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First investigations of tsunami deposits in the Dominican Republic - Results from field survey on the northeastern and southern coast

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Introduction

The Caribbean region is an area of a high tsunami risk, as various tsunami-generating mechanisms are present. Due to the geotectonic position of the Caribbean, strong earthquakes, capable of producing tsunami waves occur frequently. Tectonic processes also caused the formation of steep slopes, often bordering deep trenches, where tsunami can be triggered by submarine landslides (e.g., Hornbach et al. 2008, Grindlay et al. 2005). Tsunami generated by volcanic activity (e.g., Zahibo & Pelinovsky 2001) are of special significance in the eastern part of the Caribbean (i.e. the Lesser Antilles). In addition to local (distance of affected coastal areas to the source within 100 km) and regional tsunami (distance <1000 km), the Caribbean may also be struck by tsunami from a more distant source, like the tsunami generated by the 1755 Lisbon Earthquake, which affected several eastern Caribbean islands. O´Loughlin & Lander (2003) compiled a tsunami catalogue for the Caribbean region, covering a 500 year period from 1498 to 1998. According to these authors, 53 of 127 reported events can be attributed with certainty to tsunami activity. Of the remaining events, 8 were probable, 19 questionable and 44 very doubtful tsunami events. 3 cases definitely represented no tsunami activity. From 1998 to present 6 additional tsunami events were recorded (NGDC Tsunami Database). Although the Caribbean is frequently affected by tsunami, only a few studies on tsunami deposits exist from this area. Scheffers (2002) investigated boulder deposits on the islands of Aruba, Bonaire and Curacao, relating these deposits to 3 palaeotsunami events at ca. 3500, 1500 and 500 years BP. However, Spiske et al. (2008) questioned the tsunami origin of these deposits. Scheffers et al. (2005) studied boulder and bimodal deposits (gravel and boulders in a sandy matrix) on Guadeloupe, attributing these deposits to a tsunami event at about 2500-2700 years BP. Corresponding deposits on Grenada and St. Lucia were related to Pleistocene tsunami events by these authors. Evidence of Holocene tsunami on Barbados (4500 and 1400 years BP), St. Martin (500 years BP) and Anguilla (1500 and 500 years BP) have been found by Scheffers & Kelletat (2006). Jones & Hunter (1992) studied boulder deposits on Grand Cayman, discussing transport by tsunami waves for some of these boulders. Robinson et al. (2006), who investigated boulder deposits on Jamaica, assume that some large boulders on the northeastern coast were moved by the 1907 tsunami (2.5 m high tsunami following a magnitude 6.5 earthquake). Taggert et al. (1993) reported boulders from Isla de Mona (Puerto Rico), for which they also consider a tsunami deposition. Schubert (1994) interpreted coral gravel deposits at ca. 15 m above sea level near Puerto Colombia, Venezuela, as deposited by a large, prehistoric tsunami.

Only in Puerto Rico, detailed studies of fine-grained tsunami deposits, related to the 1918 tsunami and two prehistoric tsunami events (an older one at ca. 400 – 820 BC and a younger one at ca. 1270 – 1410 AD), have been carried out (Moya 1999).

Fig. 1: Areas of field work on the northern and southern coast of the Dominican Republic and other locations mentioned in the text. 1: Playa Coson, Peninsula de Samana, 2: Puerto Viejo, 3: southern coast between Santo Domingo and Boca de Yuma.

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In the present paper, results from field studies of fine-grained and boulder deposits, ascribed to tsunami events on coastal areas of the Dominican Republic, are reported.

Study area

Field studies have been conducted in the following areas (Fig. 1):
(1) Playa Cosón on the northern coast of the Samaná peninsula,
(2) Puerto Viejo near Azua in the southwest, and
(3) between Santo Domingo and Boca de Yuma on the southern coast.

Locations 1 and 2 are located in flat, partly swampy coastal lowlands, which provide good preservation potential for tsunami-deposited sediments. At these locations, field work has been carried out by hand drilling and digging of trenches. The area between Santo Domingo and Boca de Yuma is characterised by a rocky coast, formed by a Pleistocene carbonate platform (elevated a few metres above present sea level), making it a suitable area for the detection of wave-transported boulders.

