Research Proposal

Investigation of foraminiferal assemblages in volcanically disturbed marine shelf sediments: Capelinhos, Faial Island, Azores

Robert W. Schmieder, Frederick Belton, and Mary McGann
Cordell Expeditions, Walnut Creek, CA

26 June 2022

ABSTRACT

It is proposed to investigate foraminiferal assemblages on the western shelf of Faial Island, Azores. In 1957-58 this area was destroyed by a series of offshore volcanic eruptions that built an extension of the westernmost tip of the island (now known as Capelinhos). The event caused destruction of the entire biological community on the shelf including microscopic organisms living in sediment deposits such as foraminifera. After the cessation of volcanic activity, erosion reduced the new shoreline to about one-fifth of its post-eruption extent and created new deposits of sediment. Presumably these deposits have been, or are being, repopulated with foraminifera from outlying reservoirs.

This document is a proposal to study the process of repopulation by investigating foraminiferal assemblages on the shelf adjacent to Capelinhos. The field work will include collection of bottom sediments, processing to extract numerically significant numbers of foraminifera, and comparison with (presumably) undisturbed assemblages elsewhere on Faial and/or other Azores islands.

The goal is to elucidate the dynamics of repopulation of the shelf. Attempts will be made to model the dynamics, including species-specific efficacy of transport, growth of newly established populations, mass movement of sediment by shallow slumping, entrainment in ocean flows, and other processes. A specific goal is to assess the extent to which the shelf biota appears to be approaching, or has reached, equilibrium.

Cordell Expeditions • 4295 Walnut Blvd • Walnut Creek, CA 94596
(925) 934-3735 • info@cordell.org • www.cordell.org

FAIAL ISLAND

The Azores is an island group belonging to Portugal, lying about 1,400 km west of Lisbon. The islands are spaced across 600 km trending SE-NW (Fig. 1).

Fig. 1

The group is located on the Azores Plateau, near the intersection of the Mid-Atlantic Ridge and the Terceira Rift. This is the Azores Triple Junction, at which the North American Plate, the Eurasian Plate, and the African Plate intersect (Fig. 2).

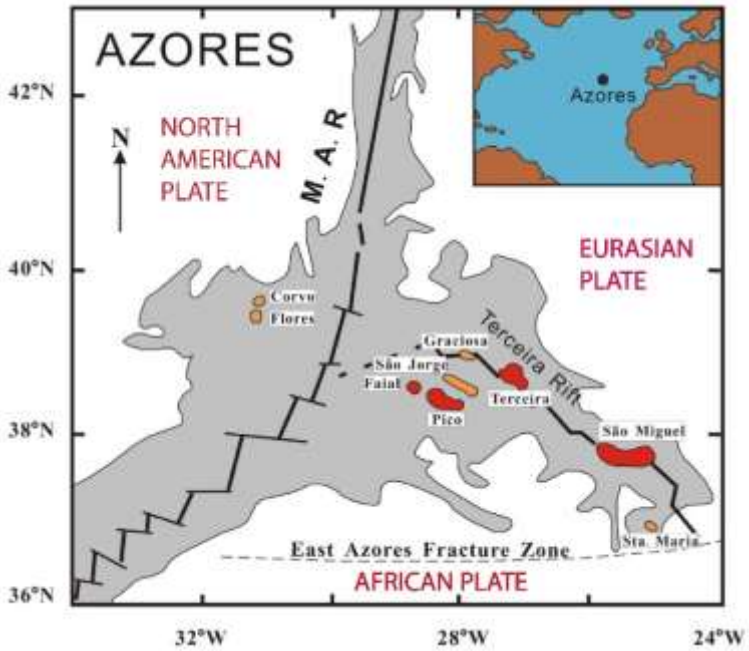

Fig. 2

The Azores is comprised of nine islands. The present proposal concerns one of those: Faial Island, located in the "Central Group" at 38°34′57″N 28°42′17″W (arrow in Fig. 3). According to Wikipedia, the island has an area of 173 km^2, coastline 80 km, highest elevation 1043 m, and population 14,334 (as of 2021).

