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Reports

Geologic Effects of Tropical Storm Agnes on Upper Chesapeake Bay

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Introduction

Tropical Storm Agnes presented scientists with an unusual opportunity to document the impact of a major storm on Chesapeake Bay. During the four days (21 to 24 June, 1972) that the storm passed through the Chesapeake Bay region, heavy rainfall produced record or near-record discharges of many of the streams that flow into Chesapeake Bay. The record flooding resulted in an influx of fresh, sediment-laden water to the Chesapeake Bay estuarine system, which markedly affected the circulation of the Bay waters and the distributions of many of its characteristic physical, chemical and biological properties (Anderson, et al, 1973). Since floods of this magnitude have an estimated recurrence interval of about 200 years, it is interesting to see how a catastrophic event such as Tropical Storm Agnes affected the depositional processes operating in upper Chesapeake Bay (Fig. 1) and what traces, if any, of the storm will be preserved in the geologic record of the Bay.

The important geological effects of Tropical Storm Agnes on upper Chesapeake Bay were depositional and not erosional in character. Rainfall accompanying the storm fell in record amounts in Virginia, Maryland, central Pennsylvania, and New York. A considerable portion of this area forms the drainage basin of the Susquehanna River, which normally discharges more than 97% of the total fresh water and suspended sediment introduced into upper Chesapeake Bay (Schubel, 1968a). The Susquehanna is the only river that empties directly into the main body of the Bay; all the other rivers flow into estuaries formed by the drowning of the lower reaches of these rivers. Suspended material carried downstream by these rivers during Agnes was trapped in the upper reaches of their estuaries (see, for example, Nichols et al, 1974). Most of the coarse material carried by the Susquehanna was trapped in the reservoirs along the lower course of the river. Still, Schubel (1974) has determined that during the ten-day period 21 to 30 June, 1972, the Susquehanna probably discharged more than 31 $\times 10^6$ metric tons of suspended sediment into the

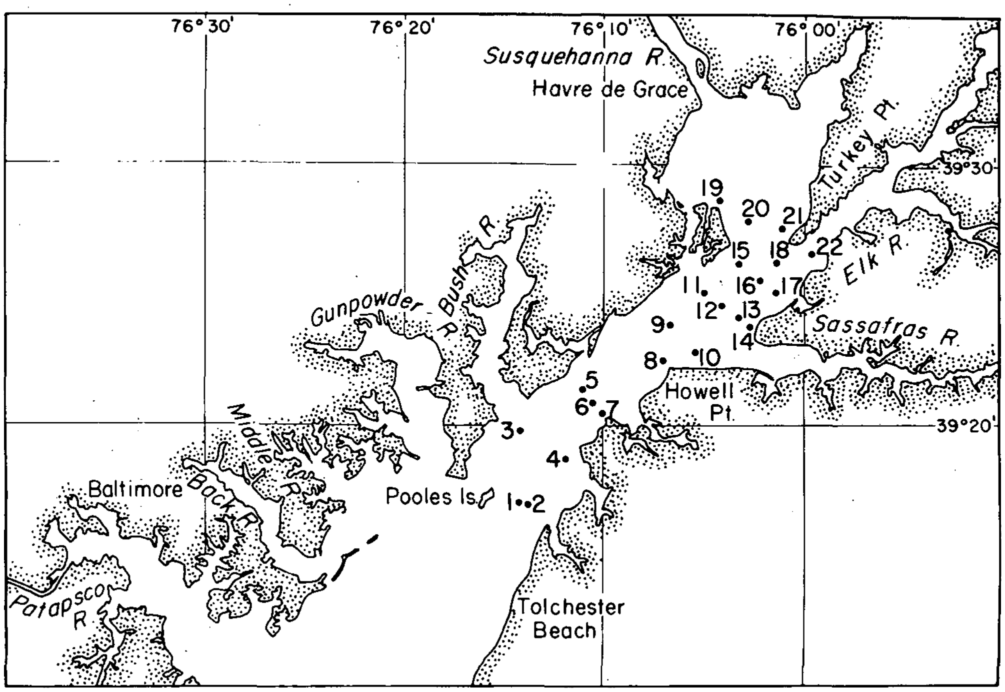


FIG. 1: Upper Chesapeake Bay. Station Location Map.

