UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geochemical Evidence for Metallization on St. Thomas and St. John, U.S. Virgin Islands

by

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Open-File Report 85-297

1985

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INTRODUCTION

The U.S. Geological Survey began multidisciplinary studies of the U.S. Virgin Islands in 1983 to assist the government of the Islands by providing necessary information for future planning and resource appraisal. The initial objective of the geochemical phase of the study was to examine the regional geochemical characteristics of the Islands including the identification of the foci of mineralization. Sampling of St. Thomas and St. John was conducted in June of 1983 and January of 1984, respectively.

The U.S. Virgin Islands are located in the Greater Antilles island arc some 64 km east of Puerto Rico (fig. 1). The major islands include St. Thomas, St. John, and St. Croix. There are about 50 smaller islands in the study area, most of which are located near St. Thomas and St. John.

St. Thomas is 19 km long by approximately 5 km wide with a surface area of some 91 km^2. St. John is 11 km long, on the average is 5 km wide, and has an area of approximately 54 km^2. The topography of both islands is mountainous. The highest elevation on St. Thomas is about 474 meters (Crown Mountain) and 390 meters on St. John (Bordeaux Mountain). The islands have irregular coastlines with many bays and offshore islets. There are only a few free-flowing streams, and these are intermittent. The climate is tropical, but annual rainfall is generally less than 130 cm. Many of the small outer islands are considered arid. Second-growth forests, which were formerly cultivated fields or plantations, now cover much of both islands.

GEOLOGIC SETTING

St. Thomas and St. John are part of the eastern portion of the Greater Antilles island arc chain, which extends to Cuba. The Puerto Rico Trench lies to the north of St. Thomas and St. John. The Annageda trough lies to the east and the Muertas trough lies to the southeast.

The geology of St. Thomas and St. John has been studied by many authors including Cleve (1882), Earle (1924), Meyerhoff (1926), and more recently by Donnelly (1959, 1966). The rocks in the study area are island-arc related Cretaceous to Tertiary volcanic and volcaniclastic sediments, near surface intrusions, and layered carbonates. In this paper the rock unit descriptions and structural relationships of the rocks have been taken from Donnelly (1959, 1966). Geologic maps of St. Thomas and St. John are given in figures 2 and 3. The stratigraphic units are listed on Table 1.

The oldest rocks in the study area occur along the southern coasts of both islands. These rocks consist of keratophyres, spilites, and radiolarites, collectively called the Water Island Formation. The keratophyres are felsic extrusive or shallow intrusive rocks of submarine origin and contain predominantly albite and quartz. Spilite is a mafic rock of submarine origin. In the Water Island Formation, spilite is slightly greenish with chlorite and albite. Remnant phenocrysts of diopside and augite are common in the spilite. Amygdules are abundant within the spilite and generally contain epidote, calcite, or prehnite.

The Louisenhoj Formation unconformably overlies the Water Island Formation. This unit is a sequence of pyroclastic to epiclastic augite andesites believed to be derived from a nearby vent. The distribution of these rocks is shown in figures 2 and 3.

Overlying the Louisenhoj Formation is the Outer Brass Limestone which consists of thinly bedded siliceous limestones.

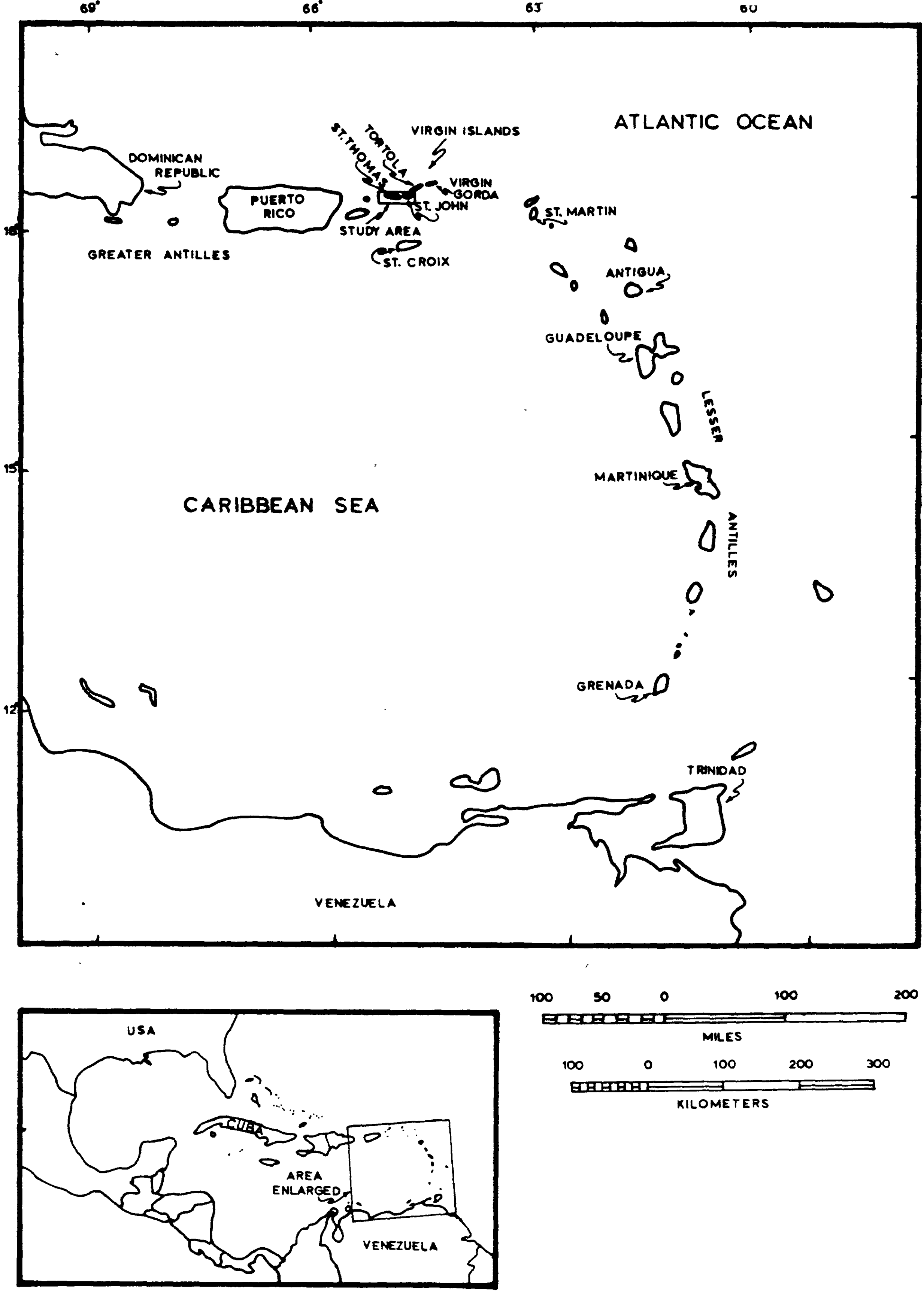


Figure 1.--Index map of the Virgin Islands and vicinity.

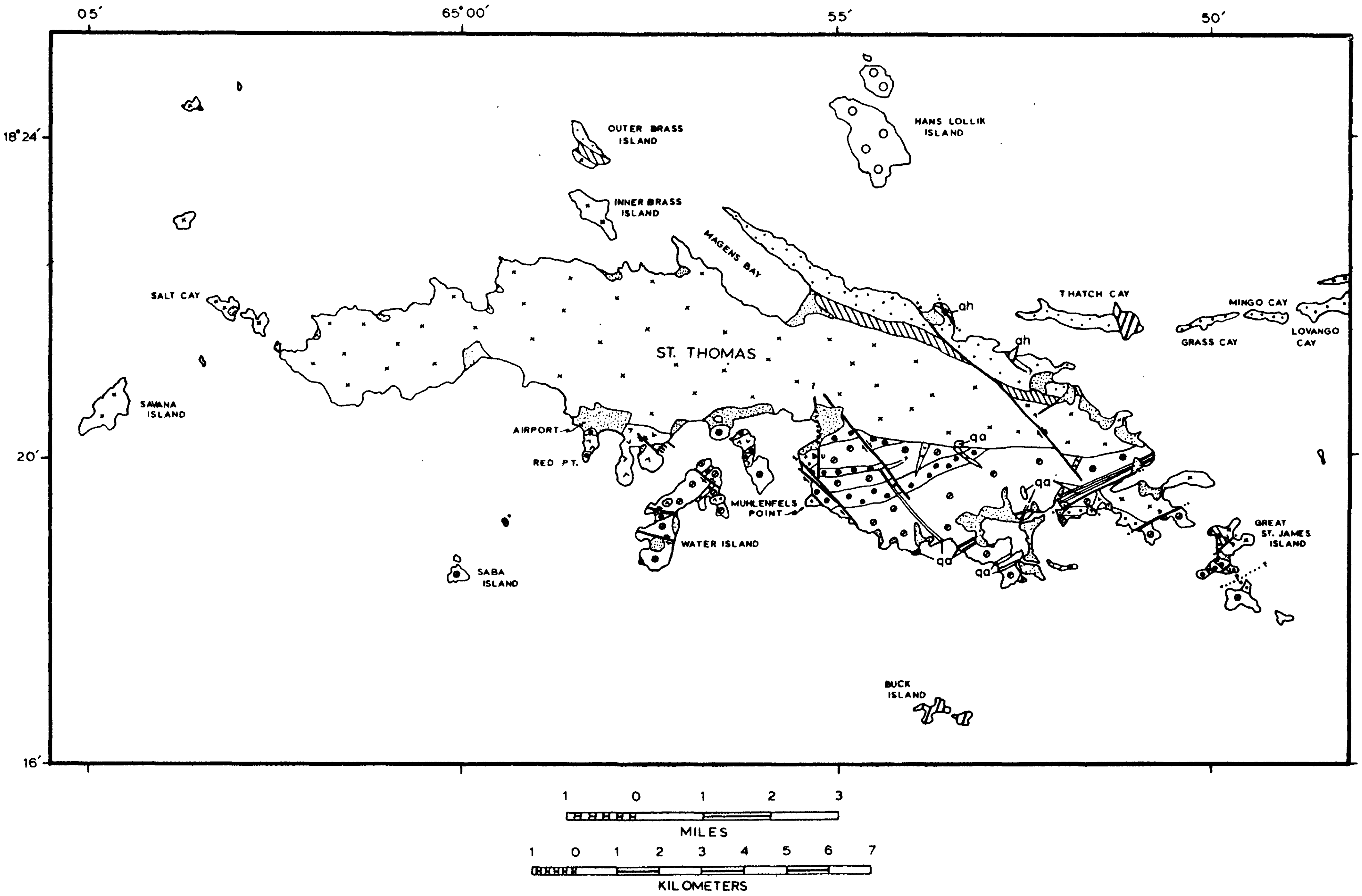


Figure 2.--Geologic map of St. Thomas, U.S. Virgin Islands. (Donnelly,1966)

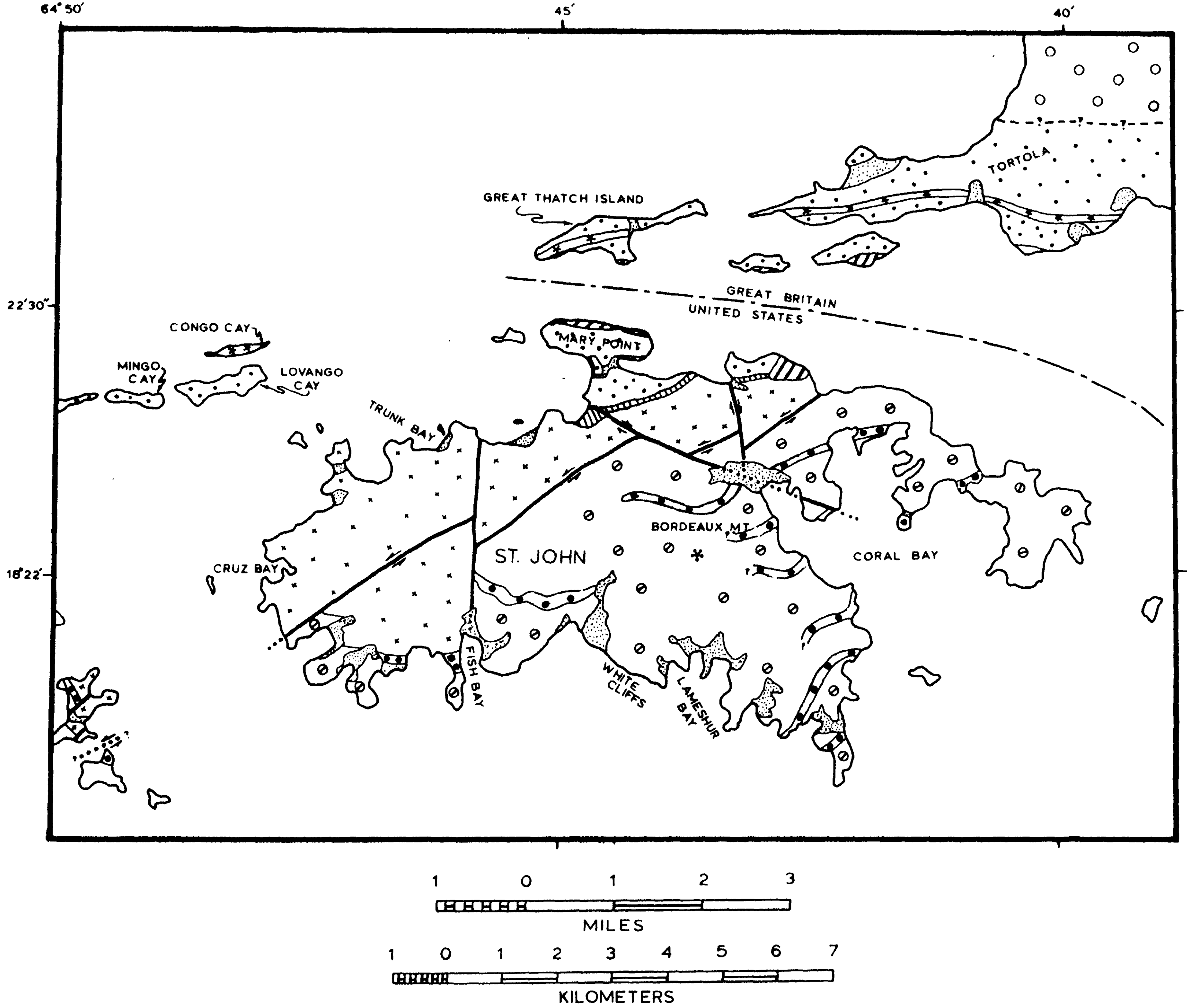


Figure 3.--Geologic map of St. John, U.S. Virgin Islands. (Donnelly, 1966)

TABLE 1.--Summarized stratigraphic relationships of the rocks on St. Thomas and St. John, U.S. Virgin Islands (Donnelly, 1966)

Age		Stratified rocks		Intrusive rocks
present	⁙	Alluvium- gravels and sands of recent origin		
Lower Tertiary to Upper Cretaceous			qa ch	Dikes and plugs: quartz-andesine porphyry; andesine-hornblende porphyry
			▨	Dioritic rocks
	○	Hans Lollik Formation augite andesite volcanic breccia and tuff		
	∴ ✱	Tutu Formation: volcanic wacke. Includes the Congo Cay Limestone Member		
	▧	Outer Brass Limestone: thin-bedded, silicious limestone		
	×	Louisenhoj Formation: augite andesite volcanic breccia and tuff, with minor conglomerate		
		UNCONFORMITY		
			∧	Quartz keratophyre dikes and plugs
	⊘ ● spilite	Water Island Formation: keratophyre flows, flow breccias and tuff: radiolarian cherts; spilite flows		

The Tutu Formation overlies the Outer Brass Limestone. This unit consists of interbedded sequences of fine- to coarse-grained volcanic wackes that appear to be reworked Louisenhoj andesites. Sedimentary textures in the Tutu Formation suggest a high energy environment of deposition (Donnelly, 1966).

The Congo Cay Limestone is a light gray coarsely crystalline limestone found only on Congo Cay in the American Virgin Islands and on the southern coast of Tortola in the British Virgin Islands (fig. 3).

The Hans Lollik Formation outcrops over the entire island of Hans Lollik (fig. 2). This rock consists of augite-andesite, pyroclastic to epiclastic in origin and is very similar in texture and composition to the Louisenhoj Formation.

Upper Cretaceous to lower Tertiary rocks are also observed. Intrusive dioritic rocks, dikes and small plugs of quartz andesine porphyry, and andesine-hornblende porphyry are found locally (figs. 2 and 3).

Hydrothermal alteration is widespread along the southern shore of both St. Thomas and St. John and on many of the small islands in the study area. Two prominent areas of argillic alteration, silicification, and iron enrichment were observed on St. Thomas, at Red Point near the airport and in the vicinity of Jersey Bay. At Red Point, a pyritized-silicic breccia pipe and copper minerals are exposed in recent excavations. Near Jersey Bay, at site 14, veins of iron oxides up to 1.5 m in width cut the intensely argillized country rock. Epidote is common in small veinlets along the southern coast. Quartz veins, commonly containing pyrite, also occur at several localities. One series of quartz veins near Muhlenfels Point, St. Thomas, contains precious metals.

In the vicinity of Bordeaux Mountain, St. John, intense argillic alteration, silicification and iron enrichment occurs over a broad region. Gossan boulders are present near the crest of the mountain. The White Cliffs area contains highly altered rocks with alunite, turquoise, sulfur, and paratacamite.

The hydrothermal alteration has been interpreted as cogenetic with the cooling of the keratophyre magma because alteration only affected the Water Island Formation (Donnelly, 1966). Interpretation of the geochemical data suggests that most of the hydrothermal alteration post-dates much of the Water Island Formation. Broad metal halos appear to have been superimposed on the original chemical compositions of the Water Island Formation, extending into the Louisenhoj Formation and to a lesser degree, into the overlying sedimentary formations. Propylitic-like alteration occurs throughout much of the Louisenhoj Formation.

A continuous skarn zone occurs on Mingo Cay, Lovengo Cay, and Mary Point, St. John. The skarn consists of marble with epidote and garnet. Pyrite occurs locally within the skarn zone, particularly on Mingo Cay. Small pods of copper minerals occur within the skarn zone on Mingo Cay.

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

Rock, soil, minus-80-mesh stream sediment, and panned-concentrate stream-sediment samples were collected from St. Thomas and St. John. Drainage basins with an areal extent generally less than 0.6 km^2 were sampled. At each drainage site four different samples were collected. A 4.5 to 7 kg composite sample of the sediment was collected for panning. A 0.2 kg composite sample of the sediment was collected and later sieved to recover the minus-80-mesh fraction. A 0.2 to 0.5 kg soil sample was collected near the stream-sediment site and, when possible, approximately 0.5 kg of rock chips were collected from a representative outcrop of the local bedrock. Veins, dikes, and altered areas were also sampled. At various locations a 4.5 to 7 kg soil sample was collected and panned. The sample localities and the geochemical anomalies discussed in the text are shown in figures 4 and 5 for St. Thomas and St. John.

All the samples were oven dried at 120°C for approximately six hours, except the panned concentrates, which were air dried. The soil samples and one portion of the stream sediment samples were disaggregated and sieved to minus-80-mesh prior to analysis. The rocks were crushed and then pulverized using ceramic plates. The panned concentrate samples were sieved to recover the minus-20-mesh fraction and then placed in bromoform (density 2.86) to separate two mineral fractions according to their density. The low density fraction contains minerals such as feldspars, quartz, and calcite. The heavy-mineral fraction contains: various rock-forming minerals (biotite, amphiboles, pyroxenes); accessory minerals (magnetite, ilmenite, sphene, zircon, and monazite); and primary or secondary base-metal minerals (sulfides, sulfates, carbonates, and oxides).

