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Annotated Bibliography of Mercury Studies Related to the Environment and Geologic Setting of Florida

By

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ANNOTATED BIBLIOGRAPHY OF MERCURY STUDIES RELATED TO THE ENVIRONMENT AND GEOLOGIC SETTING OF FLORIDA

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Introduction and Summary

This bibliography contains annotated references which were chosen to elucidate geological aspects of the occurrence of mercury in Florida. Evidence suggests that some mercury was incorporated into Florida's geologic materials when they were formed. Additional evidence suggests that anthropogenic activities have released mercury which has subsequently become concentrated in certain naturally occurring geologic materials. In order to relate the occurrences of mercury to Florida's geology, the references included in this document have been arranged in six sections, each of which is introduced by a brief commentary. Many of the papers included here contain analytical results which are reported in various concentration units. Appendix 1 is a table of units used in this bibliography and their abbreviations.

The first group of papers was chosen to provide an overview of the geologic and tectonic setting of Florida. Tectonic setting is probably the most significant factor in the assessment of an area's potential for naturally occurring, elevated levels of mercury. Geologic factors, such as the types of rocks and minerals which characterize an area, and their relations to each other provide information pertinent to the potential occurrence of mercury.

A second group of papers illustrates the tectonic and geologic settings that are classically associated with mercury deposits. Mercury deposits generally coincide with areas of tectonic activity which are often characterized by thermal activity. The deposits themselves are described as having a fairly simple and characteristic mineralogy. These two (very different) groups of papers provide an indirect perspective on the potential for naturally elevated levels of mercury in Florida.

The third group of papers presents natural background values for mercury in various rocks, soils and surficial materials. Papers containing data from areas remote to Florida are included along with a number of recent studies which consider mercury occurrences specific to Florida. These recent studies emphasize shallow sediments. Although much of Florida is underlain by limestone, few (if any) analyses are available for limestone units specific to Florida. Mercury analyses for limestones from

geologically comparable areas are included to suggest possible values for those rocks when direct analytical results are unavailable.

The fourth group of papers included here examines the relationship between mercury and organic sediments. The Everglades area of Florida is characterized by extensive organic deposits and is also an area of intense concern with respect to mercury. In addition, numerous smaller organic deposits are scattered across the state. Studies concerning organic deposits and mercury were selected for inclusion here, independent of their geographic setting, to document the importance of organic material in the concentration of mercury in the environment.

The fifth group of papers examines mercury in various fresh water settings includin lakes, rivers and ground water. Because the concentration of mercury in fish tissue may be the first indication of mercury contamination, a number of studies focus on the waters and sediments of rivers and lakes in areas of suspected point-source contamination. Concentration values for pristine waters may be important in determining whether or not contamination has occurred. Several studies are directed at the determination of mercury concentration values for natural, uncontaminated waters. Mercury values for Florida's surficial, intermediate and Floridan aquifer systems are presented along with a short note detailing problems associated with the analyses.

The sixth group of papers examines mercury in estuarine and nearshore marine environments. Population growth and development in Florida has occurred preferentially in coastal settings. Industrial activity in coastal areas may also be associated with mercury contamination. A number of studies both within and outside of Florida focus on these situations.

Analytical results reported prior to about 1980 may be artificially high when compared to more recent results, due to inadvertent contamination during sample collection and handling. Improved methods for sampling and handling are described in papers by Fitzgerald and Watras (1989) and Gill and Bruland (1990). Older analyses, thus, suggest samples for further investigation, but are not necessarily accurate.

The Geologic and Tectonic Setting of Florida

Tectonic setting is probably the most critical factor in determining the geographic distribution of significant mercury deposits. Peninsular Florida is situated on the U.S. Atlantic Continental Margin, a typical Atlantic-type or passive continental margin (Grow and Sheridan, 1988), and is characterized by a series of platforms and basins. Although faults have been mapped or inferred in some areas of Florida, there is no evidence that recent seismicity is associated with them (Lane, 1991).

Florida's Mesozoic tectonic history was characterized by rifting, in contrast with its current passive-margin tectonic setting. Smith (1982) provides a concise summary of the lithologies of the Florida basement (0.9-5.5 km below the present-day surface). Chowns and Williams (1983) examined pre-Cretaceous rocks from Florida and commented on regional implications. Arthur (1988) provided a brief overview of the geology of the basement rocks of Florida. Klitgord and others (1984) use magnetic, gravity, seismic and deep drill-hole data integrated with plate-tectonic reconstructions to examine Florida's Jurassic tectonic history of rifting, which they interpret as being related to a transform plate boundary.

Rocks of Cretaceous age which unconformably overlie basement lithologies are discussed briefly in an expanded summary by Miller (1986). Scott (1992) summarizes the stratigraphy and hydrostratigraphy of the overlying Cenozoic rocks, as well as additional aspects of Florida's geology including geologic history, structure, and geomorphology. Miller (1986) provides an extensive examination of the hydrogeologic framework of the rocks of the Floridan aquifer system with emphasis on Paleocene, Eocene and Oligocene rocks. Campbell (1986) describes the industrial minerals extracted in Florida and places them in their appropriate geological context. That study (Campbell, 1986) is included here to emphasize that geological materials, while mined commercially in Florida for a number of end uses, are not extracted for the production of mercury. Among the most recent of Florida's geologic deposits are its peats. Peat forms from partially decayed plant remains which accumulate in waterlogged environments or wetlands. Organic deposits are of particular significance with respect to the fate of mercury because they have long been known to concentrate heavy metals in the environment (Bond and others, 1986).

Arthur, J.D., 1988, Petrogenesis of early Mesozoic tholeiite in the Florida basement and an overview of Florida basement geology: Florida Geological Survey Report of Investigation No. 97, 39 p.

This document presents a brief summary of the literature related to the rocks of the Florida basement. Various studies focused on geophysical, radiometric, paleontologic and tectonic evidence have been used to compile a summary picture of the rocks of the Florida basement.

Bond, P.A., Campbell, K.M., and Scott T.M., 1986, An overview of peat in Florida and related issues: Florida Geological Survey Special Publication No. 27, 151 p.

Peat is a deposit of partially decayed plant remains which accumulates in a waterlogged environment. It is mined in Florida for a variety of mainly agricultural and horticultural uses. Peat is strongly associated with wetlands, since the presence of water serves to inhibit the activity of decomposing organisms which would normally metabolize plant matter, preventing its accumulation. Peat is considered a nonrenewable resource based on its accumulation rate. This document examines the Everglades Agricultural Area (a cultivated peatland), the permitting process as applied to peat and potential environmental impacts of large scale peat mining, and many additional aspects of the occurrences and uses of peat in Florida.

Campbell K.M., 1986, The industrial minerals of Florida: Florida Geological Survey Information Circular No. 102, 94 p.

A number of geological materials are mined in Florida. Raw materials mined for cement production include limestone, quartz sand and clay. Clays, including fuller's earth, kaolin and common clay occur in Florida and have been mined commercially. Heavy minerals mined include rutile, ilmenite and leucoxene which are used mainly for titanium dioxide pigment. Staurolite is primarily a source of iron and alumina and is also used as an abrasive. Zircon, kyanite, sillimanite, tourmaline, spinel, topaz, corundum, monazite, garnet and epidote are extracted for a variety of uses from two placer deposits in northeast Florida. Sea water has been used as a source of magnesium compounds in Florida. Oil and gas are produced from a group of fields in northwestern Florida (Escambia and Santa Rosa Counties) as well as from a group in south Florida (Collier, Dade, Hendry and Lee Counties). Peat is produced from surficial deposits scattered across the state. Phosphate occurs

in six districts in northern and central peninsular Florida. Sand, gravel, limestones and dolostones are also mined throughout much of Florida. This publication describes the geology associated with each commodity, and individual deposits where that is appropriate. Mining and beneficiation, products and uses, transportation and economic trends, reserves and environmental concerns are discussed for each product.

Chowns, T.M., and Williams, C.T., 1983, Pre-Cretaceous rocks beneath the Georgia coastal plain-regional implications, *in* Gohn, G.S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886-tectonics and seismicity: United States Geological Survey Professional Paper 1313, p. L1-L42.

Although this study focuses mainly on rocks beneath the Georgia Coastal Plain, the authors have examined pre-Cretaceous rocks in Florida. North Florida is characterized by felsic volcanic and Paleozoic sedimentary terrains. Pre-Cretaceous rocks of central Florida are described as metamorphic rocks and granites with overlying felsic volcanic rocks, associated plutons and sedimentary rocks. These lithologies are then related to comparable west African rocks. It is noted that a south Florida terrain of felsic-mafic volcanic rocks may or may not be related to similar rocks in northern Florida since they are separated by a major crustal anomaly. Ages of the south Florida rocks are uncertain.

Grow, J.A., and Sheridan, R.E., 1988, U.S. Atlantic continental margin; a typical Atlantic-type or passive continental margin, *in* Sheridan, R.E., and Grow, J.A., eds., The Atlantic continental margin: U.S.: Boulder, Colorado, Geological Society of America, The Geology of North America v. I-2., p. 1-7.

This paper introduces a volume of studies on multiple aspects of the geology of the Atlantic Continental Margin. It describes in a summary fashion, pertinent tectonic features of the passive continental margin where Florida is situated. The major basins and structural elements of the U.S. Atlantic Margin are described. The papers which were compiled to form the volume are reviewed briefly so that a reader may quickly understand the scope of the volume. A map showing major Mesozoic and Cenozoic basins as well as other major tectonic elements of the eastern United States is presented. Major structural features of an Atlantic-type or passive continental margin are shown in a cross-section.

Klitgord, K.D., Popenoe, P., and Schouten, H., 1984, Florida: A Jurassic transform plate boundary: Journal of Geophysical Research, v. 89, p. 7753-7772.

Peninsular Florida overlies a major geologic crustal discontinuity. The authors interpret the discontinuity to represent a transform plate boundary which was active during the Jurassic. The Florida-Bahamas region has been divided into a group of superimposed sedimentary basins which have Paleozoic, Late Triassic-Early Jurassic and Jurassic-Cretaceous ages. The basins have been delineated using samples from drill holes in conjunction with magnetic, gravity, and seismic data and plate tectonic reconstructions. These tectonic units are bounded by fracture zones and basement hinge zones. The tectonic significance of these basins and their bounding elements is explored in detail. The relationship of these tectonic elements to early Jurassic rifting and seafloor spreading is explored.

Lane, B.E., 1991, Earthquakes and seismic history of Florida: Florida Geological Survey Open File Report No. 40, 11 p.

This paper describes the geologic factors which result in earthquakes and explains the vocabulary associated with them. Faults have been mapped in some areas of Florida's subsurface and inferred in other areas. The author notes that no evidence exists which links these faults to earthquakes. A seismic risk for Florida is presented which divides the state into two zones. "Zone 0" designates areas which have no reasonable expectancy of earthquake damage. "Zone 1" includes areas which may experience minor damage from the largest expected distant earthquakes. A table lists known earthquakes and "tremors" felt in Florida from 1727 through January 1991 with their approximated epicenters and intensities.

Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p.

This document describes the geology and stratigraphy of the rocks which comprise the Floridan aquifer system. The aquifers and their confining units are then discussed in relation to the regional geology and stratigraphy. Late Cretaceous rocks are discussed since they make up part of the lower confining unit. The Floridan aquifer system itself is described as a thick sequence of carbonate rocks which are mainly Paleocene to early Miocene in age. These

units are hydraulically connected to varying degrees. Rocks of the upper confining unit (described here as mainly the middle Miocene Hawthorn Formation (this usage follows Miller, 1986)) lie above the carbonate Floridan aquifer system and consist of a thick sequence of siliciclastic and low-permeability carbonate rocks. The overlying surficial aquifer system is described briefly.

Scott, T.M., 1992, A geological overview of Florida: Florida Geological Survey Open File Report No. 50, 78 p.

This publication summarizes various aspects of Florida geology. A brief geologic history provides the framework for a more extensive summary of the lithostratigraphy and hydrostratigraphy of Florida. Structural features and geomorphology are discussed separately. Lithologic summaries are presented beginning with the rocks of the Paleocene Series. This publication and one by Miller (1986) overlap extensively in discussions of the Paleocene, Eocene and Oligocene rocks. Miocene and younger rocks in Florida are emphasized by Scott (1992) so that the discussions complement each other and allow the development of a summary view of Florida's lithostratigraphy. Hydrostratigraphy is considered by geographic areas which are coincident with Florida's water management districts. The surficial and intermediate aquifer systems, as well as the intermediate confining unit are summarized in some detail so that the near-surface hydrogeologic environment may be conceptualized.

Smith, D.L., 1982, Review of the tectonic history of the Florida basement: Tectonophysics, v. 88, p. 1-22.

This study reviews the evidence for an African origin for Florida's basement rocks during the early Paleozoic. Basement sedimentary lithologies and their fossil faunas are reviewed and interpreted as indicating late Paleozoic continental closure which placed the Florida basement into juxtaposition with North America. Igneous rock units of Mesozoic age are described briefly and interpreted as indicative of a Triassic hot spot which initiated rifting and the opening of the North Atlantic.

The Geology of Naturally Occurring Mercury Deposits

Mercury may be naturally released from the rocks of a given area via processes of chemical and physical weathering. The following papers are included to illustrate the types of geologic and tectonic conditions commonly associated with significant mercury-bearing deposits. Mercury deposits are not distributed randomly around the world, but, occur in "belts" which represent "zones of instability or dislocation of the earth and are often marked by the presence of hot springs and other volcanic or thermal activity" (Jonasson and Boyle, 1972). The few deposits that fall outside these belts are noted to be associated with zones of deep faulting and shearing (Jonasson and Boyle, 1972).

A group of probable requirements for the formation of large commercial mercury deposits include, among others, "source regions of fluids and mercury at temperatures above 200 °C; mercury-rich sedimentary rocks and organic matter, perhaps above subduction zones on continental margins" (White, 1981). It is noted that most larger economic deposits are associated with sedimentary rocks (especially limestone and sandstone) of Paleozoic to Recent age (Jonasson and Boyle, 1972). The relatively simple mineralogy of mercury deposits is described and their association with tectonically active areas is reiterated (Moiseyev, 1971). The association of mercury with geologic processes that occur at elevated temperatures is emphasized in a study which utilizes mercury anomalies in soils as a means of locating potential geothermal areas (Varekamp and Buseck, 1983).

Jonasson, I.R., and Boyle, R.W., 1972, Geochemistry of mercury and origins of natural contamination of the environment: The Canadian Mining and Metallurgical Bulletin, v. 65, p. 32-39.

> This paper reviews the potential for mercury contamination of the environment from natural sources. It also provides a review of the geochemical cycling of mercury. The most important mercury minerals are cinnabar and metacinnabar (HgS). Other sulfide minerals may contain various amounts of mercury ranging from parts per billion (ppb) to as much as 2 percent. These minerals occur in deposits which may act as natural sources of mercury which in turn migrates or is transported in the general environment.

The authors examine the world-wide distribution of significant mercury deposits and describe them as belts. The belts are related to areas of tectonic activity with associated hot springs, volcanic and thermal activity. All mercury occurrences outside of these belts are associated with zones of deep faulting and shearing. Large economic mercury deposits preferentially occur in sedimentary rocks (especially limestone and sandstone) of Paleozoic to Recent age. The authors note that these deposits are "invariably veins, stockworks, impregnations or replacement lodes". The binding of mercury ions to organic compounds generated by the decay of plant and animal material as well as the maturation of humus is noted. The association of fossil fuels with mercury is thought to reflect the tendency of organic matter to accumulate mercury as well as other heavy metals.

Moiseyev, A.N., 1971, A non-magmatic source for mercury ore deposits: Economic Geology, v. 66, p. 591-601.

General data on the occurrence of major mercury deposits has been compiled resulting in an alternative hypothesis for the source of mercury ore deposits. The author suggests that mercury is derived from sediments (as opposed to magmas) and is mobilized by volcanic heat. Cinnabar is frequently the only mineral of economic importance and native mercury is usually described as a secondary mineral. Cinnabar is most often associated with pyrite or marcasite. Antimony and arsenic sulfides may be present. Associated gangue (not economically desirable) minerals include calcite, dolomite, magnesite, opal, chalcedony, and quartz.

The author observes that mercury is associated mainly with tectonically active belts of the earth and cites the Pacific rim and the Alpine trend as examples. It is noted that 65 percent of all deposits are associated with volcanism. Data gathered by the author suggest that the deposits are not related to any particular volcanic rock type. Of the mercury deposits surveyed by the author 60 percent of those dated yield ages ranging from Late Cretaceous to present.

Varekamp, J.C., and Buseck, P.R., 1983, Hg anomalies in soils: A Geochemical Exploration Method for Geothermal Areas: Geothermics, v. 12, p. 29-47.

Mercury in soils was measured in an attempt to define its usefulness as a geochemical exploration method. The study was undertaken in geothermal areas of the western U.S., where mercury levels are known to be elevated. It was observed that mercury values fell into three groups. Peak values (up to several hundred parts per million (ppm)) were observed associated with fumaroles, hot springs, and overlying hot-water aquifers which are steeply dipping. Aureole (intermediate) values for mercury range up to several hundred ppb and are characteristic of zones which surround peak areas. Background values for mercury range from 7 to 40 ppb (geometric mean). Research of these authors on geothermal steam and hot spring gases suggest that most mercury in these areas comes from shallow geothermal water.

Varekamp, J.C., and Buseck, P.R., 1984, The speciation of mercury in hydrothermal systems, with applications to ore deposition: Geochimica et Cosmochimica Acta, v. 48, p. 177-185.

Mercury ores are noted from field studies to have formed at shallow depths with temperatures ranging from 100 to 200°C. In addition, mercury deposition is often associated with active geothermal systems. Two geothermal systems in California, the Sulphur Bank system and the Lassen system are considered in detail in this paper. Mercury enrichments are described as occurring in halos which surround hot springs. They also are associated with sulfide ore bodies. Mercury concentrations in geothermal halos are described as reaching levels equal to one hundred times background where background levels are 5 to 30 ppb mercury. The authors note that generally deposition of mercury ore from a hydrothermal system requires a mercury-rich source rock, high solubility of mercury over a broad temperature range and range of fluid compositions, and lastly low mercury solubility for a restricted range of conditions. This paper presents the results of calculations which clarify the speciation of mercury in hydrothermal systems. The results are applied to ore deposition problems.

White, D.E., 1981, Active geothermal systems and hydrothermal ore deposits: Economic Geology, 75th Anniversary Volume, p. 392-423.

This review paper treats hydrothermal ore deposits of various metals including mercury. The author considers a group of geothermal systems which actively deposit mercury and draws on that information in order to compile a list of probable major requirements for the formation of large commercial deposits of mercury. These include: a deep source area of both fluids and mercury at temperatures which are greater than 200°C; environments characterized by

metamorphic conditions (conditions of elevated temperature and pressure) which lie above subduction zones on continental margins; a vapor phase which passes through a significant volume of rock (as opposed to one which originates locally) and is enriched in carbon dioxide or other gases and moves along with liquid water; the tendency of mercury sulfide (HgS) to decompose to uncharged mercury and sulfur at high temperatures, with a mobile vapor necessary for any major transport of mercury at temperatures less than 200°C; a liquid phase which can exist in the presence of the vapor phase so that nonvolatile constituents may be transported.

Natural Levels of Mercury in the Geologic Environment

Most earth materials contain small amounts of mercury. Studies in this section were chosen to provide analytical values for mercury in geologic materials comparable to those found in Florida. In some cases analyses from Florida were reported. United *States Geological Survey Professional Paper 713 was published in 1970. It is a collection of (then) state-of-the-art papers on mercury's behavior in air, water and earth materials. The paper was a response to early environmental concerns, at a time when information was scant. In a subsequent paper, mercury data are collected from various surficial materials in the conterminous United States (Shacklette and others, 1971). In 1975 this study was expanded and background data was collected for 49 elements including mercury, in rocks, soils, plants and vegetables (Connor and Shacklette, 1975). This type of study was applied to soils and other surficial materials again in 1984 (Shacklette and Boerngen, 1984). Unfortunately, sampled sites were not reoccupied in this series of studies, so that analytical results may not be compared as a function of time. A recently published study (Gough and others, 1996) examined mercury, in addition to a number of other trace elements, in vegetation, water, and organic-rich sediments of south Florida.

Two studies, which emphasize soils and sedimentary rocks, are included in this section of the bibliography. In Pennsylvania, samples of sandstone, shale and limestone were analyzed for mercury. Soils were also analyzed, so that mercury levels in rocks and soils could be compared. The comparison was used to estimate the anthropogenic contribution to mercury levels in surficial materials (McNeal and Rose, 1974). This research is included because the lithologies are, at least, somewhat comparable to those of Florida. A Canadian investigation examined levels of mercury (and other minor elements) in uncontaminated soils remote to ore deposits (McKeague and Wolynetz, 1980). The authors attempted to avoid known sources of natural contamination in order to determine background levels of mercury.

The final two papers in this section contain mercury analyses from the Land-Pebble Phosphate District of Florida. One study (Altschuler, 1980) represents an average of eight composites, four pebble and four pellet concentrates, taken from one week's production at each of four mining locations. The second study (Cathcart and Botinelly, 1991) presents data from a single core. It is not possible to compare analyses from these two studies. Locations from one are poorly documented (Altschuler, 1980). In addition, samples from a single core cannot be validly compared with large composite samples.

