### ORIGIN OF THE ROCKS AT BISHOP AND CLERKS SHOAL AND COLLIER LEDGE, NANTUCKET SOUND, MASSACHUSETTS

### FIELD REPORT

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### **EXECUTIVE SUMMARY**

The Office of the Massachusetts State Geologist was asked to make a determination of the origin of the rocks at the Bishop and Clerks Shoal and Collier Ledge in Nantucket Sound, Massachusetts. The objective was to determine if the rocks at these two locations were natural features deposited by the glaciers or carried by barge and deposited by man. A field visit was conducted on September 15, 2004. The following summarizes the findings and conclusions.

**Bishop and Clerks Rocks**: The rocks located in the vicinity of the red and white beacon, formerly known as the Bishop and Clerks lighthouse site, and defined by the triangle marked by red nun #4, green bell #1 and red gong #2 on NOAA nautical chart number 13237 are natural rock features deposited by the late Wisconsinan ice sheet approximately 14,000 years ago. These rocks, commonly known as glacial boulders or erratics, were carried to this location by ice from unknown locations to the north and deposited in contact with the ice margin. The boulders were deposited and partially buried in a sand matrix. As sea level rose to present conditions after ice retreat, currents redistributed the sand leaving the boulders behind and causing a navigational hazard to shipping. The boulders are much larger than those used in construction of shore protection structures (breakwaters, rip rap, revetments, etc.), the composition of some of the boulders is similar to those found in ice contact deposits on the mainland, the distribution of the boulders is random rather than organized, and the composition of most of the boulders is different from the composition of the stone used in the construction of the former Bishop and Clerks lighthouse that was demolished in 1958.

**Collier Ledge**: Collier Ledge is a manmade feature. The rocks at Collier Ledge are small, generally less than 1.5 meters in maximum dimension, some are dimensioned indicating that they were cut for building purposes, and the composition of these rocks is very similar to the composition of the dimension stone used in the construction of the former Bishop and Clerks lighthouse. In addition, the rocks are congregated in one large pile with random orientations suggesting the material was dumped as waste.

### **INTRODUCTION**

The Massachusetts Highway Department (MHD) and the U.S. Department of Interior Minerals Management Service (MMS) asked the Office of the Massachusetts State Geologist (OSG) to determine the origin of the rocks at the Bishop and Clerks Shoal and Collier Ledge in Nantucket Sound, Massachusetts (Figure 1). Specifically, the OSG was asked to determine if the rocks at these sites were natural features or brought there by barge and deposited. A field visit to the site was made on September 15, 2004 with personnel from MHD and MMS. Samples of individual boulders and rocks from both sites were acquired and brought back to the University of Massachusetts for hand specimen identification. A photo-journal documenting each sample and the location of each sampling site is provided in Appendix A. Descriptions of the rock samples are provided in Appendix B. The following report summarizes the results of this investigation.



Figure 1. Map showing the location of Bishop and Clerks Shoal and Collier Ledge, Nantucket Sound, Massachusetts with respect to Point Gammon on Great Island and the mainland (from NOAA Nautical Chart 13237).

#### Study Area

Bishop and Clerks shoal is located 2.6 miles south southeast of Gammon Point on Great Island in West Yarmouth, Massachusetts (Figure 2). The shoal consists of a south-southeast trending elongate shallow area with depths ranging from 2 to 6 feet. Randomly dispersed throughout the

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Figure 2. Close-up view of Bishop and Clerks Shoal. The asterisks indicate halftide rocks exposed at low tide; plus symbol indicates rocks submerged just below surface at low tide. Green circle marks the location of the former Bishop and Clerks Lighthouse (from NOAA Nautical Chart 13237).

shallows are 5 to 6 half tide rocks (rocks exposed during normal low tides) and 3 to 4 submerged rocks (rocks not exposed at low tide but which lie just submerged below the surface) (Figure 3). There may be other rocks but they were not observed during the September 2004 field visit. The shoal is marked by four navigational aids on NOAA nautical chart 13237. These include the red

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Figure 3. View of the boulders at Bishop and Clerks Shoal. These boulders are 545 to 587 feet south southeast of the former Bishop and Clerks lighthouse site (see Figure 2). S-8, S-9 and S-10 represent locations where rock samples were acquired. S-7 was visited but a sample could not be obtained at this site. Note the conical shape on S-8 and pyramidal shape on S-10. Top width of Boulder S-10 is 4 meters (photo by Bob Johnson, 2004).

and white beacon at the former site of the Bishop and Clerks lighthouse, which marks the north end of the shoal, red nun #4 to the west, green bell #1 to the east and red gong #2 marking the south end of the shoal (Figure 2). The OSG was asked to determine if these boulders are natural.