The magnetite and other very magnetic minerals were removed using a hand magnet. A Frantz Isodynamic Separator was used to separate the remainder of each sample. A forward slope of 25° and a side slope of 15° was used. Very magnetic minerals were separated at a setting of 0.2 amperes and added to the minerals already removed with the hand magnet. A magnetic fraction and a nonmagnetic fraction were separated at a setting of 1.0 ampere.

All samples were analyzed by the six-step D.C.-arc semiquantitative emission-spectrographic method (Grimes and Marranzino, 1968) for 31 elements.

Mineral grains less dense than bromoform from the panned-concentrate fraction were leached with oxalic acid. The oxalic acid selectively dissolves the Fe-Mn oxide coatings on the mineral grains (Alminas and Mosier, 1975). The size fraction was minus-20-mesh to approximately plus-80-mesh. The leach was performed using 25 ml of a 5% oxalic acid solution (weight/volume) added to 5 g of sample and boiled for 10 minutes. The hot leachate was filtered, evaporated to dryness, then heated for 4 hours at 250°C to roast off the oxalate. The resulting oxide powder was analyzed by the six-step D.C.-arc emission spectrographic method.

The upper 10-20 percent of the concentration range within a particular media for each element is considered to be anomalous. Natural breaks in the frequency distribution were also used in subjectively defining the limits of the anomalous concentrations. Data results for all media are in Hopkins and others (1984).

Geochemical data

A. Rock geochemical data

The use of geochemical data is a valuable approach toward understanding geologic events that have occurred within an area and in evaluating an area's mineral potential. Examination of the rock data within the study area suggests that in many instances the concentrations of several elements are changed relative to fresh rock. These changes appear to be related to processes such as hydrothermal alteration. Large portions of both islands appear to have been affected by hydrothermal alteration.

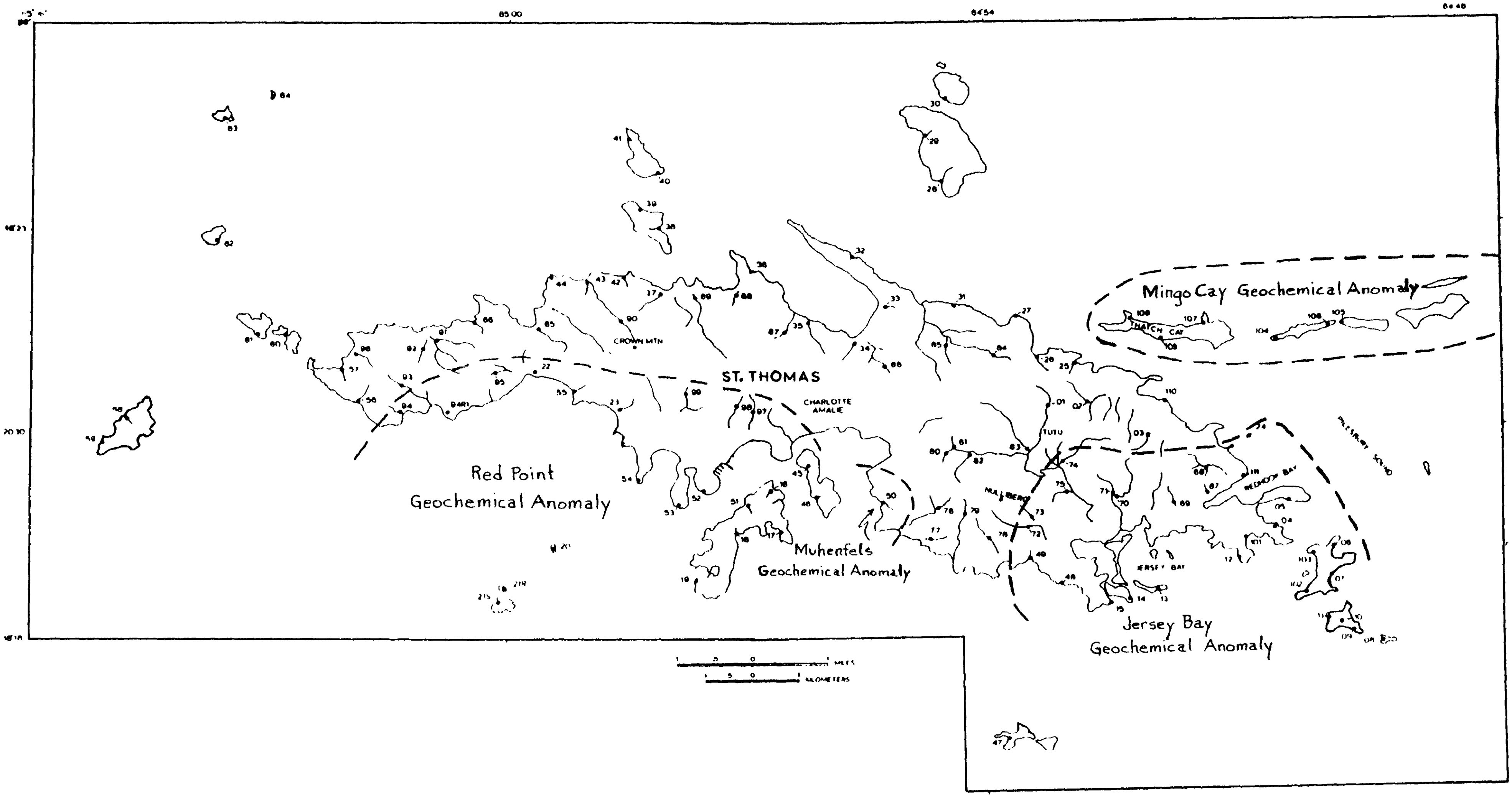


Figure 4.--Sampling sites on St. Thomas, U.S. Virgin Islands.

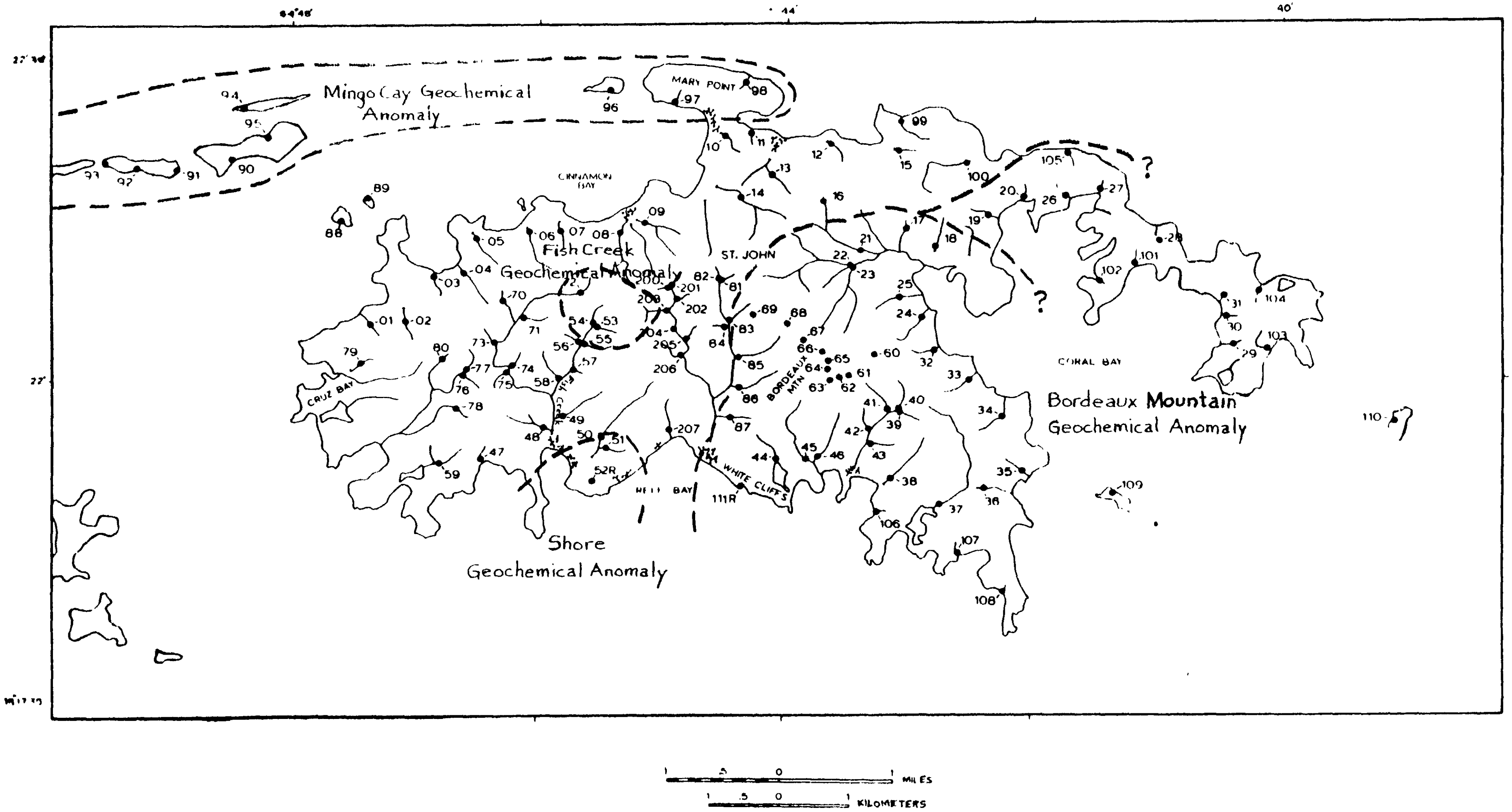


Figure 5.--Sampling sites on St. John, U.S. Virgin Islands.

The data from rocks was used to identify areas of potential mineral deposits based on the changes in the amounts of certain elements. Variations in barium concentrations in rock samples may be useful in identifying certain alteration types. The felsic rocks of the unaltered Water Island Formation generally have lower concentrations of Ba than the rocks of the Louisenhoj Formation. However, the highest Ba concentrations occur in rocks mapped as Water Island Formation (Donnelly, 1959 and 1966), from samples collected at Redhook Bay, St. Thomas, and Mary Point and Bordeaux Mountain, St. John (figs. 6 and 7). These rocks have been intensely altered, which suggests that Ba has been enriched in the felsic rocks, possibly derived from circulating hydrothermal fluids. Anomalous concentrations of Ba are found at many sites near Bordeaux Mountain, also mapped as being within the Water Island Formation. The distribution of samples with anomalous Ba concentrations on St. John is shown in figure 7.

The distribution of samples containing anomalous Cu is shown in figures 8 and 9 for St. Thomas and St. John, respectively. The felsic rocks generally have the lowest copper concentrations with the notable exception of samples from Bordeaux Mountain and Mary Point, St. John (fig. 9). Anomalous copper concentrations are not restricted to the Louisenhoj Formation but extend into the overlying sedimentary rock units on both islands.

The distribution of samples containing anomalous Mo concentrations is given in figures 10 and 11. Areas of intense argillic alteration and iron enrichment occur near Jersey Bay on the eastern end of St. Thomas and Bordeaux Mountain, St. John, and have the greatest concentration of anomalous Mo values.

Only a few rock samples have detectable concentrations of precious metals (figs. 12 and 13). The highest concentrations of Au and Ag are from iron-rich veinlets collected on or near Bordeaux Mountain, St. John, and a quartz vein on St. Thomas. The quartz veins crop out between the main dock at Charlotte Amalie and Muhlenfels Point, north of sample site 50, St. Thomas (figure 12). The largest quartz vein is approximately 1 m wide. Samples from the largest vein were taken at approximately 15-m intervals over a strike length of 135 m. Table 2 lists the Ag, Au, and Te concentrations of these samples. Secondary copper minerals were observed in veins in the adjacent country rock. This area is referred to as the Muhlenfels geochemical anomaly (fig. 4).

A large geochemical anomaly occurs in the vicinity of the Harry S. Truman airport, on St. Thomas and is referred to as the Red Point geochemical anomaly (fig. 4). Secondary copper minerals, a pyritic-quartz breccia pipe, argillic alteration and iron enriched veins are exposed in recent excavations. The small cays or islands south of Red Point (sites 20 and 21) have been intensely silicified. Samples from the islands do not contain anomalous metal concentrations but the presence of silica flooding is a possible geologic indicator of hydrothermal activity. Propylitic-like alteration extends into the Louisenhoj Formation to the north.

The rocks along the coast on the west side of Jersey Bay, St. Thomas, and nearby islands have been intensely altered to clays with iron introduced. There are nearly vertical veins (up to 1.5 m in width) of iron oxide minerals that cut the very altered country rock near site 14. There are also a series of 2-8 cm veinlets of iron oxides that form a boxwork-like texture in the cliffs. This area is referred to in the text as the Jersey Bay geochemical anomaly (fig. 4).

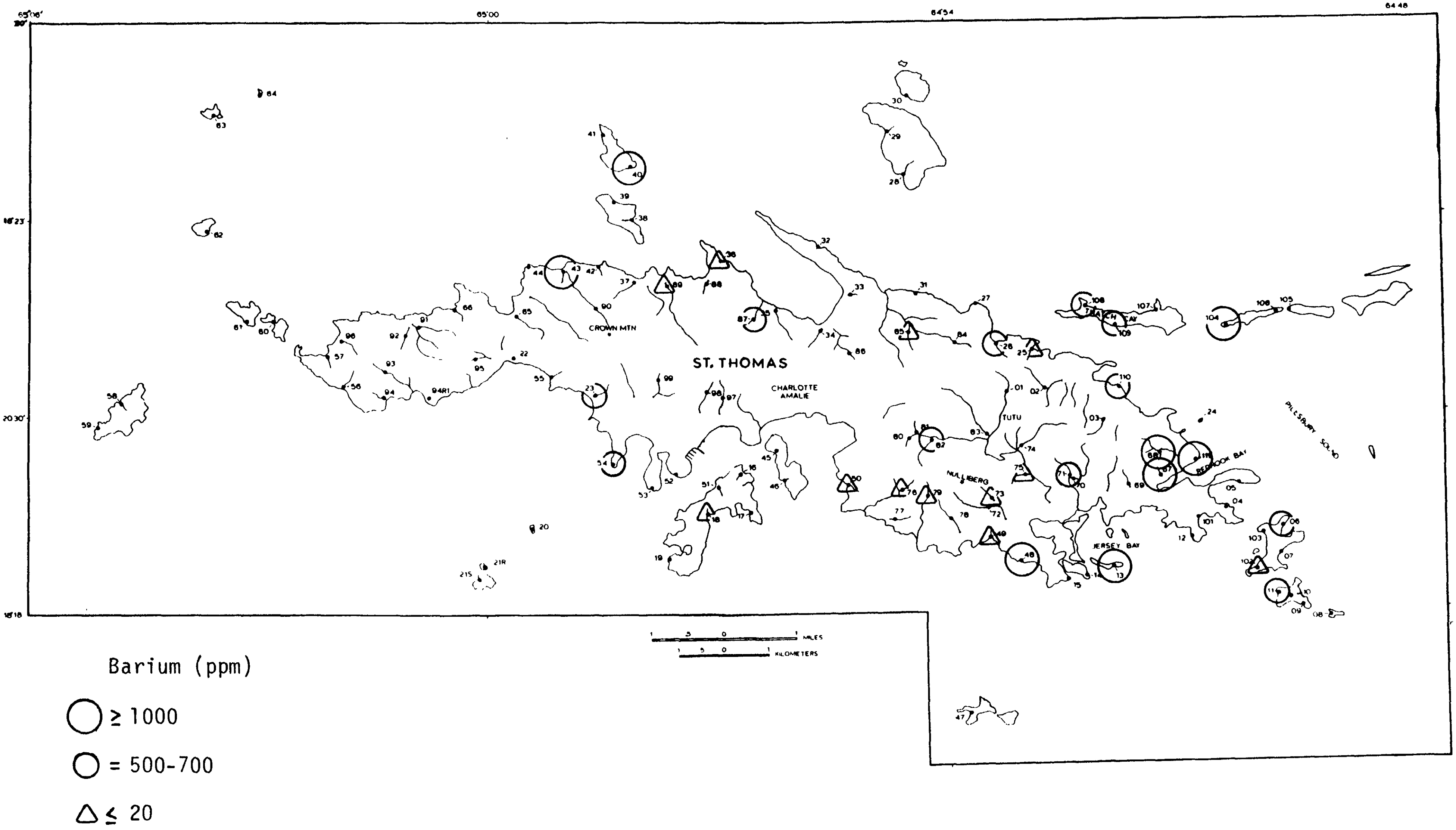


Figure 6.--Distribution of anomalous Ba concentrations from rocks on St. Thomas, U.S. Virgin Islands.

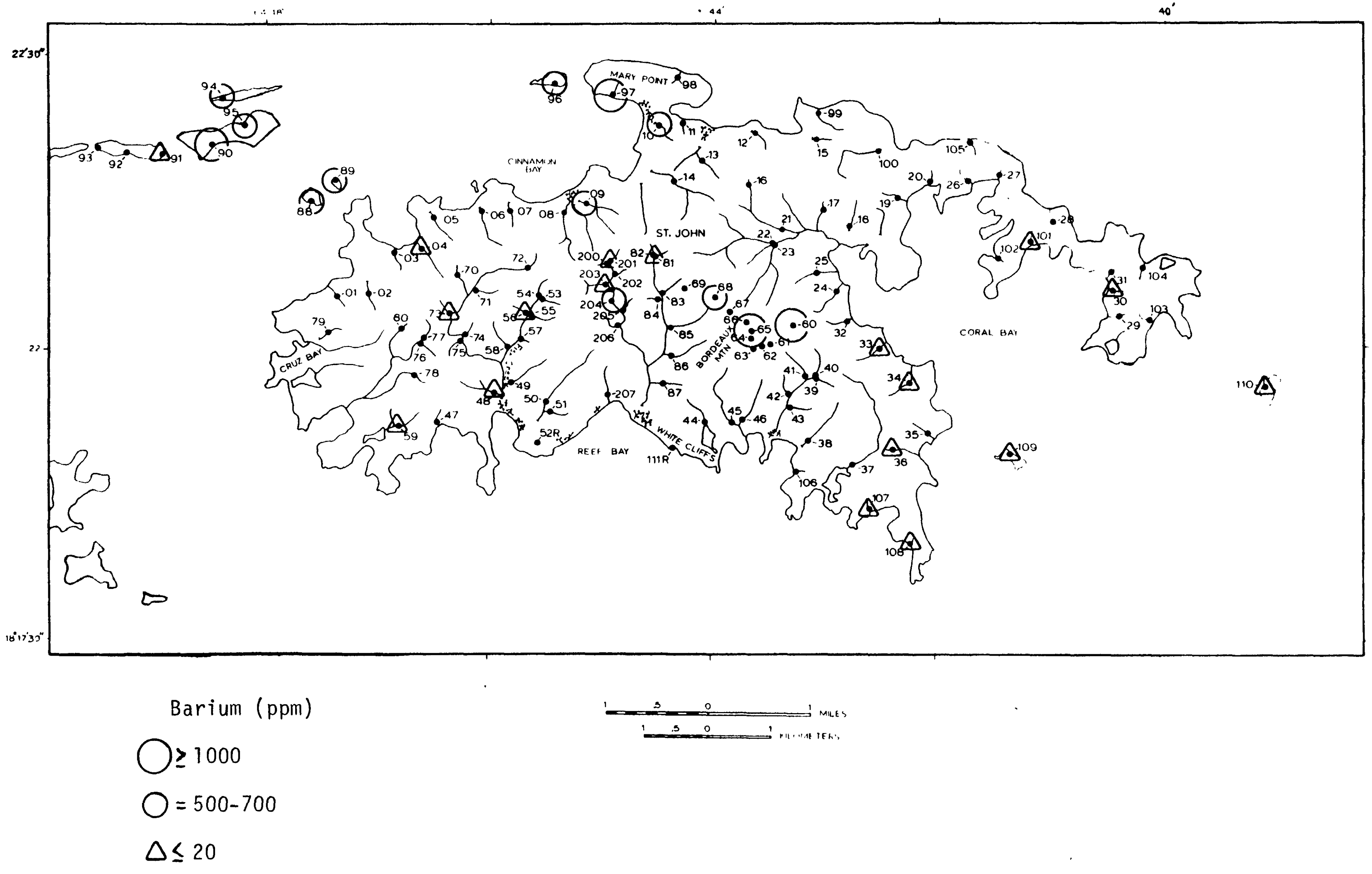


Figure 7.--Distribution of anomalous Ba concentrations from rocks on St. John, U.S. Virgin Islands.

