Data report: geochemistry of volcaniclastic sediments drilled during IODP Expedition 310 in Tahiti[1]

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Chapter contents

Abstract

Variable amounts of volcaniclastic sediments are present in the carbonate rocks that were drilled in the Tiarei, Maraa, and Faaa areas seaward of the modern fringing reefs in Tahiti during Integrated Ocean Drilling Program Expedition 310. Twenty-four representative samples of volcaniclastic sediments from the Tiarei area, ranging in grain size from clay to boulder, were analyzed for major and trace element contents. The samples are variably altered, but the least altered ones are compositionally similar to the igneous rocks of the island of Tahiti. Four samples that were dated by the $^{40}Ar/^{39}Ar$ dating method range in age from 0.3 to 0.7 Ma. Age data combined with geochemical data indicate that the bulk of the volcaniclastic sediments originated from the younger (≤1.3 Ma) rock series in Tahiti. Most of the fine-grained samples were also analyzed for their total, organic, and inorganic carbon contents; the samples show a general decrease in carbon contents with depth.

Introduction

The island of Tahiti, at 17°50′S and 149°20′W, is a volcanic island belonging to a group of Neogene–Quaternary linear volcanic chains in French Polynesia, south-central Pacific. The drowned Pleistocene to Holocene reef terraces seaward of the modern fringing reefs in Tahiti were drilled during Integrated Ocean Drilling Program (IODP) Expedition 310 in order to study environmental change, including sea level rise following the Last Glacial Maximum (LGM) (Camoin et al., 2007; see the **"Expedition 310 summary"** chapter). A total of 632 m of mostly carbonate rocks were cored from several holes in the Tiarei (northern), Maraa (southern), and Faaa (western) drilling areas off the island during Expedition 310. Uncemented to poorly consolidated volcaniclastic sediments were also recovered in all drilling areas, albeit these mainly occur as fine-grained impurities in many of the carbonate rock units and as relatively thin units interbedded with the carbonate rocks. However, a ~36 m thick sequence of alternating sand, silt, clay, and pebbly/cobbly materials was drilled in the Hole M0008A reference site in the Tiarei area near the mouth of the Papenoo River, the largest drainage system in Tahiti (see the **"Tiarei marginal sites: Sites M0008, M0010–M0014, and M0022"** chapter). This report presents geochemical and age data

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for the volcaniclastic sediments recovered during Expedition 310 in order to provide background information for future detailed geochemical work on these materials.

Materials and methods

Fourteen samples from Hole M0008A in the Tiarei area have previously been analyzed for major element contents, except Na_2O, by energy dispersive polarized X-ray fluorescence (XRF) at Bremen University (Germany) (see the **"Tiarei marginal sites: Sites M0008, M0010–M0014, and M0022"** chapter). The contents of some trace elements, including Sr, Ba, Rb, Cu, Ni, and Zn, have also been analyzed. The samples include sand-silt-clay mixtures, pebbles, cobbles, and boulders. For this report, Na_2O contents of the previously analyzed samples were determined by inductively coupled plasma–optical emission spectrometry at the Scripps Institution of Oceanography (SIO), University of California, San Diego (USA). The precision of the Na_2O analysis based on repeated analyses of the international rock standard AGV-1 is ≤3.5%.

Three additional sand-silt samples from Hole M0008A plus two sand samples from Hole M0010A and one sand sample from Hole M0021B (all in the Tiarei area) were analyzed for major elements and trace elements Ni, Cr, Sc, V, Ba, Rb, Sr, Zr, Nb, Ga, Cu, Zn, Pb, La, Ce, Th, Nd, and U by XRF at the GeoAnalytical Laboratory at Washington State University (WSU) (USA). Information on methods, precision, and accuracy of the XRF analysis at WSU are available at **www.sees.wsu.edu/Geolab/index.html.** All samples previously and newly analyzed for major elements were analyzed for loss on ignition (LOI) values at SIO and WSU, respectively.

All the above samples plus four small amounts of sand-silt samples from Hole M0021B were also analyzed for trace elements, including Rb, Sr, Y, Ba, U, Th, and Pb and the rare earth elements (REE) La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er, Tm, Yb, and Lu by high-resolution inductively coupled plasma–mass spectrometry (ICP-MS) at SIO. Samples were prepared by digesting 25 mg of powder using the HF-HNO_3 method described by Janney and Castillo (1996). Digested samples were diluted 4000× in a solution containing 2.5 wt% nitric acid and 1 ppb In as an internal standard. Time- and mass-dependent instrumental drift was corrected for by applying a mass-interpolated internal standard correction and correcting measured sample concentrations using values of a well-analyzed in-house mid-ocean-ridge basalt (MORB) standard analyzed repeatedly throughout each run. Duplicate analyses of standards and a number of unknowns were conducted, each analysis in a different run. Reproducibility was generally high (≲3%), except for elements that have low (<0.2 ppm) concentrations.