Collier Ledge is located approximately 2 miles southeast of Osterville Point (Figure 4). It consists of a pile of rocks, which when exposed at low tide covers an area of approximately 6 to 8 meters by 4 meters (Figure 5). It lies in approximately 10 to 13 feet of water (low tide measurement). It is marked on the south side by a red and green obstruction buoy (Figure 4). Collier Ledge is about 6.5 miles west northwest of Bishop and Clerks shoal (Figure 1).

### **Background**

**Bishop and Clerks Shoal** - Bartholomew Gosnold explored these waters in the early 1600's and named Point Gammon "Point Gilbert" after one of his crew in 1602 (Clark, 1992). Yelverton Crowe purchased Great Island from the Indians in 1639. From this point until sometime in the mid eighteenth century, colonial records report that the Bishop and Clerks shoal may have been part of a five-acre island. Sheep were ferried to the island from the mainland and pastured. However, rising sea level and severe storms eventually eroded the island, redistributing the sand and leaving the rocks behind (Sheedy, 1999). Clark (1992) writes:

"Two and a half miles south of Point Gammon is a dangerous ledge which extends another mile and a half south. The Bishop is the large rock at the north end; the



Figure 4. View of Collier Ledge on nautical chart. Although the ledge is marked by only one asterisk, the site consists of many individual rocks (from NOAA Nautical Chart 13237).



Figure 5. Close-up view of Collier Ledge. Note haphazard character to the pile. Width of pile from left to right is approximately 6 to 8 meters (photo by Bob Johnson, 2004).

Clerks are the small rocks to the south... This is all that remains of a five-acre island almost attached to Point Gammon. Sheep were ferried over and pastured there. But by 1791 Captain Paul Pinkham's famous chart showed "Nantucket Shoals", with over 3 fathoms between the rocks and Point Gammon"

Because of the navigational hazard posed by these rocks, a lightship was stationed on site from 1855 to 1856. Funding was appropriated for a lighthouse in 1856 and the Bishop and Clerks lighthouse was eventually completed and placed into service in 1858. The lighthouse was a 65-foot gray granite tower set on a granite base (Figure 6). The granite was cut on shore and barged to the site. John Peak served as the first lighthouse keeper from 1858 to 1886. The lighthouse flashed a white light every 30 seconds and served as a sentinel to all shipping rounding Cape Cod through Nantucket Sound.



Figure 6. Photo of Bishop and Clerks Lighthouse prior to demolition. Lighthouse was constructed of coarse-grained, gray granite set on a gray, granite base. Tower was 65 feet high. Note missing stones near base of the tower (photo from collection of Edward Rowe Snow, courtesy of Dorothy Bicknell, taken from website www.lighthouse.cc/bishop/history.html).

In 1887, improvements were made to the lighthouse as reported by Clark (1992). "A red sector was inserted to cover Cross Rip and Tuckernuck Shoals; 150 tons of rip rap stones were placed around the tower for protection of its foundation". Charles Hinckley manned the lighthouse from 1886 until it was automated in 1923. However, with the completion of the Cape Cod Canal in 1914, commercial shipping around Cape Cod declined forcing many lighthouses out of service. Bishop and Clerks lighthouse was discontinued in 1928.

The lighthouse lay dormant and was not maintained. It continued to serve as a day beacon but was vandalized over the years and damaged in a storm in 1935 (www.lighthouse.cc/bishop/history.html). The structure was leaning badly and considered a safety hazard. On September 11, 1952, 68 holes were drilled into the base of the granite tower, packed with explosives and detonated, demolishing the old structure (Clark, 1992) (Figure 7). A 30-foot (9.1 m) pyramidal day beacon was placed on the granite foundation.



Figure 7A. Illustration showing the demolition of the Bishop and Clerks lighthouse on September 11,1952 (illustration of eyewitness accounts as reported in the Boston Globe, taken from www.lighthouse.cc/bishop/history.html).

