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Keck Geology Consortium: Projects 2013-2014
Short Contributions— Earthquake Geomorphology, Costa Rica Project

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Research Advisor: Marino Protti

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ASSESSMENT OF CURRENT RADIOMETRIC DATING TECHNIQUES OF BEACHROCK ON THE NICOYA PENINSULA, COSTA RICA

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Research Advisor: David Harbor

INTRODUCTION

On the tectonically active Nicoya Peninsula, Holocene-aged beachrock deposits are a common feature of sand and gravel beaches (Marshall, 1991; Marshall and Anderson, 1995: Marshall et al., 2012). Beachrock is composed of beach sediments cemented with calcite or aragonite (Bricker, 1971) and is usually found at the level of high neap-tide in areas with a high tidal range (Snead, 1982). As earthquake events uplift the coastline, beach rock outcrops become exposed and move up the beach face. Accurate radiocarbon dating of beach rock plays an integral role in understanding the history of beach morphology and can be used as a proxy for Quaternary sea level and neotectonic studies due to its lithification at the coastline (Dermitzakis et al., 1993).

Prior methods for radiocarbon dating of Nicoya Peninsula beachrock include either extracting a large shell or coral fragment from the matrix, or sampling a "whole rock" piece of the hardened matrix (Marshall et al., 2012). Samples are taken from the rock interior, below the weathering rind to minimize contamination by younger carbon. Whole-rock samples are generally crushed and sieved (e.g., Marshall, 1991). The powdered substance that results is a combination of carbonate cement, lithic and carbonate grains from beach sand, whole shells, and occasionally older beachrock. Therefore, the age of the sample is not necessarily the age of beachrock formation, but rather an amalgamated age of the mixture, which can be skewed towards ages older than the carbonate cement due to older biogenic material (e.g. Scoffin and Stoddart, 1983; Chivas et al., 1986; Neumeier, 1998) or carbonate bedrock. Because cementation of beach rock occurs on short time intervals of months to years, even slight skews by older ages are significant (Frankel, 1968).

Beachrock has been previously dated along the Nicoya Peninsula, with ages ranging from 960 years BP (+60/-50) to 8310 years BP (+60/-120) (Marshall et al., 2012). However, in the formation of beachrock, cementation is the last event, and the other constituents, including shells, inorganic limestone, and possible bedrock carbonate, are older. Therefore, this project tests the hypothesis that whole rock ages are skewed toward ages older than cementation, by isolating and determining the age of beachrock cement. The degree of error will depend on the composition of each particular beach rock sample and, therefore, the degree of skewing will be sample specific.

METHODS

During June and July of 2013, thirty-four oriented beachrock samples were collected along beaches at Playa Langosta (Tamarindo), Playas Pleito and Cocal (San Juanillo), Playa Pelada (Nosara), Playa Garza and Playa Carrillo along with GPS positions, and photographs. Outcrop topography was surveyed using a laser range finder, hand level, stadia rod and reflector pole, which were used to construct a 3-D grid elevation model and a topographic profile perpendicular to the beach face.

Hand sample characterization included estimates of relative percent of cement, framework, and matrix as well as the degree of sorting, sphericity, and shape of the grains. Thin sections of 5 samples were analyzed for cement patterns and lithologic composition.

The goal of the laboratory analysis was to obtain ages for cement separate from the other beachrock constituents. Hand crushed samples were weighed and sieved to 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, 63 µm in a Ro-Tap® for 15-minutes. Samples were weighed initially and the contents of each sieve layer were weighed after being disaggregated in the Ro-Tap®. Samples on top of the 250 µm, 125 µm, 63 µm and <63 µm sieves were placed on a glass slide and examined using a petrographic scope that was illuminated from an adjacent light source. They were also examined using a Zeiss EVO SEM. For the sample with the best separation of cement from other constituents (CR13EO-19) a suite of sample sizes, including the whole rock sample was sent to Beta Analytics for radiocarbon dating. The samples were not pretreated before dating. The whole rock and > 125 µm CR13EO-19 samples were dated using RadiometricPLUS. The > 63 µm and < 63 µm samples were dated using Accelerator Mass Spectrometry.

Thin section analysis was conducted using a Zeiss light microscope, a Zeiss EVO 15 Scanning Electron Microscope, and energy-dispersive x-ray spectroscopy (EDS).

