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Prospectus of a Dissertation Chapter on Coral Reefs as Sites and Subjects of US Nuclear Weapons Tests

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This paper is my first attempt to tackle material relating to the US nuclear weapons tests at Bikini and Eniwetok in the Marshall Islands, a group of Pacific coral atolls just north of the equator, as part of my dissertation on the history of efforts to understand coral reef formation since the early nineteenth century. The US testing program served to stimulate and support the accumulation of a great deal of new knowledge of coral island geology, biology, and ecology, and is therefore relevant to the central questions of my dissertation. While I hope the Phun Day crowd will take some interest in my early findings on the importance of the bomb tests to mid-century reef studies, I am especially hopeful that you will help me to formulate a strategy for achieving my second (and perhaps more difficult) objective with this work, which is to propose amending the historiography of the bomb to take seriously the importance of coral reefs. So, as you read, please keep ideas in mind of how you might help me to answer the following question: how was scientific knowledge of the bomb shaped by the choice to test it on coral islands?

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Beginning with Operation Crossroads, in which two devices were detonated at Bikini, the Marshall Islands were the site of seven US test series comprising nearly 70 nuclear detonations between 1946 and 1958.[1] Knowledge of coral reefs and reef environments was augmented significantly by work done in conjunction with the Pacific testing program. This research took the form of extensive geophysical surveys of the reefs and surrounding waters, catalogues of native species, and ecological studies, and was unique to the history of reef studies in many important respects.[2] The diversity and quantity of scientists and other observers given access to the atolls was unprecedented, the massive scale of operations vastly expanded the equipment and manpower available

[1] The other test series at the Marshalls were Sandstone (1948), Greenhouse (1951), Ivy (1952), Castle (1954), Redwing (1956), and Hardtack (1958).

[2] For the most succinct review of this work see Harry S. Ladd, "Bikini and Eniwetok Atolls, Marshall Islands," O. A. Jones and R. Endean, *Biology and Geology of Coral Reefs* (New York,: Academic Press, 1973).

at these formerly remote sites, and radioactive fallout provided a qualitatively new means for studying reef ecology. It was widely noted in the 1950s that Bikini and Eniwetok had become two of the most carefully studied coral formations on earth.

Operation Crossroads called for comprehensive hydrographic, geological, and biological baseline surveys of Bikini before the July, 1946 detonations. The effects of the Able and Baker blasts were examined by the Bikini Scientific Resurvey, commissioned by the Joint Chiefs of Staff and conducted in the summer of 1947. Scientists and support personnel in ten divisions, including Geology (15 participants), Radiobiology (11), Fisheries (11), Biology (9), and Radiochemistry and Radiophysics (11), were drawn for the Resurvey from among the Army and Navy, the Atomic Energy Commission, Scripps Institution of Oceanography, the US Geological Survey, the Smithsonian, and nine universities.[3] This, and later, work at Bikini, and similar studies at Eniwetok (where the AEC established a marine biological laboratory in 1954), produced an efflorescence of published material on all elements of reef science.

The single best known publication from among these scores of articles and books on Bikini and Eniwetok is probably the 1955 paper by the ecologists Howard and Eugene Odum that pioneered study of energy flows in systems ecology.[4] "Since nuclear explosion tests are being conducted in the vicinity of these inherently stable reef communities," they wrote, "a unique opportunity is provided for critical assays of the effects of radiations due to fission products *on whole populations and entire ecological*

[3] Operation Crossroads was the largest U.S. military operation that had ever been conducted at peacetime, involving 42,000 personnel and 251 ships. It was planned as a "weapons-effects" test, and nearly one hundred vessels (mainly U.S. Navy surplus, plus three captured German and Japanese ships) were anchored in Bikini lagoon as a target fleet. For an overview of the operation and the Scientific Resurvey, see "Operation Crossroads 1946," (Washington, DC: Defense Nuclear Agency, 1984).