Figure 7B. Photograph of the aftermath following demolition of the Bishop and Clerks Lighthouse (source of photo unknown, taken from www.lighthouse.cc/bishop/history.html)



Today a 30-foot (9.1 m) red and white cylindrical steel tower, 9 feet (2.7 m) in diameter occupies the site (Figure 8). The tower sits on a concrete pad set on top of the original granite base. The granite base is 32 feet (9.8 m) in diameter and rises above grade approximately 11 feet (3.4 m). A flat apron of cut granite blocks lies at the foot of the granite base. Strewn in haphazard fashion at the foot of the structure is a mix of rounded rip-rap boulders, a few natural boulders, and curved-cut gray granite blocks that are the remnants of the demolished lighthouse tower (Figure 9).

It should be noted that most of the rocks that the lighthouse was intended to mark are located some distance to the south and southeast of the lighthouse. Specifically, there are four large boulders that were exposed at low tide on the day of the field visit in September 2004. These rocks are 545 ft (166 m) to 694 ft (211 m) from the lighthouse (Figure 3). Another half tide rock marked on NOAA nautical chart 13237 is approximately a half a mile southeast of the lighthouse but was not observed during the site visit.



*Figure 8. Photograph of the modern-day navigational structure at the site of the Bishop and Clerks Lighthouse (photo by the Massachusetts Highway Department, 2004).* 

Collier Ledge – No background information was found concerning the history of Collier Ledge.

### Sampling

Representative samples were taken from the various rocks observed at Bishop and Clerks shoal and Collier Ledge to determine the rock type. These include samples of natural boulders, dimension stone used in the construction of the original lighthouse tower, the granite apron at the base of the present-day structure, and rip rap. The sampling was done to determine if rock type can be used as a diagnostic property separating natural features from manmade features and to help identify a source area for the rocks. In addition, dimensions of various rocks were either measured or estimated and the shape and physical arrangement of the boulders noted.

### **FINDINGS**

### **Rock Types**

A total of fourteen samples were taken during the field visit on September 15, 2004. Table 1 provides a brief summary of each sample. Sample locations are provided in Appendix A. More detailed descriptions of the samples can be found in Appendix B.





Figure 9. Examples of boulders and dimension stone found at the base of the old lighthouse. A) Rounded rip-rap boulders, granite apron, granite base and remnants of the old lighthouse tower. B) Curved-cut dimension stone used in the construction of lighthouse tower (photos by Steve Mabee, 2004).

Sample No.	Location	Short Description
S-1	Rounded to conical boulder east side of lighthouse	Diorite, slightly foliated
S-2	Curved-cut dimension stone southeast side of lighthouse	Coarse gray hornblende Granite
S-3	Curved-cut dimension stone northeast side of lighthouse	Coarse gray hornblende Granite
S-4	Rounded boulder NNE side at base of lighthouse	Diorite
S-5	Flat, dimension stone forming the apron at base of lighthouse	Coarse gray hornblende Granite
S-6	Rounded boulder on north side of lighthouse	Granodiorite, slightly foliated
S-8	Large conical boulder located 577 feet SE of lighthouse	Weathered hornblende Granite
S-9	Large pyramidal boulder located 550 feet SE of lighthouse	Fine gray hornblende Granite
S-10	Large pyramidal boulder located 545 feet SE of lighthouse	Light colored Granite
C-1	Collier Ledge	Coarse gray hornblende Granite
C-2	Collier Ledge	Coarse gray hornblende Granite
G-1	Rounded boulder in deposit at Gammon Point, Great Island	Medium, gray hornblende Granite
G-2	Rounded boulder in deposit at Gammon Point, Great Island	Medium, weathered granite
GI-1	Large pyramidal boulder at Great Island	Granite

### Table 1. Brief Summary of Samples Acquired

The samples fall into three distinct groups.