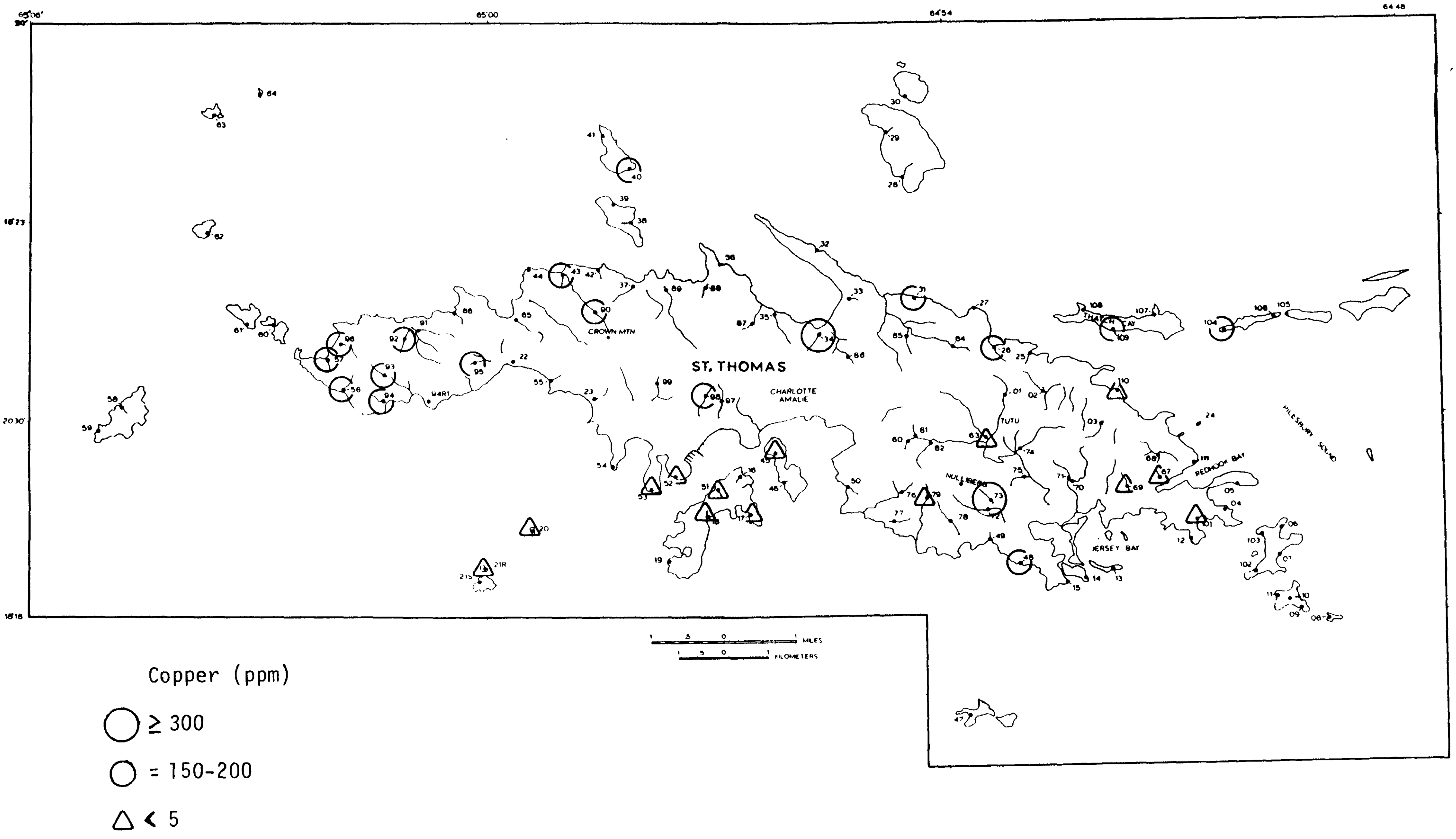
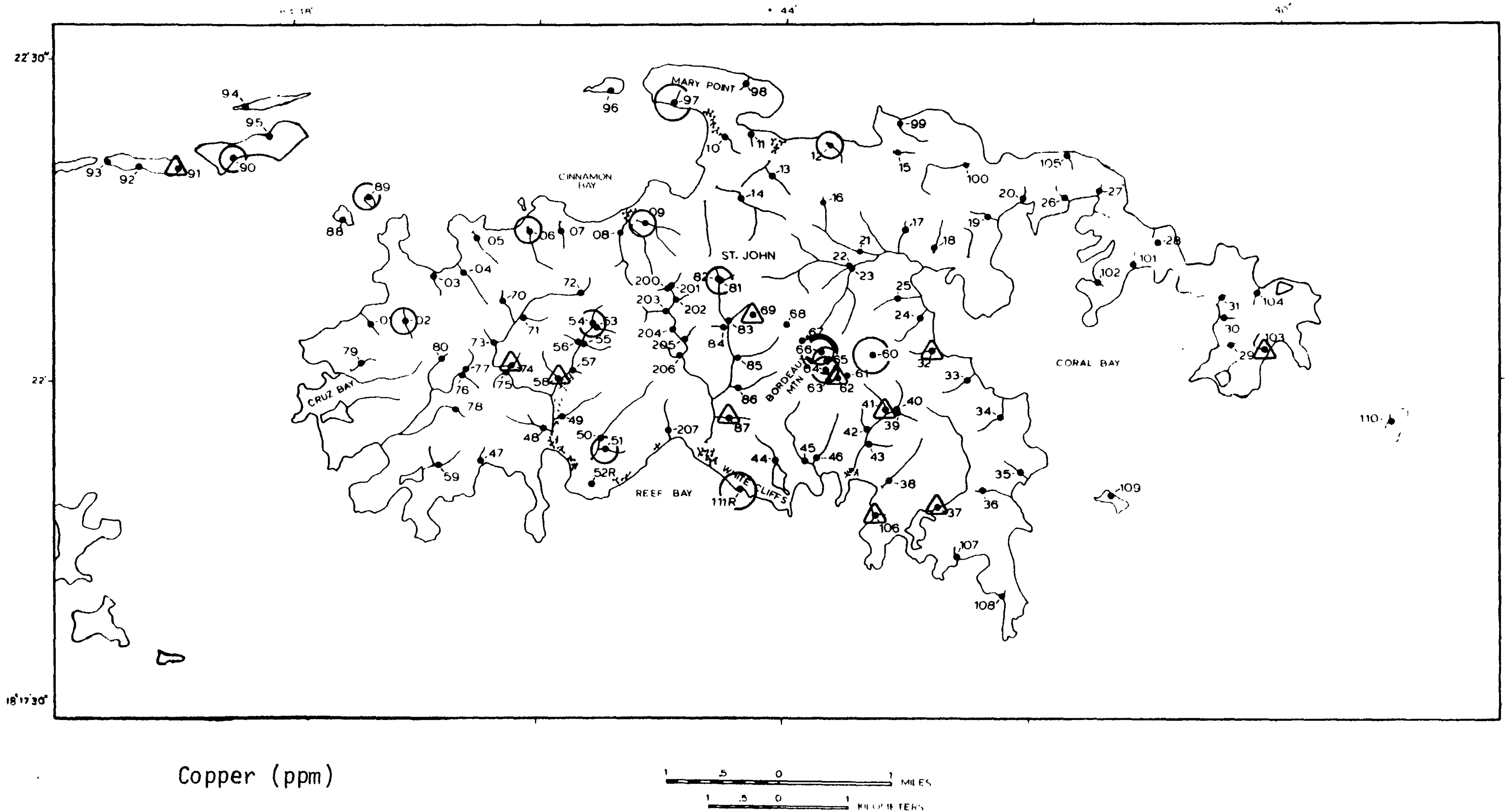


Figure 8.--Distribution of anomalous Cu concentrations from rocks on St. Thomas, U.S. Virgin Islands.



Copper (ppm)

◯ ≥ 500

○ = 150-300

△ < 5

Figure 9.--Distribution of anomalous Cu concentrations from rocks on St. John, U.S. Virgin Islands.

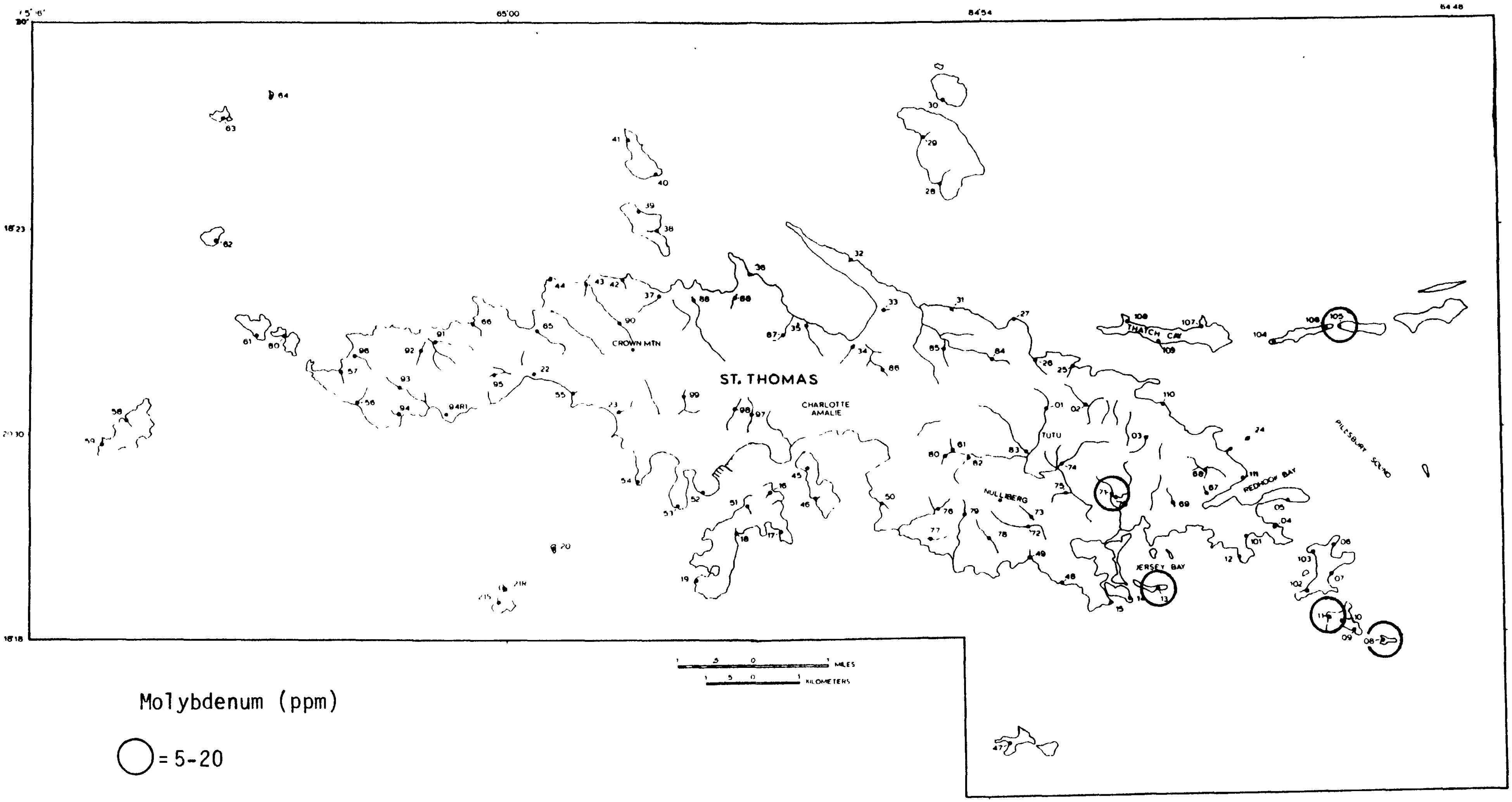


Figure 10.--Distribution of anomalous Mo concnetrations from rocks on St. Thomas, U.S. Virgin Islands.

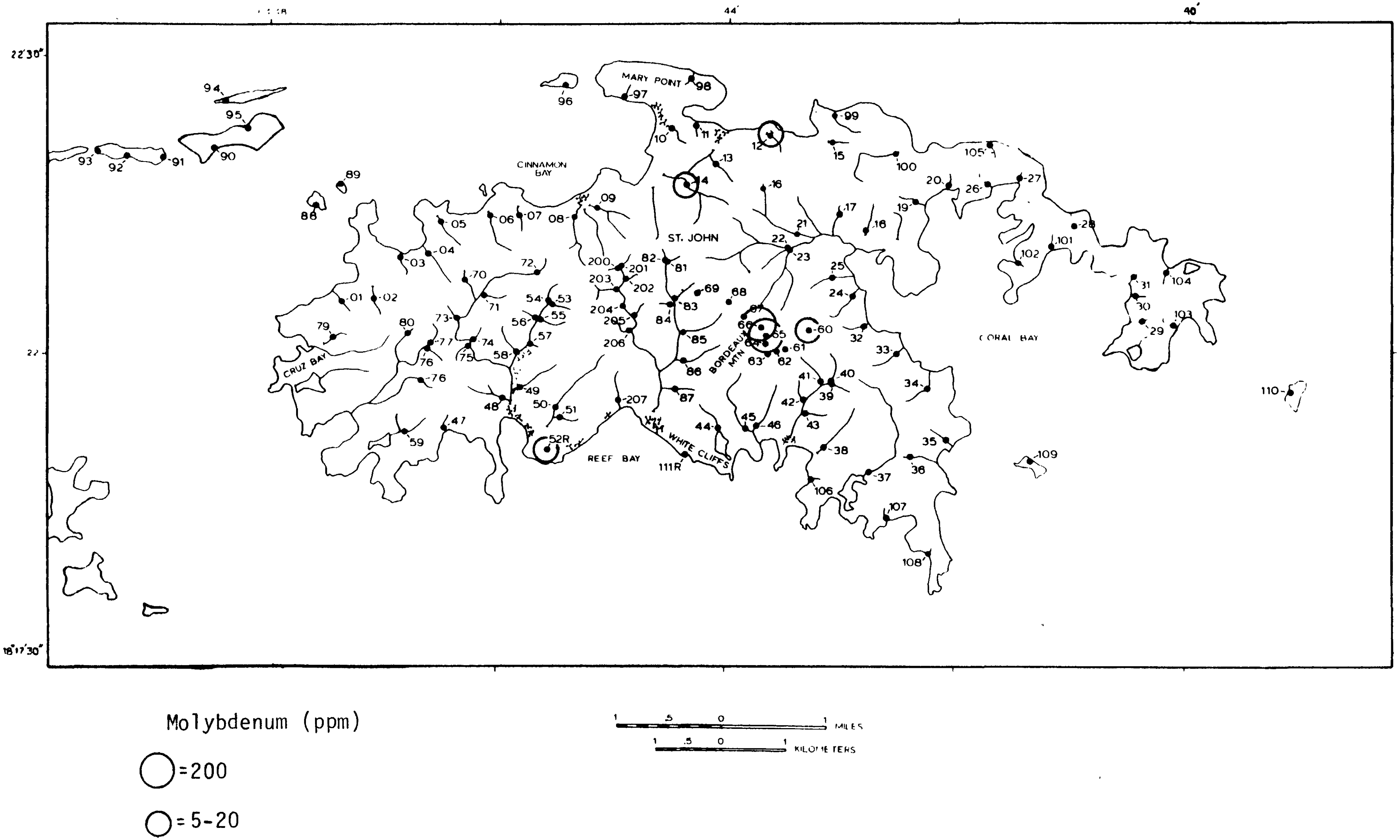


Figure 11.--Distribution of anomalous Mo concentrations from rocks on St. John, U.S. Virgin Islands.

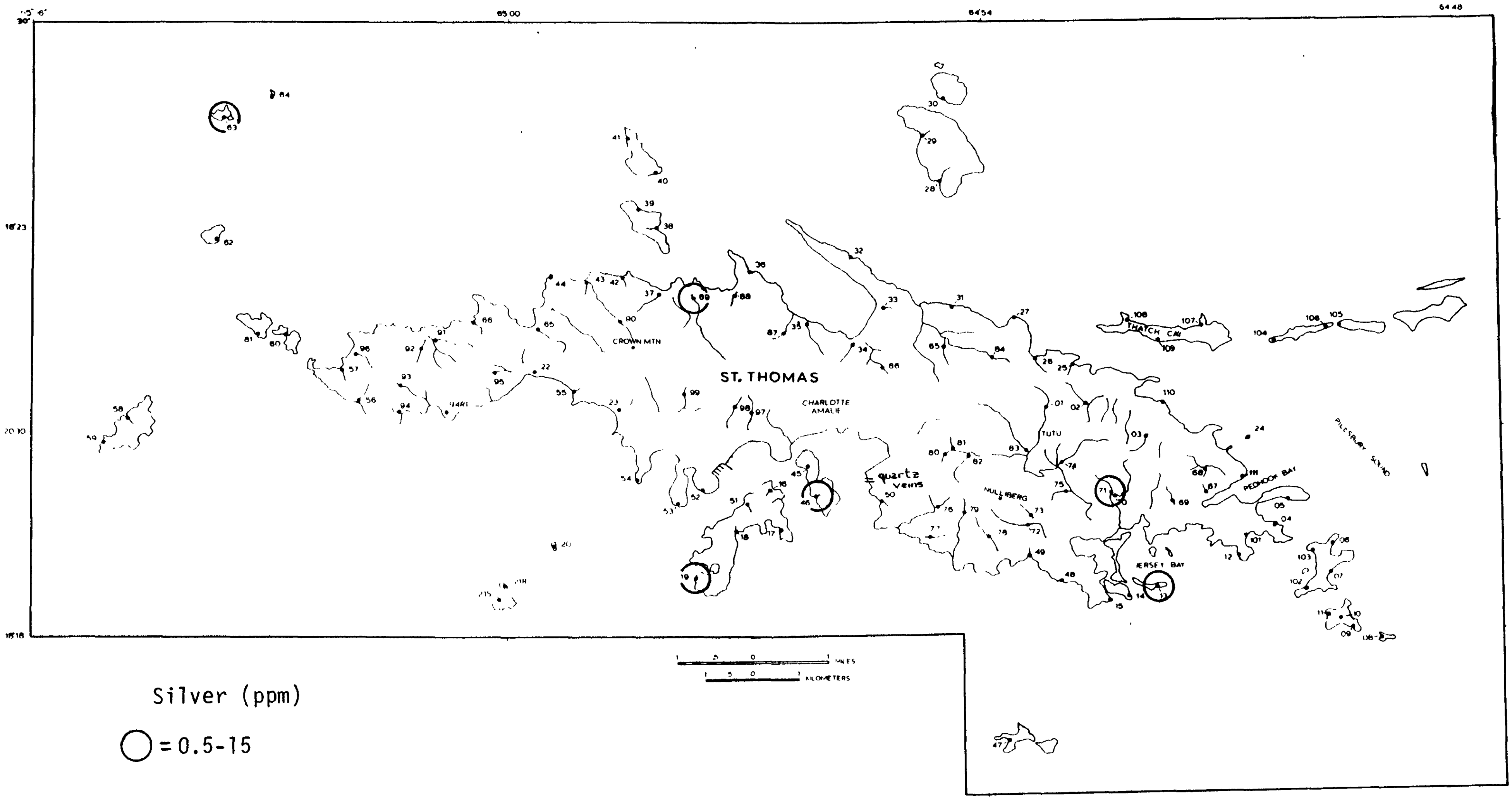


Figure 12.--Distribution of anomalous Ag concentrations from rocks on St. Thomas, U.S. Virgin Islands.

