Appendix C

Geologic History and Sea Level Rise

Geologic History and Sea Level Rise

Strata

The geology of Mathews County is more complex than is suggested by the geological map (Figure C-1). The topography is quite low, with only one area exceeding 70 ft in elevation (SummitPost, 2008). The oldest stratigraphic formations shown on the map are very small areas of the upper Pliocene to lower Miocene Chesapeake Group, and the upper Pliocene or lower Pleistocene Windsor Formation. These are exposed in the banks of Burke Mill Stream along the Gloucester-Mathews border. The middle Pleistocene age Shirley Formation is exposed on the surface where the elevation exceeds about 35 ft. The Shirley Formation is found in the northern portion of the county extending west along the Piankatank River from approximately Cobbs Creek and south roughly to the base of the slope that parallels route 198. The easily observable steep slope that marks the eastern limit of the Shirley Formation is the Suffolk Scarp (Hobbs, 2004, among others) (Figure C-2). This prominent feature, which marks an ancient shoreline, can be traced across much of the Coastal Plain of the mid-Atlantic as far south as Cape Lookout, N.C. The sediments of the Shirley Formation were deposited during an interglacial, high stand of sea level approximately 200,000 - 250,000 years ago.

Except for modern (Holocene age) marshes and beaches, the rest of the county's surficial geology is the upper Pleistocene Tabb Formation. In other regions, this stratigraphic unit is divided into three sub-units or members: the Sedgefield, Lynnhaven, and Poquoson, from oldest to youngest (Johnson, 1976; Johnson and Berquist, 1989; Mixon and others, 1989). In Mathews, the Sedgefield is separately mapped in a small zone south of route 198 abutting the Shirley Formation. The Sedgefield generally occurs at elevations above 20 ft. The remainder of the county is mapped as the Tabb Formation but undifferentiated as to sub-unit. The Tabb was deposited during the last major high stand of sea level that extend from approximately 75,000 to 135,000 years ago. It is likely that the differentiation amongst the three members of the formation are a result of small scale variations in sea level with peaks occurring about 80,000, about 105,000, and about 125,000 years ago (Toscano, 1992, among others).

According to the Virginia Department of Mines, Minerals and Energy (DMME) (2006), there were four active mine permits in Mathews County in 2006. One was licensed to produce sand, one to produce sand and clay, and two to produce sand and gravel; all of which were for construction aggregate and was mined from the Sedgefield member of the Tabb Formation. There are a few other inactive sand and gravel pits in the county.

Chesapeake Bay Impact Crater

The relatively simple surficial geology of Mathews masks an underlying complexity that results from the Chesapeake Bay Impact Crater (Poag and others, 1994; Poag, 1997; Powars and Bruce, 1999; Powars, 2000; Poag, 2004; among others). The Crater, the sixth-largest impact crater on the earth (Poag, 2004), was formed during the Eocene, approximately 36 million years ago when an asteroid or meteorite about 2½ miles in diameter, moving at a speed about 20 miles per second exploded above what today is Chesapeake Bay a small distance east of the present shore of Mathews. The explosion created a crater about 50 miles across (Figure C-2) and over a mile deep and disturbed the underlying basement rocks to depth of 9 miles (Poag, 2004). Although much of the crater was refilled almost instantly, it remained a significant depression in the surface of the earth.

Repeated episodes of deposition over the ensuing millions of years have covered the depression and surrounding areas, masking the surface expression of the crater. Because the area above the crater was a depression, it functioned as a collection basin so that the thickness of the younger deposits is greater over the crater than over the surrounding areas. As a result of the pressure from the overlying sediments, the original crater-fill material and the subsequently deposited strata have been compressed. This process continues today.

Because the compaction of the sediments occurs at different rates and to different levels from place to place, the strata have deformed and, in many cases, broken or faulted to accommodate the differential settlement. Recent geological mapping in the vicinity of the upper North River and Burke Mill Stream (C.R. Berquist, Jr, oral communication, 2008) has identified faulting in mid-Pleistocene strata. It should be noted that any earthquakes associated with the faulting would be very small. The few earthquakes recorded in the outer Coastal Plain of Virginia are near the crater rim (Johnson and others, 1998) where the greatest differences in compaction occurs.

