the intra-group correlation matrix correlations due to provenance of the stream sediments (for example magnesium with iron, manganese, titanium, and vanadium) have become stronger, whereas correlations due to other factors, such as anthropogenic sources (for example lead with zinc) have become weaker.

The strongest correlations (Tables 7 and 8) are those in the iron-manganese-titanium-vanadium group. Coefficients range from 0.5990 to 0.8687. These are reinforced by the rock unit geochemical correlations (Tables 9 and 10). This association suggests the presence of manganese- and vanadium-bearing iron-titanium oxides such as magnetite and ilmenite. Correlation coefficients of magnesium with these metals range from 0.2436 to 0.3538 in Tables 7 and 8 and from 0.5652 to 0.7425 in Tables 9 and 10. An association of magnesium silicates with iron-titanium oxides would coincide with the mafic and ultramafic components in that part of the Carolina terrane.

The relatively good association of zinc-cobalt-copper-nickel with coefficients between 0.4075 and 0.6090 may suggest the presence of zinc-copper-cobalt-nickel-bearing sulfides. Rock unit geochemical correlations range from 0.4595 to 0.5878 and reinforce this relationship. A weaker association of these metals with iron (0.2062 to 0.3378) may suggest the presence of iron-bearing sulfides or oxides with the other metals. This association in the Carolina terrane is compatible with known occurrences of base-metal sulfides in other parts of the Carolina terrane. Recalculation of correlation coefficients using rock unit geochemistry substantially weakens the association of iron with the base metal sulfides.

Alkalinity, pH, and conductivity are regionally spatially associated with tectonostratigraphic terranes and locally to individual rock units as discussed earlier in the section on stream hydrogeochemistry. The stronger association in this group is between alkalinity and conductivity. The strongest correlation is by rock unit between alkalinity and conductivity with coefficients between 0.3876 and 0.9352.

Two associations are suggested between the more felsic components. Rock unit correlation coefficients indicate a good correlation between beryllium and potassium (0.6068).

A good correlation is suggested between sodium and aluminum with a coefficient of 0.5241.

Intra-group correlation coefficients (0.4802 to 0.7463) suggest an association between the groups sodium-aluminum, iron-titanium-vanadium-manganese, pH, conductivity, and alkalinity. This association has been suggested earlier on the geochemical maps (Figures 13, 15, 17, 18, 29, 31, and 32, and unpublished GGS maps). Generally higher values for sodium, aluminum, iron, titanium, vanadium, manganese, pH, conductivity, and alkalinity are spatially correlative with the metavolcanic rocks of the Carolina terrane.

Inverse correlation between potassium and titanium-vanadium-iron (Tables 7, 8, and 9) may suggest separate sources or a fractionation of felsic (potassium) and mafic (iron-titanium-vanadium) components in stream sediments.

Correlation between lead and copper, zinc and conductivity (Tables 7 and 8) may be related to naturally occurring base-metal sulfides or to base-metal contamination discussed earlier. Intra-group correlation coefficients (Table 9) suggest that lead concentrations are not related to any of the other metals by rock unit. High lead values may be related to another factor such as anthropenic contamination.

Almost no correlation between chromium and the other metals is suggested by the data in Table 7, although spatial correlations are apparent between chromium, nickel and magnesium (Figures 21, 26, and 33). Intra-group correlations (Tables 9 and 10) suggest a possible weak relation between titanium, magnesium, manganese, and vanadium.