For the Dominican Republic four significant historic

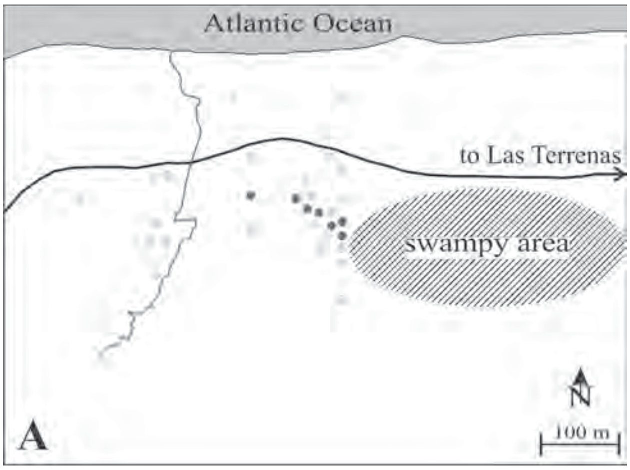

Fig. 2A: Map of the study area at Playa Coson showing trenches and drill holes where tsunami deposits were observed (dark dots) and those without recognisable tsunami sediments (bright dots).

Fig. 2B: General stratigraphy of locations where tsunami deposits occur (distance of this trench to the sea: 260 m): A sharp lower contact in a depth of about 20 cm between the tsunami sediments (bright, strongly carbonatic sand) and the underlying carbonate-free, silty clay (dark) is evident. Note the absence of tsunami sediments in the right corner of the trench. Scale (rule on top of the trench) is 1 m.

Fig. 2C: SW-directed flame structure (black circle), formed of tsunami sediment and underlying silty clay, observed in a trench located 255 m landward of the sea. Note the patchy appearance of tsunami sediments landward of the flame structure (a small lens is marked with a small circle). Scale is 1 m.

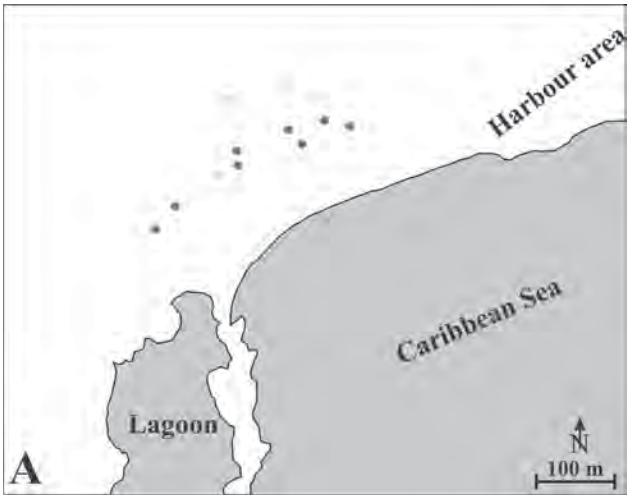

Fig. 3A: Map of the study area at Puerto Viejo showing trenches and drill holes where sandy sediments (the inferred tsunami deposits) were observed (dark dots) and those without the occurrence of sand (bright dots).

Fig. 3B: Drill core showing sandy, bioclast-rich sediments overlying bluegrey-coloured clay with sharp contact (slighty blurred) in a depth of about 49 cm. Core was taken 120 m landward of the sea.

Fig. 3C: Appearance of sand layer overlying bluegrey-coloured clay in a trench (sharp contact in a depth of about 34 cm). Distance to the sea is approx. 110 m.

Fig. 3D: Sand with marine bioclasts and gravel-sized rock fragments transported to the surface by burrowing organisms.

Fig. 4A: Largest boulder, observed near La Malena; boulder has a rectangular front side and a trapezoid horizontal projection. Boulder is located 30 m landward of the sea and approx. 5 m above sea level. Boulder dimensions are 7.7x4.0x1.7 m; weight ca. 72 t, lenght axis of the boulder is orientated parallel to shore. Person for scale (height 1.85 m).

Fig. 4B: Broken boulder near Bayahibe, located 45 m landward of the sea. Boulder dimensions are 5.9x1.8x1.1 m; lenght axis is orientated oblique (45°) to the shoreline. Scale: 1 m.

Fig. 4C: Imbricated boulders near Bayahibe, located approx. 40 m landward of the sea. Boulders dip towards the south (transport from right to left). Length of spade for scale is 1 m.

Fig. 4D: Shore-parallel (i.e. ENE-WSW) boulder ridge observed near La Uvita; distance to sea approx. 55 m.

Fig. 4E: 2 single boulders at Boca de Yuma, located 10 m landward and approx. 5 m above the sea. Scale: 1m.

tsunami events are recorded (O´Loughlin & Lander 2003; NGDC Tsunami Database). On the 4th of August 1946, an earthquake-generated (M_s=7.8; Cotilla et al. 2007) tsunami affected the northeastern coast. Maximum measured tsunami heights were 5 m at Nagua (named Julia Molina at that time; Fig. 1). Smaller wave heights (2.5 m), resulting, however, in considerably more damage, were reported from the town of Matanzas (named Matancitas today), located ca. 3 km southeast of Nagua (Lynch & Bodle 1948). An aftershock, occurring on the 8th of August, also triggered a tsunami, but no damage associated with this event has been reported. The northeastern coast was also affected by the 1755 Lisbon Tsunami, for which wave heights of 3.7 m are reported in the bay of Samaná (O´Loughlin & Lander 2003; NGDC Tsunami Database). On the southern coast, tsunami events are documented from Azua de Compostela, which seems to have been completely destroyed by a tsunami in 1751, and from Santo Domingo, where a 1.6 m tsunami was reported in 1842 (O´Loughlin & Lander 2003).