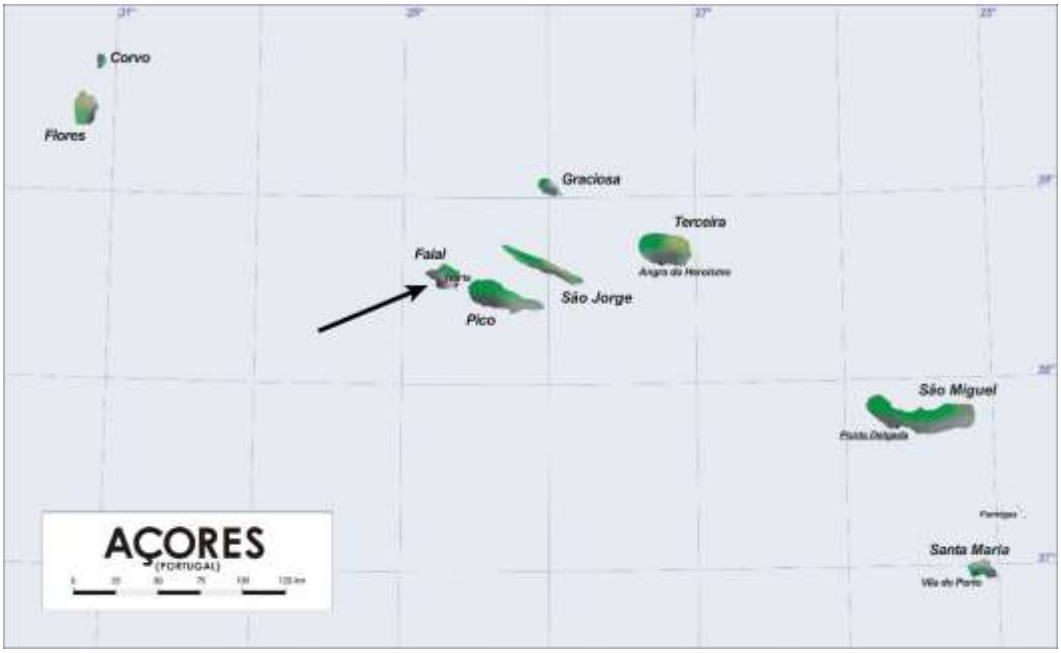

Fig. 3

Faial is roughly pentagonal, with a notable exception: the western extension of the island (called "Capelo", left Fig. 4), created by volcanic eruption in 1672.

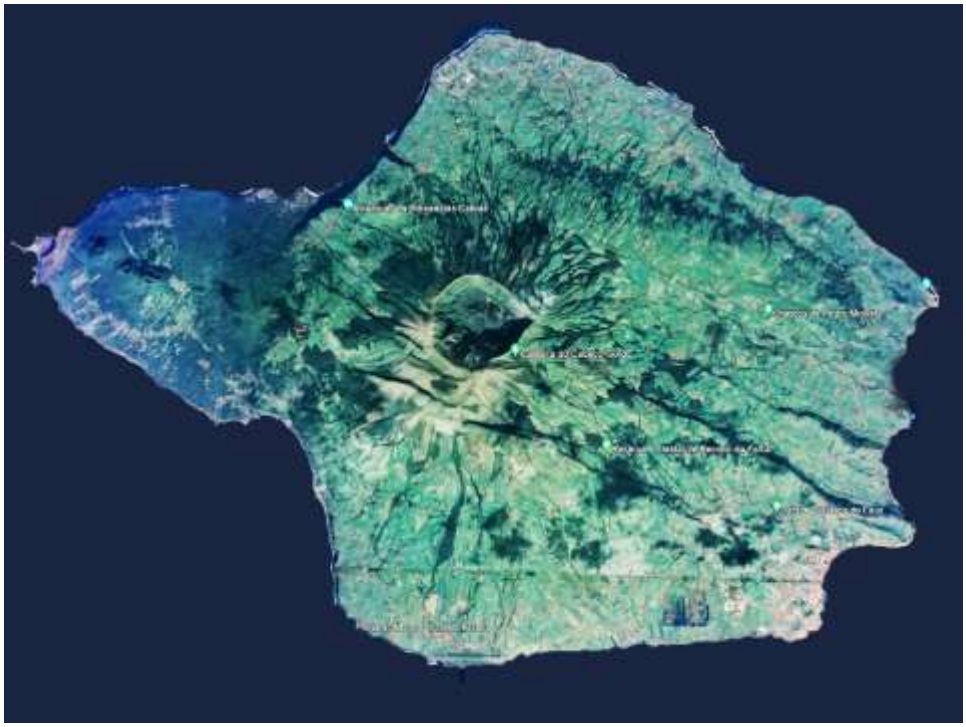

Fig. 4

A major volcanic eruption occurred on the western tip of the island (Fig. 5) which lasted 13 months: 27 Sept 1957 – 24 Oct. 1958. The eruption burst up in the sea, about a kilometer off the coast. It spawned 450 seismic events, gushing fire, lava, ashes and steam. Hundreds of houses in the surrounding villages were buried. It caused the evacuation of 1,712 people, many of whom emigrated to the United States.

Fig. 5

When the eruption stopped, Faial had gained 2.4 kilometers of land. Subsequent erosion has removed about four-fifths of the new land. Presumably much of the eroded material has been reduced to smaller lithics by surf action and moved out onto the shelf by wind-driven currents. Fig. 6 shows Capelinhos today.

Fig. 6

The following satellite images (Fig. 7 and detail in Fig. 8) show Capelinhos. The dark shadows in these images make interpretation difficult.

Fig. 7

Fig. 8

The map in Fig. 9 shows the original island (red/pink/blue) and the western addition (light and dark green, marked “1672 AC”). The tip (marked “1958 AC”) was added during volcanic eruptions in 1957-58.