Table 7. Correlation coefficients for all stream sediment and stream samples in the Oconee River Basin.

	pH	Alk.	Cond.	Al	Be	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Ti	V	Zn
pH	1.0000																	
Alk.	0.3643	1.0000																
Cond.	0.2873	0.5323	1.0000															
Al	0.1718	0.0947	0.0345	1.0000														
Be	-0.0797	-0.0282	-0.0213	0.3893	1.0000													
Co	0.0782	0.1641	0.1711	0.2186	0.2642	1.0000												
Cr	0.1591	-0.0887	-0.0393	-0.1243	-0.1178	-0.0772	1.0000											
Cu	-0.0027	0.11043	0.2190	0.2496	0.2714	0.4857	0.0079	1.0000										
Fe	0.2879	0.2527	0.1804	0.4211	0.0740	0.3378	-0.0122	0.2160	1.0000									
K	-0.0881	0.0291	-0.0375	0.2032	0.3512	-0.1108	-0.1001	-0.1498	-0.1930	1.0000								
Mg	0.2686	0.2209	0.2882	0.0066	0.1015	0.1647	-0.0497	0.2436	0.3478	-0.0528	1.0000							
Mn	0.3221	0.3098	0.2151	0.3084	0.1278	0.4796	-0.0370	0.1656	0.6782	-0.1213	0.2803	1.0000						
Na	0.2404	0.1461	0.1365	0.3596	0.1841	-0.0332	-0.0215	0.1161	0.2419	0.1275	0.0938	0.3222	1.0000					
Ni	0.1452	0.0642	0.1161	0.1955	0.2308	0.4075	0.0011	0.4932	0.2087	-0.0036	0.2245	0.1524	0.0215	1.0000				
Pb	0.1246	0.0393	0.2190	0.0348	0.0956	0.1336	-0.0202	0.3486	0.0708	-0.0129	0.0779	0.0573	-0.0274	0.1890	1.0000			
Ti	0.2192	0.2161	0.0949	0.1570	-0.0118	0.0741	0.0066	0.0754	0.6315	-0.2320	0.2345	0.5990	0.2323	0.1013	0.0299	1.0000		
V	0.2343	0.2486	0.1742	0.3905	0.0606	0.2693	-0.0138	0.2521	0.8687	-0.2546	0.3538	0.6596	0.3199	0.1710	0.0567	0.7027	1.0000	
Zn	0.0636	0.1414	0.1982	0.2302	0.2675	0.5000	-0.0371	0.6090	0.2062	-0.0472	0.1196	0.1467	0.0331	0.4583	0.3408	0.0213	0.1577	1.0000

Table 8. Ranking of correlation coefficients.

pH	Alk (0.3643), Fe (0.2879), Cond. (0.2873), Mg (0.2686), Na (0.2404), V (0.2343), Ti (0.2192)
Alk.	Cond. (0.5323), pH (0.3643), Mn (0.3098), Fe (0.2527), V (0.2486), Mg (0.2209), Ti (0.2161)
Cond.	Alk. (0.5323), Mg (0.2882), pH (0.2873), Cu (0.2190), Pb (1.2190), Mn (0.2151)
Al	Fe (0.4211, V (0.3905), Be (0.3893), Na (0.3596), Mn (0.3222), Cu (0.2496), Zn (0.2302), Co (0.2186), K (0.2032)
Be	Al (0.3893), K (0.3512), Cu (0.2714), Zn (0.2675), Co (0.2642), Ni (0.2308)
Co	Zn (0.5000), Cu (0.4857), Mn (0.4796), Ni (0.4075), Fe (0.3378), V (0.2693), Be (0.2642), Al (0.2186)
Cu	Zn (0.6090), Ni (0.4932), Co (0.4857), Be (0.2714), Al (0.2496), Mg (0.2436), Cond. (0.2190), Fe (0.2130)
Fe	V (0.8687), Ti (0.6315), Al (0.4211), Mg (0.3478), Co (0.3378), pH (0.2879), Alk. (0.2527), Cu (0.2130)
K	Be (0.3512), Al (0.2032)
Mg	V (0.3538), Fe (0.3478), pH (0.2686), Cond. (0.2882), Mn (0.2803), Cu (0.2436), Ti (0.2345), Ni (.2245), Alk. (.2209)
Mn	Fe (0.6782), V (0.6596), Ti (0.5990), Co (0.4796), Na (0.3222), pH (0.3221), Alk. (0.3098), Al (0.3084), Mg (0.2803), Cond. (0.2151)
Na	Al (0.3596), Mn (0.3222), V (0.3199), pH (0.2404), Fe (0.2419), Ti (0.2323)
Ni	Cu (0.4932), Zn (0.4583), Co (0.4075), Be (0.2308), Mg (0.2245), Fe (0.2087)
Pb	Cu (0.3486), Zn (0.3408), Cond. (0.2190)
Ti	V (0.7027), Fe (0.6315), Mn (0.5990), Mg (0.2345), Na (02323), pH (0.2192), Alk. (0.2161), K (-0.2546)
V	Fe (0.8687), Ti (0.7027), Mn (0.6596), Al (0.3905), Mg (0.3538), Na (0.3199), Co (0.2693), Cu (0.2521), Alk. (0.2486), pH (0.2343), K (-0.2546)
Zn	Cu (0.6090), Co (0.5000), Ni (0.4583), Pb (0.3408), Be (0.2675), Al (0.2302), Fe (0.2062)