Rates and Causes of Sea-level Change

The potentially ongoing compaction of the buried sediments and resultant settlement of the surface contributes to the anomalously high rate of relative sea-level rise in the lower Chesapeake Bay (Table C-1). Relative sea-level rise is change in sea level at a specific location. It is a combination of world-wide change in sea level and any local rise or fall of the land surface. The world-wide change mainly results from two factors: the addition or removal of water resulting from the shrinkage or growth of glaciers and land-based ice caps and the expansion or contraction of ocean waters resulting from a change in temperature. During the 20th century, global sea level rose at about 0.56 ft per century (1.7 mm per year)(Church and White, 2006). Mathews County's rate of sea-level rise (as shown at the Gloucester Point tide gauge) is more than double the world average rate.

Along the mid-Atlantic coast, regional subsidence coupled with compaction associated with the Chesapeake Bay Impact Crater has added to the global rise in sea level. The regional subsidence has two major causes: a broad downwarping of the outer coastal plain and continental shelf and a more localized collapse of the fore-glacial bulge. The downwarping likely results from a combination of both the very long-term transfer of sediment from the inland to the continental shelf and the water load that has been added to the continental shelf as the sea has risen since the last glacial maximum, roughly 20,000 years ago.

As the northern ice cap expanded during the late Pleistocene, the increased load on the earth's crust pressed the crust down into the plastic mantle. As the plastic material of the mantle flowed away from the pressure, it created a bulge that pushed the crust upward just beyond the edge of the ice cap. This generally is referred to as the glacial forebulge. The response is slow and lags well behind the change in load. Since the ice cap began shrinking, roughly 20,000 years ago, the load on the crust underneath it lessened and crust and mantle began returning to their earlier configuration including the relaxation or collapse of the glacial forebulge. This process continues with the result that parts of Virginia and North Carolina are sinking relative to surrounding areas.

Table C-1: Rate of sea level rise at selected sites in the mid-Atlantic. Data from NOAA (2009)

Location	mm per year	ft per century	Location	mm per year	ft per century
Atlantic City, NJ	3.99	1.31	Lewisetta, VA	4.97	1.63
Washington, DC	3.16	1.04	Gloucester Point, VA	3.81	1.25
Lewes, DE	3.20	1.05	Kiptopeke, VA	3.48	1.14
Ocean City, MD	5.48	1.67	Chesapeake Bay Bridge Tunnel, VA	6.05	1.98
Baltimore, MD	3.08	1.01	Sewells Point, VA	4.44	1.46
Annapolis, MD	3.44	1.13	Portsmouth, VA	3.76	1.23
Cambridge, MD	3.48	1.14	Beaufort, NC	2.57	0.84
Solomons Island, MD	3.41	1.12	Oregon Inlet, NC	2.82	1.93

The history of sea-level rise can help us both to interpret the present geology of the coast and to consider possible future changes. There is no history of sea-level change that is specific to Mathews County. Toscano (1992) presented a general history for the past 140 thousand years (Figure C-3). This figure depicts sea level being near the present level approximately 124,000 years ago, 103,000 years ago, and 79,000 years ago and falling to a low about 400 ft below the present about 18,000 years ago before rising to the present level. There is some controversy that in the vicinity of Chesapeake Bay the small peak about 30,000 years ago might have approached the present level of the sea (Finkelstein and Kearney, 1988; Colman and others, 1989; Toscano, 1989; Finkelstein and Kearney 1989). The low-stand at about 18,000 years ago occurred during the last glacial maximum (LGM).

The rise of sea level since the LGM is an on-going subject of study. Early interpretations suggested that sea level rose rapidly at the end of the glacial epoch until about 7,000 years ago when the rate of rise slowed and that the slow rate has continued until the present. As more information and better techniques have become available, the picture has become more complex. The information includes both measurements at specific sites and an enhanced knowledge of the events of the retreat of the ice caps. The local influences of subsidence or uplift of the land itself have to be considered in the discussion.