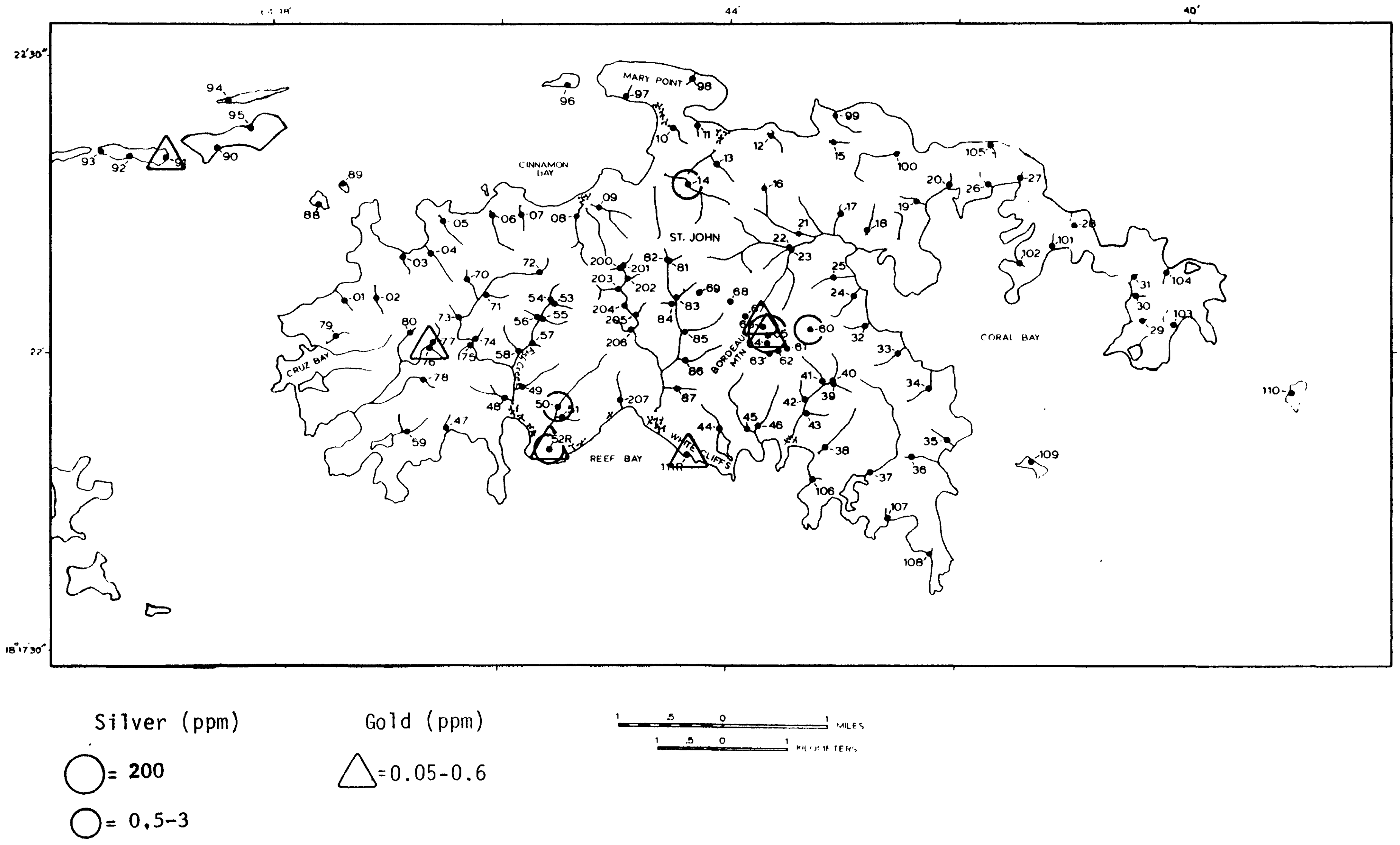


Figure 13.--Distribution of anomalous Au and Ag concentrations from rocks on St. John, U.S. Virgin Islands.

TABLE 2.--Silver, gold, and tellurium analyses of a quartz vein cropping out within the Muhlenfels anomaly, St. Thomas, U.S. Virgin Islands

[Ag analysis by six-step D.C.-arc emission spectrograph; Au and Te analyses by atomic absorption]

Sample	Ag	Au (concentration in ppm)	Te
01	0.5	1.1	6.7
03	30	2.1	24
04	5	0.35	3.7
05	100	1.3	81
06	200	5.5	35
07	15	0.45	3.9
08	150	16	240
09	100	0.90	42
10	70	0.65	31

A skarn is exposed on Mingo Cay, Lovango Cay, and Mary Point (fig. 3). A small pod and veinlets of copper and iron minerals occur on the east end of Mingo Cay along with massive garnet and epidote. A four-foot wide vein of magnetite bordered by barite veins crosscuts the uplifted limestones on the north side of the Cay. The limestone has been recrystallized to marble and contains pyrite and garnet. This area is referred to as the Mingo Cay geochemical anomaly (figs. 4 and 5). Similar skarn-type deposits are indicated on Great Thatch Island, Tortola, and other islands immediately to the north and northeast in the British Virgin Islands group (Shomburgk, 1837). It is speculated that the heat source (stock) that formed the skarns could be large enough to cause the recrystallization of the Congo Cay Limestone observed on Congo Cay and in the British Virgin Islands.

Gossan was observed at site 52R, St. John (fig. 5), and an unweathered and highly siliceous intrusive rock containing pyrite was also observed in an excavation pit. The gossan sample contains anomalous concentrations of Ag, Mo, Au, and Te. This area is referred to as the Shore geochemical anomaly (fig. 5).

Bordeaux Mountain, St. John, contains large boulders of gossan, intensely argillized areas, and nearly vertical iron oxide-rich veins. Anomalous Ag, Au, and Te values are found in many of the rock samples collected from one traverse along the crest of the mountain (fig. 13). The argillic and hematitic alterations extend from the crest of Bordeaux Mountain to the sea coast and can be identified in road cuts inland as well. This area is referred to as the Bordeaux Mountain geochemical anomaly (fig. 5).

The White Cliffs on St. John contain intensely altered rocks with alunite, jarosite, and fine-grained silica. There are turquoise veinlets, native sulfur pods and crusts, and greenish crusts of paratacamite ($Cu_2(OH)_3Cl$). Thirteen rock samples were collected in this area. The Au, Ag, and Te values are given in table 3. This area is considered to be within the Bordeaux Mountain anomaly.

TABLE 3.--Silver, gold, and tellurium analyses from rock samples from the White Cliffs, St. John, U.S. Virgin Islands

[Ag analysis by six-step D. C.-arc emission spectrograph; Au and Te analyses by atomic absorption Detection limits for each element are given in parentheses. An "L" indicates the elemental concentration was slightly lower than the lower detection limit, an "N" indicates the element was not detected]

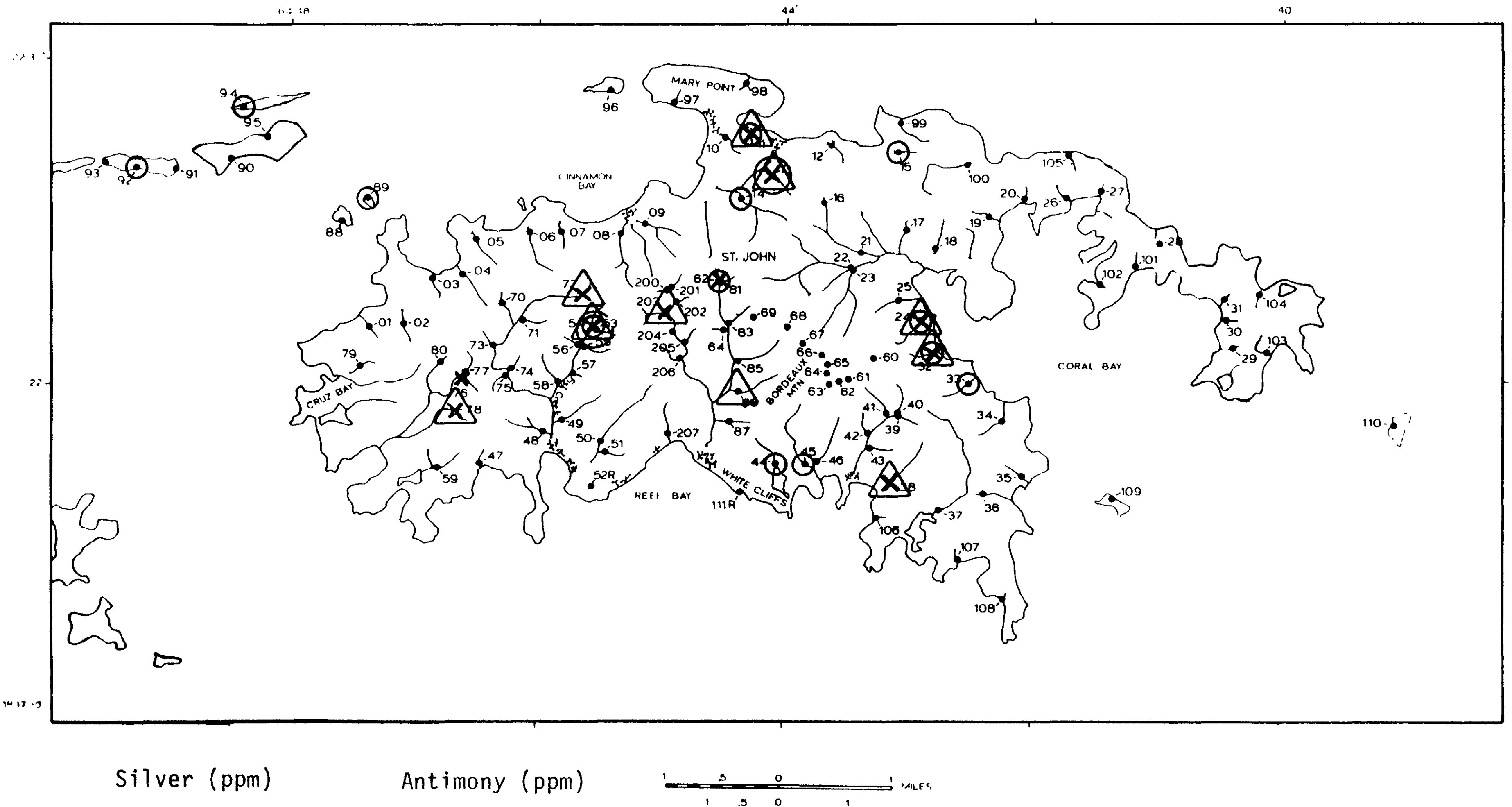
Sample	Ag (0.5)	Au (0.05)	Te (0.1)
		(concentration in ppm)	
111	N	N	0.1
111R1	1	N	5.9
111R2	L(0.5)	N	9.4
111R4	N	L(0.05)	0.8
111R5	N	0.60	5.2
111R6	N	0.05	N
111R7	N	0.05	0.9
111R8	N	N	N
111R9	N	L(0.05)	3.8
111R10	0.7	L(0.05)	0.2
111R11	1.5	L(0.05)	1.2
111R12	N	N	N
111R13	1.5	L(0.05)	0.4

B.--Nonmagmetic fraction of the panned concentrate

The nonmagnetic fraction of the panned concentrate samples is the most effective medium for identifying areas of high metal potential. Many of the minerals found in the nonmagnetic fraction are associated elsewhere with mineral deposits and hydrothermal alteration. The concentration of these minerals in this medium greatly enhances detection. Lead concentrations from most drainage basins sampled are below 100 ppm, but values greater than 10,000 ppm (1%) are found at sites 24 and 32 which are in drainages on the east side of Bordeaux Mountain. Lead concentrations in the minus-80-mesh fraction for the same samples from Bordeaux Mountain were only 70 and 20 ppm, respectively.

The Bordeaux Mountain geochemical anomaly is the most pronounced and extensive anomaly identified to date on both islands. The distribution of Ag, Bi, and Sb (fig. 14), Ba (fig. 15), Cu (fig. 16), and Pb (fig. 17) clearly show that many stream drainages from Bordeaux Mountain contain anomalous concentrations of most of the above elements.

The data from the study suggest that silver, and to a lesser degree, Bi and Sb, are possible pathfinder elements in locating basins in which precious-metal-bearing veins may be located. Anomalous concentrations of these three elements were found in samples from streams draining Bordeaux Mountain (sites 24 and 32), near Mary Point (sites 11 and 13), and in Fish Creek (sites 53 and 54). The highest silver concentration (700 ppm) occurs at site 53. Anomalous concentrations of Ag, Ba, Cu, Pb, Sb, Bi, and Sn are found in samples from sites 53, 54, 72, and 203, derived from a small area. This area is referred to as the Fish Creek geochemical anomaly (fig. 5).



Silver (ppm)

◯ = 100

○ = 1.5-10

Antimony (ppm)

△ = 200-1500

Bismuth (ppm)

× = 30-300

Figure 14.--Distribution of anomalous Ag, Bi, and Sb concentrations in the nonmagnetic fraction of the stream sediments from St. John, U.S. Virgin Islands.

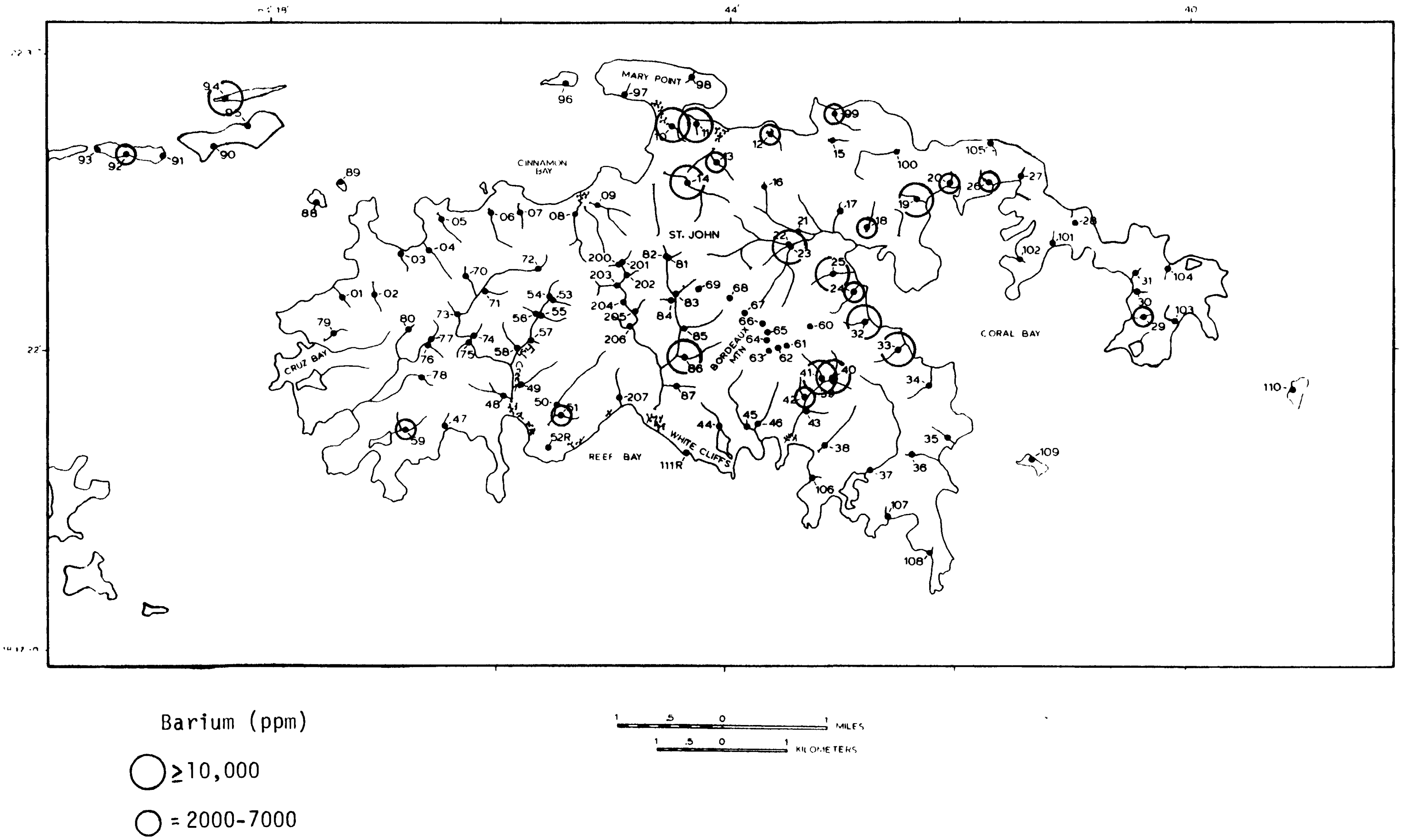


Figure 15.--Distribution of anomalous Ba concentrations in the nonmagnetic fraction of the stream sediments from St. John, U.S. Virgin Islands.