RESULTS

Beachrock Characterization

Beachrock differs in composition and percent cement, even for samples located on the same beach. In general, cement varies from10-30% of the beachrock. The lithology of beachrock on the Nicoya Peninsula varies up-and-down the coast, but is predominately a mixture of medium to very coarse sand composed of shell and lithic fragments. Sorting varies from poor to very well-sorted.

Lithology of the 5 Playa Langosta samples, the most northern beach of the study, is dominated by a shell/coral framework (60-85% of framework grains) with lesser lithic components (15-40% of framework grains). Grains are sub-rounded to sub-angular and range from medium sand to pebble. Cementation of the samples ranges from 20 to 30%. Sample CR13EO-32 and CR13EO-34 both have grains that are pebble-sized: CR13EO-32 is characterized by a large coral clast 25 mm x 6 mm in size and a lithic pebble that is 300 mm x 10 mm while CR13EO-34 has a lithic clast that is 20 mm x 15 mm in size. Other unique features include CR13EO-33 and CR13EO-34, which both have cement that have an orange/red hue.

Four beachrock samples from Playa Pleito (San Juanillo Norte) are composed of shell/coral (30-70%) and lithic fragments (30-45%). The grains are fine to very coarse sand and sub-prismoidal to sub-discoidal. Cement ranges from <10% to 30%. CR13EO-26 has a 25 mm coral clast and some intact shell fragments while CR13EO-29 has a fully intact 35 mm shell. Sample CR13EO-28 has multiple 7 mm shell fragments.

Four beachrock samples were collected at Playa Pelada in addition to one unconsolidated sand sample. Beachrock samples are poorly sorted, composed of a mixture of shells, lithic material and biological remains (sea urchin spines); up to 90% of the framework of CR13EO-01 is disaggregated shell fragments. Cement varies from < 5% to 25%, from samples CR13EO-01 and CR13EO-03 respectively. Grains varied from medium sand to pebble and sub-rounded to sub-angular.

The 12 Playa Garza samples display visual differences in cement color, extent, and lithology, across a stratigraphically continuous section. Cement ranges from < 5 % (CR13EO-05) to 30% (CR13EO-06 and CR13EO-22). Other than sample CR13EO-09 and CR13EO-24, the lithology is predominantly lithic pebbles, some up to 40 mm in size in CR13EO-10. Sorting ranges from well-sorted in CR13EO-22 to very poorly-sorted in CR13EO-21 and CR13EO-23.

Four beachrock samples and two unconsolidated sand samples were collected at Playa Carrillo. The grain size at Playa Carrillo ranges from medium to very coarse sand with sub-rounded to sub-discoidal grains. All of the samples from Playa Carrillo are weakly cemented and break easily, but cement could be seen with the naked eye in samples CR13EO-17

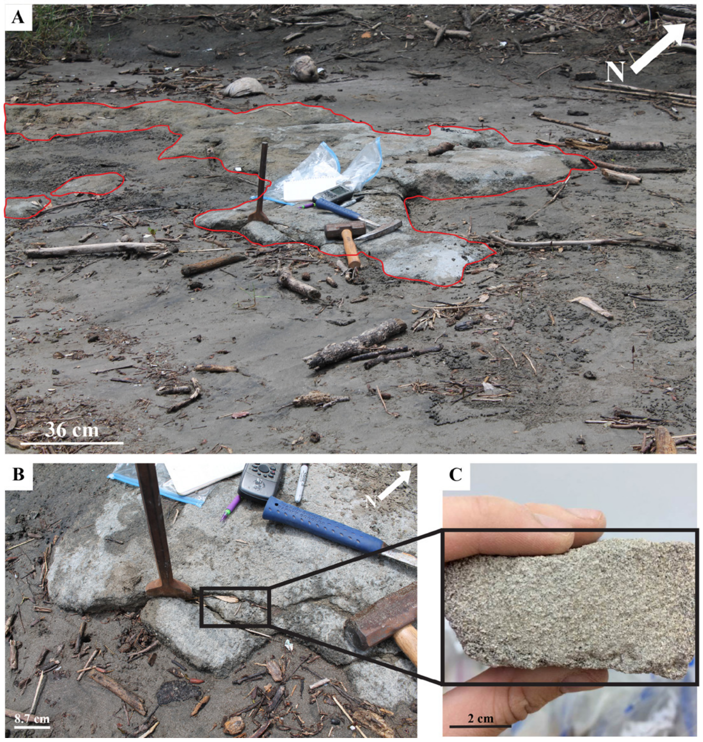

Figure 1: (A) Shows the outline of the beachrock horizon where CR13EO-19 was collected (B) Shows the up-close section where CR13EO-19 was sampled (665100.0, 1091584.0 UTM Zone 17N). (C) Hand sample view of sample CR13EO-19.

and CR13EO-18. Cement varied from 15-20% from CR13EO-18 and CR13EO-16, respectively. Sample CR13EO-19 (Figure 1) was chosen for further study based on the presence of obvious cement, ability to disaggregate and the presence of well-sorted, relatively homogenous grains.