Altschuler, Z.S., 1980, The geochemistry of trace elements in marine phosphorites part i. characteristic abundances and enrichment: SEPM Special Publication No. 29, p. 19-30.

This paper compiled trace element analyses from an international group of significant marine phosphorite deposits. Phosphorites from the Bone Valley Formation (Bone Valley Member of Scott, 1992), of Florida were included in this study. Analyses for a suite of trace elements including mercury are included for an average of eight composite samples. The material analyzed is characterized as pebbly and pelletal phosphorite from sandy and clayey phosphorites, reworked from phosphatic limestones and dolomites of the Hawthorn Group. Florida phosphorite was reported to contain 25 ppb mercury, the lowest value for deposits for which mercury analyses were available. It was noted that mercury is depleted in phosphorite when compared to the mercury value of 400 ppb for an average shale (where shale is taken to represent the general category of marine rocks). Although the author develops geochemical rationale for the depletion of certain of the trace elements, it is noted that the depletion of mercury is not understood.

Cathcart, J.B., and Botinelly, T., 1991, Mineralogy and chemistry of samples from a drill hole in the southern extension of the land-pebble phosphate district, Florida: U.S. Geological Survey Bulletin 1978, 25 p.

This publication details mineralogy and chemistry of a core taken from the southern extension of the land-pebble phosphate district of Florida (Hardee County). Francolite (the highly substituted apatite mineral of the Bone Valley Member and Peace River Formations, Hawthorn Group) samples from this core were analyzed for a suite of trace elements that included mercury. Samples of phosphate concentrate analyzed for this report include leached Bone Valley Member (0.32 and 0.40 ppm mercury) and Peace River Formation (0.04 to 0.12 ppm mercury). The authors note that these values are consistent with unpublished U.S. Geological Survey data for mercury values from the land-pebble phosphate district. The authors interpret their data as indicating that the amount of mercury in phosphate rock is "too low to be of concern".

Connor, J.J., and Shacklette, H.T., 1975, Background geochemistry of some rocks, soils, plants, and vegetables in the conterminous United States: U.S. Geological Survey Professional Paper 574-F, 168 p.

This document is mainly a compilation of data tables for 49 chemical elements including mercury. Mercury concentration values are reported for various rock types including granite, rhyolite, sandstone, chert, shale, limestone and dolostone. Mercury analyses are also listed for unconsolidated geologic deposits (terra rossa and loess), various cultivated and uncultivated soils, as well as a variety of plants. Analyses are not reported for rock units, soils or plants from Florida.

Gough, L.P., Kotra, R.K., Holmes, C.W., Brigges, P.H., Crock, J.G., Fey, D.L., Hageman, P.L., and Meier, A.L., 1996, Chemical analysis results for mercury and trace elements in vegetation, water, and organic-rich sediments, south Florida: U.S. Geological Survey Open-File Report 96-091, 29 p.

This reference is a brief report of the partial results of a two-year (1994-1995) study undertaken by the United States Geological Survey in south Florida. Mercury, in addition to other trace metals, was analyzed in vegetation, water, and organic sediments. The study is in response to the discovery of elevated mercury levels in biota, including high trophic level fish, alligators, and the endangered Florida panther. The project aims to clarify the sources, distribution, and processes associated with biogeochemical cycling of trace elements and metals, including mercury, in the organic rich sediments of the Everglades. Analyses from the 1994 studies and partial analyses from 1995 are presented in this document.

McKeague, J.A., and Wolynetz, M.S., 1980, Background levels of minor elements in some Canadian soils: Geoderma, v. 24, p. 299-307.

Uncontaminated soils, remote from orebodies, were analyzed for minor elements in order to obtain background values. Mercury was reported to have a mean value of 0.06 ppm, ranging from 0.005 to 0.1 ppm. Values are similar to those reported for soils from the United States. Correlations of mercury levels with levels of other elements or with soil properties such as clay were not statistically significant.

McNeal, J.M., and Rose, A.W., 1974, The geochemistry of mercury in sedimentary rocks and soils in Pennsylvania: Geochimica et Cosmochimica Acta, v. 38, p. 1759-1784.

Sandstone, shale, and limestone samples from Pennsylvania were analyzed for mercury. Average values obtained for these three rock types were 7, 23, and 9 ppb mercury respectively. These values were noted to be comparatively low. It was noted that mercury values vary considerably in sedimentary rocks depending on a number of factors including "effects of volcanism, organic material and sulfur in reducing environments, iron and manganese oxides in oxidizing environments, diagenesis, hydrothermal processes, and the thermal history of the rock". Soils in Pennsylvania were shown to have much higher concentrations of mercury than their parent rock and the authors suggest that mercury is added to these soils from an external source or sources. Rain was discovered to be the major pathway of mercury to the soil. Since some soil mercury then returns to the atmosphere, a cycle linking the soil, rain and the atmosphere is set up. The authors' evaluation suggested that the anthropogenic input of mercury to the environment was nearly equal to mercury input from natural sources. Based on this work, industrial mercury sources were found to be responsible for nearly 70 percent of the total anthropogenic input. Input related to fossil fuel consumption was considered to be relatively minor. It was suggested that elevated mercury levels associated with industrial sources might be localized. It was noted that further data is needed to define the mercury content of rain, volcanic exhalation, and petroleum.

Shacklette, H.T., and Boerngen, J.G., 1984, Element concentrations in soils and other surficial materials of the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.

This report presents analytical data for 50 elements including mercury. The data are presented in the form of symbols (representative of concentration ranges) on a small scale map. Thus exact concentrations and sample locations can not be recovered from this report. Mercury data from Florida are spread across the range of concentrations reported (hundredths of ppm to <6 ppm). The extremely brief text which accompanies this data notes that there is a pattern of high mercury concentrations from the Gulf Coast of Texas to (and including) northwest Florida. There is no elaboration on this observation.

Shacklette, H.T., Boerngen, J.G., and Turner, R.L., 1971, Mercury in the environment-surficial materials of the conterminous United States: U.S. Geological Survey Circular 644, 5 p.

This report presents results of mercury analyses from surficial materials for the contiguous United States. Results from Florida, as well as the remaining

states are presented on a small scale map. Each data point represents a range of mercury concentrations. Thus this paper does not allow specific concentration data to be attached to a given data point. It is also not possible to recover precise locations or types of materials sampled from this paper. The only exception is a sample from Walton County, Florida which reportedly contained the highest concentration of mercury (3,400 ppb) found in any surficial material from the eastern United States. This sample was taken from an area of humate deposits. An additional sample from the area was found to contain 2,000 ppb mercury.

United States Geological Survey, 1970, Mercury in the environment: Geological Survey Professional Paper 713, 67 p.

This document is a compilation of papers by various authors on a number of topics related to mercury in the natural environment. The literature on the inorganic chemistry of mercury is summarized, its chemical behavior in aqueous media and the relationship of biological factors to mercury chemistry are considered. Analytical methods for mercury determination in rocks and soils are also reviewed. A number of papers present analytical data but no data from Florida is presented. Mercury concentration data from various localities is presented for rocks, soils, stream sediments, natural thermal and mineral fluids, plants and the atmosphere.

Mercury and Organic Matter

The interaction of mercury (as well as other heavy metals) with organic matter has been the subject of numerous investigations. Studies included in this bibliography fall into three groups. The first group of papers documents the accumulation of mercury in peats and (by implication) coals. Peat is the geological precursor to coal and since both materials may be burned for fuels, their potential as a source of atmospheric mercury is considered. The second group of papers examines mercury in the context of peat mining. The third group of papers examines aspects of interactions between mercury and organic matter in various marsh environments.

In 1971 a short paper presented calculations which approximated the amounts of mercury released by weathering, burning of coal and industrial waste (Joensuu, 1971). Relative amounts of mercury from the three sources were compared and potential of coal as a source of mercury pollution was explored. This work responded to a documented buildup of mercury in the biomass (Joensuu, 1971). A recent study aimed at examining atmospheric sources of mercury to south Florida is included here (Pollman and others, 1995). A study (Casagrande and Erchull, 1976) which examined mercury (among other metals) in the peat-forming environment of the Okefenokee Swamp (southeast Georgia) found mercury values very similar to values measured for coals from various parts of the United States. A different type of study examined mercury deposition as a function of time (using Pb-210 dating) in two Danish peat bogs (Madsen, 1981). A recent study determined modern and historic accumulation rates for mercury (using Pb-210 and Cs-137) in two areas of Florida (Rood and others, 1995). Trace element concentrations (including mercury) were determined for several peatlands in northern Ontario (Glooschenko and Capoblanco, 1982).

Since mercury does become bound to peat, the drainage and subsequent oxidation of organic matter which accompanies peat mining, have become the focus of several studies. A study in Finland examined mercury in lake sediments as a function of widespread peatland drainage (Simola and Lodenius, 1982). An experimental study of the sorption and mobilization processes affecting mercury in a peat soil simulated the effects of acid rain, irrigation and evaporation (Lodenius and others, 1983). An extensive study examined the potential for mercury release in response to proposed peat mining in eastern North Carolina (Evans and others, 1984).

Organic matter is a significant material in the marsh environment and three studies have been selected for inclusion here which examine mercury in marsh settings.

Mercury was examined from experimental plots in a marsh which received applications of a commercial fertilizer containing sewage sludge, as a means of understanding the cycling of mercury in this complex environment (Breteler, 1980). The relationships between dissolved organic carbon and total dissolved mercury in interstitial water were compared between two marshes, one of which contained significant dredged material (Katsaounis, 1977). Mercury transfers in a Georgia salt marsh ecosystem were examined in terms of the role of macrobenthic organisms (Kendall, 1978). The diversity of these studies serves to emphasize the complex nature of the numerous relationships that influence the behavior of mercury in the modern marsh environment. A short paper is included which examines plans for restoration of the Everglades and notes that the behavior of metals including phosphorous and mercury must be included in those plans (Culotta, 1995).

Breteler, R.J., 1980, The cycling of mercury in spartina marshes and its availability to selected biota [Ph.D. dissert]: Montreal, Quebec, McGill University, 95 p.

> Experimental plots in Great Sippewissett Marsh (Cape Cod, Massachusetts) received applications of a commercial fertilizer containing sewage sludge. Since sewage sludge may contain considerable amounts of mercury, the fate of mercury was examined in these marsh sediments. The treatment resulted in elevated mercury levels in the upper 5 cm of the soil. Although mercury losses were observed from low intertidal marsh regions, calculations indicate that mercury was quantitatively retained by soils at higher marsh elevations. The losses were attributed to physical and mechanical processes such as sediment transport and erosion as opposed to various geochemical processes. Marsh grasses and organisms from experimental plots did not concentrate mercury from the enriched sediments of the plot. The authors found that bioavailability of mercury in the salt marsh system is inversely related to the amount of organic matter in the soil.