Group 1 – Dimension Stone - Group 1 comprises samples S-2, S-3, S-5, C-1 and C-2. They are all coarse grained, gray hornblende granites (granitoids) suggesting that they may have been derived from the same source rock although this is not known with certainty. One potential source rock is the Quincy granite, which has a coarse-grained texture and gray color. Another diagnostic characteristic is the presence of hornblende. Samples S-2, S-3, and S-5 are clearly stones that were quarried on the mainland and dimensioned for the purposes of construction (Appendix A). They have right-angled corners and are typically a meter or less in the maximum dimension. Some are curved cut and were part of the original Bishop and Clerks lighthouse tower (Figure 9B). The Quincy Quarry south of Boston is one possible source for these stones. Samples C-1 and C-2 have the same composition as S-2, S-3 and S-5 but their shapes are more irregular (Sample C-2 is dimensioned) but are still generally less than 1.5 meters in maximum dimension (Figure 10). However, the rocks at Collier Ledge exhibit an unnatural morphology. The rocks are arranged in a haphazard fashion as if they were dumped. Natural glacial deposits typically do not deposit boulders in such a concentrated arrangement. Boulders are usually more widely dispersed throughout the matrix in a more random fashion. Based on these observations, the morphology of the rocks and the similarity in composition, these rocks are not natural features and were brought from the mainland.

<u>Group 2 – Rip Rap</u> – Group 2 rocks comprise samples S-1, S-4, S-6. These are rounded boulders that are not dimensioned and are 1.5 to 2.0 meters in maximum dimension. Their compositions vary from foliated diorite to granodiorite to granite. One granite boulder had a piece of rebar sticking out of it (Figure 11). They are located around the foot of the granite base (Figures 9 and 11). These rocks are probably rip-rap stones that were brought to the site to protect the foundation of the structure. Accordingly, these rocks are not natural features.

<u>Group 3 – Natural Glacial Boulders</u> – Group 3 rocks comprise samples S-8, S-9, S-10, G-1, G-2, and GI-1. Samples S-8, S-9, and S-10 were taken from the large boulders located 545 to 587



Figure 10. Close-up view of rocks at Collier Ledge. Location of samples C1 and C2 are shown. Rocks consist of coarse-grained, gray hornblende granite. Stone that person is leaning on is dimensioned. Note the haphazard and irregular arrangement of the fragments. Most are under 1.5 meters in maximum dimension (photo by Steve Mabee, 2004).



*Figure 11. Granite boulder used as rip rap protection at base of Bishop and Clerks Lighthouse site. Note rebar sticking out of boulder (photo by Steve Mabee, 2004).* 

feet (166 m to 179 m) southeast of the lighthouse site (Figure 3). S-8 and S-9 are similar in composition to the dimension stone found at the lighthouse but are finer grained and more weathered than those at the lighthouse. Sample S-10 is light colored granite. However, the shape and size of these rocks is completely different from those found at the lighthouse site. These boulders are conical or pyramidal in shape (Figure 3). The base of the boulders is larger than the top. The boulder at S-9 was 5 m wide and at least 3 meters was exposed above the seafloor (Figures 12 and 13). Similarly, the boulder at S-10 has a top width of greater than 4 m (Figure 14) and is 3.2 m above the seafloor. These boulders are much larger than the stones used typically in rip-rap walls, revetments or breakwaters.



Figure 12. Measuring the top width of boulder at sample site S-9, Bishop and Clerks Shoal, approximately 550 feet (168 m) southeast of former lighthouse site. Width is approximately 4 meters (photo by the Massachusetts Highway Department, 2004).



Figure 13. Measuring the height of the boulder exposed above the seafloor at sample site S-9. Boulder is located approximately 550 feet (168 m) southeast of the former Bishop and Clerks lighthouse site. Reading on the rod is 2.2 meters at foot level (Photo by the Massachusetts Highway Department, 2004).

To verify this claim, sample dimensions were taken on a rip-rap revetment at Ned's Point in Mattapoisett, Massachusetts. Measurements were taken on October 3, 2004 from 28 randomly selected boulders. The average length, width and height of these boulders were 1.1 by 0.7 by 0.5 meters, resulting in an average weight of approximately 1.6 tons. The boulders measured at Bishop and Clerks shoal are much larger by a factor of 4 to 5 than boulders typically found in shore protection structures.

Samples G-1, G-2 and GI-1 were collected from boulders embedded in glacial deposits on Great Island (Figures 15 and 16). G-2 was collected from a 2.6 m x 1.5 m x 1.5 m boulder embedded in the cliff exposure at Point Gammon. The composition of this boulder, which is known to be of glacial origin, is very similar in composition with Sample S-10 (Figure 17). The size of the boulders observed at Great Island is also comparable to the size of the boulders at sample sites S-8, S-9, and S-10. One boulder located in the center of Great Island measures 4.5 m x 4 m x 3 m and only 50% of the boulder is exposed (Figure 16). Thus, the materials deposited by the glaciers can be quite large.