Table 9. Correlation coefficients by rock units. Intra-group correlations were calculated for each rock unit.

	Alk.	**Cond.**	**pH**	**Al**	**Be**	**Co**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**Ni**	**Pb**	**Ti**	**V**	**Zn**
Alk.	1.0000																	
Cond.	0.9352	1.0000																
pH	0.3988	0.3876	1.0000															
Al	0.4004	0.2958	0.4246	1.0000														
Be	-0.1302	-0.1427	-0.0524	0.2401	1.0000													
Co	0.4492	0.3541	0.2287	0.5218	0.2024	1.0000												
Cr	0.1686	0.1745	-0.0407	0.0157	-0.1047	0.0603	1.0000											
Cu	0.0999	0.0078	0.0562	0.6367	0.2001	0.5822	0.0764	1.0000										
Fe	0.5554	0.4980	0.3981	0.4802	-0.1086	0.3834	0.1571	0.1863	1.0000									
K	-0.2357	-0.1900	0.2046	0.0911	0.6068	-0.1859	-0.1052	-0.1125	-0.2408	1.0000								
Mg	0.5644	0.4600	0.4208	0.5996	0.1445	0.4610	0.3095	0.4241	0.6843	-0.0433	1.0000							
Mn	0.6922	0.6540	0.4519	0.5119	-0.0229	0.4720	0.2681	0.0987	0.8367	-0.1197	0.5948	1.0000						
Na	0.2734	0.2578	0.3198	0.3596	0.0613	0.2865	0.0007	0.3390	0.7463	-0.0400	0.5613	0.3684	1.0000					
Ni	0.0432	0.0031	0.2111	0.5241	0.2840	0.5878	0.1504	0.5563	0.0694	0.0941	0.3346	0.0803	0.1144	1.0000				
Pb	-0.0796	-0.0882	-0.2508	0.3081	-0.1708	-0.0997	-0.0801	-0.1615	-0.1245	-0.1853	-0.2315	-0.1105	-0.1831	-0.0641	1.0000			
Ti	0.3832	0.3282	0.3257	-0.1816	-0.0446	0.4092	0.3429	0.3211	0.7448	-0.2833	0.5652	0.7432	0.3720	0.2421	-0.1074	1.0000		
V	0.6870	0.6156	0.3732	0.6459	-0.1004	0.5042	0.2450	0.3214	0.8948	-0.3035	0.7425	0.8615	0.6386	0.1355	-0.1088	0.7410	1.0000	
Zn	-0.0547	-0.1308	-0.0734	0.2233	0.1508	0.4595	-0.0514	0.5570	-0.0988	-0.1057	0.0530	-0.0319	-0.0464	0.5537	0.2352	0.0735	0.0036	1.0000

Table 10. Ranking of correlation coefficients by rock unit.