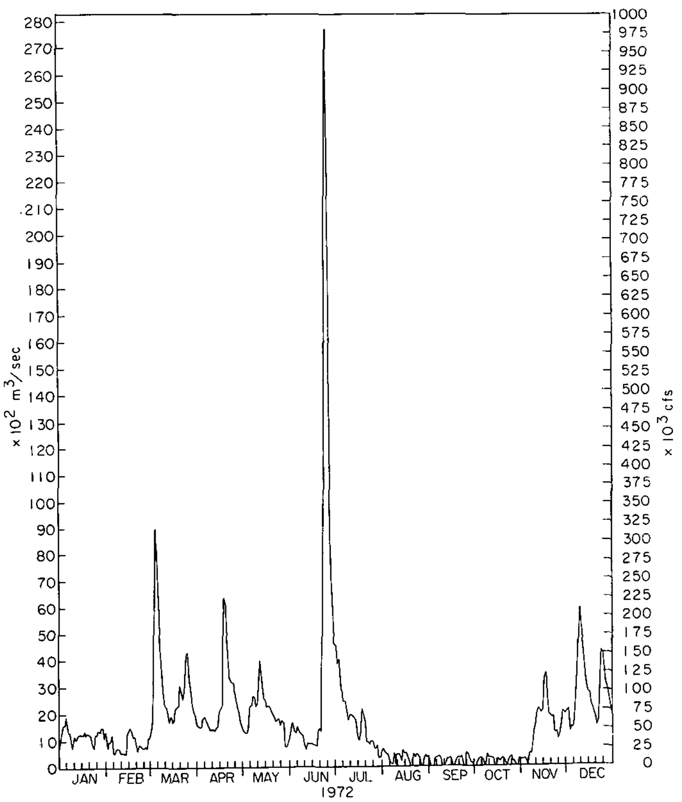


FIG. 2: Discharge of the Susquehanna River at Conowingo, Maryland, during 1972 (from Schubel, 1974).

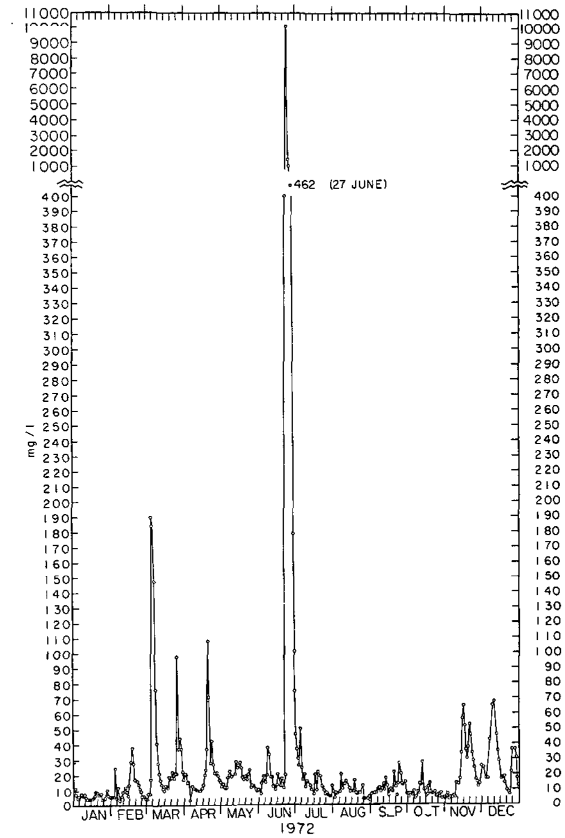


FIG. 3: Concentration of total suspended solids (mg/l) in the Susquehanna River at Conowingo, Maryland, during 1972 (from Schubel, 1974).

upper Chesapeake Bay. This figure was calculated from measurements of daily water discharge and concentration of suspended solids at the dam at Conowingo, the lowermost reservoir located about 15 km upstream from the point where the Susquehanna River empties into the Bay at Havre de Grace, Maryland (Figs. 2, 3).

