Reports

Mineral Source and Transport in Waters of the Gulf of Mexico and Caribbean Sea

Abstract. *Mineral particles suspended in the Gulf of Mexico and Caribbean Sea were analyzed in relation to clay mineral distributions in bottom sediments, to sedimentation processes active in the region, and to the prevailing currents. Circulation in the upper layers of water flowing from the Caribbean, carrying a micaceous-rich mineral assemblage, has exercised an influence on mineral transport into the Gulf of Mexico, different from the montmorillonite-rich load delivered by the Mississippi River. Particulate matter, suspended in North Atlantic water and Amazon River discharge, enters the Caribbean through the Lesser Antilles and contributes to the detrital mineral content of Caribbean water, as does that carried by the wind.*

In previous studies of sediment in the Gulf of Mexico, montmorillonite is reported as the dominant clay deposited in the delta region of the Mississippi River (*1, 2*). Studies of delta clay mineralogy disclosed the influence of the two major source areas contributing sediment; the Missouri River carrying large amounts of montmorillonite of bentonitic origin, and the Ohio River carrying illitic and chloritic clays, with their weathered, degraded constituents forming a montmorillonitic fraction. Montmorillonite abundance (40 to 50 percent) is the highest in the areas receiving sediments directly from the Mississippi delta, especially on the abyssal plain with a slight decrease in the southern part (*3*). The distribution pattern of montmorillonite and its mixed-layer species suggests its association with Mississippi River delta sedimentation and those processes which built the Mississippi cone. Transport of sedimentary material along the sea bottom in turbidity flows has been suggested (*4*) as the cone-building mechanism. Three major rivers, the Mississippi, Mobile, and Apalachicola, supply most of the clay detritus to the northeastern Gulf (*2*) in approximately the following percentages: montmorillonite, about 60 percent; illite, 20 to 25 percent; and kaolinite and chlorite, about 15 percent. In sediment from the western Gulf of Mexico, the montmorillonite content is found (*5*) to be about twice that of chlorite and illite, which are present in about equal proportions.

The regional clay mineral distribution pattern (*3*) indicates that illite, chlorite, kaolinite, and mixed-layer minerals are generally present, although montmorillonite is the most abundant. Illite, next in relative abundance, is best developed (about 20 percent)