Alk.	Cond. (0.9352), Mn (0.6922), V (0.6870), Mg (0.5644), Fe (0.5554), Co (0.4492), Al (0.4004), pH (0.3988), Ti (0.3832), Na (0.2734)
Cond.	Alk. (0.9352), Mn (0.6540), V (0.6156), Fe (0.4980), Mg (0.4600), pH (0.3876), Co (0.3541), Ti (0.3282), Al (0.2958), Na (0.2578)
pH	Mn (0.4519), Al (0.4246), Mg (0.4208), Alk. (0.3988), Fe (0.3981), Cond. (0.3876), V (0.3732), Ti (0.3257), Na (0.3198), Co (0.2287), Ni (0.2111), K (0.2046)
Al	V (0.6459), Cu (0.6367), Mg (0.5996), Na (0.5241), Mn (0.5119), Ti (0.4985), Fe (0.4802), pH (0.4246), Alk. (0.4004), Ni (0.3081), Cond. (0.2958), Be (0.2401), Zn (0.2233)
Be	K (0.6068), Ni (0.2840), Al (0.2401), Co (0.2024), Cu (0.2001)
Co	Ni (0.5878), Cu (0.5822), Al (0.5218), V (0.5042), Mn (0.4720), Mg (0.4610), Alk. (0.4492), Ti (0.4092), Fe (0.3834), Cond. (0.3541), Na (0,2846), pH (0.2287), Be (0.2024)
Cr	Ti (0.3429), Mg (0.3095), Mn (0.2681), V (0.2450)
Cu	Al (0.6367), Co (0.5822), Zn (0.5570), Ni (0.5563), Mg (0.4241), Na (0.3390), V (0.3214), Ti (0.3211, Be (0.2001)
Fe	V (0.8948), Mn (0.8367), Ti (0.7448), Na (0.7463), Mg (0.6843), Alk. (0.5554), Cond. (0.4980), Al (0.4802), pH (03981), Co (0.3834)
K	Be (0.6068), pH (0.2046)
Mg	V (0.7425), Fe (0.6843), Al (0.5996), Mn (0.5948), Ti (0.5652), Alk.).5644), Na (0.5613), Co (0.4610), Cond. (0.4600), Cu (0.4241), pH (0.4208), Cr (0.3095)
Mn	V (0.8615), Fe (0.8367), Ti (0.7432), Alk. (0.6922), Cond. (0.6540), Mg (0.5948), Al (0.5119), Co (0.4720), pH (0.4208), Cr (0.3095)
Na	Fe (0.7463), V (0.6386), Mg (0.5613), Al (0.5241), Ti (0.3720), Mn (0.3684), Cu (0.3390), pH (0.3198), Co (0.2865), Alk. (0.2734), Cond. (0.2578)
Ni	Co (0.5878), Cu (0.5563), Zn (0.5537), Mg (0.3446), Al (0.3081), Be (0.2840), pH (0.2111)
Ti	Fe (0.7448), Mn (0.7432), Mg (0.5652), Al 90.4985), Co (0.4092), Alk. (0.3832), Na (0.3720), Cr (0.3429), Cond. (0.3282), pH (0.3257), Cu (0.3211), Ni (0.2421)
V	Fe (0.8948), Mn (0.8615), Mg (0.7425), Ti (0.7410), Alk. (0.6870), Al (0.6459), Na (0.6386), Cond. (0.6156), Co (0.5042), pH (0.3732), Cu (0.3214), Cr (0.2450)
Zn	Cu (0.5570), Ni (0.5537), Co (0.4595), Pb (0.2352), Al (0.2233)

CONTAMINATION

Contamination discussed in this report concerns that related to and noted in the NURE databases that were collected during the period 1976 to 1978. As discussed earlier in this report in the section on recent stream sedimentation, a considerable amount of sedimentation occurred in the streams of the ORB during the century prior to 1950 (Trimble, 1969). In addition, some alluvial deposits may be as old as the beginning of the Quaternary, 1.65 to 2.5 million years (Morrison, 1991). The focii of this section on contamination are to identify possible sources of contamination that were noted during the sample collection period and to identify those stream sediment and stream analyses that may have been affected by those sources of contamination.