Thin Section Analysis

Microscopic evaluation of the disaggregated grains of CR13EO-19 showed that the < 63 µm size in almost completely cement, comprising 98-100% crystals, 5-75 µm long and 5-10 µm wide. Increasingly larger fractions also contained a fraction cement as smaller crystals, which adhered to grains. The sieving process was successful at isolating the cement in the < 63 µm size but not in completely separating the cement from the framework grains.

Thin sections reveal the primary constituents of sample CR13EO-19 as aragonite cement, carbonate mud clasts, calcite crystals, plagioclase, biological material, and pyroxene. The cement makes up about 30% of the sample and forms needle-like crystals that form around the individual grains and fill void spaces. In sample CR13EO-19, cement is primarily < 63 µm (Figure 2), which was confirmed by observations of sieving splits.

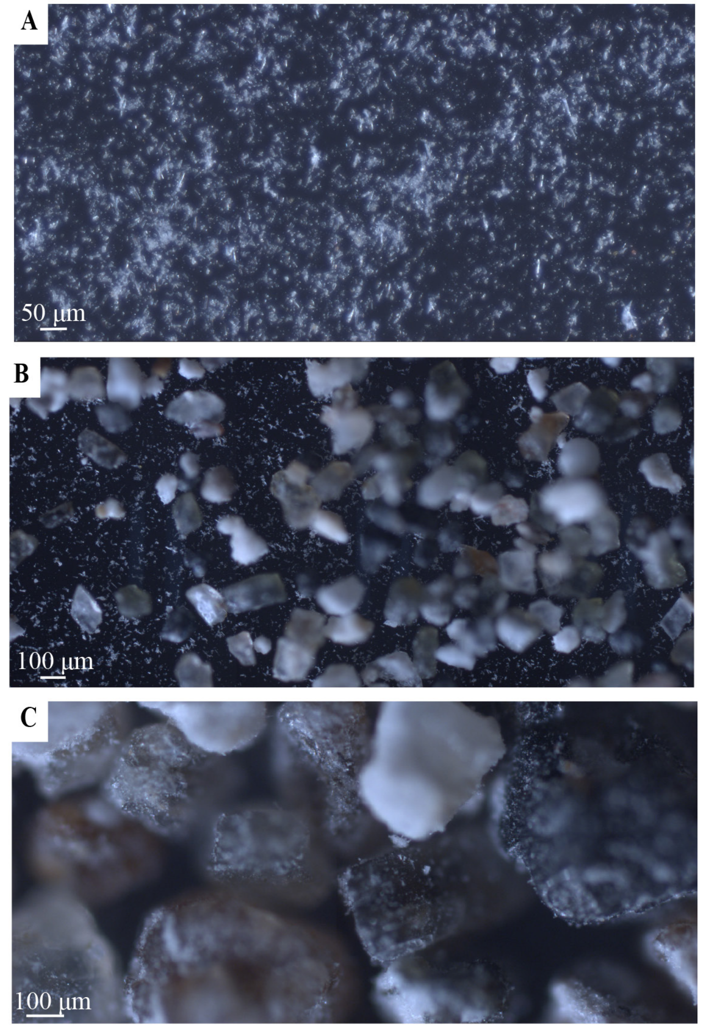

Figure 2: (A) The < 63 µm sample of CR13EO-19 with at least 95% cement crystals. (B) The > 63 µm of CR13EO-19. Individual cement crystals can be seen on the background of the slide. (C) The > 250 µm CR13EO-19 sample, focused to the larger grains present. Individual crystal grains are attached to larger grains.