Four fresh-looking coarse-grained (pebble to boulder size) volcaniclasts were dated by $^{40}Ar/^{39}Ar$ dating at the Noble Gas Mass Spectrometry Laboratory at Oregon State University (OSU) (USA). These include two large boulders that were originally suspected as parts of a pre-LGM lava flow in the upper section of Hole M0008A (see the **"Tiarei marginal sites: Sites M0008, M0010–M0014, and M0022"** chapter), a pebble in the lower section of Hole M0008A, and a pebble in Hole M0010A. Information on methods, precision, and accuracy of the $^{40}Ar/^{39}Ar$ dating method at OSU are similar to those described in Koppers et al. (2004) and are available at **www.coas.oregonstate.edu/research/mgg/chronology.html.**

Almost all fine-grained (sand, silt, and clay sized) volcaniclastics were also analyzed for total and inorganic carbon contents (organic carbon contents were calculated by mass balance) at SIO. Total carbon content was determined by combustion with O_2 using a Costech elemental analyzer in CHN mode. Inorganic carbon content was determined by reaction with phosphoric acid and measurement with a Thermo-Fisher Delta XP plus isotope ratio mass spectrometer with associated gas bench. Accuracy for total carbon measurement was 1%, whereas accuracy for inorganic measurement was 2%.

Results

Save for the highly calcareous volcanic sand Sample 310-M0021B-18R-1, 55–58 cm, anhydrous bulk rock analyses mainly plot in the basalt field (Table **T1;** Fig. **F1**) and overlap with the magmatic lineages identified in Tahiti (e.g., Duncan et al., 1987; Cheng et al., 1993). The majority of the volcaniclastic sediments are alkalic basalts that belong to the Series B magmatic lineage (0.6–1.3 Ma). It is important to note, however, that the samples are variably altered and therefore have low total weights of all major oxides (see the **"Expedition 310 summary"** chapter). Indeed, the samples have a large range of LOI values (Table **T1**), which are generally observed to positively correlate with degrees of alteration. However, although the fine-grained volcaniclastics unsurprisingly have higher LOI values (6–37 wt%) than the coarse-grained volcaniclasts (2–10 wt%), there appears to be no systematic compositional difference between the two groups in Figure **F1** except that the fine-grained volcaniclastics span a larger range of SiO_2 values. Moreover, the anhydrous oxides of the samples generally show coherent trends when plotted against MgO or TiO_2 contents (not shown). Therefore, although samples with high LOI values are most probably the most altered, it is difficult to constrain the effect of alteration on their major element composition based on LOI values alone. It is only after looking at their trace element contents that a better picture of the alteration effect on the samples emerged, as described below.

Volcaniclastic sediments have variable trace element contents, but as a whole they are generally enriched in highly incompatible relative to less incompatible trace elements (Fig. F2) as indicated by their La/Sm_N values of >1 (Table T1). Some of the samples, though, have uncharacteristically low concentrations of some incompatible trace elements such as Rb, Th, and REE, particularly the heavy ones, some of which are below the detection limit of the ICP-MS used (indicated by dashes in Table T1). These samples also have a saw-toothed pattern in spider diagrams (not shown). This trace element characteristic is shown by both fine- and coarse-grained volcaniclastics and is most probably due to alteration, but available LOI data again show that coarse-grained volcaniclasts with unusually low incompatible trace element contents do not systematically have higher LOI values than volcaniclasts with higher incompatible trace element contents. Among the fine-grained volcaniclastics, however, the low incompatible trace element content is definitely due to the dilution of the volcaniclasts by calcareous components as illustrated by the aforementioned highly calcareous sand Sample 310-M0021B-18R-1, 55–58 cm. More importantly, most of the incompatible trace elements generally correlate inversely with inorganic carbon contents, except Sr, which generally shows positive correlation (not shown). New data for the less altered samples confirm the general increase in highly incompatible elements with depth in Hole M0008A (Fig. F3; see the **"Tiarei marginal sites: Sites M0008, M0010–M0014, and M0022"** chapter).