NURE databases contain information regarding the type of contamination-related anthropogenic activity near the sample sites that might influence the analytical results. NURE databases provide only a general type of activity and do not elaborate on the size or form of the activity. Types of activities noted for the ORB included: mining, sewage, "dumps", farming, urban, and other industrial activity. Activities noted as "dumps" in the NURE databases may include a wide variety of solid waste disposal sites. Because these sites are not defined or described in the NURE databases, they will be referred to in this report as waste disposal sites. Of the 792 stream sediment sample sites, farming was noted for 259, waste disposal sites were indicated for 39, mining for 10, other industrial for 5, sewage for 3, and urban for 2 (Figure 37). The remainder of the sample sites are considered "non-contaminated", but some may have been subject to contamination by prior activity at the site or by activity upstream. Because of the large number of samples collected near farming activities and "non-contaminated" sample sites, samples with high metal contents may not be statistically significant. Because of the small number of sample sites near potential contamination sources other than farming, the quantitative impact of such sources on geochemical results may be difficult to demonstrate. However, the analytical results may qualitatively show that some activities have contributed to anomalous hydrogeochemical or geochemical analytical results.

The strongest indication of contamination in stream sediments and stream water is suggested by analyses of samples collected near waste disposal sites (Figure 37). Mean concentrations for cobalt, copper, lead, and zinc (8, 7, 24, and 28 ppm, respectively) were higher for samples collected near waste disposal sites than the mean concentrations for "non-contaminated" samples. Most of the waste disposal sites noted in the NURE database for the ORB are within these counties

Oconee (4) Morgan (5) Jasper (3)
Greene (3) Putnam (4) Hancock (4)
Jones (4) Baldwin (9).

Samples that may be affected by contamination from waste disposal sites are in Baldwin, Jones, Putnam, Jasper, and Oconee counties. One third of these samples have high metal contents with concentrations as high as:

31 ppm cobalt 38 ppm copper
30 ppm nickel 525 ppm lead
125 ppm zinc 125,000 ppm iron
40 ppm tin 20,400 ppm titanium
240 ppm vanadium.

Stream water conductivities at those sites are also anomalously high. The sample with the highest lead content also contains the highest amount of zinc and the second highest concentration of copper (31 ppm) for this group of samples. The pH of stream water at that site is 9.2, alkalinity is 0.5 meq/L, and conductivity is 180 micromhos/cm.

Stream sediments near mines (Figure 37) contained higher aluminum (53,580 ppm) and lower iron (16,960 ppm) than "non-contaminated" samples. All but two of these sites are near kaolin mines in the Coastal Plain counties of Twiggs, Wilkinson, and Washington. Other sites are in Hall and southern Putnam counties.

Lower alkalinity values (0.2 meq/L) were measured at sample sites near "other industrial" activities in the ORB (Figure 37). Such sites occur in Clarke, Oconee, Wilkinson, Washington, and Laurens counties. Average metal contents of two samples that are found in Clarke and Oconee counties were cobalt (12.5 ppm), lead (17.5 ppm), and zinc (35.5 ppm).

Samples collected near sewage sites (Figure 37) had higher alkalinity (0.5 meq/L), conductivity (99.7 micromhos/cm), and beryllium (0.8 ppm), and zinc (30.2 ppm) than "non-contaminated" samples. Sewage sites are in Jasper, Greene, and Jones counties.

Two urban sites near Milledgeville in Baldwin County (Figure 37) have higher pH (7.7), conductivity (99.0 micromhos/cm), and higher concentrations of chromium (19 ppm), iron (51750 ppm), nickel (21.5 ppm), and lead (17.5 ppm). One sample site had a conductivity of 173 micromhos/cm, and high concentrations of chromium (33 ppm), iron (92,400 ppm), nickel (33 ppm), lead (30 ppm), titanium (11,000 ppm), vanadium (120 ppm), and zinc (32 ppm).