By contrast, in a "normal" year, the Susquehanna discharges between 0.5 to 1.0 x 10^6 metric tons of suspended matter into upper Chesapeake Bay (Schubel, 1968a, b, 1969; Biggs, 1970). Although the amount of suspended material that was calculated to be in the Agnes runoff delivered to the Bay by the Susquehanna is between 30 and 60 times the normal yearly influx of sediment, Schubel (1974) feels the estimate of Agnes suspended sediment discharge is probably on the low side. It thus appears likely that from 21 to 30 June, 1972, more suspended sediment was discharged into the upper Chesapeake Bay by the Susquehanna River than during the previous decade, and perhaps than during the previous quarter of a century, or even longer.

Clearly, Tropical Storm Agnes constituted a major episode in the geologic history of the Chesapeake Bay, and raises a number of interesting questions. Can the layer of sediments deposited by Agnes be distinguished from older, underlying deposits? Will this layer be preserved in the geological record as a recognizable unit, or will it be obliterated by the normal physical, and particularly the biological, mixing processes? Can the Agnes sedimentary layer be used as a guide for identification of other flood deposits in the Bay's geological record?

To answer these questions, cores were taken at approximately two to three month intervals between August 1972, and June 1973 at the stations shown in Figure 1. A preliminary inspection of these data was reported by Schubel and Zabawa (1974).

Methods

Cores were taken with a Benthos gravity corer using 2 to 4-m lengths of 6.3 cm (inside diameter) x 7.0 cm (inside diameter) clear cellulose acetate butyrate (CAB) tubing. To help minimize the physical disturbance of the sedimentary layers during coring, the coring tubes were used without any external core barrel, nose cone, or core catcher. The cores were kept in a vertical position from the time they were recovered until they were analyzed. Immediately after recovery, the cores were examined visually in the coring tubes for any evidence of the interface between the Agnes and the pre-Agnes sediments. More detailed examinations were made in the laboratory of 6-cm wide x 1-cm thick x 25-cm long slices removed from the central portion of each core. Each slice was