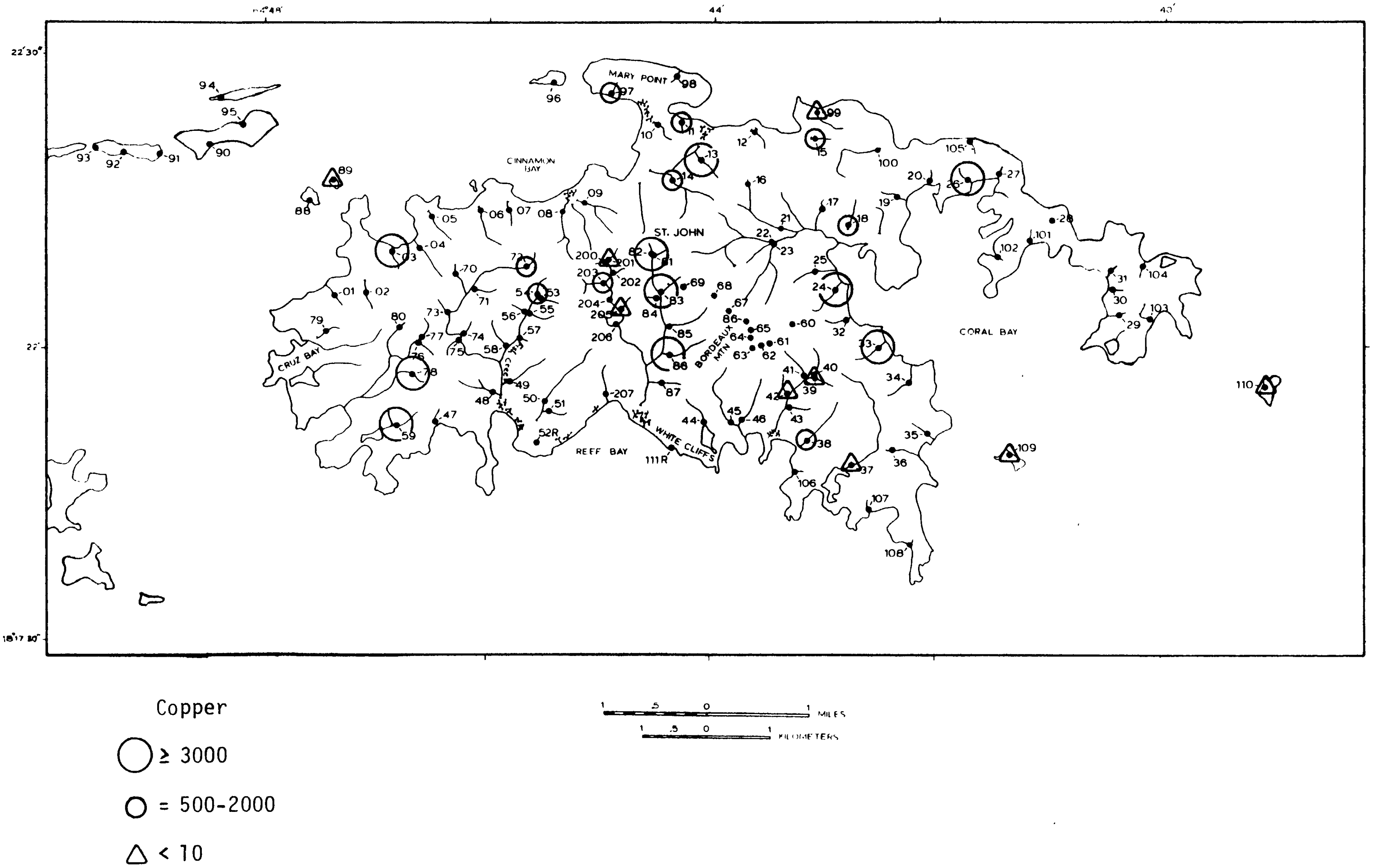


Figure 16.--Distribution of anomalous Cu concentrations in the nonmagnetic fraction of the stream sediments from St. John, U.S. Virgin Islands.

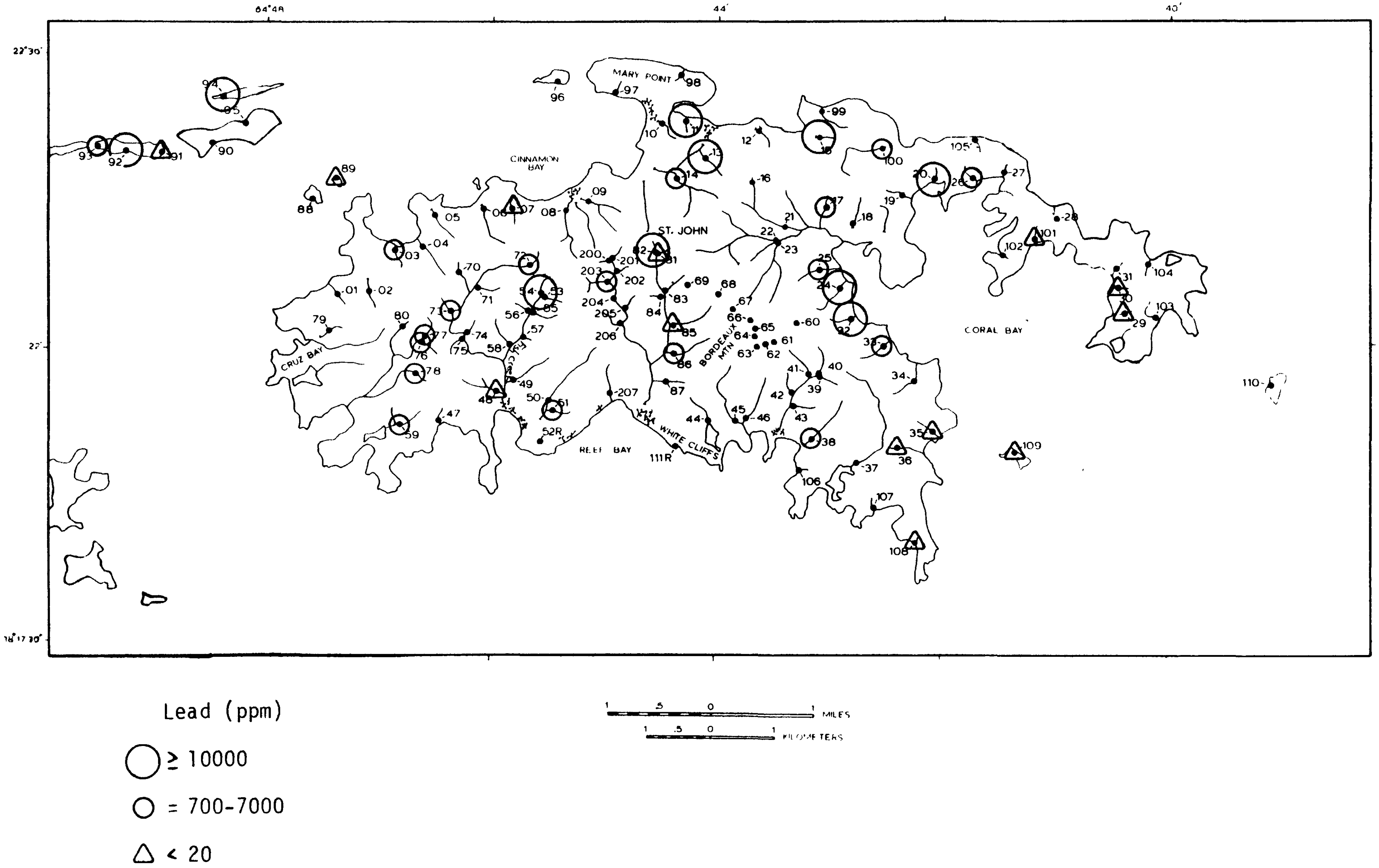


Figure 17.--Distribution of anomalous Pb concentrations in the nonmagnetic fraction of the stream sediments from St. John, U.S. Virgin Islands.

There are two drainage basins near the Shore geochemical anomaly. Anomalous concentrations of Pb, Ba, and Sn occur in these drainages.

The Red Point geochemical anomaly (St. Thomas) was delineated on the basis of anomalous concentrations of Pb and Cu (fig. 18), Ba (fig. 19), Ag, Bi, and Sb (fig. 20).

The Muhlenfels Point geochemical anomaly (St. Thomas) is detected by anomalous concentrations of Cu, Ba, Ag, Pb, and Sn at site 50.

A small nugget of Au was observed in the concentrate from site 2. This site also contains elevated concentrations of Ag, Cu, Pb, Mo, and Ba. Gold was also observed in the concentrate from site 106 (Grass Cay) and from sites 10 and 92 (St. John).

Anomalous metal concentrations occur in samples from Thatch, Grass, Mingo, Lovango, and Congo Cays (figs. 14, 15, and 17). This data coincides with the rock data.

C.--Minus-80-mesh fraction of the soil samples

The geochemical interpretation of the minus-80-mesh fraction of the soil samples generally coincides with the previously discussed sample media.

Soil samples collected near the crest of Bordeaux Mountain contain anomalous Ba (fig. 21), Pb, and Cu (fig. 22) concentrations. Slightly lower metal concentrations generally occur in soil samples from sites near the stream drainage sites. Anomalous Cu concentrations occur in the Fish Creek and Shore geochemical anomalies (fig. 22).

The soil samples do not contain anomalous metal concentrations within the Red Point and Muhlenfels Point anomalies on St. Thomas. However, anomalous Cu concentrations (fig. 23) and Pb and Ag concentrations (fig. 24) occur on the small islands between Red Point and Muhlenfels Point.

Anomalous metal concentrations occur on the east end of St. Thomas (Jersey Bay anomaly). The Ag concentrations at sites 13, 49, 67, 70, and 74 (fig. 24) are not reflected in the other media sampled. The Ag values in the soils at sites 62 and 63 coincide with rock and nonmagnetic fraction data (fig. 24).

D.--Oxalic acid leach analysis

The oxalic acid leach selectively dissolves Fe-Mn hydroxides and releases any metal ions that have been adsorbed (Alminas and Mosier, 1975). The metals observed in the leachate can give an indication of the relative importance of hydromorphic transport in the redistribution of metals released from the rocks within a basin. The results from these analyses indicate that many metals that are often relatively immobile, such as Pb and Ag, are apparently very mobile in this environment.

The distribution of anomalous Pb and Cu concentrations is given in figure 25. Anomalous Pb concentrations occur in the Bordeaux Mountain, Fish Creek, and Shore anomalies. Anomalous Pb and Cu concentrations on St. Thomas indicate the Red Point anomaly (fig. 26). Anomalous lead concentrations are also found at sites from the east end of St. Thomas, within the Jersey Bay anomaly (fig. 26).

The distribution of samples with anomalous Mo concentrations on St. Thomas appears to be more localized than the other elements discussed (fig. 27). Anomalous Mo concentrations occur at sites 21S and 54 within the Red Point anomaly (St. Thomas). Several samples from the Jersey Bay anomaly (St. Thomas) contain anomalous Mo concentrations (fig. 27).

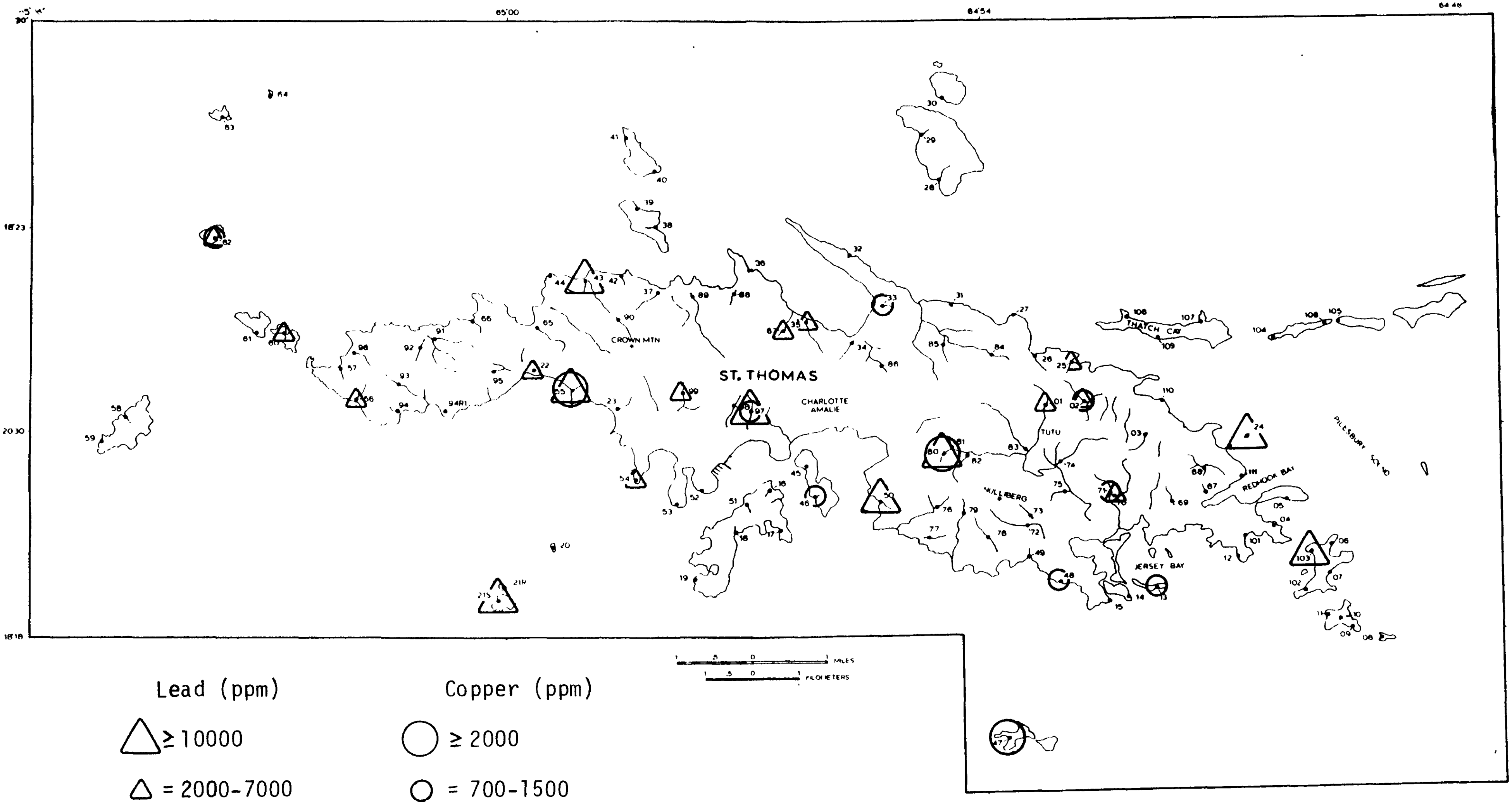


Figure 18.--Distribution of anomalous Pb and Cu concentrations in the nonmagnetic fraction of the stream sediments from St. Thomas, U.S. Virgin Islands.

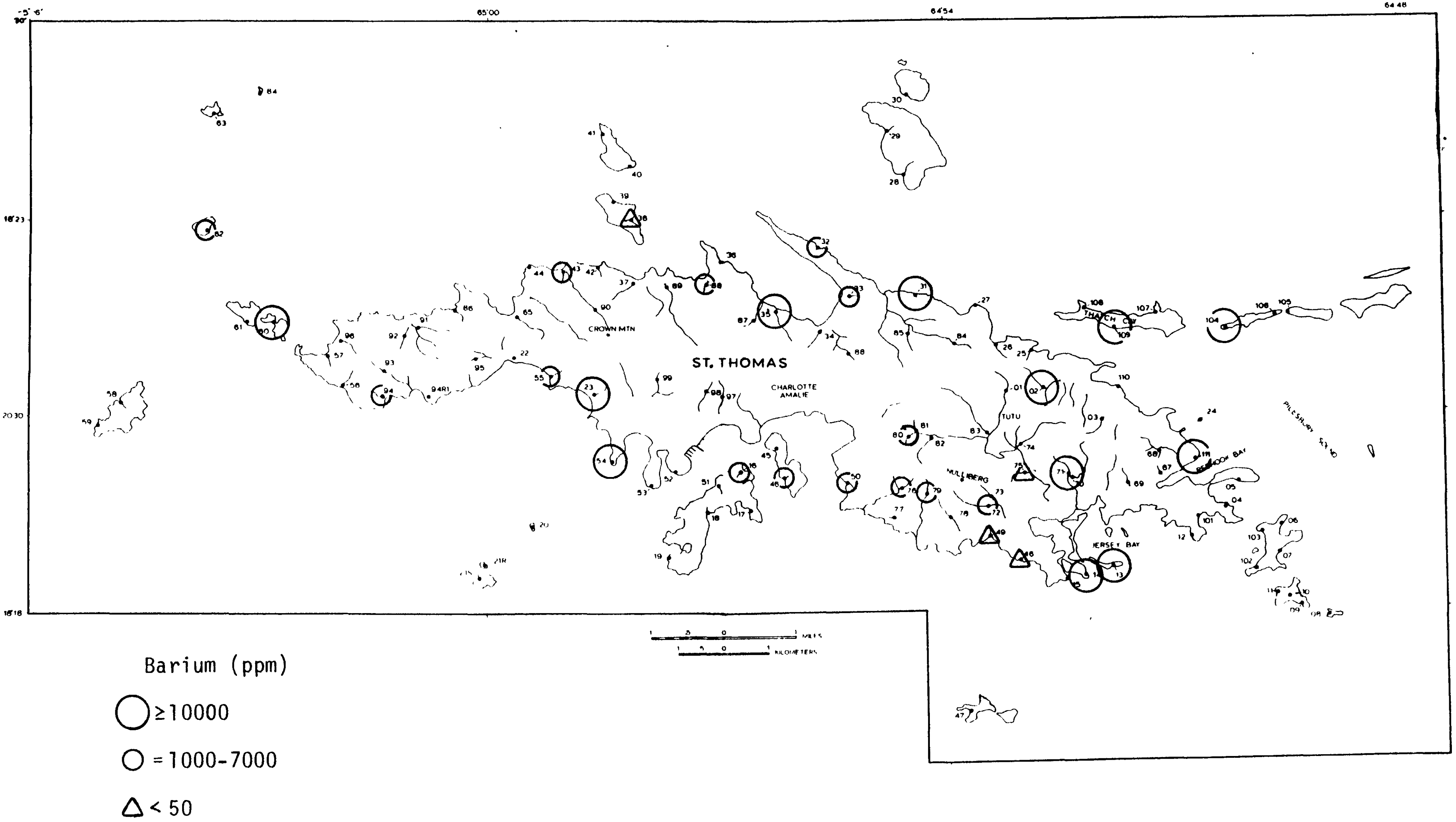


Figure 19.--Distribution of anomalous Ba concentrations in the nonmagnetic fraction of the stream sediments from St. Thomas, U.S. Virgin Islands.

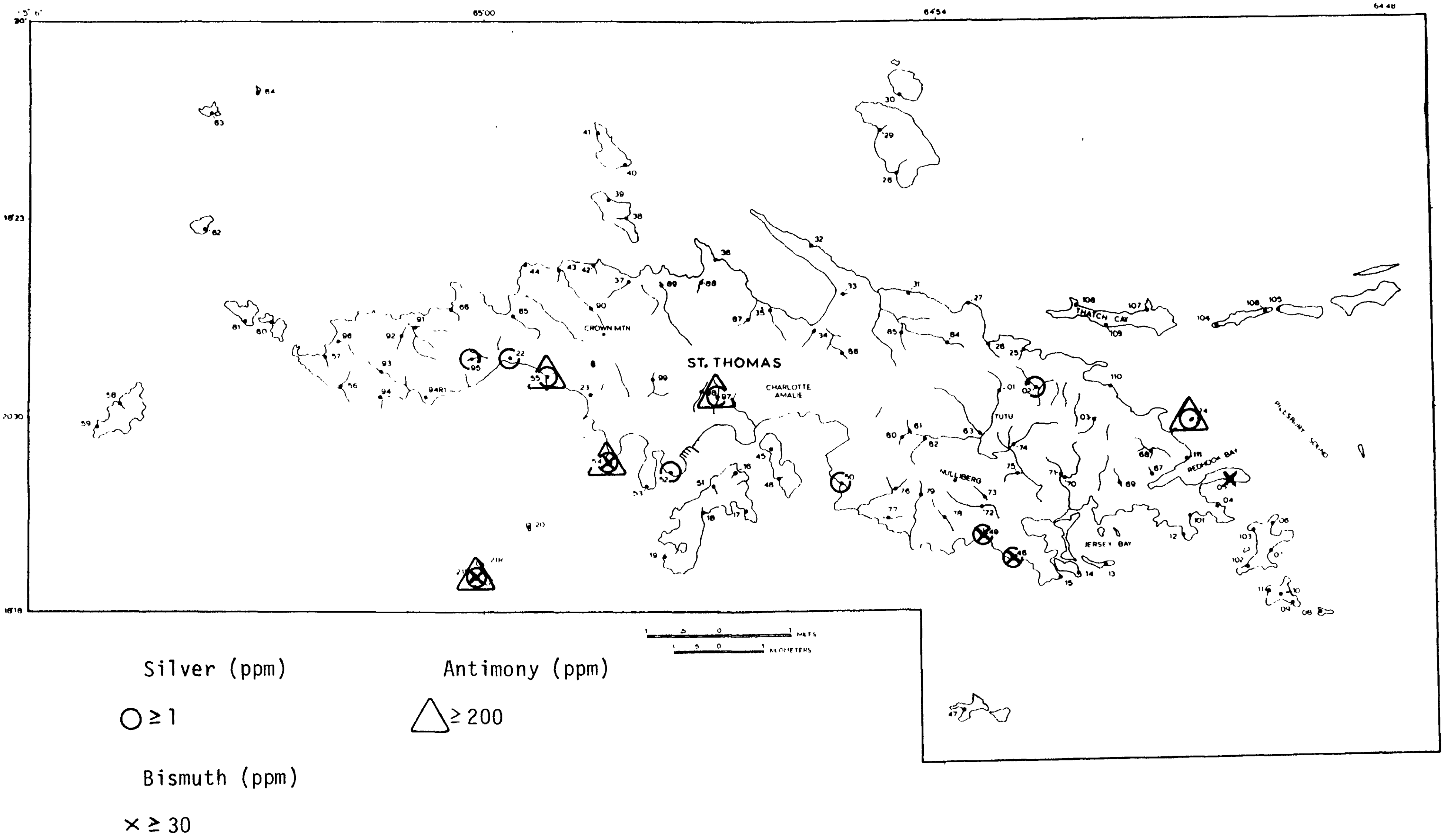


Figure 20.--Distribution of anomalous Ag, Bi, and Sb concentrations in the nonmagnetic fraction of the stream sediments from St, Thomas, U.S. Virgin Islands.