Figure 14. Measurement of boulder at sample site S-10. Boulder is located approximately 575 feet (175 m) southeast of the former Bishop and Clerks lighthouse site. A) Top width of boulder is approximately four meters and B) approximate height above seafloor is 3.2 m (photo by the Massachusetts Highway Department, 2004).

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Figure 16. Large boulder at sample site GI-1 in woods in the center of Great Island, West Yarmouth, Massachusetts. Boulder is located approximately 2800 feet (853 m) north northeast of Gammon Point. Exposed portion of boulder measures 4.5 by 4 by 3 meters (photo by Bob Johnson, 2004).

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Figure 17. Comparison of rock samples from Gammon Point and Bishop and Clerks shoal. Both rocks have granitic compositions and are light colored with alkali feldspar. Sample on left from sample site S-10 on Bishop and Clerks shoal (Figure 3) and sample on right from sample site G-2 at Gammon Point (Figure 15B)(photo by Bob Johnson, 2004).

### **Origin of Bishop and Clerks Shoal**

The boulders found at Bishop and Clerks shoal are glacial in origin and were deposited in contact with the ice. The Cape Cod lobe of the late Wisconsinan ice sheet, which covered this region, reached its terminus at Nantucket and Martha's Vineyard about 18,000 years ago. The ice began to retreat leaving the Cape area about 14,000 years ago (Oldale, 1974). However, ice retreat was irregular consisting of large stagnating blocks of ice along a ragged margin with large amounts of sediment being shed off the ice by meltwater streams. It was also not uncommon for holes to develop between downwasting blocks of ice. Boulders and large cobbles could easily tumble off the ablating ice into these holes or roll directly off the margin of the ice and then be buried by gravel, sand and silt deposited by meltwater streams. These coarse-grained materials deposited on or proximal to the ice margin are called ice-contact deposits. Older maps often refer to them as kames.

Oldale (1974) mapped Great Island as a kame (ice contact) deposit. The land surface of the island is 10 to 50 feet higher than the surrounding sand plains and has a very hummocky topography that is typical of ice-contact features. The deposit consists of coarse sand and gravel, cobbles and has many boulders of various sizes randomly embedded within it. Some boulders are exposed at the surface (Figure 16) and they often have a conical or pyramidal shape (Figure 18). The origin of ice contact deposits is well documented through the study modern glaciers



Figure 18. Pyramidal shaped boulder embedded in the ice-contact deposits along the roadway on Great Island, West Yarmouth, Massachusetts. Note the similarity in shape between this boulder and those observed at Bishop and Clerks shoal (Figures 3 and 14B)(photo by Bob Johnson, 2004).

such as the Malaspina Glacier in Alaska. These modern analogues can be used with confidence to interpret the origin of older deposits.

It is postulated that Bishop and Clerks shoal is an eroded ice contact deposit. As the ice retreated, sand, gravel, cobbles and boulders were deposited into a hole or along the margin of the stagnating ice sheet. It was very localized in a south to southeast-elongated deposit, similar to the shape of Great Island but much smaller in area. As sea level rose following deglaciation, the deposit was high enough to become isolated as an island. This may have been the island reported by early settlers. As sea level continued to rise through the 17<sup>th</sup> and 18<sup>th</sup> centuries and as storms battered the area, the island eroded. The sand and gravel matrix that held the boulders in position within the deposit was redistributed leaving behind a random collection of conical and pyramidal shaped boulders. Similar processes can be observed today at Point Gammon (Figure 19). The coarse-grained gray granite used in the construction of the lighthouse and the rip rap were all barged to the site at a later date.



Figure 19. View from Point Gammon looking south. These boulders were deposited proximal to the Late Wisconsinan ice margin when the stagnant ice margin was near Great Island. The deposit was eroded subsequently by wave action as sea level rose and as storms battered the coast. The boulders are all that remain after the sand was redistributed. Note the conical and pyramidal shapes. The boulders at Bishop and Clerks Shoal are thought to have been produced through a similar process (photo by Bob Johnson, 2004).