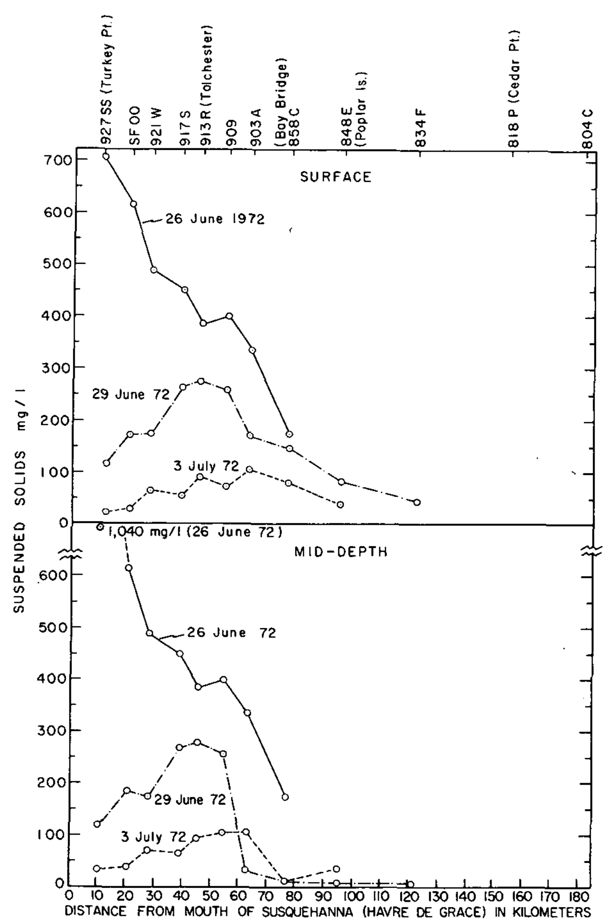
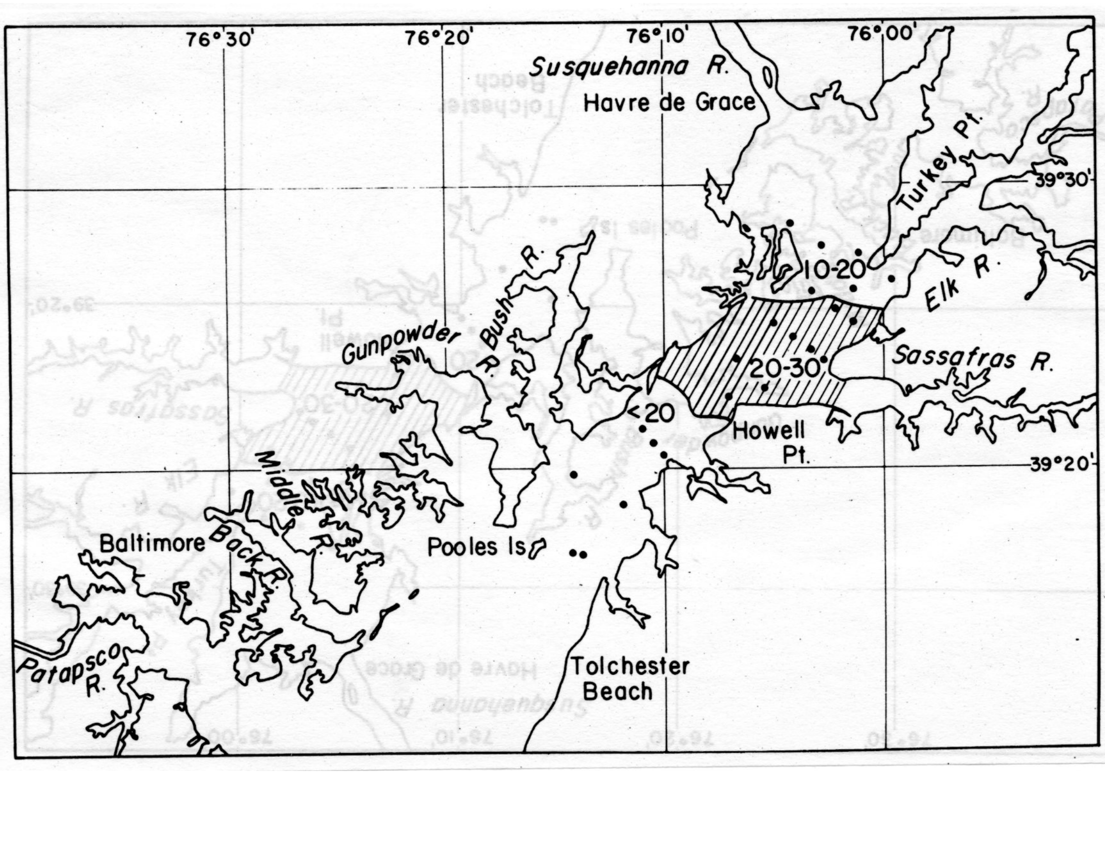


FIG. 4: Variation of surface and mid-depth concentrations of suspended sediment along the axis of the upper Bay on specific dates following Agnes (from Schubel, 1974).

FIG. 5: Map of study area showing estimated thickness of Agnes sedimentary layer. Estimates were made from X-radiographs of cores taken in August, 1972 (from Schubel and Zabawa, 1974).