Mean values for samples collected near farming activity were not different from "non-contaminated" samples. Sample sites near farming activity are concentrated in the northern end of the ORB in Jackson and Barrow counties and in the southern end of the ORB in Laurens and Treutlen counties.

In general,urban waste disposal and sewage sites may affect stream sediment geochemistry and stream hydrogeochemistry more than other activities in the ORB. The greatest concentration of these sites is near Milledgeville and immediately south of the Fall Line (Figure 37). A string of waste disposal sites is in Morgan and Oconee counties, and several smaller concentrations of these sites are near Eatonton in Putnam County.

Additional potential sources of stream sediment and stream contamination that were not or could not be addressed through the NURE stream sediment and stream databases may include metal-rich drainage from factories, mechanized farms and sewage, metalliferous insecticides and algicides, condensates from smog and factories, roads and railway beds graded with mine waste (Rose et al., 1979), discharges from manufacturing plants, and urban runoff. Road grading is probably not a major source of contamination in Georgia because of a lack of major metal mine workings. As discussed in the section on arsenic, which was not included in the stream sediment analyses, anomalously high arsenic values in soil and saprolite samples may be related to insecticides applied during the earlier part of this century.

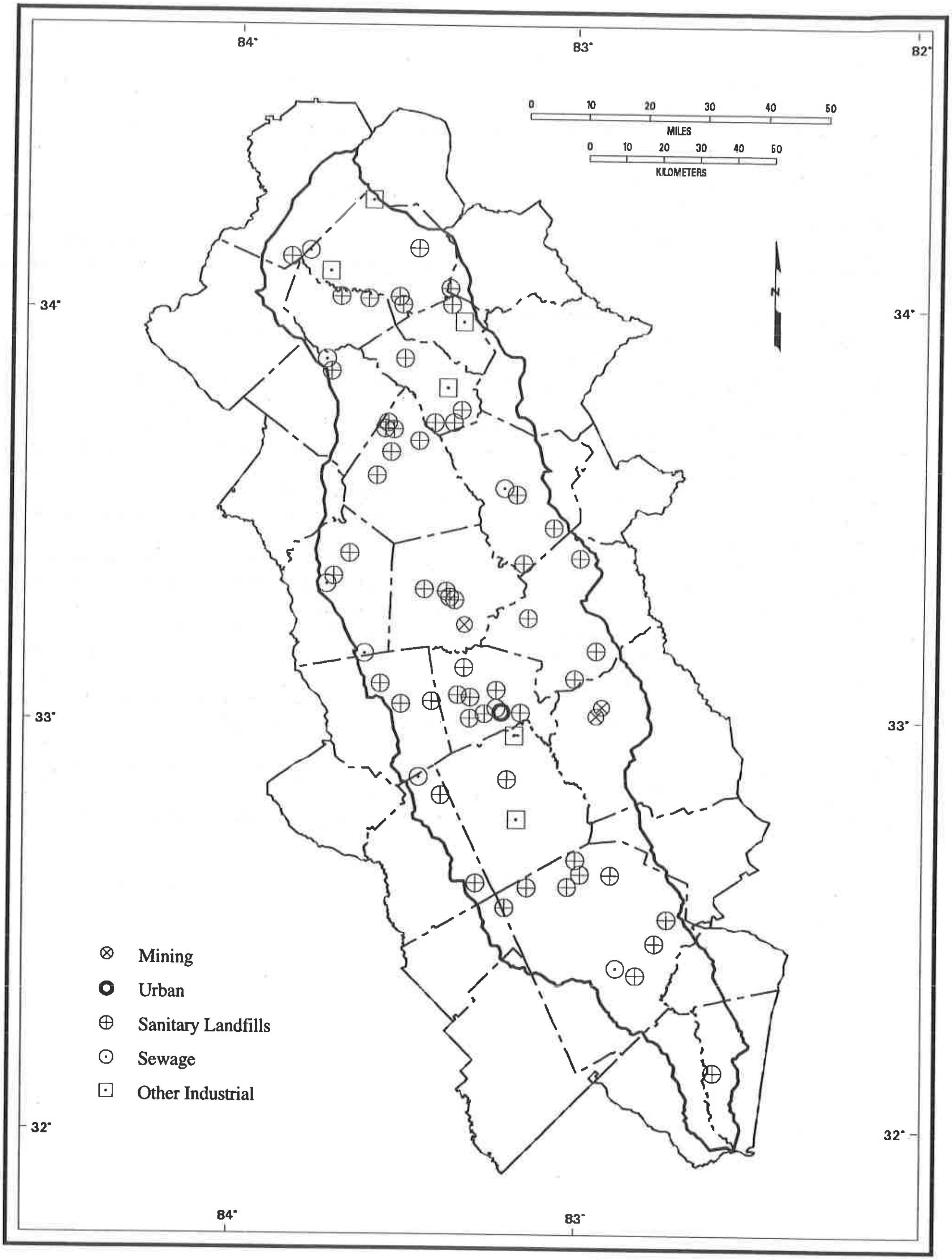

Figure 37. Potential Contamination Sources.

SUMMARY

Databases created by the U.S. Department of Energy's NURE stream sediment reconnaissance program provide important baseline geochemical data from the late 1970's. The spatial distributions of these data were analyzed using a computer-based Geographical Information System to define the background geochemistry and hydrogeochemistry of the Oconee River Basin (ORB). The most important factors which control the geochemistry and hydrogeochemistry within the ORB are regional geology, local geology, and local anthropogenic contamination. Past agricultural practices, which resulted in severe erosion have contributed abnormal amounts of sediment to the stream channels affecting stream flow and potentially water quality within the ORB.