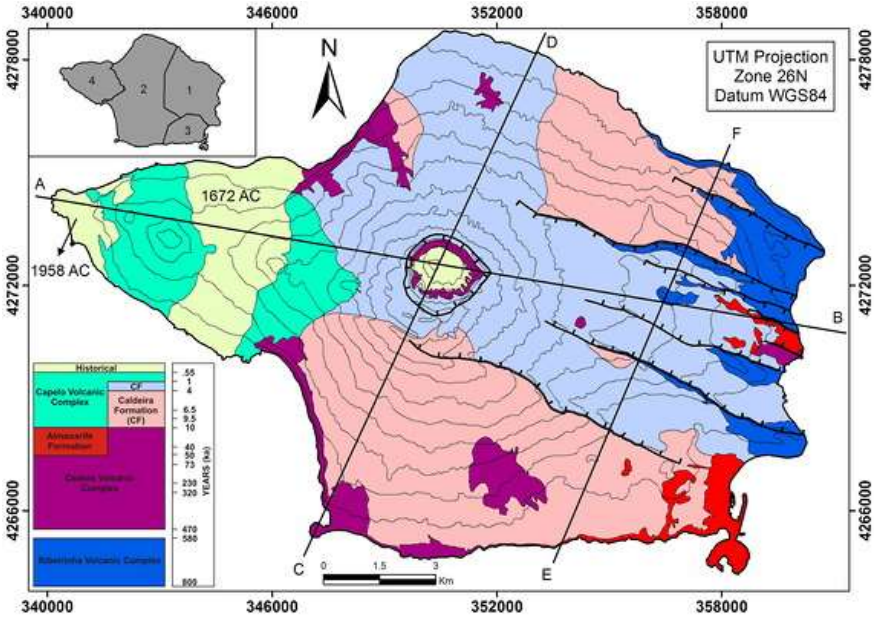

Fig. 9

The map in Fig. 10 shows data from hydrogeologic surveys 2001-2008 (ref. color key lower left). Black dots mark sediment sampling locations. Note that no collections were made around Capelos or off the relatively young Capelinhos tip.

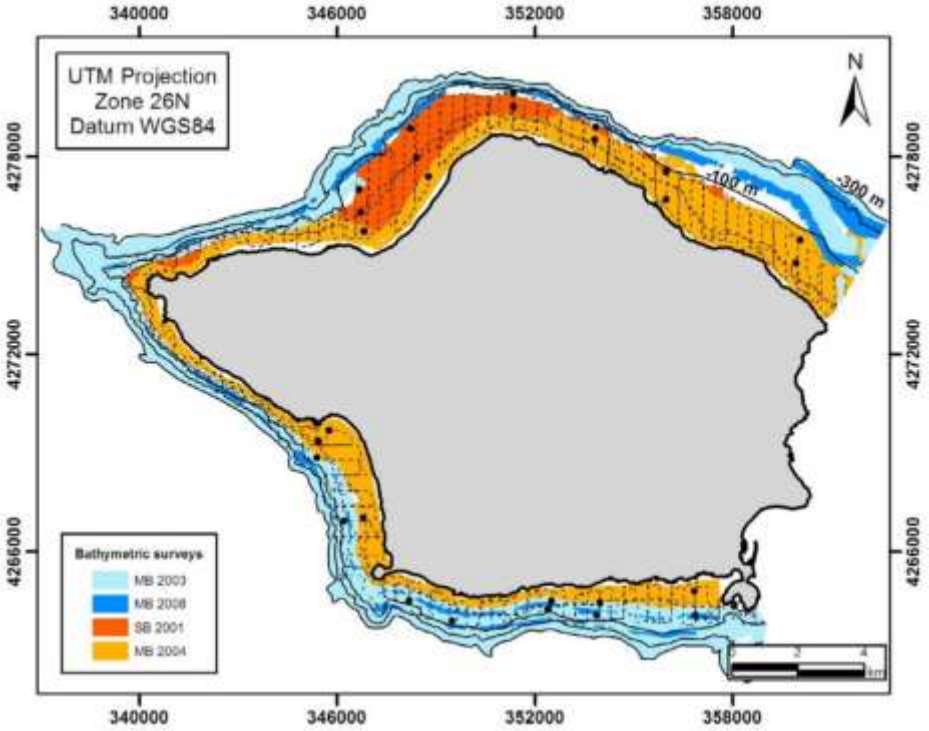

Fig. 10

FORAMINIFERA AND RE-COLONIZATION

Foraminifera ("forams") are single-celled organisms characterized by streaming granular ectoplasm for catching food, movement, and other uses. Typically, they are microscopic (ca. 0.01-1.0 mm), and are almost exclusively marine, living in the water column ("planktonic") or on the seafloor in fine sediment ("benthic"). Most foraminifera synthesize a shell (called a "test") that can have multiple chambers with openings ("foramen") between adjacent chambers. There are more than 50,000 species of foraminifera; they are found worldwide, including the waters around the Azores.