[4] Howard T. Odum, and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," *Ecological Monographs* 25, no. 3 (1955), 291-320.

systems in the field."[5] The Odums cited eleven other papers published during the previous decade on research done at Bikini or Eniwetok. A further measure of the production of reef knowledge yielded by the circumstances of the nuclear weapons testing program is that the publications of the US Geological Survey alone, in their series on "Bikini and Nearby Atolls," numbered thirty-five by 1969.

I am most fascinated by the efforts at both Bikini and Eniwetok to drill thousands of feet deep into reef limestone and recover cores of rock formed millennia earlier, analysis of which would serve as direct tests of the prevailing theories of coral reef formation. "The drilling of cores down to 1,000 and perhaps 2,500 feet" was among the specific objectives listed in the operation plan for the Bikini Resurvey, and later efforts at Eniwetok reached depths close to 5,000 feet.[6] Similar drilling efforts had been made fifty years earlier at the atoll of Funafuti, spurred by a controversy between coral reef theories. Charles Darwin proposed in 1842 that atolls were descended from reefs that encircled subsiding volcanic islands; John Murray argued in 1880 that the characteristic ring shape of atolls would be formed by coral growth on any level bank of submarine sediment.[7] Murray's theory was taken up by anti-Darwinians, and in the atmosphere of contention

[5] Odum and Odum, 1955, 291, authors' emphasis.

[6] Resurvey operations plan cited in "Operation Crossroads 1946." A summary of later drilling is found in J.A. Steers and D.R. Stoddart, "Fringing Reefs, Barrier Reefs, and Atolls," in *Biology and Geology of Coral Reefs*, ed. O.A. Jones and R. Endean (New York: Academic Press, 1973).

[7] Darwin proposed that gradual sinking by geological subsidence of an island or continent into the ocean would cause fringing reefs (which were readily explained) to evolve first into barrier reefs and eventually, if an island were to be submerged altogether, into an atoll remaining as a vestige of the island formerly within. He argued that the shape of the original fringing reef was maintained because reef-building corals required shallow depths, meaning that reefs could not expand indefinitely away from shore, but flourished only in open seawater, precluding the filling in of the channel left by a receding (sinking) shoreline. Murray, who was a naturalist on the British *Challenger* expedition (1873-1876), argued that the shape of atolls owed to the natural outward growth of coral when established on any level bank of submarine sediment, with lagoons being produced by the solution of coral limestone in acidic waters within the reef. See Charles Darwin, *The Structure and Distribution of Coral Reefs: Being the First Part of the Geology of the Voyage of the Beagle, under the Command of Capt. Fitzroy, R.N. During the Years 1832 to 1836* (London: Smith Elder and Co., 1842), John Murray, "On the Structure and Origin of Coral Reefs and Islands," *Proceedings of the Royal Society of Edinburgh* X, no. 107 (1880), 505-18.

over evolution, friend and foe alike acknowledged Darwin's coral theory as the one component of the Darwinian vision of gradual change over an immense geological timescale that could be directly tested by a crucial experiment. The three drilling attempts at Funafuti in the 1890s did not reach basement rock, and so the controversy was not conclusively settled at that time.[8] Holes at Eniwetok's Parry Island in 1951 were the first ever to be bored all the way through the limestone of a reef, whose basement was found to be basalt rock of volcanic origin. Core samples indicated that the reef limestone thousands of feet below sea level was produced by corals that live only near the surface. These drillings were celebrated as the first direct proof of the geological subsidence postulated by Darwin's theory.[9]

Several notable points regarding the theoretical impetus for the drilling and the opportunities presented by Operation Crossroads and its successors have come up in my initial examination of the papers of Harry Ladd and Joshua Tracey, two of the geologists who oversaw the borings at Bikini and Eniwetok. It has become clear that this particular work was inspired by contemporary professional discourse and debate that was ongoing without interruption since the disagreement that induced the nineteenth century drilling expeditions. It is implicit in much of the secondary literature on coral reef science that the age of gentlemanly debate over coral reef formation was incommensurable with Atomic Age reef research, and thus that the Eniwetok drillings were a very post hoc affirmation of one side in a long-dead debate. On the contrary, Ladd's letters through the

[8] The best treatment of the Funafuti drilling experiments and their aftermath is Roy M. MacLeod, "Imperial Reflections in the Southern Seas: The Funafuti Expeditions, 1896-1904," in *Nature in Its Greatest Extent: Western Science in the Pacific*, ed. Roy MacLeod, and Philip F. Rehbock (Honolulu: University of Hawaii Press, 1988).