### **CONCLUSIONS**

The isolated half tide boulders randomly distributed 500 feet (152 m) to a half a mile (0.8 km) south southeast of the Bishop and Clerks beacon are natural glacial boulders that were deposited in contact with the retreating margin of the late Wisconsinan ice sheet. The boulders were entrained in an ice contact deposit that was subsequently eroded by rising sea level and storms leaving the boulders behind as a navigational hazard. These rocks are not bedrock. Bedrock is 400 to 500 feet (122 to 152 m) below the seafloor (Oldale, 1974). The evidence for a natural glacial origin for these boulders is as follows:

- 1. The boulders are significantly larger than the stone used in man-made shore protection structures.
- 2. The boulders are conical or pyramidal in shape, are weathered, and show no evidence of drill holes, saw cuts, dimensioning or shaping.
- 3. The shapes and sizes are similar to other boulders found in an ice contact deposit on Great Island, 2.6 miles to the north.
- 4. The composition of some of the rocks is different from the composition of the rocks used in the construction of the former Bishop and Clerks lighthouse.

5. The composition of at least one sample (light colored granite) is similar to the composition of a boulder found in the ice contact deposit on Great Island.

Most of the rocks in the immediate vicinity of the former Bishop and Clerks lighthouse site are unnatural and were brought to the site by man. There are two groups: curved cut dimension stones consisting of coarse-grained, gray hornblende granite used in the construction of the lighthouse and rounded rip rap of various compositions used to protect the foundation of the lighthouse structure. The dimension stone may have been brought from the Quincy Quarries but is not known with any certainty.

The rocks at Collier Ledge are unnatural and were deposited by man. The reason for this is unknown. The rocks are small, generally less than 1.5 m in maximum dimension, some are dimensioned indicating they were shaped by man, and their composition is similar to the dimension stone found at the Bishop and Clerks lighthouse suggesting that they may have been acquired from the same quarry. The rocks are also concentrated in one large pile in such a way to appear as if they had been intentionally discarded as waste.

### NEXT STEPS

To verify further the origin of the rocks at Bishop and Clerks shoal and Collier Ledge, additional investigations can be undertaken. It is recommended that the following investigations be considered:

- 1. **Analysis of Provenance** The stone used in the construction of the lighthouse came from a specific quarry and the glacial boulders were derived from a bedrock source somewhere upgradient along the flow line of the ice sheet. By conducting x-ray fluorescence, detailed petrologic and microprobe analysis of selected samples and knowing the direction of ice flow, the exact source of the boulders and quarry stone may be identified. This work could easily be done by a student as an honor's or Master's project.
- 2. **Historical Records Search** Additional research can be conducted on the history of the Bishop and Clerks lighthouse and Collier Ledge. In particular, a search of government documents might reveal the specifications and source of the rocks used in the construction of the lighthouse and the contractor and source of rip rap used to armor the lighthouse foundation. A rigorous search may also locate a primary document with a written description of the five-acre island that was located formerly 2.5 miles south of Point Gammon. A description of the character of the island might reveal whether or not stones and boulders were part of the island landscape. This would place the boulders within a deposit that could be linked more convincingly to a glacial origin.
- 3. **Geophysical Investigations** Several transects across the shoal using sidescan sonar, ground-penetrating radar and seismic reflection might reveal the internal structure of the Bishop and Clerks deposit. These geophysical tools may identify other buried boulders and allow distinctions to be made between older ice contact, younger glaciofluvial and glaciolacustrine, and Holocene deposits. A field study in collaboration with Woods Hole

Oceanographic Institute and the Office of the Massachusetts State Geologist could be organized.

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http://www.lighthouse.cc/bishop/history.html

### Appendix A

### Photo Journal of Sampling Locations and Samples Bishop and Clerks Shoal Collected September 15, 2004



Figure A1. Top – Sample site S-1; natural boulder or rip rap. Bottom – Sample S-1; foliated diorite (photos by Steve Mabee, 2004).

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Figure A2. Top - Sample site S-2, curved-cut dimension stone from former Bishop and Clerks lighthouse. Bottom – Sample S-2; hornblende granite (photos by Steve Mabee, 2004).



Figure A3. Top - Sample site S-3, curved-cut dimension stone from former Bishop and Clerks lighthouse. Bottom – Sample S-3; hornblende granite (photos by Steve Mabee, 2004).