Liu and others (2004) determined a sea-level curve for the western pacific ocean (Figure C-4). Although their study was on the other side of the world from Chesapeake Bay, the major aspects of their curve likely apply world round. Their work depicts a steeply stepped history of sea-level change beginning about 19,000 years ago at the end of the LGM and continuing until about 7,000 years ago. The sudden, rapid rises of sea level most likely occurred as a result of collapse of major ice sheets and the release of immense quantities of melt water to the world ocean as ice dams containing huge glacial lakes failed (Blanchon and Shaw, 1995; Shaw, 2002). The Melt Water Pulses (MWPs) caused sea level to rise so rapidly that some of the scientific literature refers to "catastrophic rise events"(CREs). As an example, during MWP-1C (Figure C-4), between approximately 9,300 and 9,000 years ago, sea level rose about 50 ft or about 1 ft every 6 years.

The catastrophic rise events (Blanchon and Shaw, 1995) provide an edge to concerns about contemporary sea-level rise. As noted elsewhere, sea level is rising world-wide, especially so in the mid-Atlantic coast of the United States. There is ongoing debate about the rates of sea-level change for the next century or more (IPCC, 2007), however the possibility of a CRE generally is not considered. Blanchon and Shaw (1995), however, noted that the both the collapse of either or both of the Greenland and Antarctic ice sheets should be considered. They stated the "collapse of the West Antarctic ice sheet is a distinct possibility" and "the potential for future catastrophic sea-level rise also exists." Recent estimates indicate that the maximum rise in sea level from the total melting of the West Antarctic ice sheet would be slightly over 26 ft and total melting of the Greenland ice cover would yield over 21 ft (USGS, 2000, siting Williams and Hall, 1993).

Bratton and others (2003) determined that saline waters entered what today is Chesapeake Bay between 8,200 and 7,400 years ago as the sea rose above a level about 60 ft below the present. Prior to this time, Chesapeake Bay would have been a portion of the Susquehanna River system protected from the intrusion of salt water by large bars near its mouth somewhere on the continental shelf. Cronin and others (2007) provided further information about ancient sea levels in Chesapeake Bay and intervals of exceptionally rapid sea-level rise.

A question about the history of sea-level change through the most recent several thousand years is whether or not it ever exceeded the present level. There is a growing body of evidence that sea level have been as much as about 10 ft above the present level at least once during the past 6,000 years (Scott and Collins, 1996; Morton and others, 2000; Blum and others, 2001; among others); however, studies specific to the lower Chesapeake Bay region with its history of the collapsing glacial forebulge and subsidence associated with the crater are distinctly lacking. Newman and Munsart (1968) suggested that Italian Ridge on Parramore Island along the Eastern Shore may have formed during a high stand about 5,100 years ago, but this has not been universally accepted in the literature. Some of the geomorphology of the Eastern Shore barrier islands is highly suggestive that relative sea level was slightly above the present perhaps five millennia ago; however there is no specific evidence in the immediate vicinity of Mathews County.

References Cited

Blanchon, P. and J. Shaw, 1995. Reef drowning during the last deglaciation: Evidence for catastrophic sea-level rise and ice-sheet collapse. Geology, 23(1): 4-8.

Blum, M.D., Misner, T.J., Collins, E.S., Scott, D.B., Morton, R.A., and Aslan, A. 2001. Middle Holocene sea-level rise and highstand at +2 m, central Texas coast. Journal of Sedimentary Research, 71: 581-588.

Bratton, J.F., S.M. Colman, E.R. Thieler, andR.R. Seal, II, 2003. Birth of the modern Chesapeake Bay estuary between 7.4 and 8.2 ka and implications for global sea-level rise. Geo-Marine Letters, 22: 188-197.

Church, J.A. and N.J. white, 2006. A 20th century acceleration in global sea-level rise. Geophysical Research Letters, 33, LO1602, 4p.

Colman, S.M., R.B. Mixon, M. Rubin, A.L. Bloom, and G.H. Johnson, 1989. Comment on "Late Pleistocene barrier-island sequence along the southern Delmarva Peninsula: Implications for middle Wisconsin sea levels." Geology. 17(1): 84-85.

Cronin, T.M., P.R. Vogt, D.A. Willard, R. Thunell, J. Halka, and M. Berke, 2007. Rapid sea level rise and ice sheet response to 8,200-year climate event. Geophysical Research Letters, 34, L20603, doi:10:1029/2007GL030318, 6p.