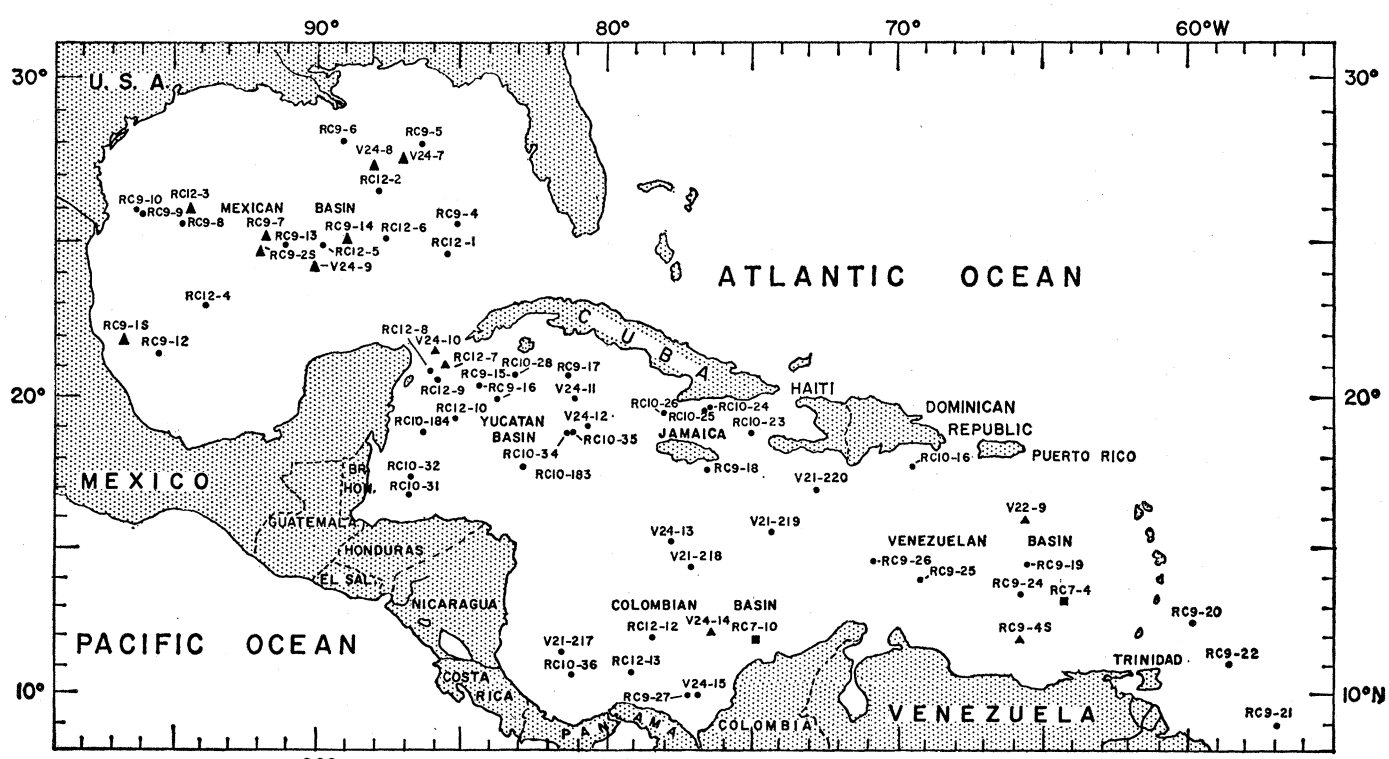
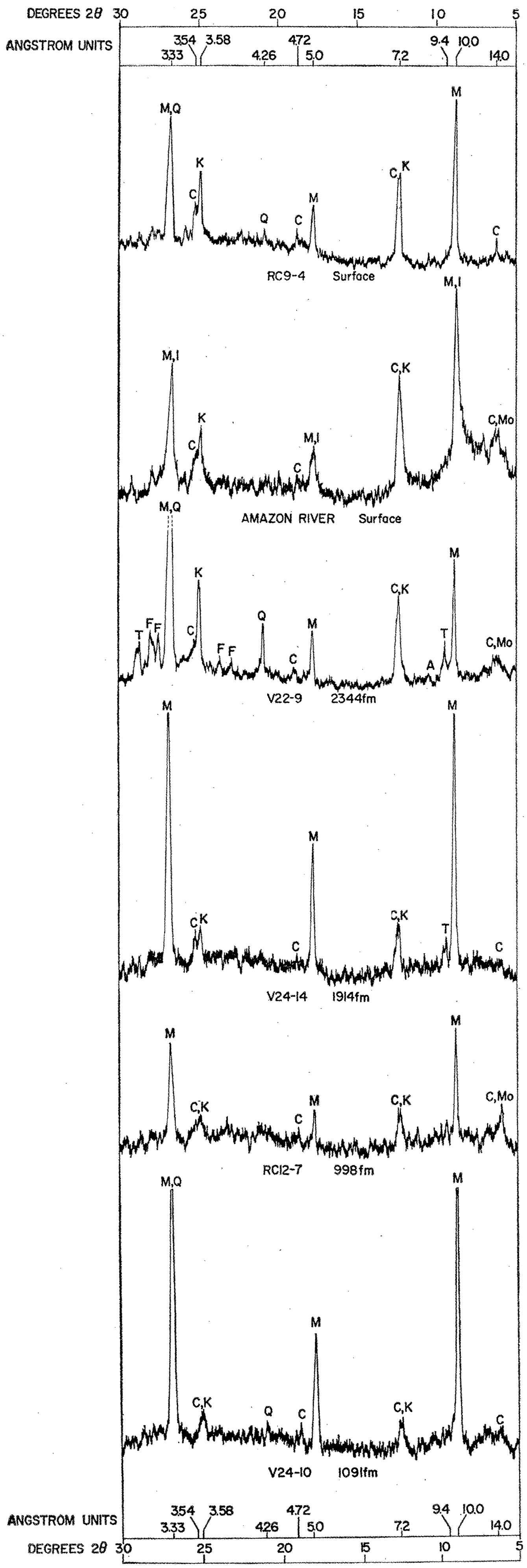


Fig. 1. Map of the Gulf of Mexico and Caribbean Sea locating positions of water samples of suspended particulate material studied for mineral content. ▲, Samples for which x-ray diffraction scans are illustrated. ■, Samples from reference (*22*).