Casagrande, D.J., and Erchull, L.D., 1976, Metals in Okefenokee peat-forming environments: relation to constituents found in coal: Geochimica et Cosmochimica Acta, v. 40, p. 387-393.

> Mercury, among other metals, was studied in two peat cores representing two major vegetational areas of the Okefenokee Swamp. One core was taken from

Chesser Prairie, a marsh site characterized by mainly aquatic plants while the other core was taken from Minnie's Lake, a swamp site characterized by trees. Mercury values ranged from 0.05 to 1.04 ppm in this study and the authors noted the values were "remarkably similar to values found in coals." Data from this study suggests that vegetation does not play a critical role in determining trace metal distribution.

Culotta, E., 1995, Bringing back the Everglades: Science, v. 268, p. 1688-1690.

This paper is a brief description of the current effort to restore the Everglades. The history of water management in the area is described and the system as it existed before human intervention is treated briefly. Hydrologic and ecologic unknowns related to the restoration effort are explored using short interviews with scientists and managers involved in the effort. Water quality issues related to both phosphorous and mercury are examined. It is reported that the source of mercury to the Everglades area remains unknown.

Evans, D.W., DiGiulio, R.T., and Ryan, E.A., 1984, Mercury in peat and its drainage waters in eastern North Carolina: Water Resources Institute of the University of North Carolina Report Number 218, 66 p.

This study was undertaken in response to proposed mining of peat in the western Pamlico-Albemarle Peninsula of eastern North Carolina. Mercury pollution from peatland drainage was raised as a concern in response to reported mercury concentrations of as much as 2.1 micrograms/liter (ug/L) from waters in canals draining the peatlands proposed for mining. North Carolina's existing water quality standard for Mercury is 50 nanograms/liter (ng/L).

Concentrations of total mercury from three depths (surface, 20 cm and 1m) in peat cores ranged from 40 to 193 nanograms/gram (ng/g) (dry weight basis). Comparisons of these values with mercury concentrations from peats in other areas suggest that the values are close to the lower end of the distribution of mercury concentrations observed in peat, but the values are not considered unusually low. Concentrations of methylmercury above the detection limit (25 ng/g) were not found in any peat sample. Concentrations of total mercury in several extractable fractions were measured and suggest that mercury in these peat cores is not very mobile (or bioavailable) even in the surface layer.

In order to examine the effect of ditching and land drainage on mercury mobilization from peatlands, samples were taken along a transect which originated at the exposed ditch face. It was concluded from this work that mobilization of mercury from peat to drainage waters during mining would probably be minor. Mercury was actually enriched at the exposed canal face with a mercury-depleted zone just beneath. The authors suggest that this pattern results from mobilization of mercury from peat to pore water accompanied by at least partial refixation of mercury in the oxidized surface layer of the peat.

Mercury concentrations were measured in sediments from the study area. Mean concentrations of mercury ranged between 8 and 16 ng/g (dry weight) in canal sediments and between <2 and 20 ng/g in Pungo River sediments. It is noted that these concentrations are low and are considered background levels by the authors of at least one review paper. No values of methylmercury above the detection limit (25 ng/g dry weight) were found in any sediment sample. The distribution of mercury between various fractions was examined and found to be very similar to peats. The data suggest that mercury in surface sediments is neither particularly mobile or bioavailable.

Glooschenko, W.A. and Capoblanco, J.A., 1982, Trace element content of northern Ontario peat: Environmental Science and Technology, v. 16, p.187-188.

This study was undertaken to determine the trace metal content of peats from various peatland ecosystems including bogs, swamps, and fens. Bogs are ombrotrophic (receive all nutrients from atmospheric precipitation). Swamps and fens are minerotrophic (receive nutrients from ground water) and differ mainly in that swamps are wooded, while fens are dominated by sedges with limited grasses, reeds, shrubs and trees. Only twelve samples were analyzed for mercury in this study. Concentrations for mercury ranged from tenths to hundredths of parts per million. Concentrations of mercury did not significantly differ in terms of peatland type or depth. The authors note that metal concentrations are comparable to those found in United States coals and suggest that combustion usage may result in increased metal input to the atmosphere.

Joensuu, O.I., 1971, Fossil fuels as a source of mercury pollution: Science, v. 172, p.1027-1028.

This study suggested that mercury accumulation in biomass might be related to mercury deposited in the environment as a result of the burning of fossil fuels (especially coal). Mercury concentration values from a number of coals were presented and used to calculate an estimate of mercury released to the atmosphere per year as a consequence of burning coal. The amount of mercury released to the environment as a result of natural weathering processes were also estimated for comparison. Based on these calculations, the author suggested that the amount of mercury released to the environment by the burning of coal was much greater than the amount released by weathering.

Katsaounis, A., 1977, Sediment interstitial dissolved mercury and carbon relationships in an artificial and natural marsh, James River, Virginia [Master's Thesis]: Norfolk, Virginia, Old Dominion University, 76 p.

The relationships between dissolved organic carbon and total dissolved mercury in the interstitial water of two marshes was examined in this study. The marshes were located near Windmill Point, James River, approximately 16 km downstream of Hopewell, Virginia. The Windmill Point marsh development site (a dredged material disposal island) was compared with a reference marsh which contained no dredged material.

No significant differences were found between concentrations of dissolved organic carbon and total dissolved mercury for the two marshes. Trends were not found in the concentration of dissolved mercury and dissolved organic carbon with depth. In the winter, mercury concentrations averaged 85 percent lower than in the summer while dissolved organic carbon was 45 percent lower in the winter. Average values for mercury concentration were 4.8 ug/L in August, 1976 and 0.70 ug/L in January, 1977. Values for dissolved organic carbon averaged 33 milligrams/liter (mg/L) in August and 18 mg/L in January.

Statistical analysis showed no correlation between total dissolved mercury and dissolved organic carbon. When the number of variables used in multiple linear regression analysis was increased, the correlation improved, suggesting that additional parameters (possibly including sulfides, chlorides, and major cations) should be examined.

Kendall, D.R., 1978, The role of macrobenthic organisms in mercury, cadmium, copper, and zinc transfers in Georgia salt marsh ecosystems [Ph.D. dissert.]: Atlanta, Georgia, Emory University, 241 p.

This study was designed to examine the role of macrobenthic organisms in the cycling of mercury, cadmium, copper and zinc in two salt marsh ecosystems in Georgia. The work includes a detailed summary of the geochemistry of mercury in the control (contamination free) and contaminated marsh ecosystems, even though its primary emphasis concerns the biologic implications of metal contamination in the ecosystems. The study area includes two estuarine salt marsh ecosystems. St. Simons estuary, near Brunswick, Georgia is heavily industrialized on its north shore and has received anthropogenic inputs of mercury. Little Ogeechee estuary, located south of Savannah near Ossabaw Island is relatively free of industry and has no anthropogenic input of the heavy metals considered in this study.

It was noted that the distribution of mercury in St. Simons estuary appeared to be governed by conservative mixing (concentration decreasing in a seaward direction) in the winter, while in the fall, mixing appeared to be nonconservative (irregular variation of concentration in the seaward direction). This difference is thought to reflect subtle differences in the total suspended organic particulate load between seasons. The association of mercury with suspended particulate matter may significantly affect the distribution of mercury in estuarine waters, especially during periods when there are high levels of suspended particulate matter.

Conversely, mercury is associated with low molecular weight fractions of dissolved organic carbon (DOC) and it is suggested that mercury distribution in water should exhibit "ideal dilution" when levels of suspended particulates are low. It is suggested that seasonal changes in suspended particulate matter in estuaries may affect the mixing behavior of metals such as mercury, especially in highly eutrophic environments. The author notes that a number of authors have established the potential importance of organic matter (both particulate and dissolved) in complexing metals. In both estuaries considered in this study, leachable metals, including mercury, were highly correlated with sediment organic matter and clay content.

The author examines a number of factors which influence bioaccumulation of metals. These factors include uptake of dissolved metals, assimilation of mercury from food (sediments), effects of organic matter (sediments), loss (depuration) of metals, environmental effects, effects of dissolved organic matter, body size and intraspecific relationships, intraspecific differences in metals and seasonal changes in macrobenthos. This study looks at the effects of mercury contamination in St. Simons estuary on invertebrates, fish, terrestrial marsh vertebrates and food chain metal bioamplification. The effects of chronic metal pollution were examined including disruptive effects of mercury (as well as cadmium, copper and zinc), synergistic effects and toxicity and adaptation. Metal fluxes through estuarine and marsh biota were calculated and a benthic mercury flux model was prepared.

Lodenius, M., Seppanen, A., and Uusi-Rauva, A., 1983, Sorption and mobilization of mercury in peat soil: Chemosphere, v. 12, p. 1575-1581.

The work presented in this paper is an experimental study of the sorption, leaching and evaporation of mercury in peat. Peat was added to 16 polyethylene lysimeter columns and mercury was in turn added to the peat. Most of the added mercury was strongly adsorbed in the uppermost 3.5 cm of the peat columns. The addition of chloride was associated with increased leaching of mercury, while the addition of fertilizer decreased leaching. Artificial acid rain added to the columns increased the adsorption of mercury to the peat soil. The addition of distilled water used to simulate irrigation resulted in increased leaching. Mercury evaporated from all the columns to which it was added.

Madsen, P.P., 1981, Peat bog records of atmospheric mercury deposition: Nature, v.293, p.127-130.

Ombrotrophic bogs depend on atmospheric input for their nutrient supply. In turn, bog plants have evolved so that these inputs, including atmospheric fall-out of heavy metals are retained. Two ombrotrophic bogs, one in northern and one in southern Jutland (Denmark) were cored and sampled for lead-210 and mercury analyses. Lead-210 samples allowed age-determinations to be calculated and these dates were then related to mercury concentrations for the appropriate time interval. Both cores showed a long-term increase in the rate of atmospheric mercury deposition since 1800-1850. The authors concluded that this increase is probably anthropogenic. Periodically elevated rates were

tentatively attributed to volcanic activity in Iceland or associated climatic events.

Pollman, C., Gill, G., Landing, W., Guentzel, J., Bare, D., Porcella, D., Zillioux, E. and Atkeson, T., 1995, Overview of the Florida atmospheric mercury study (FAMS): water, air, and soil pollution, v. 80, p. 285-290.

This paper presents a summary of the Florida Atmospheric Mercury Study, an effort aimed at characterizing mercury in rainfall, atmospheric aerosols, and total gaseous mercury. The work was in part a response to the discovery of high mercury levels in largemouth bass in Florida waterways. Results reported in this paper suggest that atmospheric mercury deposition in south Florida reflects large-scale regional processes rather than more localized influences.

Rood, B.E., Gottgens, J.F., Delfino, J.J., Earle, C.D., and Crisman, T.L., 1995, Mercury accumulation trends in Florida Everglades and Savannas Marsh flooded soils: water, air, and soil pollution, v.80, p. 981-990.