The ORB is composed of metamorphic and igneous rocks of the Piedmont and sedimentary rocks and sediments in the Coastal Plain. The Piedmont is principally composed of biotite gneiss (29.04%), granitic gneiss (13.96%), and amphibolite gneiss (5.16%). Several large granitic intrusions are exposed in the Piedmont. South of the Fall Line are Coastal Plain sandy and clayey sediments and calcareous sediments.

The major regional factors controlling the distribution of metals within the ORB are the differences between the rocks of the Piedmont versus the Coastal Plain and between the rocks of two tectonostratigraphic terranes within the Piedmont. The predominantly metavolcanic rocks of the Carolina terrane are generally of low to intermediate metamorphic grade, and the predominantly metasedimentary and metaplutonic rocks of the Inner Piedmont are of intermediate to high metamorphic grade. Stream sediments within the Carolina terrane generally have higher concentrations of base metals, iron, manganese, titanium, vanadium, magnesium, and sodium.

Streams within the Carolina terrane have higher values of pH, conductivity, and alkalinity than either streams within the Inner Piedmont or normal rainfall. The rocks, saprolite, soils, and stream sediments within the Carolina terrane apparently react with and modify stream water to a greater degree than similar materials in the Inner Piedmont terrane. The greater reactivity or higher susceptibility to chemical weathering may be related to: 1) relatively unstable composition (e.g., iron-rich); 2) lower metamorphic grade resulting in lower degree of crystallinity and greater permeability; and 3) greater susceptibility of volcanic rocks to alteration because of metastable phases (e.g., devitrified glass).

Stream sediments spatially associated with the mafic metavolcanic and metaplutonic rocks of the Carolina terrane contain higher concentrations of chromium, cobalt, copper, nickel, zinc, iron, manganese, titanium, vanadium, and sodium than most other rock types within the ORB.

