Digging into the Geologic Record of Environmentally Driven Changes in Coral Reef Development

ANSWER KEY

Pre-Lab Activity

The pre-lab activity requires students to complete Table S1 in the Student Activity Sheet. The answer key is provided here.

TABLE S1A. A summary of the environmental changes that occur in the Gulf of Panamá for the educator. A blank version of this table is used in the pre-lab activity to allow students to research the environmental conditions and anticipated impacts on coral reefs during the lesson activities. Note that El Niño and La Niña conditions can have different effects on coral reefs elsewhere in the Pacific from the effects they have in Panamá, depending on longitude, which is the axis of the oscillation and local controls on climate.

CLIMATIC CONDITION	ENVIRONMENTAL PARAMETER	ENVIRONMENTAL CONDITION	ANTICIPATED IMPACTS ON CORAL CONDITION
ENSO-neutral	Upwelling	Moderate seasonal upwelling	Coral growth and reef accretion occur, although cold temperatures seasonally slow coral growth
	Temperature	Water temperatures up to ~10°C cooler during upwelling	
	Nutrients	Seasonally high nutrients with upwelling	
	Turbidity	High turbidity relative to most reef ecosystems	
El Niño	Upwelling	Reduced upwelling	More variable reef growth. Strong El Niño events can cause coral bleaching and mortality. Coral growth can also be more rapid in a mild El Niño due to reduced upwelling (~2°C warmer temperatures during El Niño), less turbid water, and reduced nutrients
	Temperature	Water temperatures increase	
	Nutrients	Lower nutrients	
	Turbidity	Less turbid than in ENSO-neutral years because of lower rainfall	
La Niña	Upwelling	Stronger upwelling	Corals experience cold temperatures that can cause reduced growth and mortality. Increased turbidity can block the light needed for symbiotic algae to photosynthesize
	Temperature	Cooler and more variable temperature	
	Nutrients	Elevated nutrients compared with ENSO-neutral years	
	Turbidity	More turbid than in ENSO-neutral years because of greater rainfall	

Pre-Lab Activity Discussion Questions

1. How do the environmental parameters change in the Gulf of Panamá among ENSO-neutral, El Niño, and La Niña periods?
   During ENSO-neutral conditions, coral growth and reef accretion occur, although cold temperatures seasonally act to slow coral growth. During El Niño events, reef growth is more variable. Strong El Niño events can cause coral bleaching and mortality. Mild El Niño events can cause more rapid coral growth due to reduced upwelling (~2°C warmer water temperatures during El Niño). During La Niña events, colder water temperatures reduce coral growth and mortality; however, increased turbidity can block light needed for symbiotic algae to photosynthesize.

2. Create a diagram that explains the environmental changes that occur during an ENSO-neutral, El Niño, and La Niña conditions.
   Students' diagrams will vary.

Gravinese et al., 2020, https://doi.org/10.5670/oceanog.2020.113

Activity 1

Activity 1 images in Handout S1 include three fossilized coral images recovered from three different cores collected from the Gulf of Panamá. A randomization grid for student use during the activity is also provided in Handout S1. The grid will facilitate random sampling of the corals within each core. The students will randomly draw numbers to determine which 15 grids should be analyzed within each core. We also provide a key in Handout S1 that the students can use if needed. The key provides a side-by-side comparison of the potential core material that maybe found within each grid.

Activity 1 requires students to complete Tables S2 and S3 in the Student Activity Sheet. The answers will vary due to the random sampling associated with the activity. The general trend in the student data should be as follows:

TABLE S2A–S3A. Summary table of the trends students should observe during Activity 1.

TIME INTERVAL	TRENDS
1,500–1,000 yr BP	>75% reef-building corals (*Pocillopora*) in good taphonomic condition
4,000–2,000 yr BP	>75% *Psammocora* and coralline algae; poor taphonomic condition of corals
5,000–4,000 yr BP	>75% reef-building corals (*Pocillopora*); in good taphonomic condition

Activity 1 Discussion Questions

1. What temporal differences did you observe in the species of the corals present in the cores?
   *More framework-building coral (*Pocillopora*) from 5,000 yr BP to 4,000 yr BP, and again after 1,500 yr BP, compared with 4,000–2,000 yr BP, which has more* Psammocora *and coralline algae.*

2. How did the corals' taphonomic conditions change across the sampling intervals in the cores? Explain.
   The taphonomic conditions of reef-building corals changed from good condition during 5,000–4,000 yr BP to poor condition during 4000–2000 yr BP. Corals were again in good taphonomic condition during the period 1,500–1,000 yr BP.