Di Bella, et al., (2015) studied sediments collected during a Eurofleet marine geological survey offshore Terceira Island, Azores, in September 2011. The authors were motivated to "obtain a seafloor characterization in a natural stressed environment like active volcanic areas of the Azores Islands." They found that "living specimens dominated the collections," and that "live and dead assemblages in most samples were similar", suggesting that "the first generation of foraminiferal colonisers was found." They concluded that "the recolonization process and the spatial distribution patterns are strongly influenced by the sea bottom high hydrodynamic regime which is responsible for volcanic deposit transport and depositional events." They found that one species, *Angulogerina angulosa*, colonizes new sediments rapidly, an opportunistic behavior. Fig. 11 shows scanning electron microscope images of foraminifera presented by these authors (*A. angulosa* = #9-13). The scale bars are 100 μm.

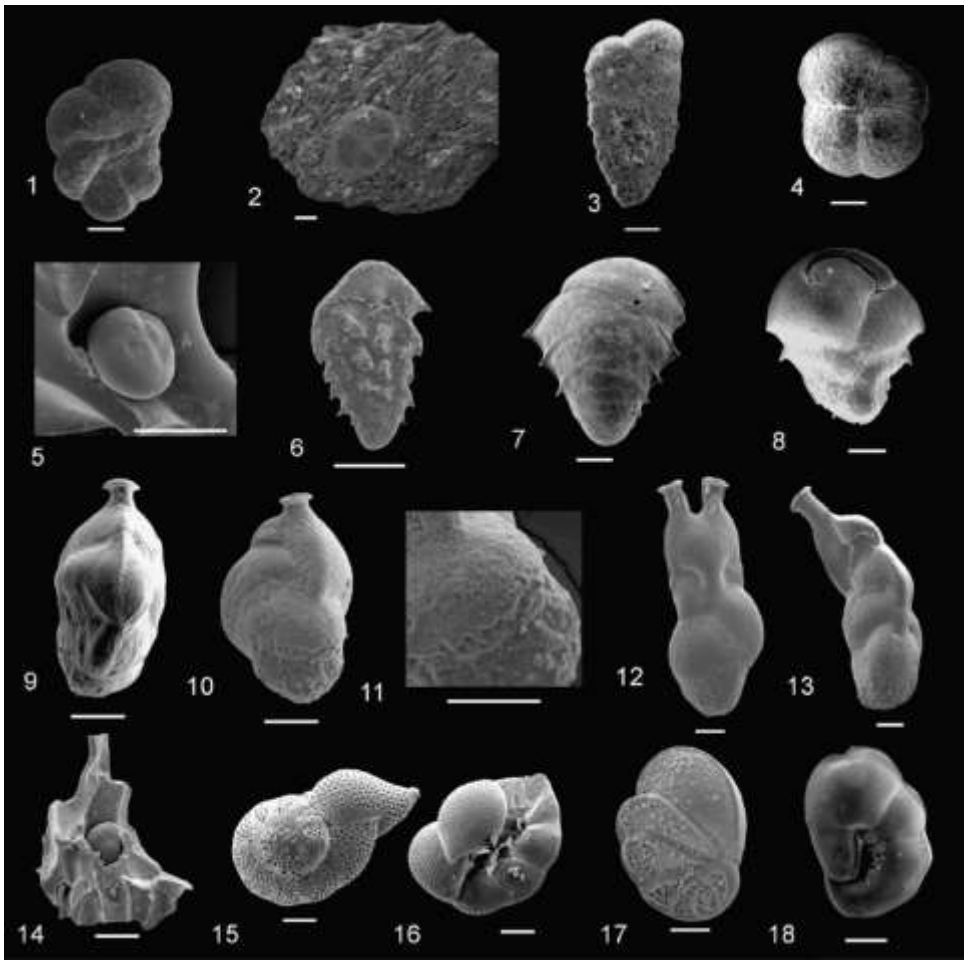

Fig. 11

Schiebel, et al., (2002) studied planktonic forams in order to track the movement of the Azores Front Current System (AFCS) (shown Fig. 2 as the dashed line labelled East Azores Fracture Zone (EAFZ)). It lies some 250 km south of the central group of the Azores. The front is known to move in response to seasonal and long-term environmental changes. The authors make use of the principle that the foraminiferal assemblages record the location of the AFCS, hence could be used to determine the Azores Front and thereby determine the varying position of the Late Quaternary Azores Current.

Foraminifera were collected in the water column (August 1997 and January 1999), and in surface sediments (October 1999) across the Azores Front. The faunal compositions of the foraminiferal assemblages, in both the water column and in the surface sediments, are different in the north and south of the islands. Analysis of the assemblages, including using oxygen isotope ratios $\delta^{18}O$ and $\delta^{13}O$ which can give the temperature of the water in which the forams lived, enabled various inferences about the Azores Current.