Streams within the Coastal Plain that are spatially associated with sandy and clayey sediments have distinctly lower pH, conductivities, and alkalinities than those streams which are spatially associated with calacareous sediments. The carbonates apparently buffer rain and surface water by raising the pH and alkalinity and contribute more dissolved solids as measured by the higher alkalinities and conductivities. High permeability, non-reactive compositions (i.e., quartz sand and clay), and higher amounts of decaying carbonaceous matter contribute to the lower pH, conductivity, and alkalinity of non-calcareous streams in the Coastal Plain.

Although several mineral belts extend through the ORB, the only mineral resource which has been extensively developed are the kaolin deposits within the Coastal Plain. The mining and processing of the kaolin may have affected the concentration of aluminum in the stream sediments and stream conductivities. Further data are needed to determine the effect of the kaolin industry on stream sediment geochemistry and stream hydrogeochemistry.

Base and precious metal mining has occurred in the past and is presently underway in the Carolina terrane immediately east of the ORB. Precious metal mining is currently an important industry in the Carolina terrane of South Carolina. Anomalous heavy metals within the Carolina terrane of the ORB suggest the presence of mineralization similar to that to the east of the ORB. The association of certain toxic metals such as mercury, antimony, and arsenic with the mineral deposits east of the ORB may also exist within the geologically similar terrane of the ORB. Stream sediment samples were not analyzed for these elements in the NURE program.

Statistical analyses of basin-wide data suggest several elemental associations: 1)iron-manganese-titanium-vanadium-magnesium, 2) copper-nickel-cobalt-zinc-lead, 3) beryllium-potassium-aluminum, and 4) sodium-aluminum. The first group may be related to iron-magnesium mafic silicates and iron-titanium oxides and reflect the distribution of mafic metavolcanic and metaplutonic rocks. The second group may be related to base-metal sulfides and reflect their presence as disseminated or vein mineralization. The beryllium-potassium-aluminum group may be related to pegmatites or granitic plutons. The sodium-aluminum relation appears to reflect the presence of sodic feldspars or sodic amphiboles in the metavolcanic suite of the Carolina terrane. Correlation coefficients, as well as spatial distributions suggest that groups 1, 2, and 4, plus pH, alkalinity, and conductivity are related to each other and to the Carolina terrane. A spatial correlation between ultramafic rocks and the metals chromium, nickel, and magnesium probably indicates a causative relationship.

Correlation coefficients for samples grouped by rock unit strengthen some of the above relations and weaken others. Correlations between iron-magnesium-titanium-vanadium-manganese become stronger. Relatively good correlations exist between the groups iron-magnesium-titanium-vanadium-manganese, sodium and aluminum, and alkalinity, pH, and conductivity. High values for these metals and hydrochemical parameters are spatially coincident with rock units within the Carolina terrane. The base-metal association becomes stronger except for lead which exhibits very little correlation with any other metal. This suggests that the lead association is not related to lithology but perhaps to other factors such as anthropogenic contamination. The association between beryllium and potassium becomes stronger when grouped by rock unit. The association of chromium with magnesium is strengthened by the intra-group correlations.

A limited number of rock, soil, and saprolite samples for the Athens quadrangle were analyzed for arsenic. Eighty percent of these samples contained greater than 100 ppm arsenic. More than 40 percent of that group contained 250 to 825 ppm arsenic. It is suggested that the arsenic is a residue from past agricultural practices rather than related to local geology.

Some stream sediment samples and associated stream samples in the NURE database may be affected by nearby human activities. These activities may have increased the concentration of certain heavy metals and affected the pH, conductivity and alkalinity of the streams. Activities which appear to have affected the geochemistry of the streams and stream sediments the most include: urban activities, waste disposal sites, and sewage. A number of these activity sites are near Milledgeville, Eatonton, and immediately south of the Fall Line. An unusually high conductivity in a stream near Sandersville may be related to the kaolin industry developed within this part of the Coastal Plain. High lead contents of some stream sediments and the apparent non-association of lead with other metals by rock unit may be the strongest evidence for anthropogenic contamination in the ORB.

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