One of the objectives of carbon content analysis (Table T1) is for possible future paleoenvironmental reconstructions such as carbon storage on exposed shelves during the LGM (e.g., Sifeddine et al., 2004; Montenegro et al., 2006). In Tahiti, the presence of a shoreline is suggested by a gray to orange color transition in the volcaniclastic sediments in Sample 310-M0008A-8R-1, 100 cm (see the **"Tiarei marginal sites: Sites M0008, M0010–M0014, and M0022"** chapter). A deep brown paleosoil horizon containing fine plant roots occurs directly below the color transition. In Hole M0008A, total carbon contents of the fine-grained volcaniclastics range from ~0.1 to 1.4 wt% above the transition and are <0.1 wt% below it (Table T1). Thus it would be difficult to investigate in detail the elemental and isotopic composition of organic carbon in the purported shoreline (Fig. F3). Another, though less distinct, gray–orange color transition occurs in the bindstone unit in Section 310-M0021B-19R-1 (see the **"Tiarei outer ridge: Sites M0009, M0021, and M0024–M0026"** chapter), which suggests another possible shoreline farther offshore in the Tiarei area. Here total carbon contents of the fine-grained volcaniclastics range from 6.0 to 11.5 wt% above the color transition and from 3.8 to 4.2 wt% below it (Table T1). However, organic carbon contents of the brown fine-grained volcaniclasts are only ≤0.1 wt%, and thus it would also be difficult to investigate the elemental and isotopic composition of organic carbon in the volcaniclastic sediments below the color transition at this site.

The four coarse-grained volcaniclasts analyzed by the $^{40}Ar/^{39}Ar$ dating method range in age from 0.3 to 0.7 Ma (Table T2). Although the two boulders in Hole M0008A have the same age, they are relatively old (~0.7 Ma) to be a lava flow that covered the LGM shoreline. Moreover, although one of the boulders is highly altered (Table T1), available data suggest that they may have come from two different lava flows (see the **"Tiarei marginal sites: Sites M0008, M0010–M0014, and M0022"** chapter). In general, the ages of the samples combined with major element data (Fig. F1) suggest that the bulk of the volcaniclastic sediments drilled during Expedition 310 were derived from the younger (≤1.3 Ma) rock series in Tahiti.

Summary

1. The volcaniclastic sediments drilled from offshore Tahiti during Expedition 310 are variably altered.
2. Unsurprisingly, the bulk composition of the least altered volcaniclastic sediments is similar to that of the volcanic and igneous rocks in Tahiti.
3. The bulk of the volcaniclastic sediments was derived from the younger (≤1.3 Ma) alkalic to highly alkalic (<0.6 Ma) rock series in Tahiti.
4. Age data suggest that there is no post-LGM lava flow in the Tiarei area.
5. Total carbon and organic carbon contents are low in the deeper sections of the fine-grained volcaniclastic sediments drilled from offshore Tahiti.

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Figure F1. Diagram of total alkalis vs. silica, recalculated on a volatile-free basis, for volcaniclastic sediments drilled in the Tiarei area in Tahiti. Solid circles = fine-grained volcaniclastic sediments, open triangles = more altered coarse-grained volcaniclast samples, solid triangles = less altered coarse-grained volcaniclast samples (high degree of alteration based on unusually very low incompatible trace element content). A, B, and C fields = magmatic lineages identified in Tahiti (e.g., Duncan et al., 1987; Cheng et al., 1993).