Radiometric age-dates using Pb-210 and Cs-137 were obtained from eighteen sediment cores, allowing rates of mercury deposition to be calculated. The work was undertaken in response to elevated levels of mercury in sportfish taken from these areas. It is noted that the average accumulation rate of Hg has increased 4.9 times over the average rate at around the turn of the century. The accumulation apparently results more from global or regional atmospheric deposition than transport by surface water.

Simola, H., and Lodenius, M., 1982, Recent Increase in mercury sedimentation in a forest lake attributable to peatland drainage: Bulletin of Environmental Contamination Toxicology, v.29, p.298-305.

Peat cores from two lakes in Finland were compared in order to examine the effects of widespread peatland drainage on mercury levels. The lakes contain varves which allow precise dating of the system under consideration, but differ in terms of land use in their respective drainage areas. The annually laminated sediments of Lake Polvijarvi record a history of rapid eutrophication during the 1970's which is attributed to extensive peatland drainage and fertilization in its drainage area. Lake Paajarvi is considered typical of the whole of southern Finland and is considered to be near its natural oligotrophic state. No clear

increase in mercury influx was observed for Lake Paajarvi, while elevated concentrations of mercury in Lake Polvijarvi were closely related to drainage activities. On this basis atmospheric deposition was considered negligible for the two lakes.

Stephenson, F., 1997, Florida's mercury menace: Florida State University Research in Review, v.8, p. 10-21.

This paper presents a nontechnical summary of the results of the Florida Atmospheric Mercury Study. Atmospheric mercury sampling stations were erected at nine locations, eight of which were located in south Florida, in response to elevated mercury concentrations in Everglades wildlife. This research showed that five to eight times as much total mercury fell during wet-weather months as in winter months. Results of this research suggest that mercury from various sources in the northern hemisphere (both in the U.S. and abroad) are eventually transported west across the Atlantic by the tradewinds to Florida. The huge convective thunderstorms which characterize Florida's weather pattern from June to September are thought to scavenge out the mercury from the layer of air seven to ten miles over Florida.

Mercury in Fresh Water Settings

A number of studies focus on mercury in fresh water environments (mainly rivers and lakes). This section contains two papers which summarize aspects of the behavior of mercury in aqueous systems. An early study (D'Itri, 1972) reviews natural and domestic sources of mercury, while focusing on its biological methylation in aqueous systems. A more recent survey chapter (Moore and Ramamoorthy, 1984) provides a review of numerous aspects of the chemistry of mercury in natural waters. Anthropogenic and natural discharges of mercury to the environment are also reviewed and toxicity of mercurial compounds in the aquatic environment is considered briefly. Taken together, these two papers provide an interesting commentary on the development of scientific understanding of the mercury problem.

Since mercury in the aquatic environment was first identified as a potential problem, the need has existed for reliable data on its concentration in pristine waters. The most general and broad study included in this bibliography was undertaken in order to provide baseline data for streams supplying water for municipal and industrial uses (Durum and others, 1971). A more recent study examined surface waters in lakes of rural Wisconsin. Concentrations obtained in this study were 20 to 100 times lower than values previously estimated for lakes in the area, prompting the authors to note that uncompromised clean procedures are essential in sample collection and analysis (Fitzgerald and Watras, 1989). Fitzgerald and Watras (1989) provide a description of their collection and analytical procedures. An additional study of mercury speciation in surface fresh water systems examined a range of environments, from a pristine alpine lake to a system characterized by mercury-contaminated sediments (Gill and Bruland, 1990). The authors again report concentrations which are low when compared to comparable historical results, emphasizing the need for clean sampling and analytical techniques.

Mercury contamination in fresh water systems is a subject of continuing concern due to the toxicity of mercurial compounds. Five studies are presented here in which aspects of mercury contamination in various fresh water systems were examined. A recent study of fish, water, and sediment of the Everglades Canal System of south Florida is presented (Stober and others, 1995). A unique study attempts to infer natural background concentrations for mercury in an aquifer system, using values for pristine surface waters, the mineralogy of the rocks comprising the aquifer system, and the chemical behavior of mercury in natural waters (Dooley, 1992). Data for mercury concentrations in the surficial, intermediate and Floridan aquifer systems of Florida are presented (Upchurch, 1992). Difficulties with the analyses (Upchurch,

1992) are detailed in a short note (Silvanima, 1995). The Great Lakes were examined for new sources of mercury contamination (Glass and others, 1990), and such sources were located, even though major improvements in water quality have been achieved since 1978. Sediment samples from four Alabama rivers were analyzed for mercury after high concentrations in fish flesh prompted closure of commercial fishing and official discouragement of sport fishing (Lloyd and others, 1972). Sediments of the highly industrialized Elizabeth River (Virginia) were analyzed for mercury and contamination was found to be related to heavy industrial, commercial, and domestic inputs (Johnson and Villa, 1976). These studies illustrate the vulnerability of differing surficial fresh water systems to various sources of mercury contamination.

D'Itri, F.M., 1972, Mercury in the aquatic ecosystem: Institute of Water Research, Michigan State University, Technical Report No. 23, 87 p.

This document discusses in detail the biological methylation of mercury which changes the mercuric (2+) ion to methylmercury, the species which is biologically accumulated by aquatic organisms. Sources of mercury are also reviewed. Natural sources of mercury to the aqueous environment are reviewed. Anthropogenic sources of mercury are also reviewed. At the time this document was prepared those sources included discharge from urban and industrial sanitary sewer systems, burning or other utilization of fossil fuels and smelting of copper, lead and zinc ores. Mercury concentration ranges are included for peat, coal, bitumens, asphalts, fuel oil, gasoline, crude oil and associated products and natural gas.

Dooley, J.H., 1992, Natural sources of mercury in the Kirkwood-Cohansey aquifer system of the New Jersey coastal plain: New Jersey Geological Survey, Geological Survey Report 27, 18 p.

This study arose from the discovery that mercury in excess of the 2 ug/L maximum contaminant level (MCL) (state and federal potable water standards) was present in domestic wells throughout southern and southeastern New Jersey. The aqueous mercury was found to be geographically widespread and well-defined point sources were present. It was thus suggested that elevated mercury levels were possibly due to a lithogenic (natural) contaminant source.

This report examines geochemical and lithologic factors affecting aqueous mercury concentrations in the surficial Kirkwood-Cohansey aquifer system.

The geologic occurrences of mercury are reviewed including sulfide minerals and ores. It is noted that the geologic setting of mercury deposits is unlike that of the Coastal Plain of New Jersey. The occurrence of mercury in minerals and common sedimentary rocks is examined and mercury concentration values are compiled from various sources and presented in tables. The mineralogy and lithology of the Kirkwood-Cohansey aquifer system are reviewed in detail although specific analytical data are not available. Data are presented for soils and surficial waters. It is suggested, based on this information, that lithologic sources contribute insignificant amounts of mercury to the Kirkwood-Cohansey aquifer system. Ground-water data are reviewed for the Kirkwood-Cohansey aquifer system, as well as other areas, and it is concluded that locally elevated mercury concentrations are probably due to multiple, past and current, anthropogenic inputs of mercury.

Durum, W.H., Hem, J.D., and Heidel, S.G., 1971, Reconnaissance of selected minor elements in surface waters of the United States, October 1970: U.S. Geological Survey Circular 643, 49 p.

This report summarizes the results of a nationwide reconnaissance of selected minor elements (including mercury) from surface waters. The study was initiated in response to an increased need for data on minor elements in water (including toxic metals). It was designed to provide baseline data mainly for dry-weather flow conditions of streams which provide water for municipal and industrial uses. Dissolved and total mercury were reported. The difference between dissolved and total mercury reflects the fact that a portion of the mercury in a surface water body will adhere to particulate matter. Data was gathered for 17 sites in Florida. Dissolved mercury was not reported at any site. Mercury was detected at 9 of the 17 sites sampled and total mercury ranged from 0.6 to 65.1 ppb.

Fitzgerald, W.F., and Watras, C.J., 1989, Mercury in surficial waters of rural Wisconsin lakes: The Science of the Total Environment, v. 87/88, p. 223-232.

Samples of unfiltered surface waters from eight lakes in rural north central Wisconsin were collected for mercury analysis. The lakes were selected as representing a broad range of clear-water lake types, from small, dilute

seepage kettles which receive mainly precipitation input, to large drainage lakes. Sampling and analytical work for this study utilized ultra-clean, trace-metal-free techniques originally developed to accurately measure low levels of mercury found in pristine, oceanic environments. When data from this study were compared with available historical data for one lake in the study area, it was found that mercury concentrations apparently decreased dramatically over time (concurrently with the development of "cleaner" techniques for the collection and handling of samples). Mercury levels in the lakes were found to be very similar to open ocean values (total mercury ranging between 1 and 11 pico-molar (pM). A preliminary mass balance for mercury in the area suggests that the estimated amount of mercury deposited from the atmosphere could be responsible for the total mass of mercury in fish-flesh, water, and sediment. It was also noted from this preliminary mass balance, that the amount of mercury which has accumulated in the sediment is sufficiently large, that if even a small amount were remobilized, it could account for the methylmercury held in fish-flesh.

Gill, G.A. and Bruland, K.W., 1990, Mercury speciation in surface freshwater systems in California and other areas: Environmental Science and Technology, v. 24, p. 1392-1400.

This paper reports mercury concentrations and speciation information which was determined from surface waters of selected lakes and rivers in California, as well as other areas. Sampling sites were selected to include a broad range of values for pH, alkalinity, and dissolved organic matter. The availability of historical data for mercury content of fish flesh was also considered in choosing sites for study. The authors found that the organo-mercury component can comprise the majority of dissolved mercury in many of the water bodies which were sampled and consider it their most significant result. It was conjectured that methylmercury species were the dominant organo-mercury component, although that was not determined analytically. Mercury concentrations ranged from 2.4 to 520 pM, reflecting the wide variety of environmental conditions sampled. The particulate fraction was always a significant (10 to 92 percent) part of the total mercury for a given sample. The authors note that the interaction between solution complexes of mercury (II) and organo-mercury forms are presumably, biologically mediated. They suggest that an understanding of the influence of different environments and water chemistry on the partitioning of mercury between solution complexes of mercury (II) and organo-mercury species will be necessary for an understanding of the processes that control bioaccumulation.

Glass, G.E., Sorensen, J.A., Schmidt, K.W., and Rapp, G.R., Jr., 1990, New source identification of mercury contamination in the Great Lakes: Environmental Science and Technology, v. 24, p. 1059-1069.