Finkelstein, K. and M.S. Kearney, 1988. Late Pleistocene barrier-island sequence along the southern Delmarva Peninsula: Implications for middle Wisconsin sea levels. Geology, 16(1): 41-45.

Finkelstein, K. and M.S. Kearney, 1989. Reply to Comments on "Late Pleistocene barrier-island sequence along the southern Delmarva Peninsula: Implications for middle Wisconsin sea levels." Geology, 17(1): 86-88.

FitzGerald, D.M., M.S. Fenster, B.A. Argow, and I.V. Buynevich, 2008. Coastal impacts due to sea-level rise. Annual Review of Earth and Planetary Sciences, 36: 601-647.

Hobbs, C.H., III, 2004. Geological history of Chesapeake Bay, USA. Quaternary Science Reviews, 23: 641-661.

Horton, J.W., Jr., D.S. Powars, and G.S. Gohn, 2005. Studies of the Chesapeake Bay Impact – Introduction and Discussion. Chapter A of Horton, J.W., Jr., D.S. Powars, and G.S. Gohn (eds.) Structure Studies of the Chesapeake Bay Impact Structure – NASA Langley Corehole, Hampton, Virginia, and Related Coreholes and Geophysical Surveys. U.S. Geological Survey Professional Paper 1688.

IPCC, 2007. Climate change 2007: the physical science basis, summary for policy makers. Contribution of the Working Group I Fourth Assessment Report, Intergovernmental Panel on Climate Change, Cambridge, UK (cited in FitzGerald and others 2008)

Johnson, G.H., 1976. Geology of the Mulberry Island, Newport News North, and Hampton Quadrangles, Virginia. Report of Investigations 41, Virginia Division of Mineral Resources, 72p.

Johnson, G.H. and C.R. Berquist, Jr., 1989. Geology and mineral resources of the Brandon and Norge Quadrangles, Virginia. Publication 87, Virginia Division of Mineral Resources, 28p.

Johnson, G.H., S.E. Kruse, A.W. Vaughn, C.H. Hobbs, III, and D.S. Powars, 1998. Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern, Virginia. Geology, 26(6): 507-510.

Kaye, C.A. and E.S. Barghoorn, 1964. Late Quaternary sea-level change and crustal rise at Boston, Massachusetts, with notes on the autocompaction of peat. Geological society of America Bulletin, 75: 63-80.

Liu, J.P., J.D. Milliman, S. Gao, and P. Cheng, 2004. Holocene development of the Yellow River's subaqueous delta, North Yellow Sea..

Mixon, R.B., C.R. Berquist, Jr., W.L. Newell, G.H. Johnson, D.S. Powars, J.S. Shindler, and E.K. Rader, 1989. Geologic map and generalized cross sections of the Coastal Plain and adjacent parts of the Piedmont, Virginia. U.S. Geological Survey Miscellaneous Investigations Series, Map I-2033.

Morton, R.A., Paine, J.G., and Blum, M.D. 2000. Responses of stable bay-margin and barrier-island systems to Holocene sea-level highstands, Western Gulf of Mexico. Journal of Sedimentary Research, 70: 478-490.

Newman, W.S. and C.A. Munsart, 1968. Holocene geology of the Wachapreague Lagoon, Eastern Shore peninsula, Birginia. Marine Geology, 6: 81-105.

NOAA, 2009. Tides and Currents, Sea Level Trends (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml) (accessed January 8, 2009)

Pilkey, O.H. 2003, A Celebration of the World's Barrier Islands. Columbia University Press, 309p

Pizutto, J.E. and A.E. Schwendt, 1997. Mathematical modeling of autocompaction of a Holocene transgressive valley-fill deposit, Wolfe Glade, Delaware. Geology, 25(1): 57-60.

Poag, C.W., 1997. The Chesapeake Bay bolide impact – a convulsive event in Atlantic Coastal Plain evolution. In Segall, M.P., Colquhoun, D.J., and Siron, D. (eds.), Evolution of the Atlantic Coastal Plain – Sedimentology, Stratigraphy, and Hydrology. Sedimentary Geology, 108:49-50.