Results

Playa Cosón, Peninsula de Samaná: When surveying the region affected by the tsunami of 1946, only at one location, at Playa Cosón, definite sedimentological evidence of tsunami-induced deposition was observed. In the area of Matanzas, which was reportedly most affected, no field evidence for the 1946 Tsunami was detected (partly due to reconstruction and construction activities). Also, in apparently undisturbed areas north and south of Matanzas, no sedimentologically recognisable tsunami traces were found.

At Playa Cosón, tsunami deposits occur discontinuously along a NW-SE orientated stripe (Fig. 2A). Maximum distance of the tsunami deposits is about 260 m landward of the present shoreline (mean high tide level).

The following stratigraphy was observed (Fig. 2B): Brown-coloured, carbonate-free, silty clay is disconformidably overlain by a layer of ochre-coloured, strongly carbonatic, slightly cohesive fine sand. This carbonate sand is interpreted as deposited by one of the August 1946 tsunami events. A well-defined upper contact separates the sand from the overlying dark brown, carbonatic, sandy loam (post-tsunami limnic/fluviatile sediment, main zone of post-tsunami soil formation). The upper contact of the tsunami deposit lies at depths of about 8-12 cm, the lower contact to the brown clay between 20-50 cm below surface (depending on the thickness of the tsunami sand). Generally, thicknesses are 10-15 cm, with a maximum thickness of ca. 40 cm. Filling of pre-tsunami topographic lows (e.g., crab holes) is also evident. A flame structure, orientated perpendicular to the stripe (i.e. SW-directed) was observed in one of the trenches (Fig. 2C). The tsunami sand, which contains a few foraminifers from deeper water environments, like *Nuttalides*, *Cibicidoides*, *Lenticulina* and *Siphonina* (Scheucher et al. in prep.), appears as a massive layer without visible sedimentary structures and shows no optically-recognisable grain size variation in both, lateral and vertical directions.

Puerto Viejo, Azua: The town of Azua, which was once located at the sea, was abounded and rebuild at its present position after the destruction by a tsunami on the 18th of October, 1751 (O´Loughlin & Lander 2003). Sediments, possibly associated with this event, were detected at Puerto Viejo (which means old harbour in English; Fig. 3A). There, carbonate-rich, sandy sediments overlying loamy to silty, also carbonatic clay occur. Generally, there is a sharp contact between the sandy sediments (the possible tsunami deposits, Figs. 3B, 3C) and the underlying clay, but, due to bioturbation effects, this contact is often blurred. There is a gradual upper contact of the inferred tsunami sediments to the overlying brown loam (with soil development; Fig. 3C). The thickness of the sand varies from 15 to about 70 cm (greatest thicknesses were observed in former mangrove swamps). The proportion of bioclastic carbonate fragments, which are frequent in this sand, varies laterally (no spatial trend observable). Quartz, rock fragments (occasionally up to cm-size) and heavy minerals are macroscopically recognisable. A few individuals of well-preserved land snails are also present. In some of the drill cores and trenches graded bedding is weakly indicated. The sand layer occurs in distances up to 150 m landward of the present shoreline, which is also proven by sand, gravel-sized rock fragments and marine bioclasts transported to the soil surface by fossorial organisms (Fig. 3D).

Southern coast between Santo Domingo and Boca de Yuma: Wave-transported boulders have been investigated at various locations on the southern coast: near Las Americas International Airport, La Malena, Cumayasa, La Uvita, Bayahibe and Boca de Yuma (see Fig. 1). All boulders are composed of lithified coral limestone, originating from the local carbonate platform. Generally, the larger boulders (i.e. longest axis >1 m) occur as single boulders or accumulations of 2 to 4 boulders in distances of 30-50 m to the sea. Near La Uvita a several hundred metres long boulder ridge, located 30 to 50 m landward of the sea, has been observed (Fig. 4D). Imbrication of some boulders, which occur as accumulations or in the mentioned ridge, is evident (Fig. 4C). The largest observed boulder is located near the village of La Malena, occurring about 30 m landward of the sea and approx. 5 m above sea level (see Figs. 1 and 4A). Its dimensions are: 7.7 m (longest axis, orientated parallel to the shoreline), 4.0 m (shore-normal axis) and 1.8 m (height). Given the rectangular front side and a trapezoid horizontal projection, this boulder has a volume of approx. 40 m^3 and a weight of 72 t (assumed density: 1800 kg/m^3). A few boulders, like those seen on Fig. 4B, have been broken during impact. It seems likely, that this was a singular impact, happening at the end of the transport by the tsunami. In general, large boulders can also be transported by storm waves. However, a stepwise transport by a series of storm waves probably would have separated the two fragments more distinctly. Concerning the potential of storm waves to move large blocks, an observation from Boca de Yuma is interesting. Here, two single boulders (see Fig. 4E), deposited approx. 5 m above sea level and 10 m landward of the sea, were reportedly not moved during the passage of Hurricane Georges in 1998, although Georges made landfall as a major Category 3 hurricane only 15 km south of Boca de Yuma. Hydrodynamic equations (Nott 2003) can be used to determine storm and tsunami wave heights necessary to move a boulder. Applying these equations to the largest observed boulders (like those seen on Figs. 4A and 4B), storm wave heights of more than 25 m and tsunami wave heights from 6 to 8 m would be required to transport them. Thus, a tsunami origin, at least for the larger boulders, is more likely.