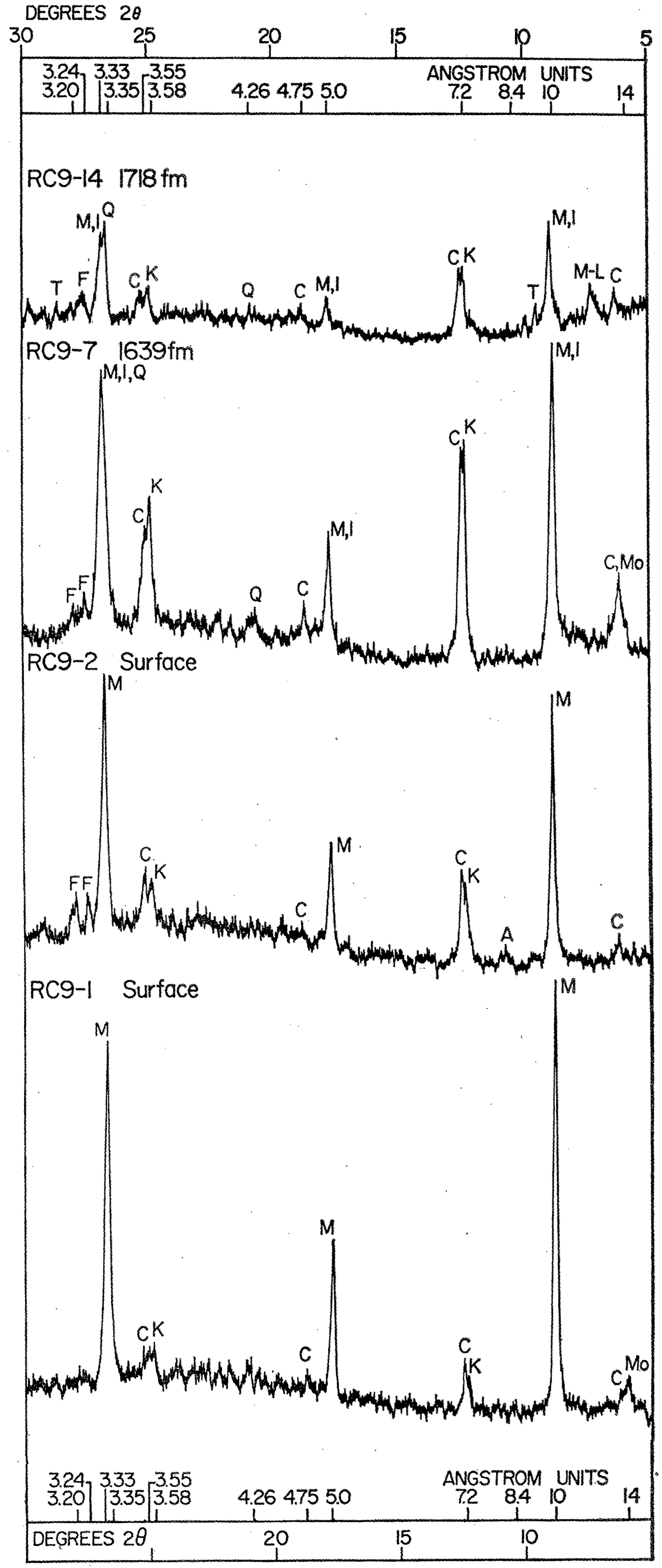


Fig. 2 (left). X-ray diffraction scans of minerals suspended in surface and deep-water samples from the Caribbean Sea and Amazon River. Samples mounted in preferred orientation. Abbreviations are: I, illite; M, mica; C, chlorite; K, kaolinite; T, talc; Mo, montmorillonite; Q, quartz; F, feldspar; A, amphibole.