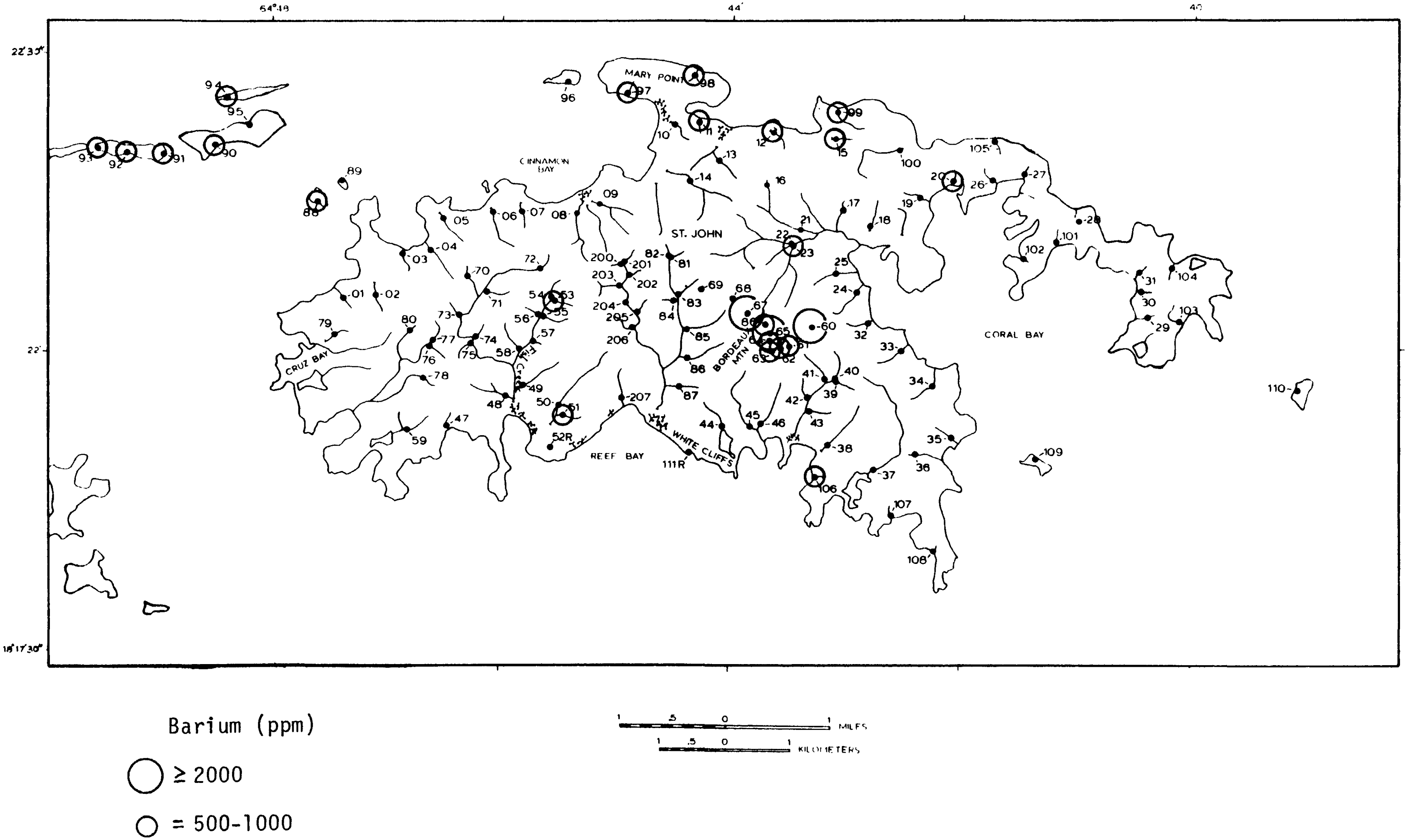


Figure 21.--Distribution of anomalous Ba concentrations from the minus-80-mesh fraction of soil samples from St. John, U.S. Virgin Islands.

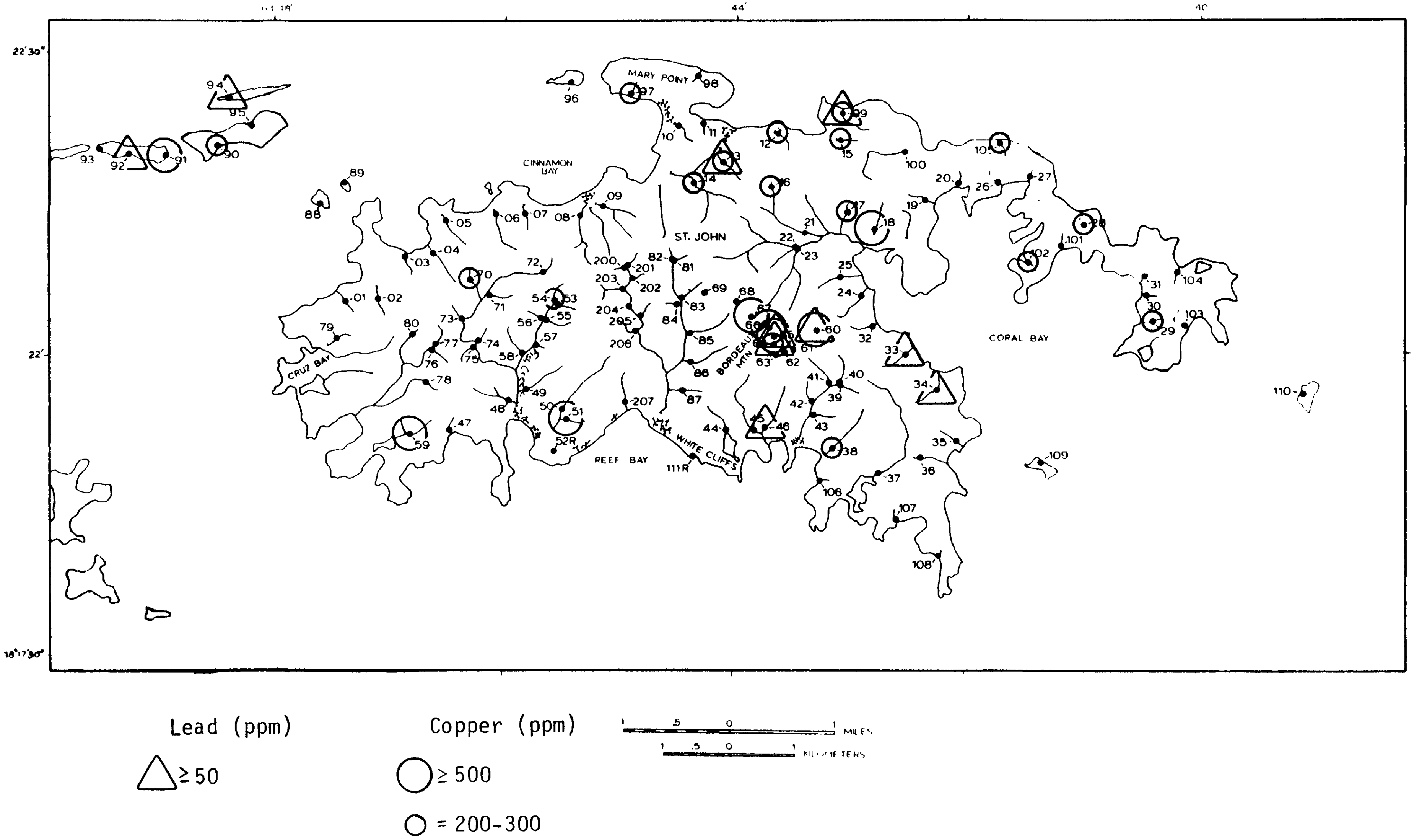


Figure 22.--Distribution of anomalous Pb and Cu concentrations from the minus-80-mesh fraction of soil samples from St. John, U.S. Virgin Islands.

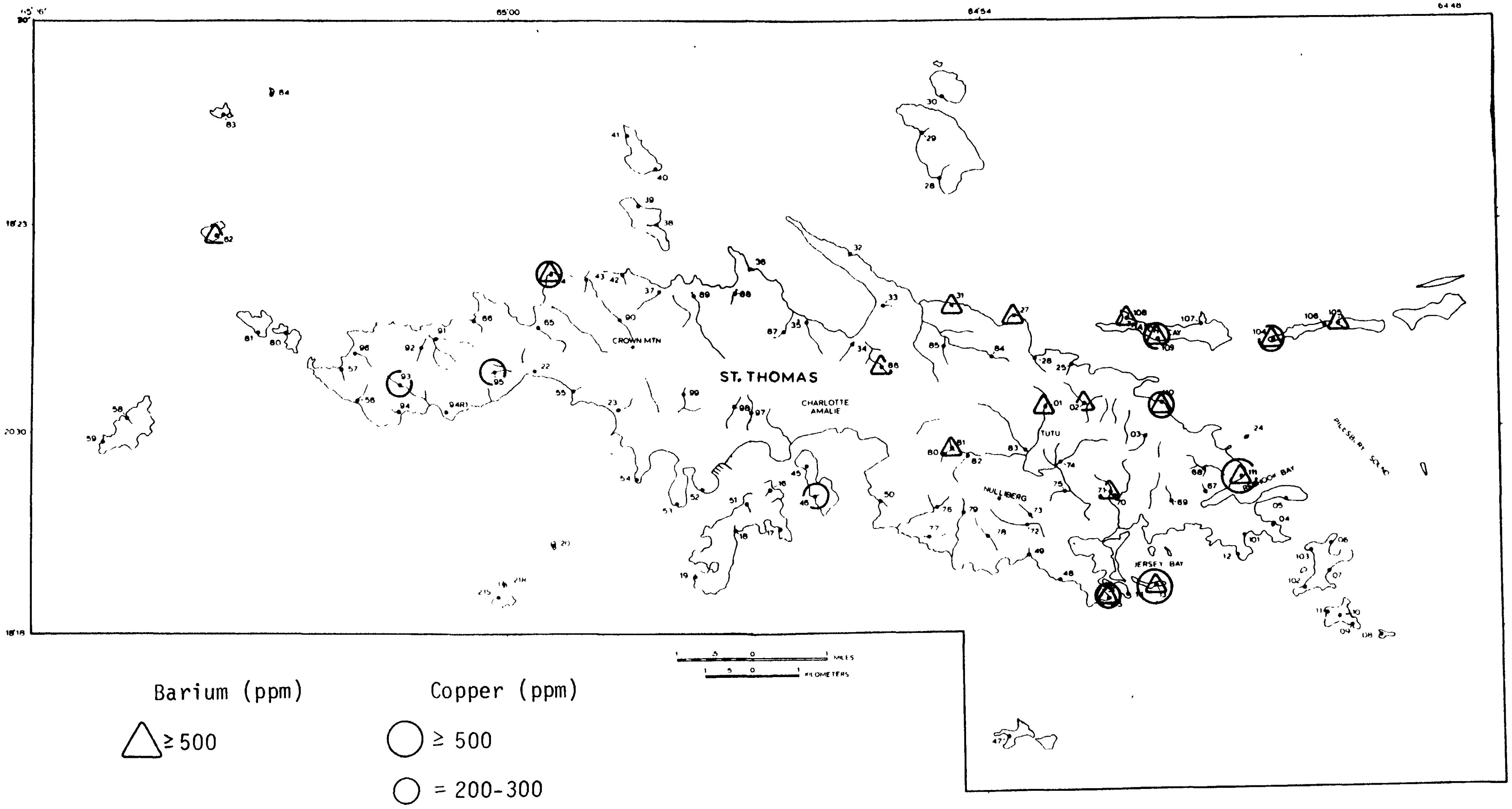


Figure 23.--Distribution of anomalous Ba and Cu concentrations from the minus-80-mesh fraction of soil samples from St. Thomas, U.S. Vifgin Islands.

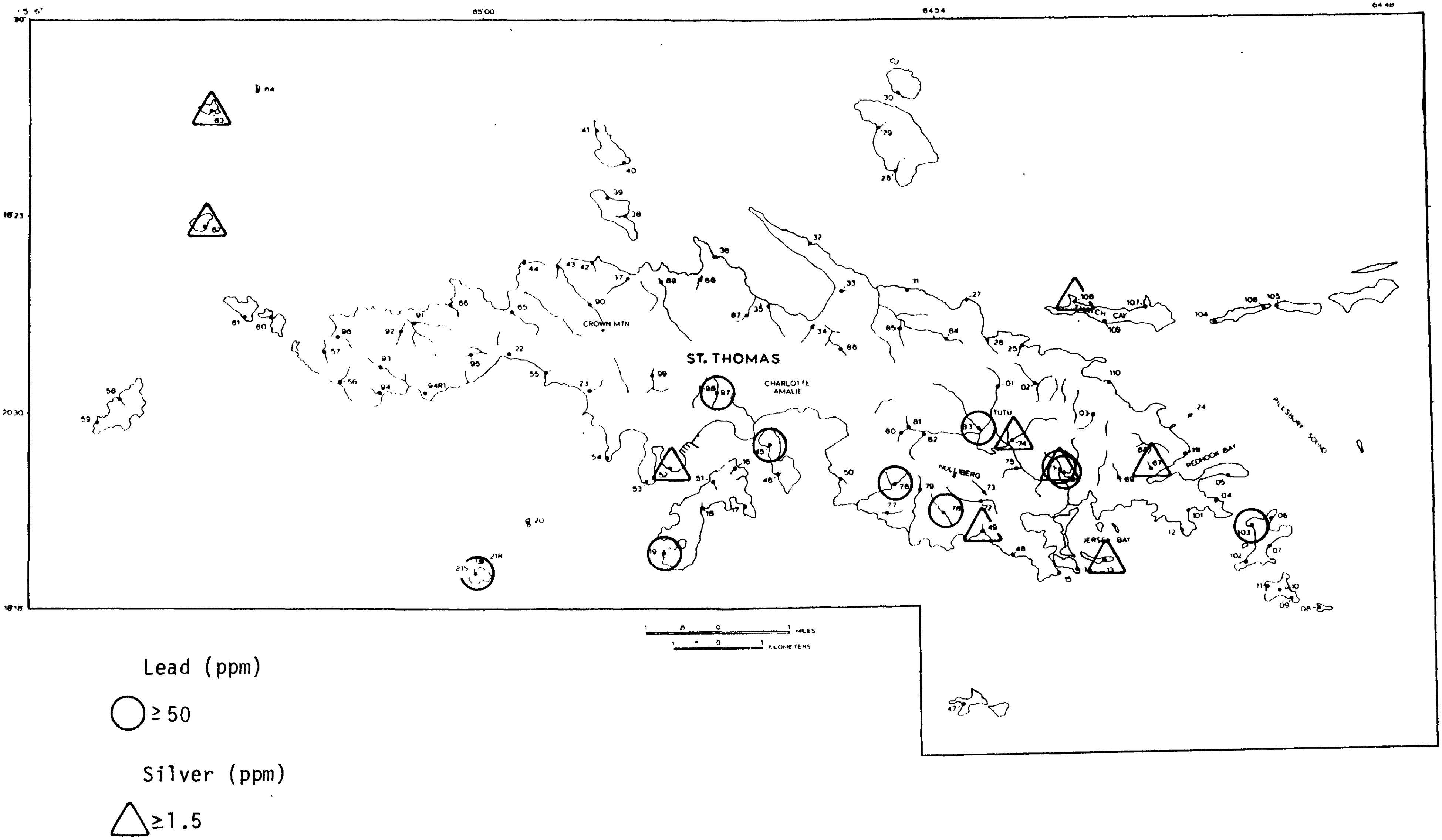


Figure 24.--Distribution of anomalous Pb and Ag concentrations from the minus-80-mesh fraction of soil samples from St. Thomas, U.S. Virgin Islands.