References

Cotilla, M.O., Cordoba, D. & Calzadilla, M. (2007): Morphotectonic Study of Hispaniola. - Geotectonics, **41**: 368-391.

Grindlay, N.R., Hearne, M. & Mann, P. (2005): High Risk of Tsunami in the Northern Caribbean. - EOS, **86**, 121-123.

Hornbach, M.J., Mondziel, S.A., Grindlay, N.R., Frohlich, C. & Mann, P. (2008): Did a submarine landslide trigger the 1918 Puerto Rico tsunami? - Science of Tsunami Hazards, **27**: 22-31.

Jones, B. & Hunter, I.G. (1992): Very Large Boulders on the Coast of Grand Cayman: The effects of Giant Waves on Rocky Coastlines. - Journal of Coastal Research, **8**: 763-774.

Lynch, J.J. & Bodle, R.R. (1948): The Dominican Earthquakes of August, 1946. - Bulletin of the Seismological Society of America, **38**: 1-17.

Moya, J.C. (1999): Stratigraphic and Morphologic Evidence of Historic and Pre-Historic Tsunami in Northwestern Puerto Rico. - Sea Grant College Program, University of Puerto Rico, Mayaguez Recint, 56 pp.

NGDC Tsunami Database: http://www.ngdc.noaa.gov/hazard/tsu.shtml

Nott, J. (2003): Waves, coastal boulder deposits and the importance of the pre-transport setting. - Earth and Planetary Science Letters, **210**: 269-276.

O'Loughlin, K.F. & Lander, J.F. (2003): Caribbean Tsunamis: A 500-Year History from 1498-1998. - Kluwer Academic Publishers, Dordrecht, 263 pp.

Robinson, E., Rowe, D.A.C. & Khan, S.A. (2006): Wave-Emplaced Boulders on Jamaica´s Rocky Shores. - Z. Geomorph. N.F., Suppl.-Vol. **146**: 39-57.

Scheffers, A. & Kelletat, D. (2006): New Evidence and Datings of Holocene Paleo-Tsunami Events in the Caribbean (Barbados, St. Martin and Anguilla). - (In: Mercado-Irizarry, A., Liu, P. (Eds): Caribbean Tsunami Hazard), World Scientific Publishing, Singapore, pp. 178-202.

Scheffers, A., Scheffers, S. & Kelletat, D. (2005): Paleo-Tsunami Relics on the Southern and Central Antillean Island Arc. - Journal of Coastal Research, **21**: 263-273.

Scheffers, A. (2002): Paleotsunamis in the Caribbean: Field Evidences and Datings from Aruba, Curacao and Bonaire. - Essener Geographische Arbeiten, **33**, Essen, 181 pp.

Scheucher, L.E.A., Vortisch, W. & Piller, W.E. (in preparation): First detection and detailed sedimentological analyses of tsunami deposits in the Dominican Republic: Playa Cosón, Peninsula de Samaná.

Schubert, C. (1994): Tsunamis in Venezuela: Some Observations on their Occurrence. - Journal of Coastal Research Special Issue, **12**: 189-195.

Spiske, M., Böröcz, Z. & Bahlburg, H. (2008): The role of porosity in discriminating between tsunami and hurricane emplacement of boulders - A case study from the Lesser Antilles, southern Caribbean. - Earth and Planetary Science Letters, **268**: 384-396.

Taggert, B.E., Lundberg, J.L., Carew, L. & Mylroie, J.E. (1993): Holocene reef-rock boulders on Isla de Mona, Puerto Rico, transported by a hurricane or seismic sea wave. - Geological Society of America Abstracts with Programs, **25**: 61-61.

Zahibo, N. & Pelinovsky, E.N. (2001): Evaluation of tsunami risk in the Lesser Antilles. - Natural Hazards and Earth System Sciences, **1**: 221-231.