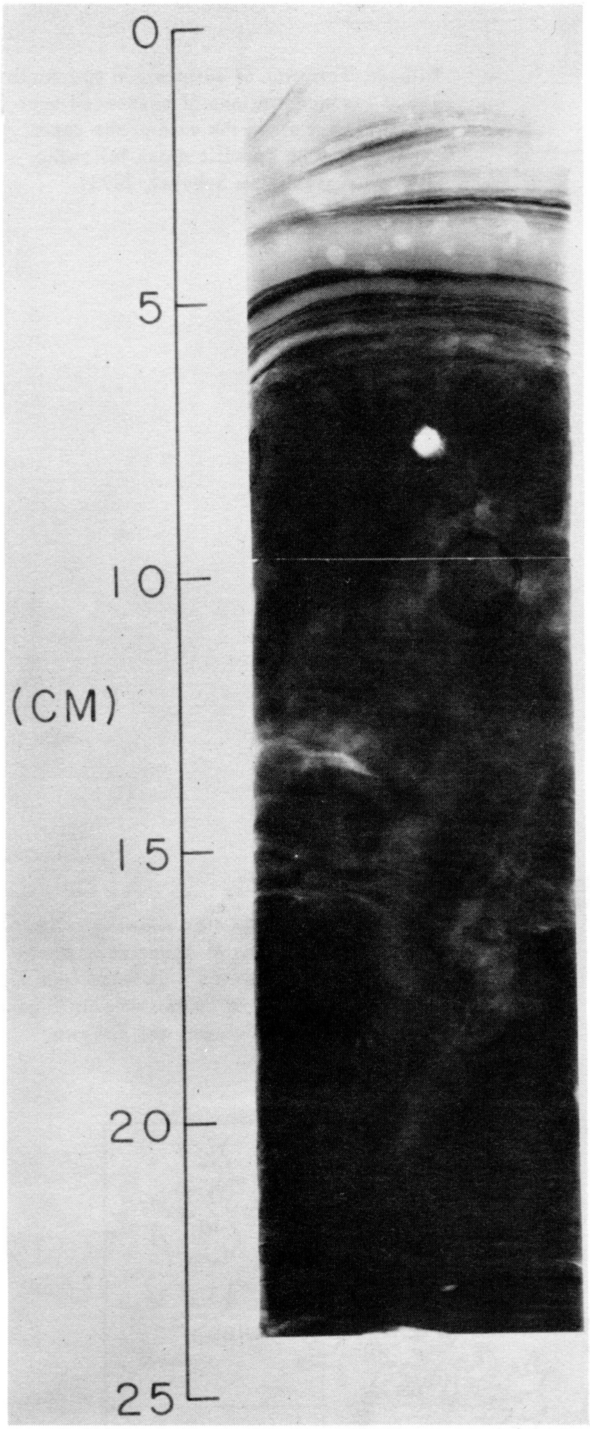


FIG. 6: X-radiograph of core taken at Station 2 in August 1972. The Agnes layer is identified as the upper 4 - 5 cm of the core.