For reference, here are the foraminiferal species listed by Schiebel, et al.:

Dentagloborotalia anfracta
GIobigerinoides sacculifer
GIoborotalia truncatulinoides (dex)
Globigerina bulloides
G. falconensis
Globigerinella siphonifera
Globigerinita glutinata
Globigerinoides conglobatus
G. ruber (pink)
G. ruber (white)
Globorotalia hirsutq
G. inflata
G. scitula
G. truncatulinoides (sin)
Globoturborotalita rubescens
G. tenella
Hastigerina pelagica
Neogloboquadrina dutertrei
N. incompta
N. pachyderma (sin)
Orbulina universa
Turborotalita humilis
T. quinqueloba

The Schiebel study is a good example of the power of foraminifera assemblages to record the conditions at their creation, and also some aspects of their life.

Di Bella, et al., (2014) provide an important comparison of recolonization after 20 and after 110 years [underline added for emphasis]:

> "The Azores area has been affected by a recent volcanic activity occurred in 2001..., while the last submarine eruption of Pantelleria Island [Mediterranean] dates at 1891. <u>The different periods of eruption of the two areas allow to investigate on the way and time of the re-colonization process by foraminiferal assemblages</u>. … the foraminiferal assemblages of the Azores area are dominated by opportunistic species (*Angulogerina angulosa*) and represent the first stage of re-colonisation after the eruption occurred in 2001, while the associations of Pantelleria Island (*Globocassidulina subglobosa*, *Lenticulina rotulata*, *Lobatula lobatula* and miliolids) have to be considered as an advanced stage of resettlement with stable rich and well diversified assemblages. Moreover, in the Azores area many morphological abnormalities were recognized, confirming a more stressed environment than the Pantelleria bottom."

In this context, the paper of Hess, et al. (2001) is especially interesting. The paper reports a multiyear study of the recolonization of the ash layer of Mt. Pinatubo by benthic foraminifera. The volcano, located in the Philippines, erupted on 15 June 1991. According to Wikipedia, "Surrounding areas were severely damaged by pyroclastic surges, pyroclastic falls, and subsequently, by the flooding lahars caused by rainwater re-

mobilizing earlier volcanic deposits. … Benthic communities were blanketed by 8-9 cm of volcanic material…buried and decimated. … When first visited in 1994, some communities were found to be in the initial stages of recovery."

Hess, et al., continue: "Benthic foraminifera represent an ideal group for such studies because they are abundant in the deep sea and well-preserved in the geological record. However, only a few investigations are available on recent recolonization processes." They reference several papers that indicate that the recovery time is "on the scale of years."

These authors monitored the re-establishment of the benthic foraminiferal community on Mt. Pinatubo over seven years. They emphasize the complexity of the overall process, potentially involving: (1) sediment gravity transport; (2) nutrient recycling and phytodetritus flux; (3) composition of the new habitat; (4) great distance for recolonizing species to reach the new habitat from the margins; and (5) potential predation. To this list the authors of this proposal might add: (6) Irregular disturbance by violent weather events; (7) bioturbation by nonpredator fauna; (8) co- or counter- flow currents aiding or resisting dispersal of immigrates; (9) Movement of trapped volcanic gases, including steam, into the new habitat, generating mechanical movement, chemical modification, and possible effects on the biota.

A very simple but potentially valuable parameter was used by Hess and Kuhnt (1996) to organize colonizers in order of their succession. It was assumed that the fraction of living specimens in a sediment sample is a measure of the time of colonization: a high fraction of living specimens implies that the area was recolonized recently, whereas a low fraction implies it was colonized much earlier. Fig. 12 shows the data of Hess, et al., for the living/dead ratio vs density of specimens. Clearly, there is an approximately linear anticorrelation relationship: R+cN =1, where R=ratio of live specimens to dead, N=number of specimens per 100 ccm, and c ≈ 1/500. This relation seems to confirm the ability to determine the sequence of recolonization by using the live/dead ratio and the density of specimens.