Poag, C.W., 2004. Coring the Chesapeake Bay Impact Crater. Geotimes, January. 6p. http://www.geotimes.org/jan04/feature_Chesapeake.html (accessed January 7, 2009)

Poag, C.W., Powars, D.S., Poppe, L.J., and Mixon, R.B., 1994. Meteoroid mayhem in Ole Virginny: source of the North American tektite strewn field. Geology, 22(8):691-694.

Powars, D.S., 2000. The Effects of the Chesapeake Bay Impact Crater on the Geologic Framework and Correlation of Hydrogeologic Units of Southeastern Virginia, South of the James River. U.S. Geological Survey Professional Paper 1622, 53p.

Powars, D.S. and Bruce, T.S., 1999. The Effects of the Chesapeake Bay Impact Crater on Geologic Framework and Correlation of Hydrogeologic Units of the Lower York-James Peninsula, Virginia. U.S. Geological Survey Professional Paper 1612, 82p.

Reed, D.J., D.A. Bishara, D.R. Cahoon, J.donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson, 20006. Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region. Report to Climate Change Division, U.S. Environmental Protection Agency, EPO5W003217, 49p.

Shaw, J., 2002. The meltwater hypothesis for subglacial bedforms. Quaternary International, 90: 5-22.

Scott, D.B. and E.S. Collins, 1996. Late mid-Holocene sea-level oscillation: a possible cause. Quaternary Science Reviews, 15: 851-856.

Summit Post, 2008. The highpoints of Virginia. http://www.summitpost.org/list/223516/ virginia-county-city-highpoints.html (accessed January 6, 2009)

Toscano, M.M, 1989. Comment on "Late Pleistocene barrier-island sequence along the southern Delmarva Peninsula: Implications for middle Wisconsin sea levels." Geology. 17(1): 85-86.

Toscano, M.A., 1992. Record of oxygen-isotope stage 5 on the Maryland inner shelf and Atlantic Coastal Plain – Post-transgressive-highstand regime. In Fletcher, C.H., III, and J. F. Wehmiller (eds.), Quaternary Coasts of the United States: Marine and Lacustrine Systems, SEPM Special Publication No. 48. p89-99.

USGS, 2000. Sea Level and Climate Change. USGS Fact Sheet 002-00. U.S. Geological Survey. http://pubs.usgs.gov/fs/fs2-00/ (accessed January 27, 2009)

Virginia Department of Mines, Minerals and Energy, 2007. Mineral Resources and Industries in Mathews County. http://www.dmme.virginia.gov/DMR3/mathews.shtml (accessed January 7, 2009)

Williams, R.S. an D.K. Hall, 1993. Glaciers, in Chapter on the cryo-sphere, in Gurney, R.J., J.L. Foster, nd C.L. Parkinson (eds.) Atlas of Earth observations related to global change. Cambridge University Press, p./401-422. (cited in USGS, 2000)