[9] See, for example, H. W. Menard, "Foreword," in *The Structure and Distribution of Coral Reefs* (Berkeley: University of California Press, 1962), Steers and D.R. Stoddart, "Fringing Reefs, Barrier Reefs, and Atolls."

1930s show him actively engaged with older reef scientists on the merits of Darwin's theory and its alternatives.[10] In 1945, US success in the Pacific Theater of World War II stimulated Ladd to write a report in which he proposed "that systematic geologic investigations of the Pacific islands now under U. S. military or civil control be undertaken immediately by the Geological Survey."[11] At the time of his writing the war had not yet ended, and Ladd enumerated both short-term priorities that "should be financed by the War Department" at recently captured islands and long-term research that would be undertaken when possible at any "Pacific islands remaining under U.S. control or influence." One of the long-term projects Ladd proposed was research into the "Coral Reef Problem," which anticipates the work he actually began at Bikini within two years of writing.[12] Ladd's belief that the military might fund this work must have stemmed in part from the fact that US amphibious assaults in the Pacific had suffered from lack of intelligence regarding reef topography, most notoriously at Tarawa in late 1943, where the US suffered heavy casualties when landing crafts were held up on the reef.[13] Ladd circulated a revised version of this report, dated 4 January 1946, in which he refined his recommendation for reef drilling to include the suggestion of a specific site: Breakfast islet in Jaluit Atoll, one of the other Marshall Islands.

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[10] See Ladd Papers, Smithsonian Institution Archive, box 1, folder 5.

[11] Ladd, "Geologic Investigations of Pacific Islands." Draft found in Ladd Papers, SIA, Box 1, folder 3.

[12] "Coral Reef Problem. There are many geological and biological questions connected with coral reefs – both elevated and existing reefs – that remain unanswered. It is believed that many valuable data bearing on the general coral reef problem would be accumulated by the proposed island survey. It would be possible by using he proper type of drilling equipment to bore through a living coral reef at a strategic location and obtain a large core recovery. With a good recovery of large diameter core it would be possible to differentiate between transported material and reef rock made up of corals and algae in position of growth. Evidence of this sort has never yet been obtained and might be decisive at least as far as some coral reef theories are concerned.

[13] Ronald Rainger has argued that the coincidence of military interests with longstanding scientific questions around Operation Crossroads (including a newly broad Naval concern with oceanography) was in large part the product of the distinctive role of amphibious warfare in World War II. Ronald Rainger, "Science at the Crossroads: The Navy, Bikini Atoll, and American Oceanography in the 1940s," *Historical Studies in the Physical and Biological Sciences* 30, no. 2 (2000), 349-71.

Ladd's papers indicate some of the dynamics of including this research into Operation Crossroads, including the compromises he made to his theoretical program in order to cash in on the opportunity occasioned by military and political interest in Bikini. One of Ladd's long time correspondents was the geologist R.A. Daly of Harvard, whose "Glacial Control Theory" of 1910 proposed that it was a rising sea level after the last ice age, and not geological subsidence, that served as the agency responsible for present day atolls.[14] In a letter of 16 February 1948 thanking Ladd for a reprint of his publication on the Bikini drilling, Daly suggested that further boring should be done: "Breakfast Island of Jaluit atoll would be a good place to bore – so far inside the reef that it would not cut merely talus. At…Bikini the expensive drilling was in the main atoll reef – the wrong place!"[15] Ladd wrote back assuring Daly that he agreed with the selection of Breakfast Island as an ideal drilling location, mentioning that he had advocated the site himself under earlier circumstances. The story of why he abandoned that plan made clear how he had negotiated his way through the complex economy of the bomb tests:

> When Operation Crossroads developed, Bikini Atoll was studied intensely […]. Even after the completion of the first Bikini Survey in 1946, I still talked about the advantages of Breakfast Island as a drill site. Bikini was later agreed upon for purely practical reasons. Actually, there was no choice, for we found that, whereas we could obtain funds for a limited drilling program at Bikini by tying the work into the Crossroads Resurvey, we couldn't have gotten funds for any kind of an independent operation at Jaluit.[16]

This is the most explicit statement I have yet come across to demonstrate the specific ways in which the nuclear weapons program constrained or directed reef researchers, even as it provided unprecedented support for their research in the form of access,

[14] Reginald A. Daly, "The Glacial-Control Theory of Coral Reefs," *Proceedings of the American Academy of Arts and Sciences* 51, no. 4 (1915), 155-251.
[15] Daly to Ladd, February 16, 1948. Ladd papers, SIA, Box 1, folder 5.
[16] Ladd to Daly, February 24, 1948. Ladd papers, SIA, Box 1, folder 5.

materiel, and funding, and the radioactivity that permitted original assessments of reef ecology.

If the bomb provided new avenues to understanding coral reefs, was any knowledge of atomic bombs determined by the fact that they were tested on the coral islands of Bikini and Eniwetok? I think there is a case to be made that these reefs deserve more attention from historians of the bomb, and it strikes right at the heart of what is distinctive about coral reefs and what was novel about the atomic bomb. While the bomb was unique among weapons for producing both a massive immediate physical impact and also long lasting biological damage, coral reefs are unique forms in nature in that they are massive physical entities propagated biologically.[17] Thus it might be argued that coral reefs were particularly well suited as inscription devices on which to record the full range of effects produced by atomic weapons. There can be no doubt that the Army and Navy administrators of Operation Crossroads recognized that atolls, in their own right, represented distinctive and discrete test subjects for the bomb: not only was Bikini surveyed before and between the two blasts, but control surveys were also conducted at the neighboring (upwind) atolls of Rongelap, Rongerick, and Ailinginae.[18] The Bikini Scientific Resurvey was explicitly directed to include "physiological, geological, and oceanographic studies of organisms and reef-building processes in order to gain basic information for better understanding of the possible biological effects of Operation Crossroads" among investigations into the persisting effects of the two Crossroads

[17] Reef-building corals and coralline algae secrete calcium carbonate that accumulates in reefs, which are also solidified by (non-biological) cementation of sediment.
[18] See Ladd, "Bikini and Eniwetok Atolls," p. 95.

blasts.[19] As Rear Admiral W.S. "Deak" Parsons, head of the Joint Crossroads Committee, wrote to Ladd after the Bikini Resurvey, "Studies conducted by your group of geologists on the reefs of Bikini added significantly to the evaluation of the effects of radioactivity."[20] While I cannot demonstrate that these features of coral reefs were taken into account in choosing the Marshall Islands as the location for nuclear weapons tests, it does appear that having chosen Bikini and Eniwetok, serious efforts were made to exploit the distinctive record that detonations inscribed on the atolls.[21]

[19] Memo from W.S. Parsons, Chairman, Navy Department Joint Crossroads Committee, to Atomic Energy Commission, 4 June 1947. NARA II AEC 800.92.
[20] Parsons to Ladd, October 30, 1947. Ladd Papers, SIA, Box 2, folder 4.
[21] The reasons cited for selection of Bikini were its warm temperatures and predictable wind and weather patterns, the large lagoon for anchoring of the target fleet, and the island's remoteness and its (near) lack of population. Jonathan Weisgall implies that the suitability of the Marshalls for a bomb test may have prompted Truman, two weeks before the tests were announced (January 24, 1946) to "insist that [the USA] be sole trustee under the United Nations of the Pacific islands captured from Japan during the war." Jonathan M. Weisgall, *Operation Crossroads: The Atomic Tests at Bikini Atoll* (Annapolis: Naval Institute Press, 1994), 32.