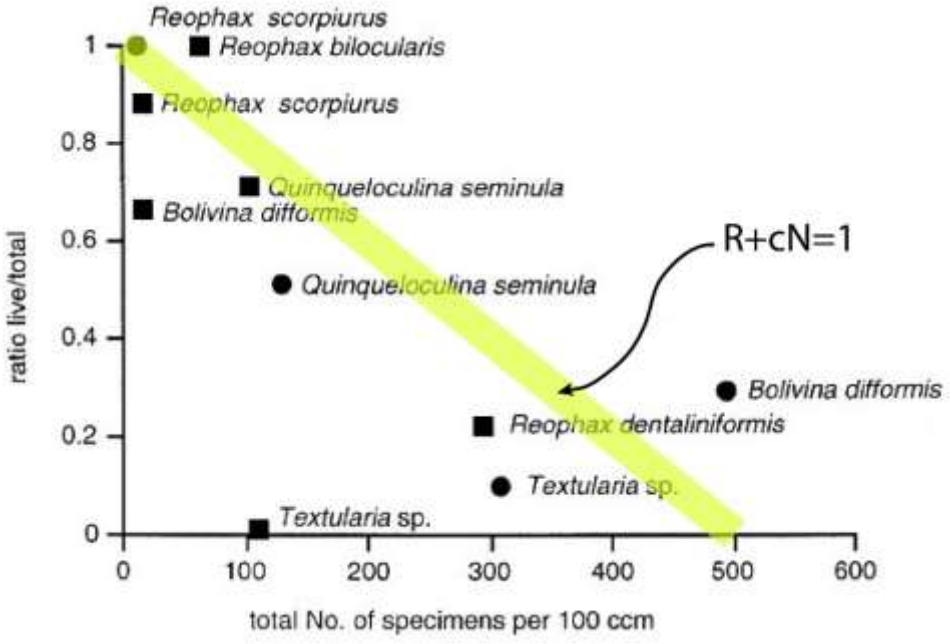

Fig. 12

THIS PROPOSAL

Our interest was drawn to the Azores by a three-week visit by one of the present authors (FB), and by professional interest in foraminifera by the other two authors (RWS and MM). An important issue emerged from the extensive marine surveys and the volcanic history of the Azores, and Faial Island in particular: Assuming that the entire population of foraminifera on the marine shelf at Capelinhos was destroyed by the volcanic activity in 1957-58, how can we characterize the recovery of the populations after the cessation of the activity? In other words, if a long-established foraminiferal assemblage is destroyed in a short-term event, how will the assemblage be re-established? The question is nontrivial, because different species can have different abilities: to propagate from distant reservoirs, to establish new resident populations, to survive the altered environment on the modified shelf, to resist being preyed upon and being swept away by sediment motions, etc.

Thus, this proposal is relatively simple, in principle: Make collections of the present foraminiferal assemblages on the shelf offshore from Capelinhos and compare them with collections that were not affected (or "less" affected) by the 1957-58 volcanic event. We believe that any significant differences will suggest mechanisms for the repopulation of the shelf and therefore give some insight into the dynamics of foraminiferal populations. This proposal takes advantage of a fortuitous circumstance: Capelinhos appears to be a classic case of destruction of the populations in a sudden violent event, and slow recovery by natural regional processes.

PRE-EXPEDITION PREPARATION

A preliminary planning trip to the Azores is being made by one of the authors (RWS) during 28 June-7 July 2022 to the Islands of Terceira, Faial, and Sao Miguel. Besides meeting with people potentially interested and/or involved with the present project, he hopes to make initial arrangements for equipment and services for the September project. These might include a small boat, bottom sampling equipment, library access, archived samples of sediment, etc. RWS will also attend an international meeting of the Explorers Club (GLEX) in Ponta Delgada 4-–7 July 2022.

The authors of this proposal are interested in developing contacts with scientists and organizations with interest in this work. The purposes of such contacts are to take advantage of facilities and services that might be available on Faial, and to enable scientific collaboration. Because there is no outside funding for this project, we will be looking for collaborative support. If you are interested in advising, collaborating, or participating, please contact the first author of this proposal (RWS).

FIELD WORK

The field work will be done during 16-29 September 2022.

Fig. 13 shows a nominal boundary for this proposed work. Generally, sediment collections will be made within the semicircle, but this is not a fixed requirement.