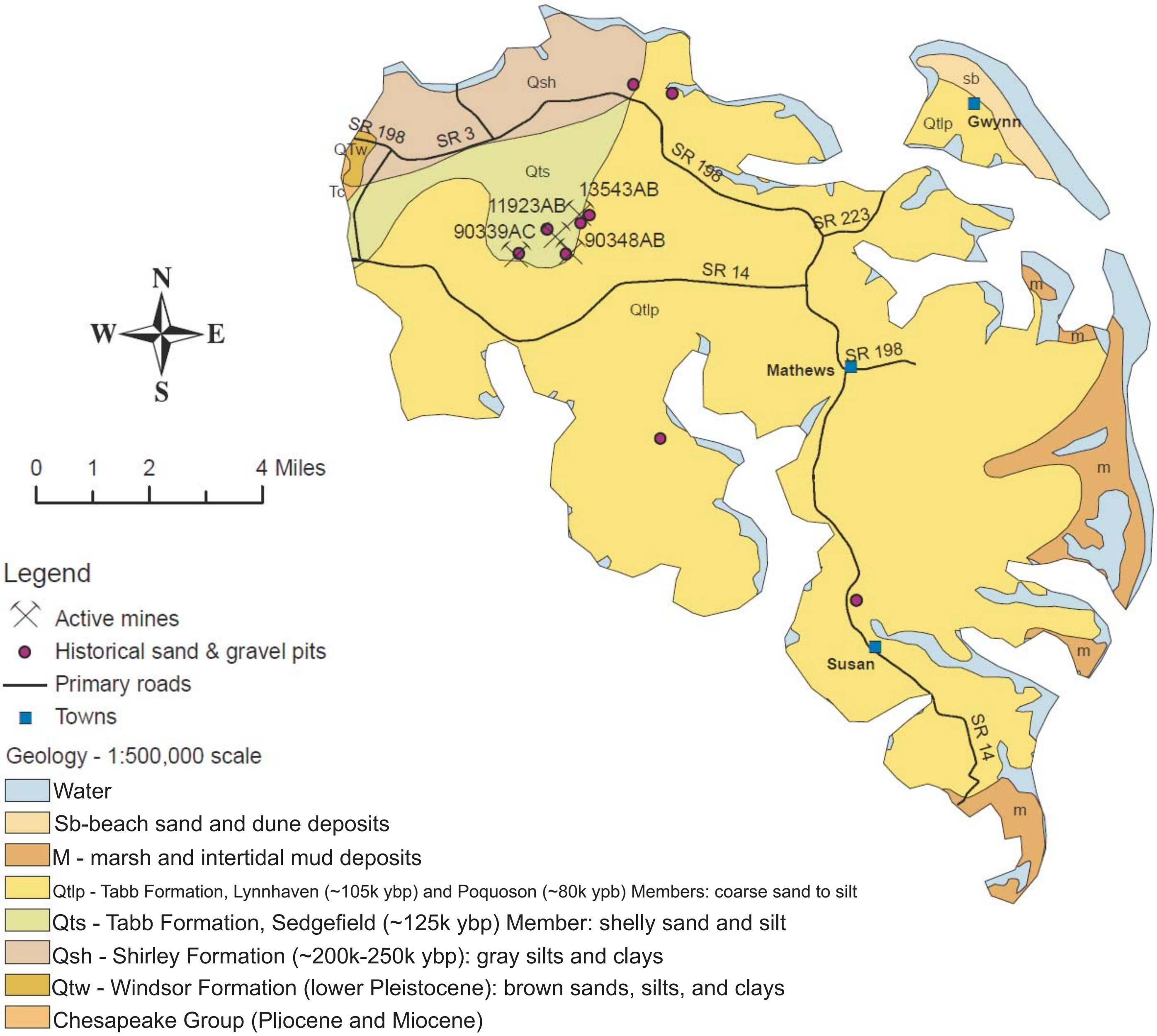

Figure C-1. Geologic map of Mathews County, Virginia. Modified from Virginia Department of Mines, Minerals and Energy, 2007.