Radiometric Ages

Radiocarbon dating of sample CR13EO-19 at the whole rock, > 125 µm, > 63 µm, and < 63 µm size revealed that the date of the samples is dependent on the size of the grains in the sample (Table 1). The cement is the youngest, whereas the coarse sand fractions are older than both the shell and whole-rock ages. The ages of the four samples do not overlap

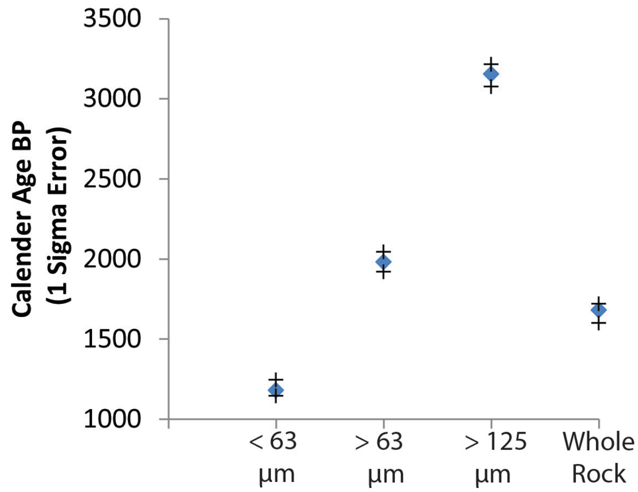

Figure 3: Graph showing the ages of all dated samples. The dates are shown as the intercept of radiocarbon age with the calibration curve. The error bars represent the 1 sigma calibrated variation. The < 63 µm sample is the youngest at 1180 +35/-65 ybp. The > 63 µm sample is 1980 +60/-65 ybp while the > 125 µm sample is the oldest at 3155 +80/-60 ybp. The whole rock sample is 1680 +80/-40 ybp.

(Figure 3), including a date from a whole shell collected in the same stratigraphic unit but 30 m to the west, CR13-CFCS1 (Freimuth, this volume).

DISCUSSION

Given that beachrock forms on the timescale of months to years (Frankel, 1968), a nearly 2,000 year age difference between rock elements is undoubtedly significant. Clearly, cementation is the last event and the < 63 µm sample, which is estimated to be 100% cement, has the youngest age. Larger size fractions are increasingly old, likely caused by a decreasing amount of cement mixed into the older framework grains of each size split. The whole rock date is the second youngest, which is a result of capturing the "young" cement and the "old" shells and other carbonate material. Relative to other samples dated at Playa Carrillo (Table 1), the whole rock date in this study is a bit young, even when compared to

Table 1: Table showing all of the dated beachrock from Playa Carrillo to date. CR13EO125, CR13MORE63, CR13EOWR, and CR13EOLESS63 were all dated as part of this study. CR12Q-01 and CRQ-01 were dated by Jeff Marshall (2012) and are both are whole rock dates. CR13-CFCS-1 is a whole shell dated by Fremuth (2014, this volume).

Sample Name	Location	Measured Age (BP)	Conventional Age (BP)	Calibrated Age Range (Cal BP)	Calibrated Calendar Age (Cal BP)
CR13EO125 (>125 microns)	Playa Carrillo	3170 +/- 30	3550 +/- 30	3125 to 3075	3155 +80/-60
CR13EOMORE63 (> 63 microns)	Playa Carrillo	2230 +/- 30	2600 +/- 30	2045 to 1920	1980 +60/-65
CR13EOWR (Whole Rock)	Playa Carrillo	1990 +/- 30	2300 +/- 30	1720 to 1600	1680 +80/-40
CR13EOLESS63 (<63 microns)	Playa Carrillo	1500 +/- 30	1860 +/- 30	1245 to 1145	1180 +35/-65
CR12Q-01*	Playa Carrillo, BR Horizon 2	2920 +/- 30	3240 +/- 30	2880 to 2680	2750 +70/-30
CR12Q-02*	Playa Carrillo, BR Horizon 1	2570 +/- 30	2920 +/- 30	2490 to 2280	2340 +80/-30
CR13-CFCS1**	Playa Carrillo	2400 +/- 30	2840 +/- 30	2420 to 2300	2300 +30/90

* sample dated by Jeff Marshall (2012)

** sample dated by Clayton Fremuith (2014) other whole rock ages, CR12Q-01 and CR12Q-02 (Marshall, 2012). The dated shell from nearby (CR13-CFCS1) is the second oldest (Fremuith, this volume), which therefore brings into question the age distribution of shells on Carrillo; the shell dated here could be an "old" anomaly, representative of all of the shells on the beach. But, how well does this single shell represent the age of biological material on the beach? Being whole, it might be assumed to be a "young" shell, which means that older, more broken up shell fragments help increase the age of the > 125 µm. If it is equal to or older in age to most of the shell fragments on the beach, then an even older source must exist, such as older micrite or organic carbonate or radiometrically "dead" Cretaceous limestone eroded from outcrops. The age range for sample CR13EO-19 indicates a 1,975 year age difference between the > 125 µm sample and the < 63 µm sample. This could be result of the > 125 µm sample being obscured to a higher degree by older carbonate present, whether it is older biological carbonate or radiometrically dead carbonate (Cretaceous limestone).