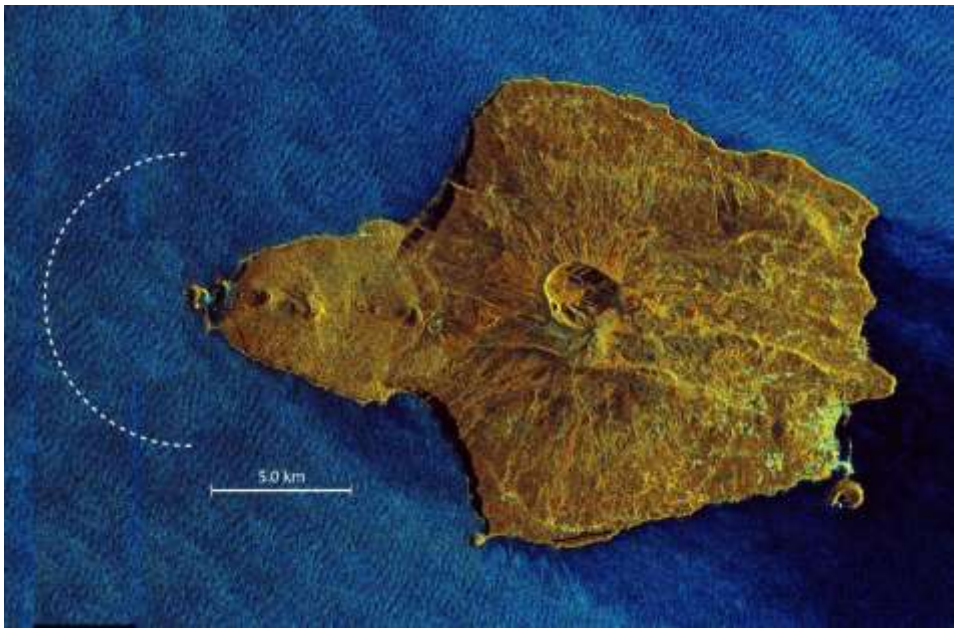

Fig. 13

Samples of shelf sediment will be obtained using a bottom sampler; the location of each collection will be recorded with a GPS. The sediment will be held in coded Ziplock bags pending transfer to a land-located facility. The individual collections will be washed, dried, and repackaged in sterile containers. The individual collections will be separated by sieving with the following meshes: #5 (4000μm), #10 (2000μm), #35 (500μm), #60 (250μm), #120 (125μm), #230 (63μm). A preliminary microscopic examination will be made of each size fraction to determine the general nature of the sediment. It is expected that most foraminifera will be found in the finest sieve (#230). If desired, the sub-collections will be distributed to interested colleagues, and voucher collections will be deposited in the appropriate archives for permanent storage. Upon completion of the processing appropriate fractions of the collections will be shipped to the U.S. Geological Survey (USGS) in Menlo Park, California, and from there to labs in the USGS and Cordell Expeditions in Walnut Creek, California.

PROJECTED RESULTS OF THE PROJECT

By making collections on the shelf around the Capelinhos area, this work will provide completion of the materials available from the coastline of Faial Island. Because considerable effort has been made by numerous researchers to understand the asymmetry of the environment around the Azores, completing this inventory of samples, together with additional interpretations, will be integral to extending understanding of that environment. The original data, including numerical results, images, field notes, and specimens, will be transferred to the appropriate agency for permanent archiving. Publications that might result will of course take significant time, perhaps years, and it is

assumed that collaborations established within this project will be reflected in the authorship of the publications.

In addition to the observation of foraminifera in the volcanic activity zone, we have the possibility of learning something of the dynamics of repopulation through modelling. As a first step, one of the authors (RWS) has implemented a model of competing populations using ordinary differential equations. Numerical calculations of this model were done with Mathematica.

Fig. 14 shows a typical result of numerical calculations with this model. Weassume there are three species of foraminifera (R,G,B), and a population of organisms representing foram food, and a population representing foram predators. We omit the details of the calculations because these are only illustrative.

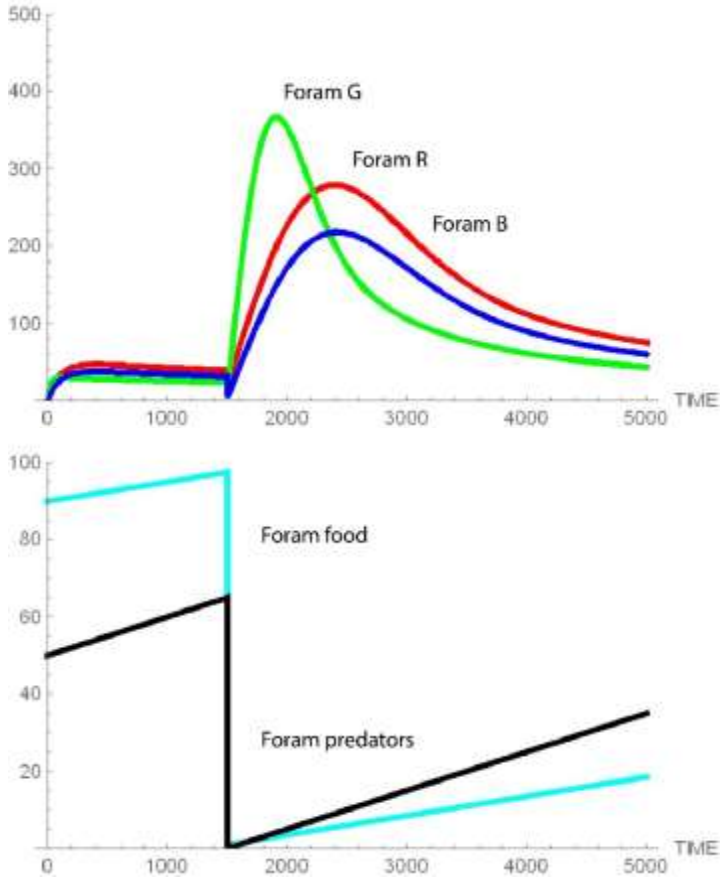

Fig. 14

The dynamics illustrated in these plots that all five populations have reached some sort of near equilibrium. Then at time 1250 (no units), a catastrophe (i.e., the volcanic eruption) occurs, killing all five species. The foraminifera bounce back rapidly, since they need very small resources, but the food and predator populations return more slowly. Eventually the foraminifera reach peaks (due to their mutual competition) and begin to return to their pre-eruption equilibrium levels. The recovery of the food and predators is much slower because there is insufficient resources for them to grow and multiple.

While these simulations cannot claim to be reality, they do give a qualitative idea of one dynamic that will be important to recolonization, namely species competition for food. This subject has been thoroughly elaborated (Murray, 1993).