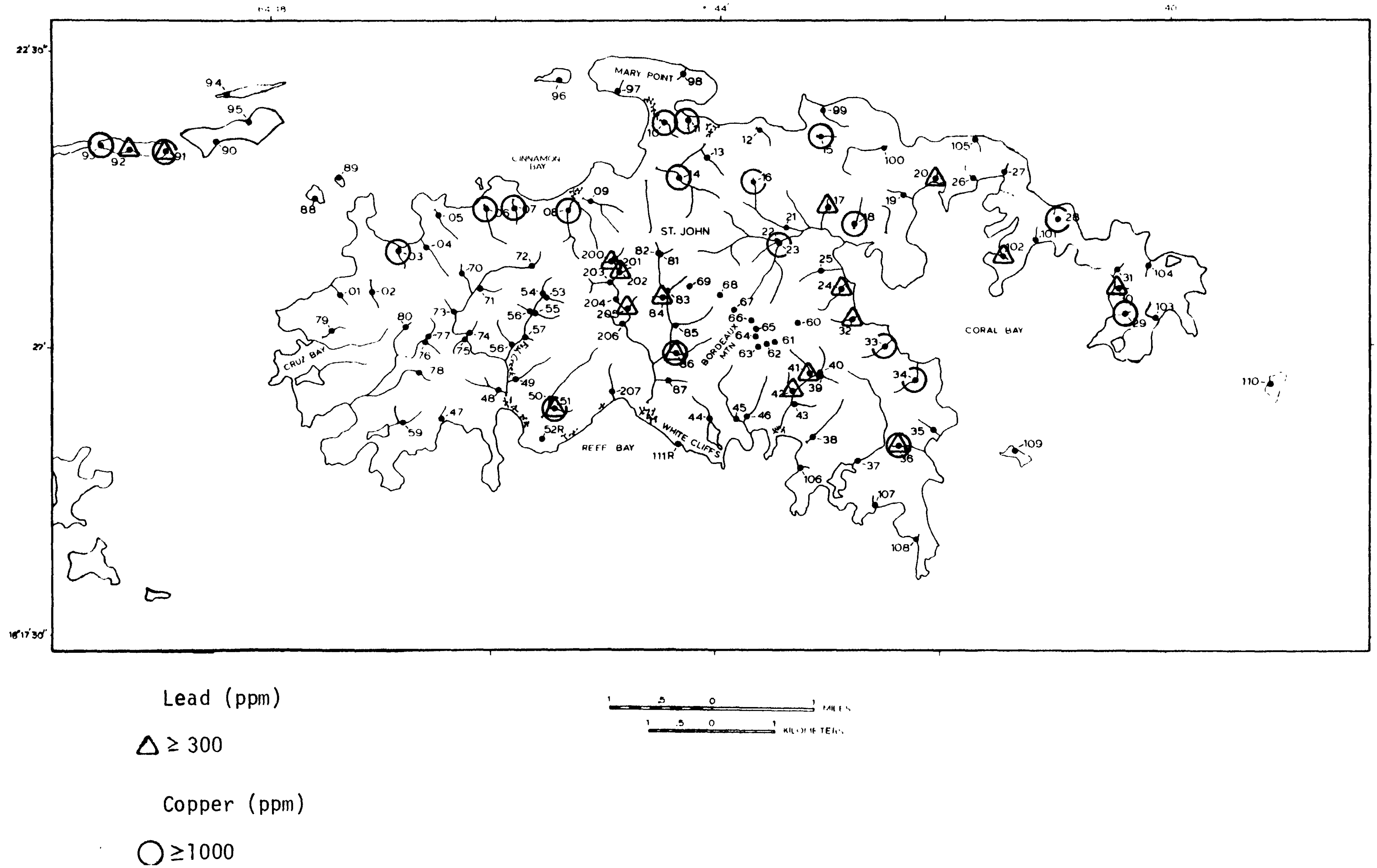
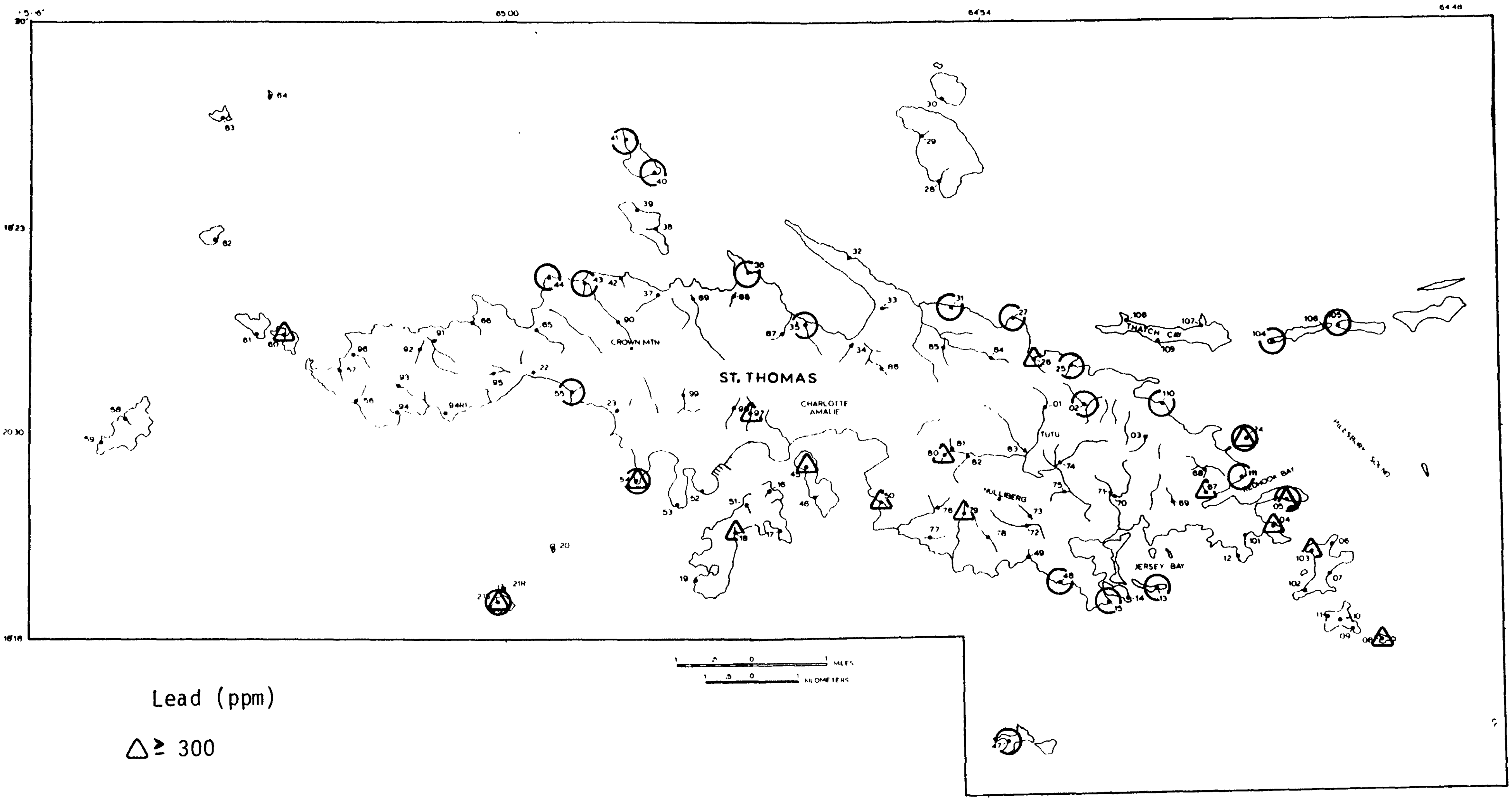


Figure 25.--Distribution of oxalic acid soluble Pb and Cu concentrations in coarse, light sediments from St. John, U.S. Virgin Islands.



Lead (ppm)

△≥ 300

Copper (ppm)

○≥1000

Figure 26.--Distribution of oxalic acid soluble Pb and Cu concentrations in coarse, light sediments from St. Thomas, U.S. Virgin Islands.

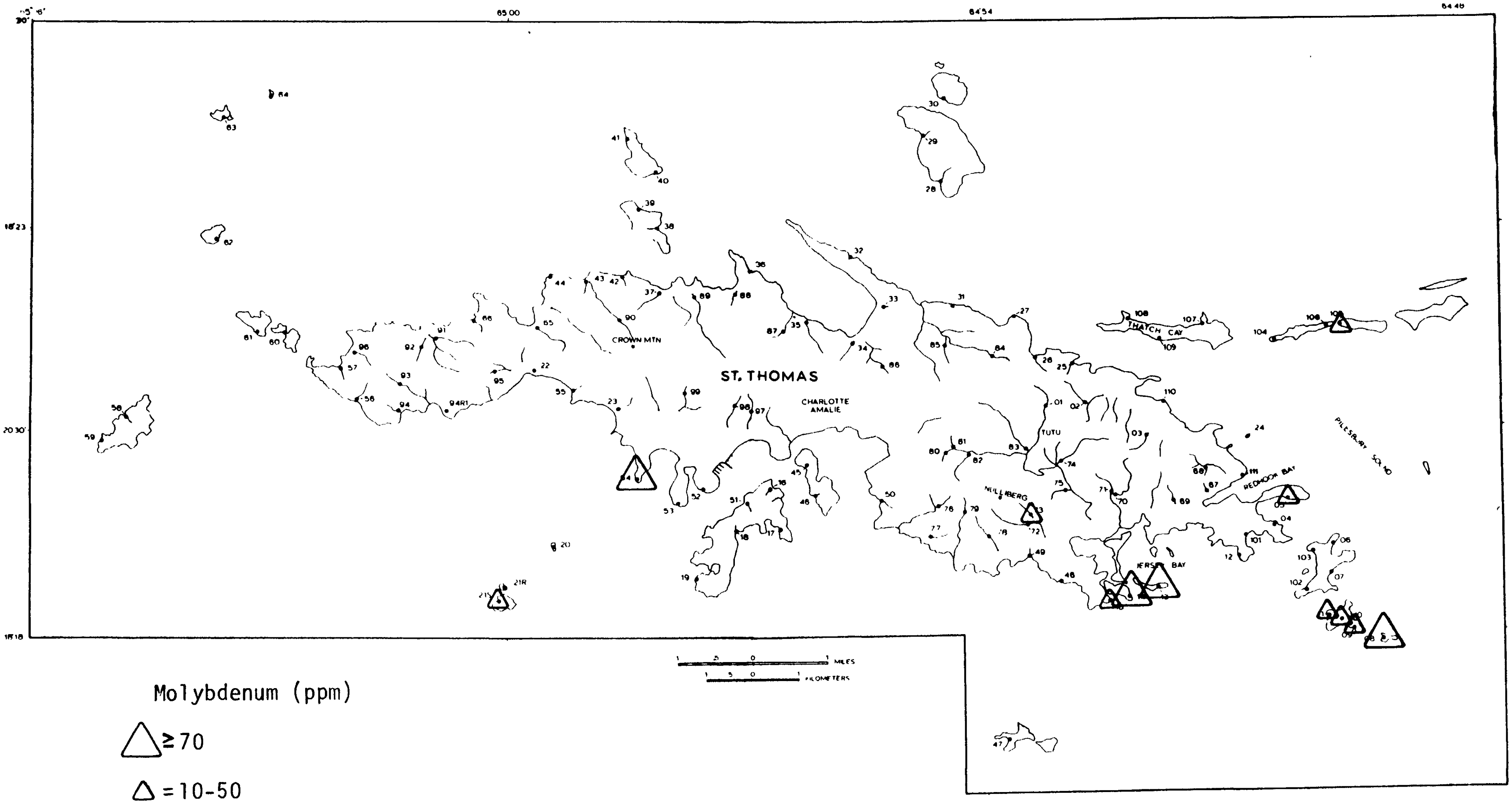


Figure 27.--Distribution of oxalic acid soluble Mo concentrations in coarse, light sediments from St. Thomas, U.S. Virgin Islands.

Anomalous silver concentrations occur throughout both islands (figs. 28 and 29). The distribution of anomalous values cannot be characterized by locality or by association with any specific rock type.

E.--Magnetic fraction of the panned concentrates

The interpretation of analyses of the magnetic fraction of the panned concentrates can often be complicated because of certain geochemical characteristics of the minerals selectively isolated in this medium. The magnetic fraction may contain minerals such as hornblende, ilmenite, garnet, and sphene. These minerals may contain high concentrations of elements such as Pb, Sn, Nb, Zn, and Cu (Hurlbut, 1971; Parker and Fleischer, 1968). The abundance of these minerals must be taken into consideration when defining geochemical anomalies.

The magnetic fraction can be very useful in detecting potential metallization that may occur at depth (Alminas and VanTrump, 1978; Miller and others, 1982; Tucker and others, 1982). The magnetic fraction amplifies the effect of the magnetic minerals or coatings precipitated from hydrothermal fluids emenating from a metalized stock. These minerals may selectively incorporate many metals from the hydrothermal solutions.

The distribution of anomalous Ba and Pb concentrations from St. John is given in figure 30. These metals delineate the Bordeaux Mountain anomaly. Anomalous copper concentrations are found in samples surrounding Coral Bay and on the cays west of Mary Point. The Fish Creek and Shore geochemical anomalies are not well represented by this fraction. Samples in the Mingo Cay anomaly have anomalous concentrations of Pb and Ba (fig. 30).

Anomalous concentrations of Pb, Ag, and Mo on St. Thomas are shown in figure 31 and Cu and Ba are shown in figure 32. Many of these elements occur from samples in the Red Point and Muhlenfels Point geochemical anomalies. The Jersey Bay geochemical anomaly contains anomalous concentrations of Pb, Ag, and Mo which coincides with the oxalic acid leach data and the rock data from this area.

F.--Minus-80-mesh fraction of the stream sediments

The minus-80-mesh fraction of the stream sediments is a composite sample representing the major rock-forming minerals, Fe-Mn hydroxide coatings, and heavy minerals. It is difficult to determine the relative contributions of each component to the overall content of the stream sediment. The predominance of barren rock fragments and minerals cause a dilution and thus a dampening of the anomaly to background contrast. This fraction was not utilized in mineral appraisal; however, the data may be useful in other applications.

DISCUSSION

The Bordeaux Mountain anomaly is the most intense and continuous geochemical anomaly identified in the study area and is represented by all the media discussed. The anomaly is characterized by Fe, Ag, Ba, Bi, Cu, Pb, Sn, and Zn in many of the drainage samples (for elements not previously discussed see Hopkins and others, 1984). The anomaly is particularly well delineated by the magnetic and nonmagnetic stream-sediment-concentrate fractions. Rock and soil samples collected on a single traverse along the crest of Bordeaux Mountain

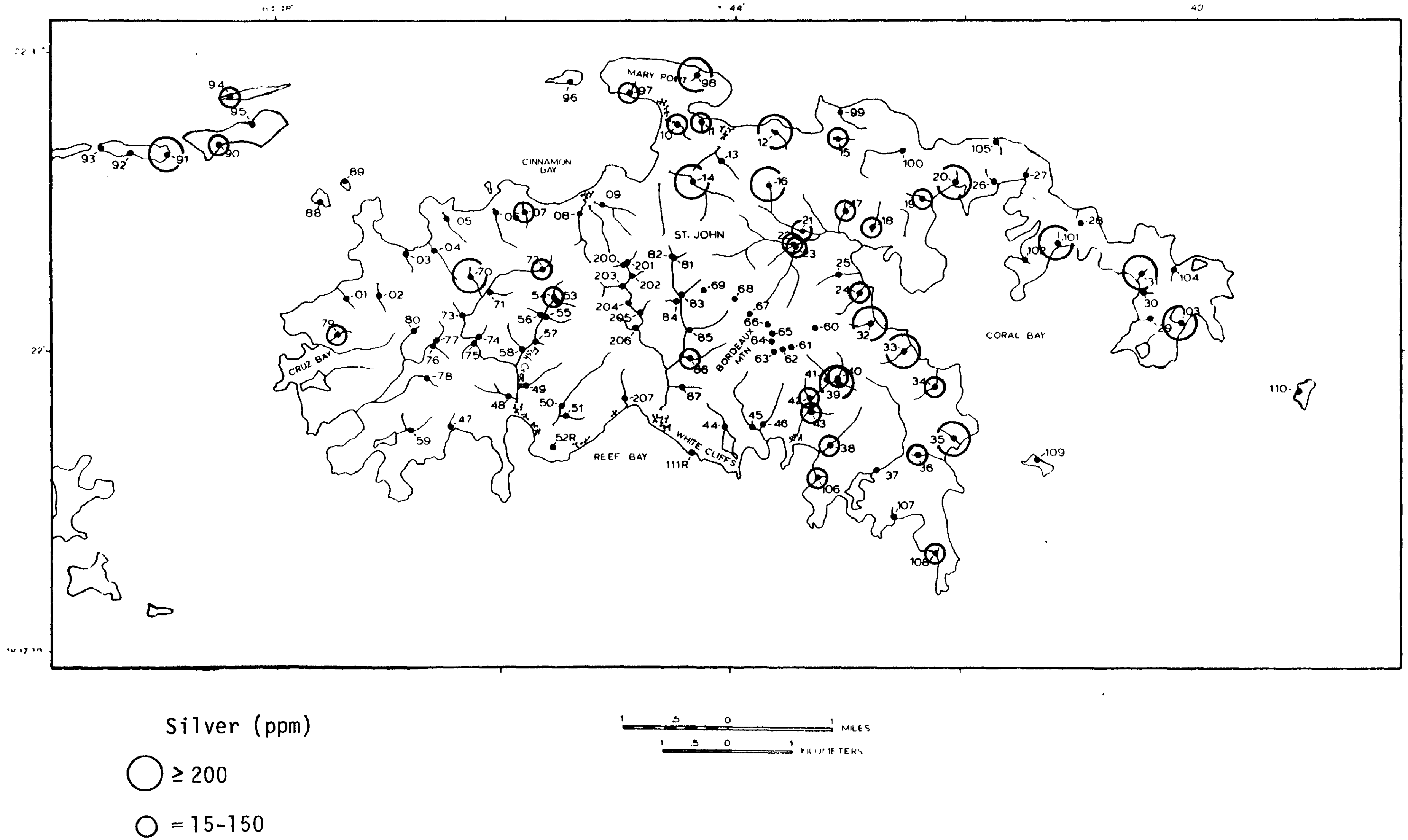


Figure 28.--Distribution of oxalic acid soluble Ag concentrations in coarse, light sediments from St. John, U.S. Virgin Islands.

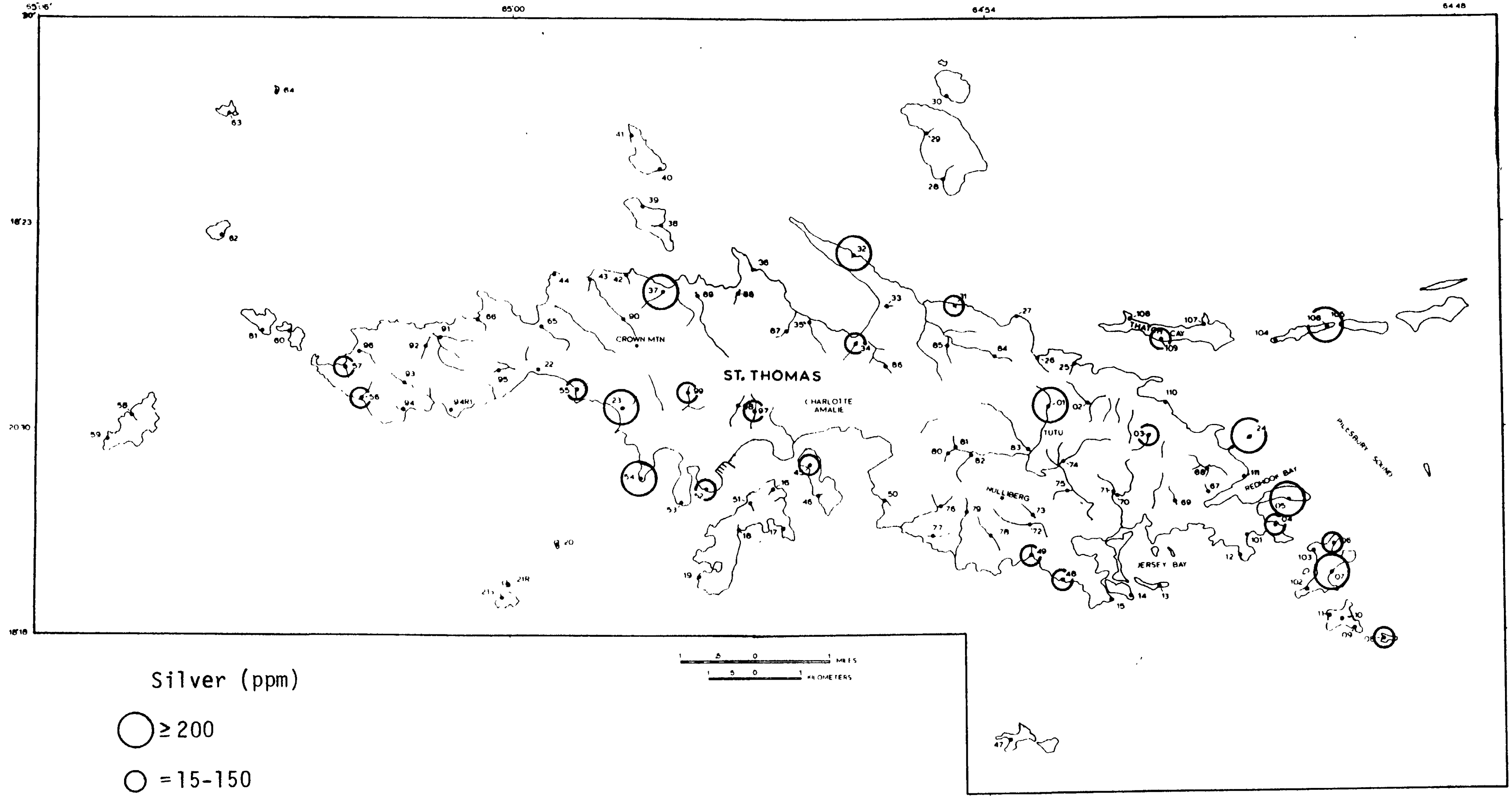


Figure 29.--Distribution of oxalic acid soluble Ag concentrations in coarse, light sediments St. Thomas, U.S. Virgin Islands.