Fig. 3 (above). X-ray diffraction scans of minerals suspended in surface and deep water samples of the Gulf of Mexico. Specimens mounted in preferred orientation. Abbreviations are: I, illite; M, mica; C, chlorite; K, kaolinite; T, talc; Mo, montmorillonite; M-L, mixed-layer clay; Q, quartz; F, feldspar; A, amphibole.

around the periphery of the Campeche Bank, on the continental slope, and in the Florida Straits. The continental slopes east and west of the delta and the Campeche Bank contain the most chlorite (10 to 15 percent), while kaolinite is a minor constituent (5 to 10 percent) with an overall uniform distribution. Mixed-layer material occurs in greatest abundance on the Campeche and West Florida Banks and in the Yucatan Channel and Florida Straits.

Studies undertaken on suspended mineral particles in water of the Gulf of Mexico and Caribbean Sea have indicated that mica and mica clay (illite) are generally prevalent in the water. Since predominant montmorillonite compositions have been found in the sediments of the Mexican Basin, it may be asked why micaceous minerals and not montmorillonite clays are more abundant in the water. It is unlikely that illite has remained preferentially in suspension in the Gulf, because differential settling experiments (*6*) in saline water indicate illite is one of the fastest clays to settle (15.8 m/day at 26°C) and montmorillonite is one of the slowest (1.3 m/day). Diagenetic change, with the absorption of potassium and magnesium by weathered and degraded illite and chlorites entering the marine environment (*1, 7*) may account for some portion of the micaceous material in suspension. The mineralogical data, however, prompted further study of the influences on source and transport of minerals in suspension in the Gulf. Water samples (200 liter) were collected; the suspended particulate matter was recovered on shipboard by a continuous centrifugation process. Bottom sediment was sampled from the tops of trigger weight cores taken from the same locations (Fig. 1) as the water barrels for mineralogical comparisons.

The upper waters that flow into the Caribbean Sea enter between the Lesser Antilles and are a mixture of North Atlantic and South Atlantic water. Active, wind-driven circulation characterizes the upper waters, with velocities of 40 to 50 cm/sec in the eastern Caribbean, diminishing to 30 cm/sec in central portions, and increasing to the west and in the Yucatan Straits (*8*). It takes approximately 2 to 3 months for surface waters to traverse the Caribbean (*9*). Water below a depth of 1200 m appears to be a homogeneous, sluggish-moving water mass (*8*). The topography of the Caribbean is rugged, with basins and ridges of high relief resulting in a lack of horizontal communication between most of the basins through vertical distances of 3000 to 4000 m.

The Amazon River and, to a lesser extent, the Orinoco River have far-reaching effects on the surface characteristics of the Caribbean Sea (*9*). Amazon River discharge, estimated to be 18 percent of the total drainage of all the world's rivers, causes a reduction of the surface salinity at the Amazon delta and along a pathway far into the Caribbean Sea. From surface salinity distributions (*10*), it is seen that the low salinity feature (less than 35 per mille) maintains its identity as a well-defined zonal feature to approximately 75°W in the summer and 80°W during the winter, centered along 16°N. The influence of the river water of the Amazon is observed in the western Caribbean, where the surface salinity is lowest along the main axis of the Caribbean current. During the summer and autumn months, the Orinoco River effluence lowers the surface salinity near Trinidad and contributes to the low saline band related to the Amazon.

Several distinct water masses enter the Caribbean and pass through into the Gulf. A tongue of subantarctic intermediate water, formed in the South Atlantic (48°S to 52°S) and extending along the northern coast of South America, enters the Caribbean through the Lesser Antilles passages with salinities of 34.7 per mille, or less (*10*), minimum subsurface values. Subtropical underwater with subsurface maximum salinities (*10*), probably formed in the tropical North Atlantic, can be traced through the Caribbean into the Gulf at an average depth of 150 m (*11*).

Free circulation of the upper layers of water exists through the Caribbean into the Gulf. Salinity, temperature, and oxygen content analyses indicate that circulation at this upper level in the Gulf of Mexico is sufficient to produce a major change in the western Gulf within a 1-year period (*12*). Gulf waters are replenished by the northward flow of water from the Yucatan Basin over a sill between 1650 and 1900 m in depth (*11*); according to another source, the sill lies at 2200 m (*8*). The Yucatan current turns eastward and exits the Florida Straits over a sill of 800 m depth, where it is known as the Florida Current. It is suggested (*11–14*) that the circulation in the central western Gulf may be clockwise and that it is driven in some manner by the Yucatan current.