3. Hypothesize what may have driven the changes you observed. Explain.
   The changes were likely driven by long-term changes in ENSO, which exhibited wider swings between El Niño and La Niña conditions from 4,000 yr BP to 2,000 yr BP than in the other two intervals.

Gravinese et al., 2020, https://doi.org/10.5670/oceanog.2020.113

Activity 2

TABLE S4A. Answer key showing the length and time span for each section of the mock cores used in Activity 2. Students first determine the length and time span of each section of the mock cores. They then determine the accretion rates (m/1,000 years) using the formula provided in the methods for Activity 2. The accretion-rate data should be used to answer the discussion questions for Activity 2.

CORE	CORE SECTION	LENGTH (cm)	TIMESPAN (yr BP)	ACCRETION RATE (m/1,000 yr)
1	Green	142	1,007	1.41
	Red	37	3,295	0.11
	Blue	188	1,034	1.81
2	Green	151	995	1.52
	Red	50	3,600	0.13
	Blue	199	636	3.12
3	Green	176	1,017	1.73
	Red	44	3,324	0.13
	Blue	138	1,110	1.24

Activity 2 Discussion Questions

1. What changes did you observe among the sections of the cores? Describe the relationships among the core ages and core lengths.
   The green and blue sections of the cores grew over ~1,000 years. The red sections of the cores grew over ~3,000–3,500 years. The lengths of the green and blue sections were similar, and the red sections of the cores were always the shortest sections.

2. Which sections of each core had the fastest accretion rate? The slowest accretion rate? Explain and defend your answer using your data as evidence.
   The green and blue sections of the cores had the greatest accretion rates, ranging from 1.4–1.7 m of reef accretion per 1,000 years. The red sections had much slower accretion rates at approximately 0.1 m per 1,000 years.

3. Hypothesize what may have driven the changes you observed. Explain your reasoning.
   These results suggest that the local environment was changing, and that environmental changes during the red intervals of the cores inhibited accretion.

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Activity 3

TABLE S5A. Preparation and answer key for the elemental ratio calculations in Activity 3. The ratios are calculated using the formula provided in the methodology. The teacher should be sure to reiterate that these small changes in geochemical ratios are representative of the data actually collected from the core. Paleoclimatologists use very precise methodology to determine these ratios and are looking for small changes in the geochemistry to help explain climatic trends. Sr is a proxy for temperature, while Ba is a proxy for upwelling. These data are designed to model the average trends observed in an actual core.

RATIO	TIME INTERVAL	ELEMENTAL COUNTS (total per element)		CALCULATED RATIO (use formula provided)
Sr/Ca	1,500–1,000 yr BP	Sr = 10	Ca = 50 × 10	9.148
	4,000–3,500 yr BP	Sr = 8	Ca = 39 × 10	9.383
	5,000–4,500 yr BP	Sr = 9	Ca = 44 × 10	9.356
Ba/Ca	1,500–1,000 yr BP	Ba = 8	Ca = 55 × 10	4.245
	4,000–3,500 yr BP	Ba = 6	Ca = 31 × 10	5.649
	5,000–4,500 yr BP	Ba = 7	Ca = 42 × 10	4.864

TABLE S6A. Answers for the predicted environmental conditions at each time interval in Activity 3.

TIME INTERVAL	SURMISED ENVIRONMENTAL CONDITIONS
1,500–1,000 yr BP	Less upwelling, warmer
4,000–3,500 yr BP	Stronger upwelling, cooler temperatures; similar to conditions experienced during La Niña
5,000–4,500 yr BP	Less upwelling, warmer

Activity 3 Discussion Questions

1. What temporal changes did you observe in the Sr/Ca ratio? The Ba/Ca ratio?
   The geochemical ratios were similar in the older and younger time intervals. There was an increase in both ratios in the middle time interval.

2. The magnitudes of the observed changes are small, but they provide a lot of information about past climate. Based on the small changes observed, what do the environmental conditions you inferred suggest about the impacts of environmental change on the health and growth of coral reefs in the Gulf of Panamá? Use the summarized data from the class observations for this activity. Support your answer with evidence from the lab activities.
   There was likely an increase in the frequency and intensity of La Niña at the beginning of the period of slow reef growth. The geochemical changes indicate that temperatures were cooler and, therefore, that there was more upwelling.

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