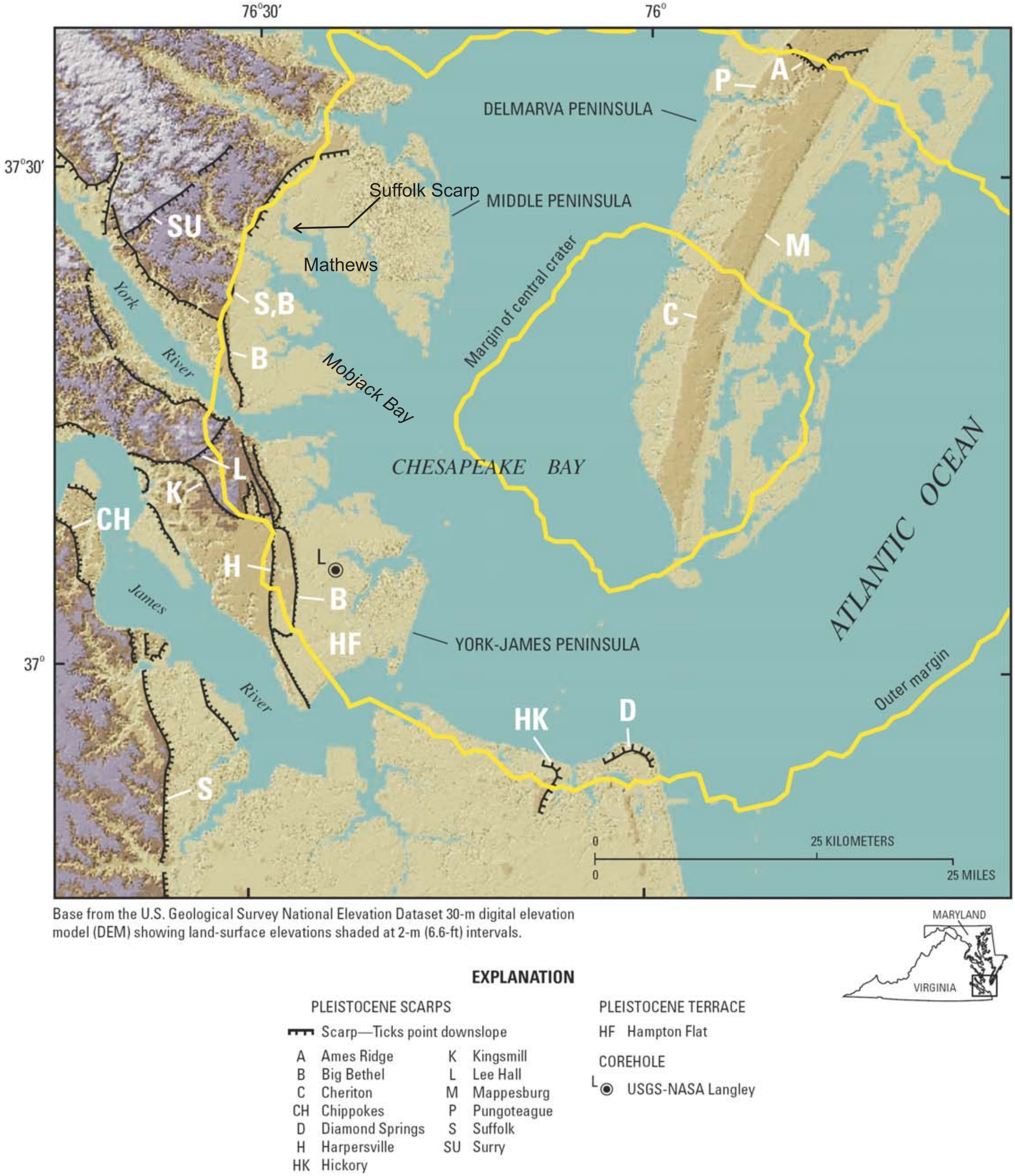

Figure C-2: Map depicting the extent of the Chesapeake Bay Impact Crater and indicating the location of several Pleistocene scarps and terraces. (From Horton *et al*., 2005.