Subtropical underwater has been recognized in the Gulf at an average depth of 150 m and with salinity of 36.75 per mille (*11*), and subantarctic intermediate water was found at 900 m in the center of the Eastern Gulf Loop with a salinity of about 34.86 per mille. The water below about 2500 m in the Gulf has approximately constant potential temperature of about 4.02°C and constant salinity of about 34.97 per mille (*14*).

The commonest plant life members suspended in ocean water, viewed under optical and electron microscopes, are diatoms, pollen, fibrous cellulose debris, and algae; skeletal remains of foraminifera and dinoflagellates and fragmented spicules are commonly occurring animal remains. Spherical bacteria with fragmented flagella also appear on electron micrographs (*15*). The petrologic components are clay minerals and other phyllosilicates, accessory detrital minerals with quartz, feldspar, and amphibole most common, and, depending on the locale, volcanic ash. Chemical treatment necessary for x-ray diffraction analysis involves removal of carbonate (*16*), organic material (*16*), and free iron oxides (*16, 17*).

There are many difficulties inherent in performing quantitative work of any degree on the particulate matter because of its nature. Small sample size, on the order of 20 mg, prohibits removal of amorphous silica and alumina components during processing and prohibits size separation of many of the samples. The amount of amorphous material present cannot be measured by x-ray diffraction because its effect on total diffraction remains an unknown from sample to sample, and such quantitative techniques that involve internal standards or binary mixtures are not feasible in the presence of undetermined amorphous components. The variability of particle size, which for most of these samples is less than 10 μ, offers additional sources of error in quantitative work because of the particle size effect on the averaging of the absorption process. For Cu$K\alpha$ radiation, the mass absorption coefficient is on the same order of magnitude for many clay minerals, quartz, and feldspars of 1-μ size (*18*). Although most of the suspended clays are of this size, the quartz and feldspars are not. Further difficulties come from the iron-containing clays, micas, and chlorites present, which have absorption coefficients of much greater magnitude. Different minerals, as well as various atomic planes within them, do not have the same ability to diffract x-rays.

The following procedure was used in order to obtain as much meaningful data of a semiquantitative nature as possible. After prior treatment, the samples were water-sedimented onto glass slides to effect preferred orientation of the layered silicate minerals. Glycolation and heat treatment were used to complete mineral identifications. Background levels were determined and integrated peak intensities were measured by means of a polar planimeter. The following "relative weights," derived from form factor functions, were considered with intensity data for mineral comparisons: four times 10 Å illite peak area for comparison to montmorillonite peak area at 17 Å (*19*); 2.5 times 10 Å illite peak area for comparison with overlapped kaolinite and chlorite 7 Å peak area (*20*). After peak intensities and their relative "weights" were considered, the following relative scale of abundance was derived: abundant: 35 to 50 percent of total; moderate, 20 to 35 percent of total; and small, 0 to 20 percent of total.

The water entering the Caribbean carries a larger concentration of illite and micaceous material relative to the other clay constituents commonly present. Micaceous and illitic members are abundant in surface and deep water in the Venezuelan Basin (Fig. 2), with a moderate portion of kaolinite, and lesser amounts of chlorite, montmorillonite, mixed-layer clay, and talc. Micaceous and illitic material continue to prevail in water sampled at various locations and depths along the westward passage through the Caribbean and over the Yucatan sill.