CONTACT INFORMATION

Principal contact:
Dr. Robert W. Schmieder
Director, Cordell Expeditions
4295 Walnut Blvd.
Walnut Creek, CA 94596
Phone: (925) 934-3735 (incl. FAX)
Email: schmieder@cordell.org
Website: http://www.cordell.org

Co-author:
Frederick Belton
Cordell Expeditions
825 Fitzpatrick Road
Nashville TN 37214
Phone: (615) 479-1705
Email: fbelton3555@gmail.com

Co-author:
Dr. Mary McGann
U. S. Geological Survey
Pacific Coastal and Marine Science Center
345 Middlefield Road
Menlo Park, CA 94025
Email: mmcgann@usgs.gov
Phone: (650) 329-4979
Fax: (650) 329-5441

FIGURE CREDITS

Fig. 1 Google Earth, "Azores"
Fig. 2 Huimin Yu, Miami Univ.
Fig. 3 Wikipedia Commons, "Azores"
Fig. 4 Google Earth (processed)
Fig. 5 Portugese Historical Museum
Fig. 6 Wikipedia "Capelinhos"
Fig. 7 Google Earth, "Faial"
Fig. 8 Google Earth, "Faial"
Fig. 9 Quartau, et al., (Fig. 2a)
Fig. 10 Quartau, et al., (Fig. 4)
Fig. 11 DiBella, et al., (Fig. 6)
Fig. 12 Hess, et al., (Fig. 4)
Fig. 13 Wikimedia Commons, "Azore_islands_Faial_ESA348302"

REFERENCES

Catalogue of Portugese Foraminifera, https://foraminifera.eu/apf.html.

Chang, Y.-C., Mitchell, N.C., Quartau, R., Hübscher, C., Rusu, L., Tempera, F., 2022. Asymmetric abundances of submarine sediment waves around the Azores volcanic islands. *Marine Geology* **449**:106837.

Cole, P., Guest, J., Duncan, A., Pacheco, J.-M., 2001. Capelinhos 1957–1958, Faial, Azores: deposits formed by an emergent Surtseyan Eruption. *Bull. Volcanol*. **63**:204–220. https://doi.org/10.1007/s004450100136.

Di Bella, L., Frezza, V., Conte, A.M., Chiocci, F.L., (2015). Benthic foraminiferal assemblages in active volcanic area of the Azores Islands (North Atlantic Ocean). *Ital. J. Geosci*., **134**(1):50-59, (doi:10.3301/IJG.2014.22).

Di Bella, L., Frezza, V., Conte, A.M., Martolelli, E., Chiocci, F.L., Sposato, A., Chiocci, F.L., 2014. oraminiferal assemblages in active volcanic areas: two study cases from Azores Archipelago (Atlantic Ocean) and Pantelleria Island (Mediterranean Sea). Conference: CONGRESSO SGI-SIMP 2014 "The Future of the Italian Geosciences - The Italian Geosciences of the Future" at: MilanVolume **31**. Sept. 2014.

Hess, S. and Kuhnt, W, 1996. Deep-sea benthic foraminiferal recolonization of the 1991 Mt. Pinatubo ash layer in the South China Sea. *Mar. Micropaleontol*. **28**:171-197.

Hess, S., Kuhnt, W., Hill, S., Kaminski, M.A., Holburn, A., de Leon, M., 2001. Monitoring the recolonization of the Mt. Pinatubo 1991 ash layer by benthic foraminifera. *Marine Micropaleontrology* **43**:119-142.

Mitchell, N.C., 2003. Susceptibility of Mid-Ocean Ridge Volcanic Islands and Seamounts to Large-Scale Landsliding. *J. Geophys. Res*. (doi:10.1029/2002JB001997).

Mitchell, N.C., Schmitt, T., Isidro, E., Tempera, F. Cardigos, F., Nunes, J.C., Figueiredo, J., 2003. Multibeam sonar survey of the central Azores volcanic islands. *InterRidge News* **12**(2): 30-33.

Murray, J.D., 1993. *Mathematical Biology*. Springer-Verlag.

Pacheco, J., 2001. Processos Associados Ao Desenvolvimento De Erupçoes Vulcanicas Hidromagmaticas Explosivas Na Ilha Do Faial E Sua Interpretaçao Numa Perspectiva De Avaliaçao Do Hazard E Minimizaçao Do Risco. PhD thesis. Universidade dos Açores.

Quartau, R., Tempera, F., Mitchell, N.C., Pinheiro, L.M., Duarte, H., Brito, P.O., Bates, C.R., Monteiro, J.H., 2012. Morphology of the Faial Island shelf (Azores): The interplay between volcanic, erosional, depositional, tectonic and mass-wasting processes. *Geochemistry, Geophysics, Geosystems* **13**(4). https://doi.org/10.1029/2011GC003987.

Schiebel, R., Schmukera, B., Alves, M., Hemleben, C., 2002. Tracking the Recent and late Pleistocene Azores front by the distribution of planktic foraminifers. *Journal of Marine Systems* **37**(1–3):213-227.