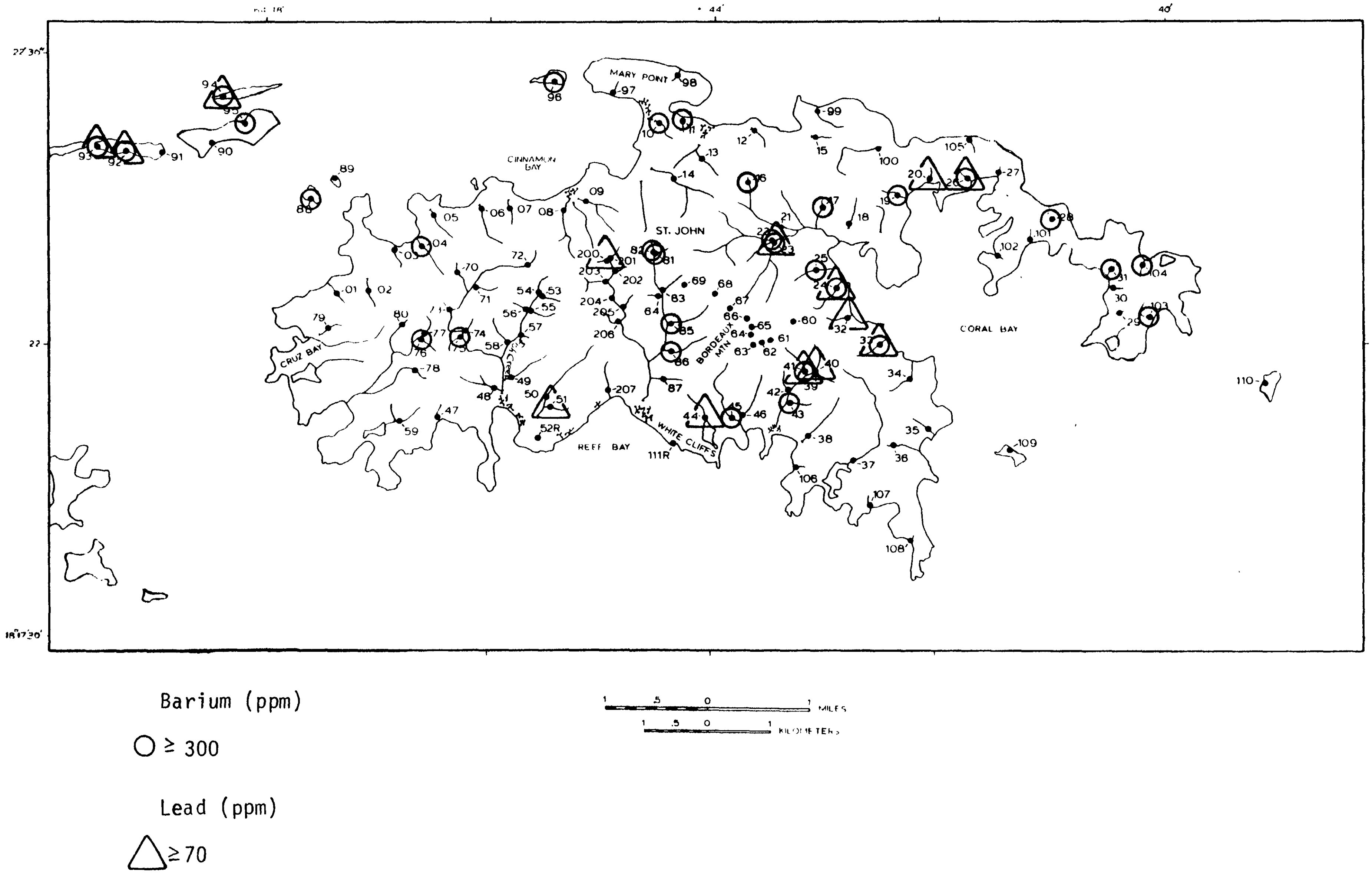


Figure 30.--Distribution of anomalous Ba and Pb concentrations from the magnetic fraction of the panned concentrate samples, St. John, U.S. Virgin Islands.

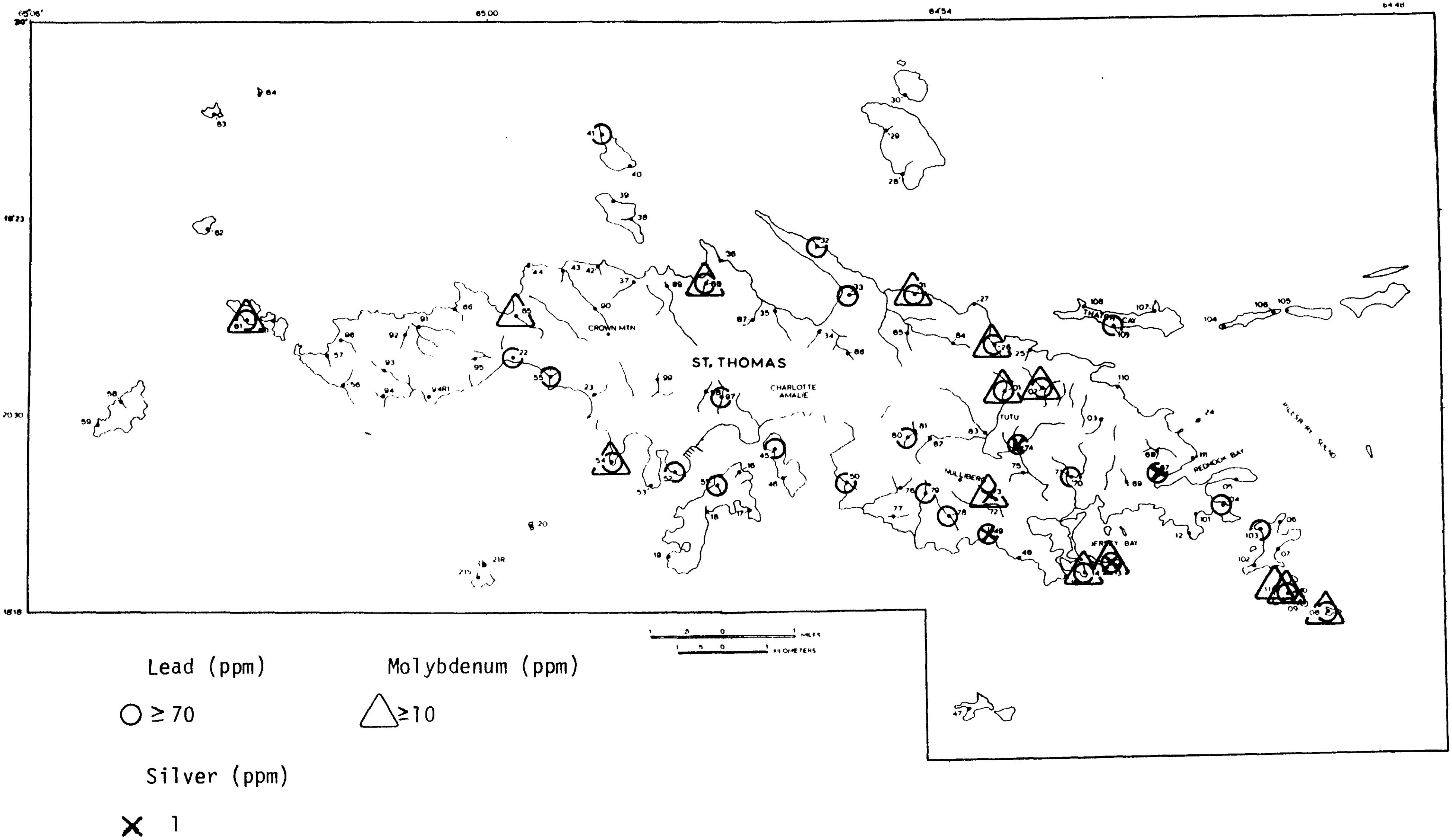


Figure 31.--Distribution of anomalous Pb, Ag, and Mo concentrations from the magnetic fraction of the panned concentrate samples, St. Thomas, U.S. Virgin Islands.

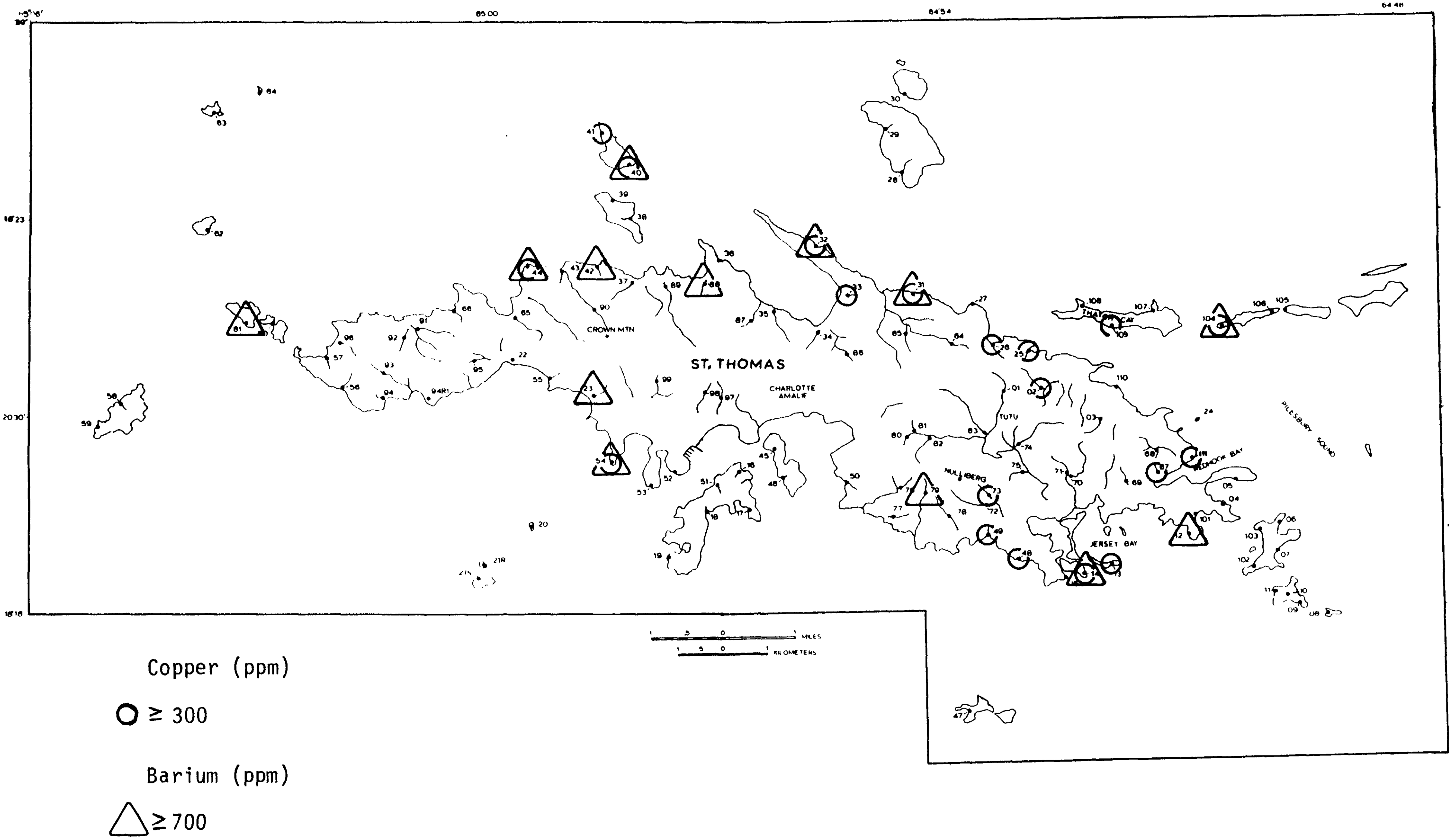


Figure 32.--Distribution of anomalous Cu and Ba concentrations from the magnetic fraction of the panned concentrate samples, St. Thomas, U.S. Virgin Islands.

contain anomalous concentrations of Ba, Ag, Au, Pb, Cu, Zn, and Mo. Soil and rock samples from the surrounding area generally contain slightly lower metal concentrations than those from the crest. The elements observed in the various sample media and the distribution of these elements suggests that a metallizing event occurred in the vicinity of Bordeaux Mountain. The focus of the metallization possibly occurred near the crest and metal-rich fluids migrated through the surrounding rocks. The large gossan boulders on the crest indicate that abundant sulfide minerals were once present. The geochemical halos and metal associations around Bordeaux Mountain are similar to those that occur in the vicinity of known metal deposits such as Red Mountain, Colorado (Westra and Keith, 1981; Wallace and others, 1978), Pine Grove, Utah (Westra and Keith, 1981), and Marysvale, Utah (Cunningham and others, 1984). The Red Mountain and Pine Grove deposits are porphyry-type molybdenum deposits with associated vein-type base-metals occurring in the upper levels of the deposits. These deposits occur in a rhyolitic to granitic terrain.

The White Cliffs area (St. John) appears to be an ancient hot springs, which, owing to its proximity to Bordeaux Mountain, may be genetically related to a metallizing event that apparently occurred in the Bordeaux Mountain region. Alunite, silica, and iron oxides occur in the vicinity. A similar occurrence of ancient hot springs with alunite, iron minerals and other minerals also occur near Marysvale, Utah. The alunite rich areas near Marysvale have been interpreted as hot springs genetically related to the emplacement of a metallized intrusive in the central mining district (Cunningham and others, 1984). The alunite on Alunite Ridge, west of Marysvale, Utah, has been interpreted as reflecting outgassing of thermal fluids genetically related to the emplacement of a postulated porphyry-type deposit (Cunningham and others, 1984). Studies of outcrop samples (Tucker and others, 1981) and stream-sediment-concentrate samples (Tucker and others, 1982) in the Mount Belknap-Marysvale area identified geochemical suites and characteristics related to the emplacement of the postulated metallized intrusive. Many of the same geochemical suites are present in samples from the Bordeaux Mountain anomaly.

The presence of rhyolitic rocks, extensive argillic alteration, iron enrichment, copper minerals, alunite, and gossan all indicate that the metallization in the Bordeaux Mountain anomaly is related to the emplacement of an intrusive body that was pregnant with metals. The postulated metallized intrusive under Bordeaux Mountain may contain porphyry-type metallization.

There are known metallized areas within the region extending from Puerto Rico (Learned and others, 1980; 1981; Miller and others, 1982). The abandoned mine on Virgin Gorda contained supergene and primary copper minerals, precious metals, and molybdenite (Martin-Kaye, 1955).

The high concentration of many metals in the oxalic acid leach may reflect hydromorphic transport. Many of the basins around Coral Bay have anomalous concentrations of Ag, Pb, and V. It would be interesting to examine areas of quiescence in Coral Bay for chemical precipitates of these metals.

The Fish Creek and Shore anomalies have similar geochemical signatures to that of the Bordeaux Mountain anomaly. These two areas are near Bordeaux Mountain and may also be related to the Bordeaux Mountain metallizing event. The Fish Creek anomaly is a small, possibly fault controlled, metallized zone or zones that are best represented in the nonmagnetic fraction, suggesting that the metallization may be near the surface within the basins of sites 53, 54, 72, and 203. The geochemical data further suggest that the metallized zones may contain precious metals. Detailed rock and soil samples could further define the source and extent of this anomaly.

The Shore anomaly is best represented in the rock data. However, anomalous metal concentrations are found in the sediments from nearby basins which give subtle indications of the metallized zone. Detailed rock and soil sampling would be useful in delineating the halos around the anomaly, and possible mineral potential.

The skarn-type metallization observed in the Mingo Cay anomaly contains anomalous concentrations of Pb, Ba, Cu, Sn, Ag, and Au. A dioritic intrusive is exposed on Mary Point and on Tortola, which may have been the heat source to form the skarn. The geochemical data suggest that hydrothermal fluids may have introduced many metals into the original skarn.

The Congo Cay Limestone has been mapped as a distinct rock unit within the Tutu Formation (Donnelly, 1959 and 1966). Anomalous metal concentrations are found in samples from all the cays which suggests that a similar metalizing event has affected the whole area. The rocks on Tortola south of the Congo Cay Limestone member are mapped as limestone, however, descriptions of these rocks by Schomburgk (1837) indicate the presence of marble and garnet in these rocks. These observations are very similar to those noted on Mingo Cay and suggests that the originally uniform sediment has been thermally and chemically altered to varying degrees. The limestone near the thermal source was recrystallized to marble and contains garnet, epidote, and pyrite. The Congo Cay Limestone does not contain the above minerals but has a very coarse crystalline texture and anomalous metal concentrations. On Tortola, the limestone north of the Congo Cay Limestone member is apparently unaltered (Donnelly, 1966).

The geochemical characteristics of the data from St. Thomas are more difficult to interpret than those from St. John. The Jersey Bay and Red Point anomalies appear to represent two centers of anomalous metal concentrations with overlapping boundaries.

The Jersey Bay anomaly contains anomalous concentrations of Ba, Cu, Pb, Mo, and Ag in all of the sample media. This anomaly can be characterized in the rock data by Ba halos extending some 2 km inland from the area of intense argillic alteration and iron-rich dikes near sites 13, 14, and 15. Anomalous Ag and Mo concentrations in the rocks are restricted to a somewhat smaller area. Anomalous Pb and Cu concentrations in the nonmagnetic fraction tend to form extended halos around the altered zone. Anomalous Cu concentrations are found in soil samples in the altered zone and anomalous Ba, Pb, and Ag concentrations in the soils are more widespread. The distribution of Mo in the oxalic acid leach is very localized in the altered zone and Ag seems to form a broad halo around the Mo. Anomalous Pb, Ag, Mo, Cu, and Ba concentrations in the magnetic fraction extend from Jersey Bay to the northern coast. The magnetic minerals precipitated from hydrothermal solutions may trap other metals from the parent solution, thus giving an indication as to the metal potential and the depth of the parent stock (Alminas and VanTrump, 1978). There are a number of faults in the area which could have allowed the hydrothermal fluids to migrate through the rocks from the postulated intrusion at Jersey Bay. The interpretation of the geochemical data suggests that a metal-rich, possibly porphyry-type intrusive was responsible for the alteration and metal overprints within the area. The high number of metals in the magnetic fraction also suggests that the metal-rich intrusive may be at greater depth than the Bordeaux Mountain intrusive.

The Red Point anomaly (St. Thomas) can be identified in all the sample media but is not as distinct as the Bordeaux Mountain or Jersey Bay anomalies. The geologic features observed in the Red Point area are possibly the best indicators of a metallizing event. The small cays south of Red Point exhibit