Percentage concentrations of 50 or greater for illite are reported (*21*) for Atlantic sediments to the east of the Lesser Antilles, and the following concentrations are reported for the eastern Caribbean sediments: illite, 50 percent;

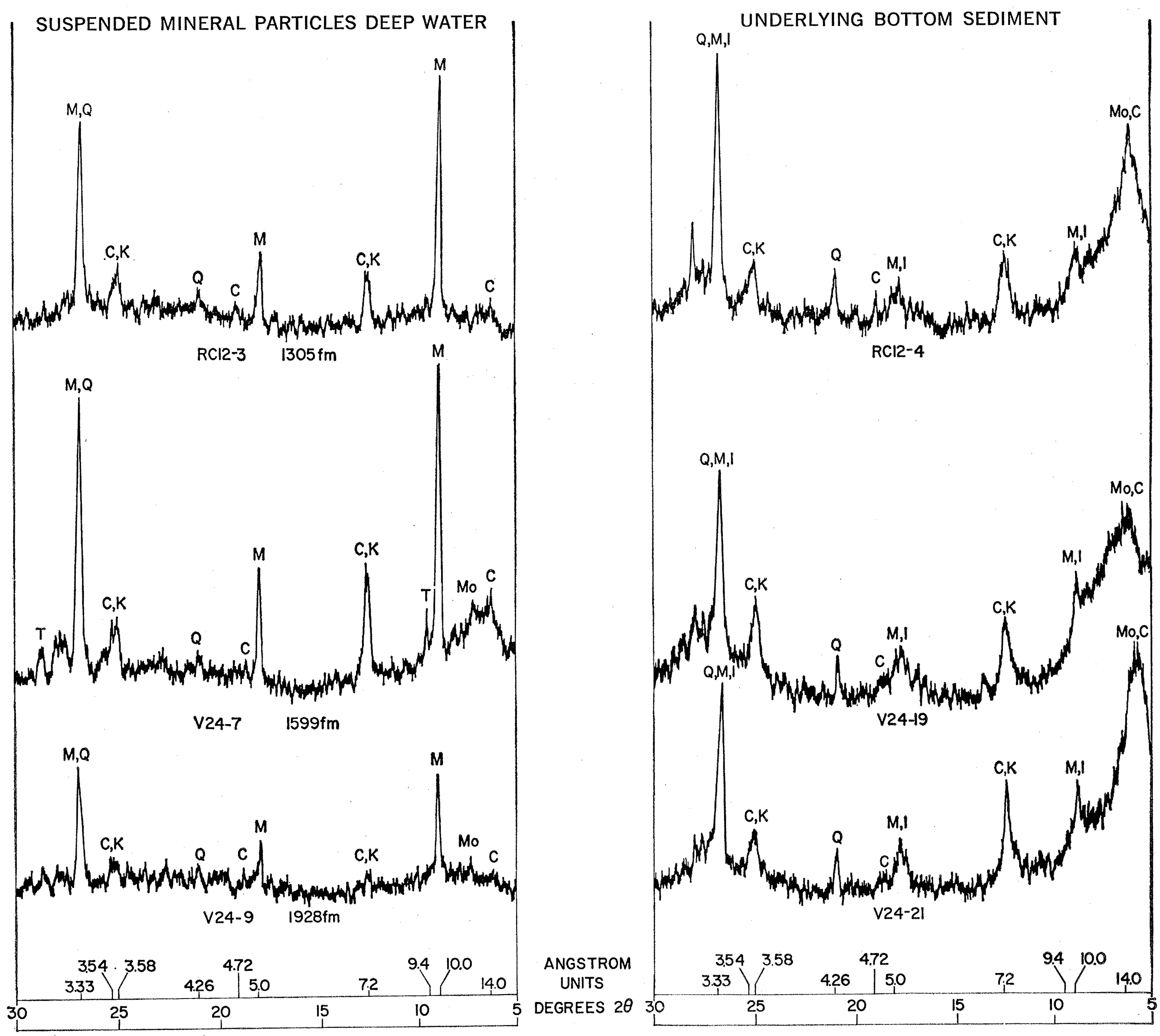


Fig. 4. X-ray diffraction scans of mineral particles suspended in deep water and of underlying bottom sediment sampled at the same location in the Gulf of Mexico. Specimens mounted in preferred orientation. Abbreviations are: I, illite; M, mica; C, chlorite; K, kaolinite; T, talc; Mo, montmorillonite; Q, quartz.

montmorillonite, 10 to 19 percent; kaolinite, 15 to 24 percent; and chlorite, 5 to 9 percent. Recent investigations of suspended minerals and bottom sediment (*22*) in the eastern Caribbean have results which are comparable to the reported distributions of illite, kaolinite, chlorite, and montmorillonite, and also note the presence of mixed-layer clay, gibbsite, feldspar, quartz, talc, and amphibole.