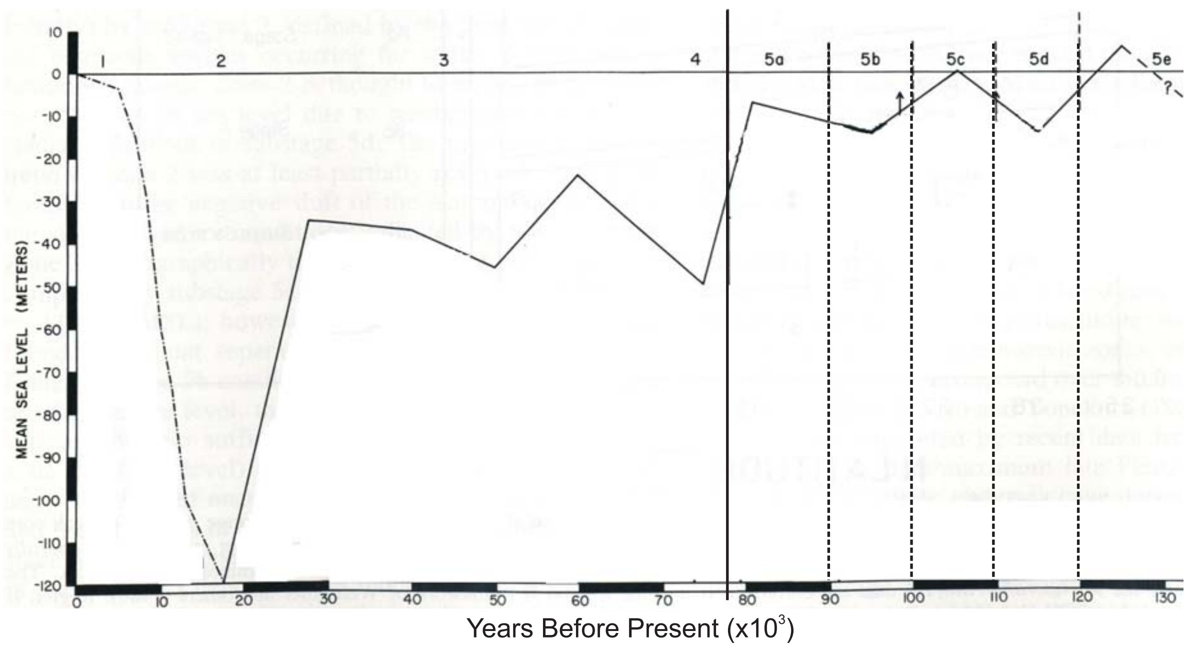

Figure C-3: A graph of sea level for the past 140 thousand years. The numbers across the top refer to the Oxygen Isotope Stage; even numbered stages are “ice ages” when sea level falls and odd numbered stages are “interglacial times” when sea level rises. Modified from Toscano, 1992.

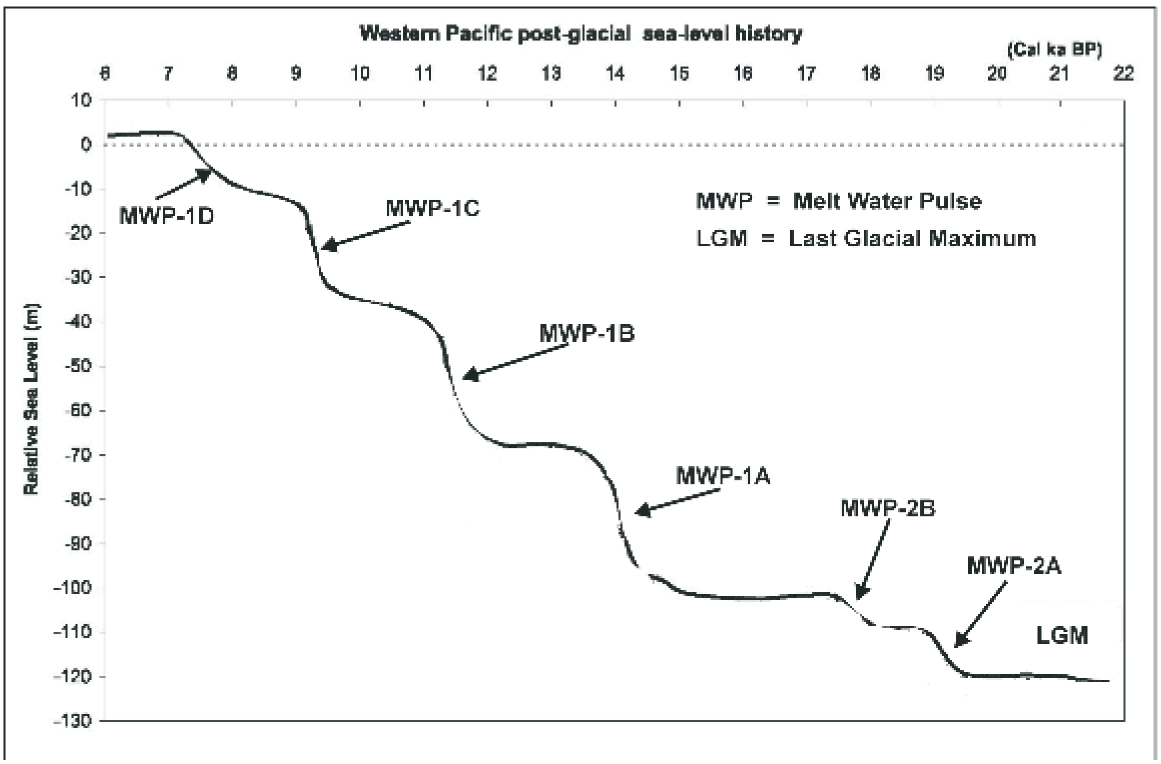

Figure C-4. Graph of sea-level change between 6 thousand and 22 thousand years ago in the western Pacific. Modified from Liu *et al.* (2004).