This study examined two Great Lakes estuaries for sources of mercury contamination and revealed high concentrations (previously unmeasured) of mercury in water, sediments, and precipitation. The study areas chosen for this investigation included the St. Louis River estuary of Minnesota (primary area) and the Fox River/Green Bay of Wisconsin (secondary area). The authors sought to identify sources and causes for continuing contamination in various water bodies associated with the Great Lakes. Analytical methods were improved, allowing identification of point and area sources of mercury contamination. The authors' data showed that 66 percent of the total mercury in the St. Louis River estuary may be attributed to discharge of the Western Lake Superior Sanitary District plant. Adjacent to the discharge from this plant, concentrations of mercury in water (364 ng/L) and sediments (1-5 micrograms per gram (ug/g)) were high. Precipitation values were also high (22 ng/L). In the case of this plant, it is noted that the incineration operation significantly increases the amount of mercury which enters the waste treatment process because stack gas scrubber water is added to wastewater inputs. The authors suggest that the potential exists for many undocumented point and area sources of mercury contamination in North America. Concern is expressed for municipal waste facilities which use incineration.

Moore, J.W., and Ramamoorthy, S., 1984, Heavy metals in natural waters: New York, Springer-Verlag Inc., 268 p.

Chapter 7 (p.125-160), entitled "Mercury", presents a review of many aspects of the element's chemistry beginning with its production and uses. Discharges of mercury into the environment from natural and anthropogenic sources are summarized. The speciation of mercury in natural waters is discussed in terms of binding to inorganic and organic ligands, as well as particulates. Sorption and desorption of mercury by sediments is considered. The methylation of mercury by biological and abiological processes is discussed since, in contaminated waters, it is noted that almost all mercury in fish is methylmercury. Mercury concentrations are presented and discussed for water, precipitation and sediment, in addition to aquatic plants, marine and freshwater invertebrates, and fish. Reservoirs (artificial water impoundments) and geological sources of mercury are discussed specifically in relation to elevated levels of mercury in fish. Toxicity is discussed for aquatic plants and invertebrates, fish and humans.

Johnson, P.G., and Villa, O., Jr., 1976, Distribution of metals in Elizabeth River sediments: U.S. Environmental Protection Agency, Technical Report No. 61, EPA 903/9-76-023, various pagings.

This study was undertaken in order to develop a metals contamination inventory for the Elizabeth River. The Elizabeth River, a tributary of the James River, located in Virginia is largely estuarine in nature and was, at the time of this report, heavily utilized in terms of waste assimilation. The three branches of the river received domestic waste from primary sewage treatment plants, toxic wastes from a variety of industrial concerns, and were plagued by frequent oil spills and waste discharges from extensive shipyard and docking facilities.

Concentrations of metals were reported for each branch of the Elizabeth River in units of milligrams/kilogram (mg/kg). The Main Branch had a low value of < 0.01 mg/kg, an average value of 0.10 mg/kg and a high value of 0.65 mg/kg. The Eastern Branch had a low of < 0.01 mg/kg, an average of 0.37 mg/kg, and a high of 2.73 mg/kg. The Western Branch had a reported low of 0.10 mg/kg, an average of 0.24 mg/kg and a high of 0.47mg/kg. Lastly, the Southern Branch had a low of < 0.01mg/kg, an average of 0.38 mg/kg and a high value of 1.49 mg/kg.

Lloyd, N.A., Chaffin, H.S., Jr., and McLendon, J.T., 1972, Mercury concentrations in sediment samples from the Tennessee, Mobile, Warrior and Tombigbee Rivers, Alabama, June 1971: Geological Survey of Alabama Circular 79, 12 p.

Elevated concentrations of mercury in fish flesh (>0.5 ppm) taken from three Alabama rivers provided the impetus for this study. Sediment samples were taken from four rivers and mercury was analyzed using atomic absorption spectrophotometry. Analytical data from the Mobile and Tombigbee Rivers were inconclusive. Sediment samples from the Warrior River were reported to contain an average mercury concentration of 0.4 ppm. Mercury was apparently uniformly distributed in these samples, which was interesting since sampling sites were immediately downstream from known sources of industrial mercury effluents. In the area of the Warrior River sampled, sandstone, shale and siltstone bedrock were veneered with sand, silt and clay. Sediment samples from the Tennessee River contained mercury concentrations ranging from 0 to 550 ppm. Maximum mercury concentrations were found 2,000 feet

downstream of an industrial effluent outlet. This was apparently controlled by river bottom geology in that the river bottom was characterized by extremely smooth rock near the outlet while an area of broken rock existed approximately 2,000 feet downstream. This area of broken rock in the river bottom seems to have trapped fine material from upstream.

Silvanima, J., 1995, Mercury data analysis:Florida Ground Water Quality Monitoring Network Newsletter, v. 3, p. 7-8.

This short note is included since it notes that all mercury data collected by the Florida Ground Water Quality Monitoring Program (1984-1994) are likely to be spurious. The mercury data presented by Upchurch, S.B. (1992) were collected as part of this program. It is suggested that samples were contaminated inadvertently during collection and analysis.

Stober, J., Jones, R.D., and Scheidt, D.J., 1995, Ultra trace level mercury in the Everglades ecosystem: Water, Air, and Soil Pollution, v. 80, p. 991-1001.

A pilot study, initiated as part of a comprehensive risk assessment of mercury contamination, examined fish, water, and sediments in the Everglades Canal System to determine the magnitude of total and methylmercury. The existence and spatial gradients in the system were determined. This study determined that north to south (high to low) gradients were apparent for total mercury and methylmercury in water. It was found that the gradients were reversed (south to north) for total mercury in sediments and fish.

Upchurch, S.B., 1992, Quality of water in Florida's aquifer system, *in* Maddox, G.L., Lloyd, J.M., Scott, T.M., Upchurch, S.B., and Copeland, R., eds., Florida's Ground Water Quality Monitoring Program Background Hydrogeochemistry: Florida Geological Survey Special Publication No. 34, p. 12-51.

This study represents a compilation of water quality data from the Background Network of the Ground Water Quality Monitoring Program for the state of Florida. The Background Network was designed to monitor general ground-water quality on a regional basis. Data reported in this study were collected from 1984-1988 for the purpose of establishing baseline values for the parameters which were measured. The maximum allowed concentration of mercury is 0.002 mg/L according to Florida Primary Drinking Water Standards

(Florida Department of Environmental Regulation, 1989). Mercury values which exceeded the standard were most common in samples from the surficial aquifer system. Three percent of the samples from the intermediate aquifer system exceeded the standard, which was considered surprising in light of the combination of reducing conditions, and clay and organic content characteristic of that aquifer system. Few samples from the Floridan aquifer system exceeded the mercury standard as was expected.

Mercury in Estuarine and Nearshore Marine Environments

Estuarine and nearshore marine environments are the subject of a number of studies concerned with mercury. Increasingly, coastal areas are considered desirable for human settlement. Development associated with this population influx generates increased waste disposal. In addition, major estuaries are frequently associated with industrialization and ship traffic, and may inadvertently produce mercury contamination. Two early studies (Andren, 1973; Andren and Harriss, 1975) included in this bibliography are mainly concerned with the geochemical behavior of mercury in estuaries associated with the Gulf of Mexico. An additional study (Huerta-Diaz, 1989) examines the mercury content of pyrite, an authigenic phase occurring naturally in anoxic marine sediments.

Several other studies focus on pollution in the estuarine environment. A short paper (Brinkman and others, 1975) examined mercury in water, plankton and sediment samples from various sites in Chesapeake Bay. The authors noted that mercury was apparently concentrated in petroleum fractions isolated from highly polluted sediments. A study directed toward elevated mercury levels in Matagorda Bay, Texas (Holmes, 1977) suggested the distribution of mercury-bearing sediments resulted from the sedimentological regime of the bay system which was produced by tidal currents in a dredged channel. An additional study (Daughdrill, 1974) examined the distribution of mercury associated with the Pearl River (Louisiana-Mississippi boundary) and its associated marsh, delta and flanking estuaries, noting that mercury was concentrated in sediments from the brackish area of the coastal region. A study of estuarine sediments in Florida proposed a method for separating contamination from natural variation for some metals (Schropp and others, 1990).

Two studies are included here which examined mercury contamination associated with industrial activities. Elevated mercury levels in fish flesh from Princess Royal Harbour, Australia prompted a study of biota and sediments (Talbot, 1990) as a basis for further management decisions. This study is interesting with respect to Florida, since the mercury discharge to the harbour area originated from a fertilizer (superphosphate) plant. Concentrations of mercury in the Louisiana "oil patch" and Timbalier Bay were examined to determine if toxic metals in the marine environment might be related to petroleum drilling and/or production activities (Montalvo and Brady, 1979).

Three studies specific to Florida round out this section of the bibliography. Fine-grained, organic-rich sediments, thought to result from regional development, have

become trapped in Manatee Pocket (part of the St. Lucie Estuary) where there are elevated levels of mercury (Trefry and others, 1992). The distribution and concentration of mercury, as well as other heavy metals, in suspended particulates and bottom sediments was examined in the area of the Upper Florida Keys, Florida Bay and Biscayne Bay in an early study which considered potential sources for the metals (Manker, 1975). Selected pesticides and trace metals, including mercury, were examined offshore of the Florida Keys (Strom and others, 1992).

Andren, A.W., 1973, The geochemistry of mercury in three estuaries from the Gulf of Mexico [Ph.D. dissert.]: Tallahassee, Florida, Florida State University, 140 p.

This study examined the distribution of mercury in three Gulf of Mexico estuaries with varying physical characteristics. The Mississippi River was sampled from Baton Rouge to the mouth of South Pass. The Mobile River and Mobile Bay estuary were sampled. Lastly, the Barron River Canal from Immokalee to, and including, Chokoloskee Bay estuary were (apparently) sampled and are referred to in this document as the "Everglades" although the study area actually consists of a portion of the Big Cypress Swamp ("apparently" is inserted here because sampling stations were omitted from the location map in the original document.) The first section of the study presents and compares geochemical budgets for the Mississippi River and Mobile Bay. The second section of the study examines the physical and geochemical factors that control the behavior of mercury in its suspended and dissolved forms. The third section treats in further detail the geochemistry of mercury in sediments.

The Mississippi River was chosen because it represents the principal sediment source for the Gulf of Mexico. This river has been the recipient for significant amounts of mercury-bearing industrial waste and is characterized by predominantly inorganic sediments. At Head of Passes the Mississippi branches into three major distributaries which include Pass a Loutre, South Pass, and Southwest Pass. In the Mississippi about 100 kg of mercury settles in these three distributaries annually, while 1.24×10^5 kg reaches the Gulf. Of the mercury reaching the Gulf, 78 percent is in suspended form and 22 percent is in dissolved form. In Mobile Bay, 4.5×10^3 kg of mercury is deposited in the estuary while 4.8×10^3 kg of mercury enters the Gulf. Mercury which enters the Gulf will exist both dissolved in the water column

(42 percent) and on suspended sediment (58 percent). The author did not calculate a mercury budget for the Everglades but utilized data from the area to illustrate that high levels of mercury can exist without apparent sources of mercury discharge in the area. The average dissolved mercury concentration for the Everglades was reported as 0.10 micrograms per liter while the average value reported for particulate mercury was 1,270 micrograms per kilogram.