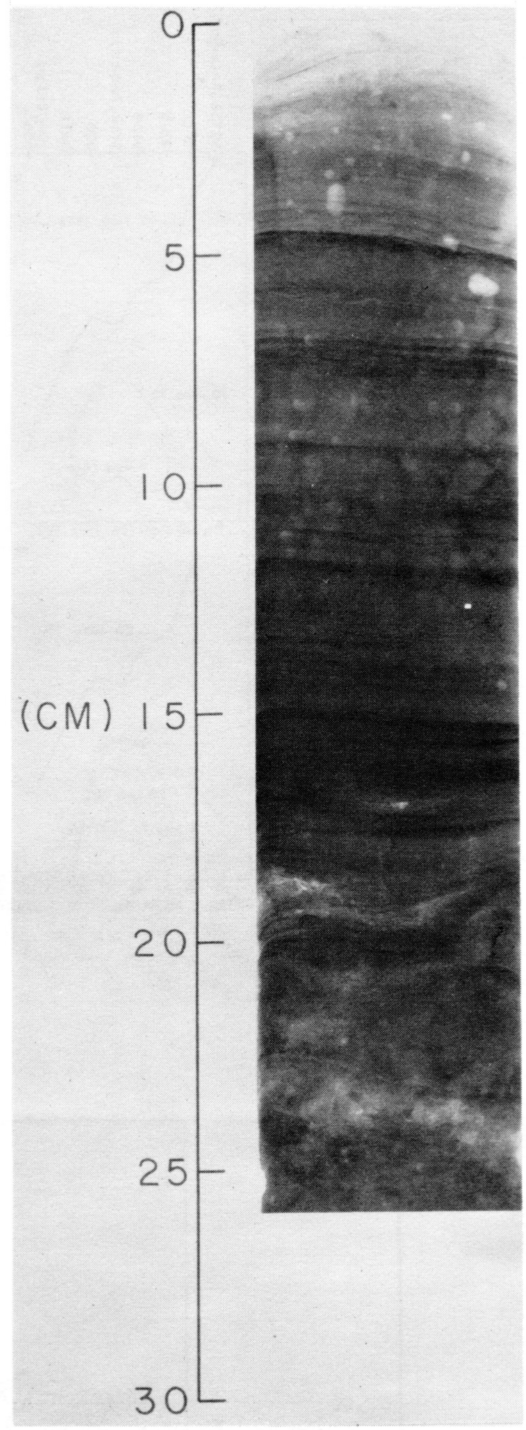


FIG. 7: X-radiograph of core taken at Station 10 in August 1972. The Agnes layer is identified as the upper 15 - 20 cm of the core, although the lower part of the layer may have been deposited during the normal spring freshet earlier in the year.

examined visually with a hand lens and with a low power microscope for color, texture, and organisms. It was then X-rayed with a hospital X-ray unit for evidence of internal sedimentary structures that might characterize the Agnes layer and help identify its lower surface. Using the X-radiograph as a guide, the core slice was carefully dissected under a microscope to attempt to relate the X-ray transmission pattern to variations in the physical character, particularly the texture, of the sediment. Samples were removed from the surface layer and from underlying layers for size and mineralogical analyses. Size analyses were made with standard pipette techniques, and mineralogical analyses with standard X-ray diffraction techniques.

Discussion

The large influxes of suspended sediment carried by the Susquehanna and other tributary rivers produced anomalously high concentrations of suspended sediment throughout much of the Chesapeake Bay estuarine system. The effects of the Susquehanna discharge on the distribution of suspended sediment were most apparent in the upper Bay, where concentrations measured were higher than any previously reported (Schubel, 1974, Fig. 4). By 29 June, 1972, concentrations of suspended sediment had decreased considerably in the upper Bay, primarily as a result of sedimentation. Most of the sediment discharged by the Susquehanna River was deposited upstream of Station 909, which is located at the southern edge of the study area (Fig. 1).

A significant, but undetermined amount of the sediment discharged by the Susquehanna past Conowingo during Agnes was deposited immediately below Havre de Grace, where the Susquehanna opens into the broad, shoal region known as the Susquehanna Flats. Approximately 4×10^2 m^2 (10 acres) of new islands and several hundred thousand square meters of new inter-tidal areas were formed as a result of Agnes. In addition, more than 38,000 m^2 of sediment had to be dredged from the section of the main shipping channel just below Havre de Grace to restore it to its original project depth, and there was appreciable shoaling in other stretches of the channel farther downstream on the Flats. The U.S. Army Corps of Engineers made several bathymetric transects of the Flats following Agnes, but the results have not yet been analyzed (J. McKay, personal communications, 1974).

South of the Flats, examination of the cores suggests that the rate of deposition of the Agnes sediment was greatest in the part of the upper Bay between Howell Point and Turkey Point (Fig. 5). This is an area where fine-grained suspended sediment, derived both from tidal resuspension of bottom materials and from fluvial sources, is concentrated by the net non-tidal estuarine circulation (Schubel, 1968a). However, during the time when the Agnes sediment was introduced into the upper Bay, conditions resembled a spring freshet, when the Susquehanna dominates the entire circulation of the upper Bay. The characteristic net non-tidal estuarine circulation was absent and the net flow was seaward at all depths. During the time of the introduction of the Agnes sediment, the tidal reaches of the River extended nearly to the Bay Bridge at Annapolis.

Unfortunately, we do not have any cores from this segment of the Bay for the months immediately preceding Agnes. Consequently, identification of the lower boundary of the Agnes sedimentary layer must be based on circumstantial evidence. For example, the Agnes layer was interpreted to be the brown layer of sediment only a few millimeters thick overlying black muds in a grab sample taken in August 1972, immediately above the Bay Bridge (40 km south of the study area).

Farther north, the most useful criterion for interpreting the Agnes layer are the small scale internal structures, both primary and secondary, as revealed by the X-radiographs of cores. In the first set of cores, taken in August 1972, the Agnes layer could be identified with some assurance at most of the stations. The layer was composed of laminated silts and clays, with minor amounts of fine sand. The sandy material is primarily quartz and detrital coal, with some pellets. The individual laminations making up the layer ranged in thickness from less than 1 cm in the south of the study area to 3 cm in thickness farther north. This layer was typically separated from the underlying, structureless, bioturbated layer by a sharp boundary.