Figure A4. Top - Sample site S-4, rounded rip rap boulder used for protection at base of former lighthouse structure. Bottom - Sample S-4, diorite (photos by Steve Mabee, 2004).





Figure A5. Top – Sample sites S-5, granite apron at tower base and S-6, large rip-rap boulder; Left – Sample S-5; hornblende granite; Bottom – Sample S-6; foliated granodiorite (photos by Steve Mabee, 2004).







Figure A6. Top – Sample sites S-7, S-8, S-9 and S-10; glacial boulders. No sample acquired from site S-7. No photograph of sample from S-9. Left – Sample S-8, weathered hornblende granite; Bottom – Sampling at site S-9; fine-grained hornblende granite (top photo by Bob Johnson, 2004; middle photo by Steve Mabee, 2004; Bottom photo by the Massachusetts Highway Department, 2004).





Figure A7. Top – Sampling site S-10; Bottom – Sample S-10; light-colored granite (top photo by the Massachusetts Highway Department, 2004; bottom photo by Steve Mabee, 2004).



Figure A8. Top - Sampling at Collier Ledge. Bottom – Samples C-1 and C-2, both hornblende granites (top photo by the Massachusetts Highway Department, 2004; bottom photo by Steve Mabee, 2004).



Figure A9. Top - Sample site G-1 at Gammon Point on Great Island. Bottom – Sample G-1; medium-grained, hornblende granite (top photo by Bob Johnson, 2004; bottom photo by Steve Mabee, 2004).



Figure A10. Top – Sample site G-2 at Gammon Point on Great Island. Bottom – Samples G-2; weathered granite (top photo by Bob Johnson, 2004; bottom photo by Steve Mabee, 2004).



Figure A11. Samples of rip-rap stones. From left to right: Sample S-1 (diorite); S-4 (diorite); S-6 (foliated granodiorite)(photo by Steve Mabee, 2004).



Figure A12. Samples of hornblende granite. From left to right across the middle are S-2, S-3, S-5 from the former Bishop and Clerks lighthouse materials; C-1 (top) and C-2 (bottom) from Collier Ledge (photo by Steve Mabee, 2004).



Figure A13. Samples of glacial boulders with granitic compositions. From left to right are G-2 (left two samples) from Gammon Point, Sample S-8 (middle) from gacial boulder at Bishop and Clerks shoal and GI-1 (right) from large boulder in the woods in the middle of Great Island (photo by Steve Mabee, 2004).

### **Appendix B**

### Rock Identifications and Descriptions Bishop and Clerks Rocks Collected September 15, 2004

Descriptions made by S. Seaman, P. Panish, and S. Mabee on October 1, 2004

#### Sample S-1

Medium-grained, euhedral, slightly foliated, Diorite; biotite, hornblende, quartz, feldspar, foliation may be magmatic, uncertain

#### Sample S-2 and S-3

Coarse-grained, gray, hornblende Granite (Granitoid); approximately 50% quartz, 10% hornblende, no biotite, minor hematite stain

#### Sample S-4

Fine to medium-grained, Diorite; biotite, hornblende, quartz, plagioclase

#### Sample S-5

Coarse-grained, gray, hornblende Granite (Granitoid), 10% hornblende, 30 to 50% quartz, no biotite

#### Sample S-6

Medium to coarse-grained, foliated, Granodiorite; biotite, hornblende

#### Sample S-8

Weathered, coarse-grained, hornblende, Granite (Granitoid), <10% hornblende, chlorite, orthoclase?

#### Sample S-9

Fine-grained, gray, hornblende Granite (Granitoid); 50% quartz, 10% hornblende, no biotite

#### Sample S-10

Light-colored, hematite stained Granite (Granitoid); <10% hornblende, pink orthoclase, feldspar, quartz

#### Sample G-1

Medium-grained, hornblende Granite (Granitoid); quartz, no biotite

#### Sample G-2

Medium-grained, weathered Granite; orthoclase, plagioclase, biotite, hornblende, chlorite

### Sample GI-1

Medium to coarse grained, Granite; orthoclase, plagioclase, quartz, hornblende, biotite

### Sample C-1

Coarse-grained, gray, Granite (Granitoid); plagioclase, quartz, hornblende, no to trace biotite

### Sample C-2

Medium-grained, gray, Granite (Granitoid); plagioclase, quartz, hornblende