The author examined various aspects of the geochemistry of mercury. Dissolved organic matter from the Mississippi and the Everglades was fractionated into different weight ranges and mercury was analyzed for each fraction. Evidence from this study suggests that mercury is strongly associated with the dissolved organic matter in the < 500 molecular weight fraction and that dissolved methylmercury is present at concentrations of < 1 ng/L if the species exists at all. Between 60 percent and 80 percent of the mercury in water was found to be associated with the particulate phase, the highest association occurred in the Mississippi River while the lowest occurred in the Everglades. The organic matter-mercury associations were observed to be of the humic and fulvic type. Measurements of mercury from interstitial waters, which were presumed to be anoxic, indicated that mercury did not become immobilized by the formation of insoluble sulfides.

Andren, A.W., and Harriss, R.C., 1975, Observations on the association between mercury and organic matter dissolved in natural waters: Geochimica et Cosmochimica Acta, v. 39, p. 1253-1257.

Dissolved mercury from estuarine waters of the Florida Everglades was found to be associated with dissolved organic matter having the properties of fulvic acids associated with soils. Water samples were analyzed by ultrafiltration and it was shown that mercury and dissolved organic carbon were selectively concentrated in the < 500 molecular size fraction. In the Everglades it was shown that dissolved organic matter of high molecular weight decreased with increasing salinity in the Everglades. It is suggested that some dissolved mercury coprecipitates with these large organic molecules providing a partial control on dissolved mercury in the Everglades.

Brinckman, F.E., Jewett, K.L., Blair, W.R., Iverson, W.P., and Huey, C., Mercury distribution in the Chesapeake Bay, 1975, *in* Krenkel, P.A., ed., Heavy Metals in the Aquatic Environment: Oxford, England, Pergamon Press, Ltd., p. 251-252.

The National Bureau of Standards examined the distribution of mercury in Chesapeake Bay as part of its program on heavy metals pollution. Water, sediment and plankton were sampled at a number of sites in the bay. The results of a preliminary survey of the sediments from the upper Bay are presented here. Concentrations were reported to vary from 0.80 ppm at Colgate Creek near Baltimore (noted at that time to be a heavily polluted area) to 0.02 ppm in the middle of the ship channel below Annapolis. Total mercury concentrations from zoo- and phytoplankton averaged 0.92 ppm for 15 stations. Total mercury concentration for unfiltered water from 17 stations was reported to average 0.24 ppb. In this preliminary paper, plankton was considered to act as an intermediate "sink" for mercury. In addition, it was noted that mercury was concentrated in petroleum residues isolated from sediment. These petroleum residues also contained elevated levels of elemental sulfur, although its effect (or lack of effect) on the sequestering of mercury had not been determined at the time of publication of this paper.

Daughdrill, W.E., 1974, Distribution and accumulation of mercury pollutants in the Pearl River, its delta and the flanking estuaries [Ph.D. dissert.]: New Orleans, Louisiana, Tulane University, 102 p.

This study covered a portion of the Pearl River (the southeastern boundary between Mississippi and Louisiana), its delta, and the marsh and estuaries which flank the delta. Mercury (as phenyl mercuric acetate) was introduced into the Pearl River from a paper manufacturing plant for approximately 25 years and this work sought to examine its fate. Large mercury concentrations were not found in the fresh water environment of the river. Sediments from the brackish area of the coastal region were documented to contain 20 times more mercury than sediments associated with fresh water portions of the Pearl River. The sediments associated with mercury concentration were described as poorly consolidated detritus, rich in fine-grained organic material. The sediments were noted to be rich in hydrogen sulfide and the precipitation of mercuric sulfide species was considered as a mechanism of mercury concentration.

Huerta-Diaz, M.A., 1989, Geochemistry of trace metals associated with sedimentary pyrite from anoxic marine environments [Ph.D dissert]: College Station, Texas A&M University, 218 p.

Sedimentary pyrite is a major authigenic mineral found in anoxic-sulfidic sediments. This work demonstrates that pyrite can act as an important sink

for a number of trace metals including mercury. Sediment cores were taken from three contrasting environments of the Gulf of Mexico region: the Fe-poor, H_2S-rich Baffin Bay (coastal Texas) coastal lagoon; the Fe-rich, H_2S-poor Mississippi-Atchafalaya delta system; and the Gulf of Mexico continental shelf and slope.

In the Baffin Bay sediments, mercury, along with several other trace metals, became enriched in the pyrite fraction. The author concluded that in anoxic-sulfidic sediments pyrite is able to act as an important sink for several trace metals including mercury. It was further suggested that under certain conditions pyrite might act as a source for those trace metals if it becomes reoxidized or weathered.

It was noted that mercury was incorporated early in the formation of the pyrite phase in the Atchafalaya Bay-Mississippi Delta sediments. In sediments where pyrite formation was low, incorporation of mercury (as well as arsenic and molybdenum) were also low. It was also suggested that since mercury (along with arsenic and molybdenum) are enriched in the pyrite fraction, reoxidation of these sediments by mechanical means such as dredging might release large amounts of these metals into the water column as pyrite becomes oxidized.

In Gulf of Mexico shelf and slope sediments, pyrite forms slowly with depth in the sediment column and oxic and anoxic-nonsulfidic zones were found to be greatly enlarged relative to those zones in Baffin Bay and in Atchafalaya Bay. Mercury (as well as arsenic and molybdenum) eventually became highly concentrated in pyrite deep in the sediment (where most pyrite was encountered).

Holmes, C.W., 1977, Effects of dredged channels on trace-metal migration in an estuary: Journal of Research of the U.S. Geological Survey, V. 5, p. 243-251.

This study was undertaken in response to a survey of 31 elements (including mercury) which showed mercury levels in the southern part of the Matagorda estuarine system to be abnormally elevated. The Matagorda system is located on the southeastern Texas Coastal Plain and is a drowned valley complex separated from the Gulf of Mexico by the Matagorda Peninsula, a postglacial barrier spit and island. High mercury levels had previously been reported in the estuarine system, but were assumed to be localized in the immediate vicinity of a chloralkali plant. Eight hundred samples of bottom sediment from Lavaca

and Matagorda Bays were analyzed for total mercury content. Values ranged from near 10 ppm to a background level of less than 0.02 ppm.

It is suggested that the distribution of mercury-rich sediments is a result of the sedimentological regime of the estuarine system which is influenced strongly by tidal currents in a dredged (13 m deep) ship channel. The author suggests a mechanism in which mercury was "precipitated" initially in a small turning basin (possibly characterized by an oxygen-poor, low-salinity water mass) prior to ship channel construction. This mercury would, subsequently, be subject to solubilization due to the influx of oxygen-rich, highly saline waters from the Gulf of Mexico via tidal currents associated with the ship channel. Assuming the oxygen-rich water mass contained significant particulate matter, solubilized mercury would be immediately sorbed onto suspended matter and transported with it. Low concentrations of dissolved mercury in the water mass support the contention that most mercury is sorbed onto suspended particles. Mercury was highly concentrated in the upper 5 to 7 cm of sediment cores, decreasing to background levels below 7 cm, suggesting that Mercury deposition is recent and postdates dredging of the channel.

Manker, J.P., 1975, Distribution and concentration of mercury, lead, cobalt, zinc, and chromium in sediments-upper Florida Keys, Florida Bay, and Biscayne Bay [Ph.D. dissert.]: Houston, Texas, Rice University, 125 p.

This study examined lead, mercury, zinc, cobalt, and chromium concentrations in a study area naturally divided by the Florida Keys. Metals were examined at sites associated with the modern reef tract, offshore of the Keys and also at sites in the lagoonal areas of Florida Bay, Barnes Sound, Card Sound, and Biscayne Bay. Metal concentrations were determined in bottom sediments, the four-micron size fraction of bottom sediments, and in suspended particulates from the study area. Highest concentrations were found in suspended sediments and in the four-micron fraction of the bottom sediments. This pattern was attributed to the greater surface area provided by finer-grained particles. It was also noted that organics associated with fine particulates allowed additional uptake of mercury.

Elevated metal concentrations in the study area were generally correlated with areas of dense population. Densely populated areas are commonly associated with high boat and automobile traffic, in addition to improperly monitored and maintained sewage disposal systems. It was noted that pollutants, including sewage and metals, introduced into the northern, more populated part of the

study area could be moved southward via longshore drift and counter-currents present at the shelf margin.

Montalvo, J.G., Jr., and Brady, D.V., 1979, Concentrations of Hg, Pb, Zn, Cd, and as in Timbalier bay and the Louisiana oil patch: *in* The Offshore Ecology Investigation: Effects of Oil Drilling and Production in a Coastal Environment, Rice University Studies, v. 65, p. 235-243.

This two year study was designed to examine the effects of petroleum drilling and production activities in Timbalier Bay and the Louisiana "oil patch". Specifically the authors were concerned with the addition of toxic metals to the water column. Samples were analyzed for mercury in addition to lead, cadmium, zinc, and arsenic. The sampling locations were designed to include areas near oil platforms. Transects were then laid out to include samples at various distances and in various directions from oil platforms, as well as locations remote to platforms. During the sampling period, mercury values ranged from <0.3 to 6.9 ug/L , with an average value of 0.6 ug/L, in bay water column samples. For the same time period, mercury in the offshore area ranged from <0.3 to 7.5 ug/L, with an average value of 0.4 ug/L. The authors drew no conclusions from their mercury data as to risk of chronic biological effects related to the presence of that metal in Gulf and Bay waters.

Schropp, S.J., Lewis, F.G., Windom, H.L., Ryan, J.D., Calder, F.D., and Burney, L.C., 1990, Interpretation of metal concentrations in estuarine sediments of Florida using aluminum as a reference element: Estuaries, v. 13, p. 227-235.

The authors devised a method for examining metal contamination in estuarine sediments using aluminum as a reference metal. Natural variability of metals in sediments was noted to be great. The variability causes problems when defining contamination. The authors analyzed data for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Mercury was found not to correlate with aluminum and was not considered further.

Strom, R.N., Braman, R.S., Jaap, W.C., Dolan, P. Donnelly, K.B., and Martin, D.F., 1992, Analysis of selected trace metals and pesticides offshore of the Florida Keys: Florida Scientist, v. 55, p. 1-13.