At Station 2 located in the southern portion of the study area, X-radiographs of cores taken in August 1972, show this layer quite clearly (Fig. 6). It is 4 to 5 cm thick, and is composed of internally laminated silts and clays, overlying structureless, heavily bioturbated sediments. The overlying Agnes deposit is separated from the material below by a sharp contact that is interpreted as erosional.

At Station 10 located off Howell Point, the Agnes layer is interpreted to be 17 cm thick and is composed of internally laminated silts and clays, with some fine sand (Fig. 7). The laminations here are between 1 and 3 cm in thickness. The lower 2 to 3 cm of this layer are more thinly laminated and appear to be coarser grained; this may represent the deposit from the normal spring freshet deposited earlier in 1972. There is some evidence of erosion between this lower set of thin laminae and the upper set of thicker laminae. The entire thickness of laminated sediments is underlain by structureless, bioturbated sediments.

Using the X-radiograph as a guide, material was selected from the upper laminated layer and from the lower structureless layer in several cores. The samples were analyzed to see if any significant differences in either grain size distribution or in clay mineralogy existed between the layer interpreted to be the Agnes layer and the underlying deposits. Size analyses and X-ray diffraction studies failed to reveal any significant difference between the two. Since the dams along the lower reaches of the Susquehanna trap most of the coarse-grained sediment, it should not be surprising that the Agnes sediments differ little texturally from the sediments deposited in the Bay under normal conditions. However, prior to construction of the dams, flood deposits probably contained considerably more coarser-grained material than the normal estuarine sediments.

Because no significant differences in grain size or in mineralogy exist between sediments deposited by Tropical Storm Agnes and the underlying sediments, recognition of the storm deposit in the geologic record of the Chesapeake Bay sediments will be dependent solely on preservation of the small internal sedimentary structures in the Agnes layer. Repeated coring at the sampling stations between November 1972 and June 1973, shows the Agnes layer was slowly obliterated by the activity of burrowing organisms. By June 1973, almost no trace remained of the lamination in the layer interpreted as the Agnes deposit.

An exception to this appears to be in areas where the laminated layer is thickest, such as at Station 10. Here, the laminations appear to be largely unaffected by bioturbation before June 1973, when the coring was discontinued. An X-radiograph of a core 1.5 m long taken at Station 10 revealed two lower horizons where laminations are preserved. These laminated horizons are from 10 to 20 cm in thickness, and are separated by intervals of structureless, bioturbated sediment. X-radiographs of long cores taken at several of the other sampling stations also revealed buried horizons where bioturbation had not appreciably destroyed sedimentary structures. Our knowledge of the processes that produced these structures is not sufficient to interpret the record of past depositional events; but these intervals of interpretable record are deserving of further study.

All of the cores taken in August 1972 were examined to make an estimate of the thickness of the Agnes sedimentary deposit in the segment of the Bay from Turkey Point to Pooles Island (Fig. 1). While it was generally possible to identify the Agnes edimentary layer, one of the most striking features revealed by the X-radiographs was the extreme lateral variability in the thickness of the layer and in the internal structures, over relatively small distances in the estuary. Our best estimate of the thickness of the Agnes layer is summarized in Figure 5. This corresponds very roughly to a volume of about 30×10^6 m^3 of in-place sediment, which is equivalent to approximately 13×10^6 metric tons of dry sediment. This estimate is not discordant with the estimated input of sediment from the Susquehanna River during Agnes of 31×10^6 metric tons. This is roughly equivalent to 76×10^6 m^3 of in-place sediment, which, if spread uniformly over the segment of the Bay from Turkey Point to Tolchester, would form a deposit about 19 cm thick. Not all the sediment discharged by the Susquehanna was deposited in this segment of the Bay, of course. Significant amounts were deposited farther upstream on the Susquehanna Flats and farther downstream in the Bay.

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