In order to explain the whole-rock age being the second to youngest age at 1680 +80/-40 Cal BP, I created 3 models: one based on weight percentage from the sieves, one from visual thin section estimates, another simply based on getting the whole rock age correct. (1) For the weight percentage model, the < 63 µm sample is estimated to be only 2%, the > 63 µm sample 5%, the > 125 µm sample 38% and the shell sample 10% of the sample. Given these percentages, the > 250 µm would constitute 33% of the whole rock sample and would need to be a mere 364 years old in order to maintain a whole rock date of 1670 Cal BP. Given the date of the cement, this is impossibly young and means that the sieving must have missed some cement. (2) The second model is based on visual thin section estimates. The < 63 µm fraction is estimated to be 30% of the sample. The > 63 µm sample is estimated to be 20%, the > 125 µm sample 12%, and the shell sample 12%. Given these percentages, the > 250 µm would constitute 25% of the rock and be 1,000 years old. This age is also younger than the < 63 µm sample and is therefore unreasonable (3) Lastly,

Table 2: Table that models the effect of cement percentage on radiometric age. Sieve fractions are actual mass measurements post sieving. Fraction cement is an estimate based on visual analysis.

	Sieve Fraction (g)	Fraction Cement*	Cement (g)	Shell (g)	Missing Carbonate (g)	Siliciclastics (g)
2 mm	14.4	0.05	0.72	1.44	0.288	12
1 mm	5.6	0.05	0.28	0.56	0.112	4.6
> 500 µm	8.7	0.1	0.87	0.87	0.174	6.8
> 250 µm	20.9	0.2	4.18	2.09	0.418	14.2
> 125 µm	33.8	0.3	10.14	3.38	0.676	19.6
> 63 µm	4.4	0.4	1.76	0.44	0.088	2.1
< 63 µm	1.4	1	1.4			0
Total	89.2		19.35	8.78	1.756	59.3
		% of Total	21.7	9.8	2	66.5
		Age	1180	2300	4090**	

*estimated

**resulting age of limestone or older organic carbonate based on radiocarbon ages and model percentages

I estimated 2,000 BP as a reasonable age for the > 250 µm sample, which was based on the ages of the shell and > 125 µm sample dates. If this were the case, the < 63 µm cement would need to constitute 60% of the carbonate portion of the sample, which is clearly incorrect.

Ultimately, these models suggest that reconciling the age distribution requires that the cement be included in sand size splits and/or that most of the framework grains are non-carbonate mineralogy. By examining sieved grains under a petrographic microscope, analysis shows that cement is still present up to the > 500 µm size, albeit in significantly smaller amounts as grain size increases (Figure 2). However, the effect of cement percentage on age can be modeled (Table 2). In this table, shell composition is estimated to be 10% of the carbonates, limestone (or old shells) is estimated to be 2%, and cement decreases with increasing sieve size. With these estimates, and ages for the cement and shell fragments, an estimate of limestone (and/or old carbonate) age of 4090 years gives a reasonable age for the missing material not specifically being samples for age dating.

CONCLUSION AND FUTURE WORK

This research shows that radiometric dates of whole beachrock are only maximum limiting ages. In order to obtain accurate dates of the cement and, therefore, the age of beachrock formation, it is important to understand the nature and age of the cement. This process is achieved by investigating and removing the cement by sieving or hand picking and by determining the age of the shell and cement material. By constraining the age of cementation of beachrock, the precision of beachrock ages is increased and therefore a more accurate uplift estimate for the peninsula can be determined.

In order to understand the applicability of this method, future work should focus on performing cement vs. whole rock dates on other beaches, especially along the Nicoya Peninsula. An increased database of these ages could hopefully lead to a “correction factor” that would enable the use of previously-dated whole rock beachrock ages. In addition, the models in this paper would benefit from our ongoing thin section analysis and point counts to better establish the real percentage of beachrock constituents.

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