The influence of Amazon water in the Caribbean, previously noted by salinity measurements, is also observed by mineral particles in suspension (*23*). Quartz is the major component of the suspended load of the Amazon, with micaceous material second in abundance. Third, chlorite and kaolinite occur in approximately similar concentrations with moderately plentiful feldspars. Lesser quantities of pyroxenes, amphiboles, gibbsite, and montmorillonite are present. The fraction containing particles less than 1 μ in size (Fig. 2) contains only mica, illite, kaolinite, chlorite, and montmorillonite, and none of the detritals found in the larger grain size fractions.

Water entering the Gulf of Mexico (Fig. 3) carries abundant portions of comminuted mica and illite (mica clay), both with a first order basal reflection at 10 Å and overlapping of subsequent reflections. The very sharp peak, indicative of good crystallinity, is characteristic of mica, while the skew of the peak to the right belongs to illite. In addition to the micaceous particles, deep water from the central Gulf (Fig. 3, RC9-7 and RC9-14) carries moderate amounts of kaolinite and chlorite, and small amounts of montmorillonite and mixed-layer illite-montmorillonite. Plentiful quartz, lesser feldspar, and small amounts of amphibole and pyroxene are accessory minerals. Surface water from the central Gulf (Fig. 3, RC9-2s, particles less than 2 μ), contains abundant micaceous material, moderate amounts of kaolinite and chlorite, and no detectable montmorillonite. The silt size fraction appears similar, except for the presence of more chlorite relative to kaolinite and the presence of quartz, feldspar, and amphibole. A surface sample taken from shallow, nearshore water in the southwestern portion of the Gulf (Fig. 3, RC9-1s, particles less than 2 μ) is characterized by abundant micaceous minerals, and small amounts of kaolinite, chlorite, and montmorillonite.

The difference in mineral abundance suspended in the water and occurring in the bottom sediments is illustrated in Fig. 4. Abundant micaceous material prevails in sample V24-7 from the northeastern Gulf, and a moderate portion of montmorillonite is present, showing the influence of the nearby Mississippi River delta. Chlorite, kaolinite, quartz, and talc are also present. Montmorillonite, however, is the most abundant clay found in the bottom sediment (core V24-19) at the same location. The 10-Å material is a mixture of illite and comminuted mica, occurring in a moderate amount along with chlorite, kaolinite, and quartz. This relationship has been generally observed in the Gulf and is illustrated (Fig. 4) by water sample (RC12-3) and underlying sediment core (RC12-4) from the northwestern Gulf, and by water sample (V24-9) and sediment core (V24-21) from the central Gulf.

The mineral assemblage suspended in water of the Florida Current leaving the Gulf, consists of abundant illite, with moderate kaolinite and small amounts of chlorite and montmorillonite. Albite, potassium feldspar, amphibole, and a little talc are present, with quartz being the most abundant. The dominant clay mineral reported in the clay size fraction of bottom sediments of this region of the western Atlantic is illite (*21*), constituting greater than 50 percent.

It is suggested that circulation in the upper layers of water flowing from the Caribbean has exercised an influence on mineral transport into the Gulf of Mexico. The montmorillonite-rich sediments of the Mississippi River appear to be flocculated and deposited near the front of the delta, where slumping and turbidity flows transport them along the bottom to the central areas of the basin, leaving very little montmorillonite in suspension. Mineral analyses of suspended particulate material have revealed the waters flowing into the Caribbean to be rich with micaceous material, as are the North Atlantic water on the east side of the Lesser Antilles and the bottom sediments of the area. The influence of discharge from the Amazon River extends into the Caribbean with measurable water properties and a suspended load in which the 10-Å minerals are most abundant. Although the suspended mineral load coming in from the Caribbean probably has a dilution effect on the mineral content of the Gulf waters, not much of it actually settles there because the Florida Current material is also high in suspended material. In addition to materials carried by rivers and those transported by the Caribbean flow, wind-borne material, particularly mica and quartz, may be considered as a possible contributor to the predominance of 10-Å material observed in these surface waters.

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