Levels of total mercury and other trace metals, along with selected pesticides, were examined at stations off the Florida Keys from Biscayne National Park to the Dry Tortugas. At each station producers, consumers, and bottom sediment were analyzed. Producer material included plant material, mainly *Thalassia* leaves and the upper portion of the algae, *Halimeda*. Consumers included a variety of sponges and a zoanthid. Bottom sediments consisted mainly of well sorted sand-sized fragments of coral, *Halimeda* plates and shell material. Mercury values of less than 0.1 ppm were obtained from the producer fraction. Sediments also yielded values of less than 0.1 ppm total mercury. Consumer values ranged from 0.02-0.4 ppm total mercury. The authors considered these levels of mercury to be low and attribute the low values to the inherently low concentrations of mercury in seawater and also the absence of local manufacturing activities.

Talbot, V., 1990, Mercury levels in biota and sediments of Princess Royal Harbour, Albany, Western Australia: interpretation and management implications: Journal of Coastal Research, v. 6, p. 545-557.

A fertilizer (superphosphate) plant acting as a source of mercury contamination to Princess Royal Harbour resulted in elevated mercury levels in fish-flesh and shellfish taken from the harbour. Mercury levels were shown to be generally low, but patchy, in the harbour and this study examined mercury distribution as a function of sediment type in an attempt to explain this problem. Cores were taken to examine the distribution of mercury with depth, as a function of sediment type. Analysis of core data showed that the highest mercury values occurred in surface samples regardless of area which was sampled. This was attributed to mercury binding with organic matter in surficial sediments. Slightly increased mercury levels with depth were considered a result of low Eh, due to organic buildup which caused mercury precipitation in sandy mud flats and detrital beach sediments.

Although the harbour is well flushed, low wave energy and turbulence allow abundant mercury-rich detritus to remain trapped in the area. Sandy mud flats exhibit limited mercury accumulation related to their low content of organic matter. Clean quartz-rich sands in the vicinity of the more recent outfall pipe could not sustain sea grass growth (which traps polluted organics) and were characterized by the lowest mercury levels in the area. Mercury levels in beach sediment are variable, reflecting the intermittent accumulation and rotting of large amounts of mercury-contaminated seagrass and detritus. Two seagrass meadows serve as sinks for mercury and the highest levels are found there, especially associated with finer detritus.

Trefry, J.H., Chen, N.C., Trocine, R.P., and Metz, S., 1992, Impingement of organic-rich, contaminated sediments on Manatee Pocket, Florida: Florida Scientist, v. 55, p. 160-171.

Fine grained organic-rich sediments have been trapped in Manatee Pocket (St. Lucie County), a part of the St. Lucie Estuary, located near the confluence of the estuary with the Indian River Lagoon and the Atlantic Ocean. These materials are characterized as black, fine-grained (>60 percent silt and clay-sized particles), organic-rich (>4 percent organic carbon) sediments with a water content of 75 percent by weight. These sediments (described by the authors as muck sediments) attain an average thickness of 84 cm. The authors dated sediments and calculated sediment accumulation rates using Pb-210 and Cs-137. From this work it is noted that deeper pre-1950's sediment has natural metal levels with the authors calculating that 70-85 percent of the total muck is uncontaminated. In the shallower sediments showing elevated levels of metals, the degree of contamination was found to exceed natural levels by a factor of 5-10. A single site was characterized by mercury concentrations as high as 17 ppm (at least 200 times greater than natural levels). It was suggested that the southwest prong of Manatee Pocket might represent a potential source area, given the localized nature of this elevated value.

Discussion

Mercury in the environment has both natural and anthropogenic sources. In order to arrive at a geological perspective for the occurrence of mercury in Florida, the state's tectonic and geologic settings must be considered. Florida is situated at the southeastern "corner" of the United States. Thus the state lies on a typical Atlantic-type or passive continental margin (Grow and Sheridan, 1988). This tectonic setting has important implications for the natural occurrence of mercury in the state. Most significant mercury deposits occur in tectonically active belts (Moiseyev, 1971) associated with hot springs, and volcanic and thermal activity (Jonasson and Boyle, 1972), in marked contrast to the Florida setting. Mercury deposits which lie outside of these areas are associated with zones of deep faulting and shearing (Jonasson and Boyle, 1972). While Florida's inferred Jurassic and Triassic tectonic settings (Chowns and Williams, 1983; Klitgord and others, 1984) are consistent with the potential for elevated levels of mercury, the rocks are too deeply buried to affect mercury levels in the shallow and surficial geologic environments.

Geologically, the picture is somewhat less clear cut. Two studies present analyses for mercury associated with Florida's phosphate deposits (Altschuler, 1980; Cathcart and Botinelly, 1991). In both cases the authors consider concentration values to be low. No surficial mercury-bearing ore deposits have been found in Florida (Campbell, 1986). Virtually all rocks and soils, however, contain at least a small amount of mercury. These data (Shacklette and Boerngen, 1984; Shacklette and others, 1971) are unavailable for most of Florida's soils and major rock units.

The role of organic matter in the distribution of mercury in Florida is likely to be especially complex. Peat is associated with wetlands and wetlands occur in a variety of hydrogeologic settings in Florida (Bond and others, 1986). It is well known that organic matter concentrates mercury, as well as other heavy metals. The papers presented here do not provide "bottom-line" answers with respect to the role of peatlands in the environmental cycling of mercury. Instead, the studies may be used to suggest pertinent research issues. A number of studies (not in Florida) document the concentration of mercury in deposits of peat and its geological progeny, coal (Joensuu, 1971; Casagrande and Erchull, 1976; Madsen, 1983). Peatland drainage and proposed peat mining in other areas have prompted studies which are designed to clarify the potential for mercury release in connection with these activities (Simola and Lodenius, 1982; Lodenius and others, 1983; Evans and others, 1984). A final group of studies examined various aspects of mercury systematics in modern marsh environments (Breteler, 1980; Katsaounis, 1977; Kendall, 1978). The significance of organic deposits in the cycling of mercury in Florida remains poorly understood as is

emphasized in a brief note concerning the proposed restoration of the Everglades (Culotta, 1995).

Several papers presented here focus on obtaining reliable data for mercury in pristine waters, an essential step in the understanding of contamination (Durum, and others, 1971; Fitzgerald and Watras, 1989; Gill and Bruland, 1990). Such studies are complicated by the inherent difficulty in locating potentially pristine waters and also by the extremely low concentrations of mercury in such waters. A literature study was used to infer a mercury concentration value indicative of probable contamination in a subsurface aquifer (Dooley, 1992) since available analytical techniques were inadequate to measure very small concentrations associated with pristine groundwater. Upchurch (1992) reports on mercury data collected from the Background Network of the Ground Water Quality Monitoring Program for Florida, while Silvanima (1995) reports problems with the data from that study.

The behavior of mercury in fresh water settings is of continuing significance in the effort to understand the pathway by which that element becomes concentrated in fish tissue. Certain studies of mercury in fresh water systems are initiated in response to suspected situations of point-source mercury contamination (Glass and others, 1990; Johnson and Villa, 1976). These studies, in which potential sources were identified at the outset, were generally successful in documentation of mercury contamination. The discovery of high concentrations of mercury in fish tissue motivated a study of sediment samples from four Alabama rivers (Lloyd and others, 1972). This study recovered only one sediment sample with an elevated level of mercury, suggesting possibly that additional samples were needed. Alternatively, it was noted that mercury in fish tissue might not be simply related to mercury sequestered in sediments.

Mercury concentrations in estuarine and nearshore marine environments have been examined with various objectives. The geochemical behavior of mercury in estuaries associated with the Gulf of Mexico was examined in two early studies (Andren, 1973; Andren and Harriss, 1975). A number of studies which were undertaken in response to potential sources of contamination were reviewed. In an Australian study, the contamination associated with a fertilizer (superphosphate) plant was examined within the harbour which had earlier received its discharge (Talbot, 1990). In a Louisiana study (Montalvo and Brady, 1979) mercury levels were found to be higher in the Gulf of Mexico than at sites in Timbalier Bay associated with petroleum drilling and production. It is important to note that industry is not necessarily associated with mercury contamination.

Three studies specific to Florida provide an interesting basis for further research (Trefry and others, 1992; Manker, 1975; Strom and others, 1992). Each of these investigators anticipated potential mercury contamination associated with the population growth and development that has characterized Florida over the last two decades. An early study (Manker, 1975) examined the distribution of mercury and other heavy metals in the upper Florida Keys, Florida Bay and Biscayne Bay and, predictably, found toxic metal concentrations to be related to areas of dense population and improperly monitored and maintained sewage disposal systems. A more recent study (Strom and others, 1992) in that approximate area, noted only small amounts of mercury in any sample and ascribed that finding to the generally low concentrations of mercury in seawater and also to the lack of manufacturing in the area. A study which focused on organic-rich sediments in Manatee Pocket, a part of St. Lucie Estuary, found concentrations of mercury (and other metals) associated with the upper organic-rich layers. This indicated that although sedimentation is a long-standing problem, metal contamination of the sediment is more recent (the authors estimate contamination became a problem in the 1950s) (Trefry and others, 1992).

The geological perspective of mercury's occurrence in Florida is incomplete. Mercury in the environment has both natural and anthropogenic sources. The contributions of naturally occurring earth materials cannot be adequately defined based on available data. Geological sources of mercury are probably minor given Florida's passive margin setting. Mercury analyses are, however, unavailable for most of the state's lithologic units. Organic deposits have long been known to concentrate various heavy metals, including mercury, and Florida is host to extensive wetlands, which provide the necessary (waterlogged) conditions for organic accumulation. A few fairly localized studies document the occurrence of mercury in freshwater, estuarine and nearshore marine environments and emphasize the extent to which the geologic aspects of mercury occurrence remain to be investigated. Eventually the geologic occurrence of mercury in Florida will be understood in terms of its sources, sinks and the processes by which it is transported between them.

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Appendix 1

UNITS USED IN THIS BIBLIOGRAPHY

The work of a number of authors is included in this bibliography and they report the results using various units. In order to facilitate the use of this document, a table of units with appropriate abbreviations, equivalents, and conversions is provided here.

Weight (wt)	Equivalent
kilogram (kg)	1000 grams (g)
milligram (mg)	10^{-3} gram
microgram (ug)	10^{-6} gram
nanogram (ng)	10^{-9} gram
picogram (pg)	10^{-12} gram

Units of concentration may be expressed as a weight term divided by a weight term (wt/wt) or a weight term divided by a volume term, usually the liter (L for liquids (wt/L).

Units of concentration	wt/wt	wt/L
1 part per million (ppm)	1 ug/g or 1 mg/kg	1 mg/L
1 part per billion (ppb)	1 ng/g or 1 ug/kg	1 ug/L
1 part per trillion (ppt)	1 pg/g or 1 ng/kg	1 ng/L

Molarity

Molarity (M) is defined as the number of moles of solute per liter of solution. In order to convert concentrations expressed in terms of molarity to concentrations expressed in terms of wt/v, the following relationship is provided:

(moles per liter) x (grams per mole) = (grams per liter)

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