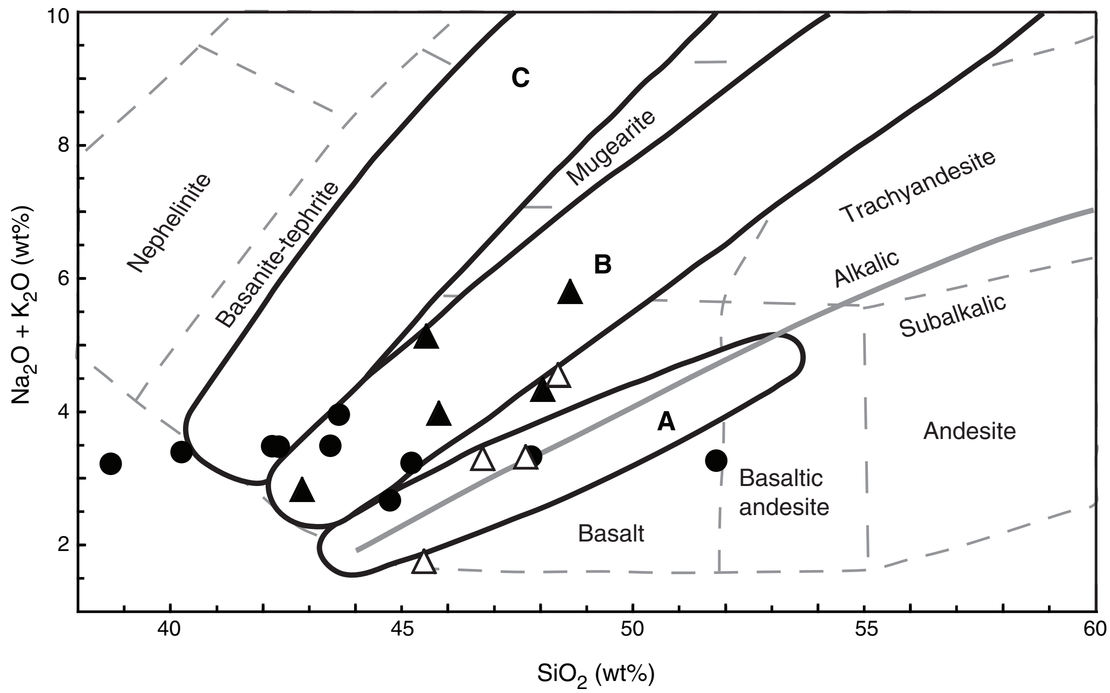

Figure F2. Primitive mantle–normalized incompatible trace element concentrations of the least-altered volcaniclastic sediments drilled from Tahiti. Solid triangles = coarse-grained volcaniclast samples. Gray lines enclose the field for Tahiti igneous rocks compiled in the GEOROC database (**georoc.mpch-mainz.gwdg.de/georoc/Entry.html**). Primitive mantle normalizing values are from Sun and McDonough (1989).

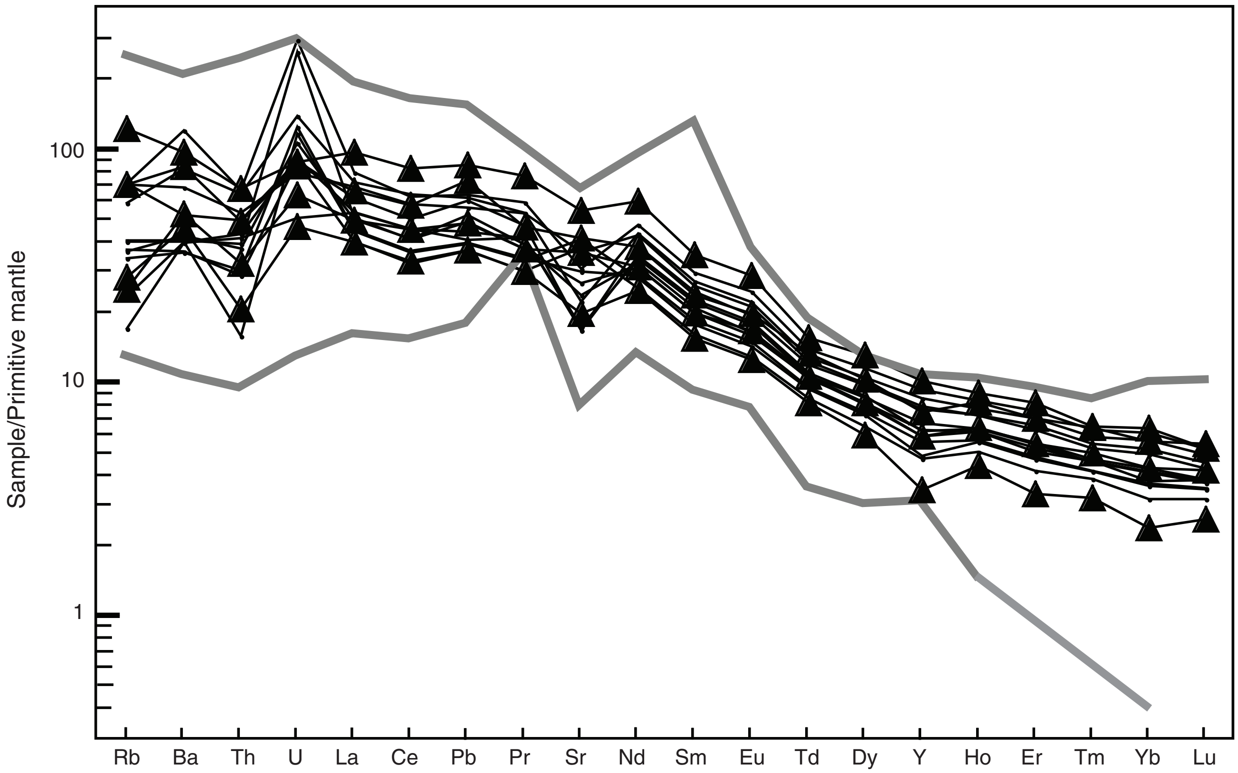

Figure F3. Plot of Ba, La, Ba/La, and organic carbon contents of the volcaniclastic sediments vs. depth, Hole M0008A.

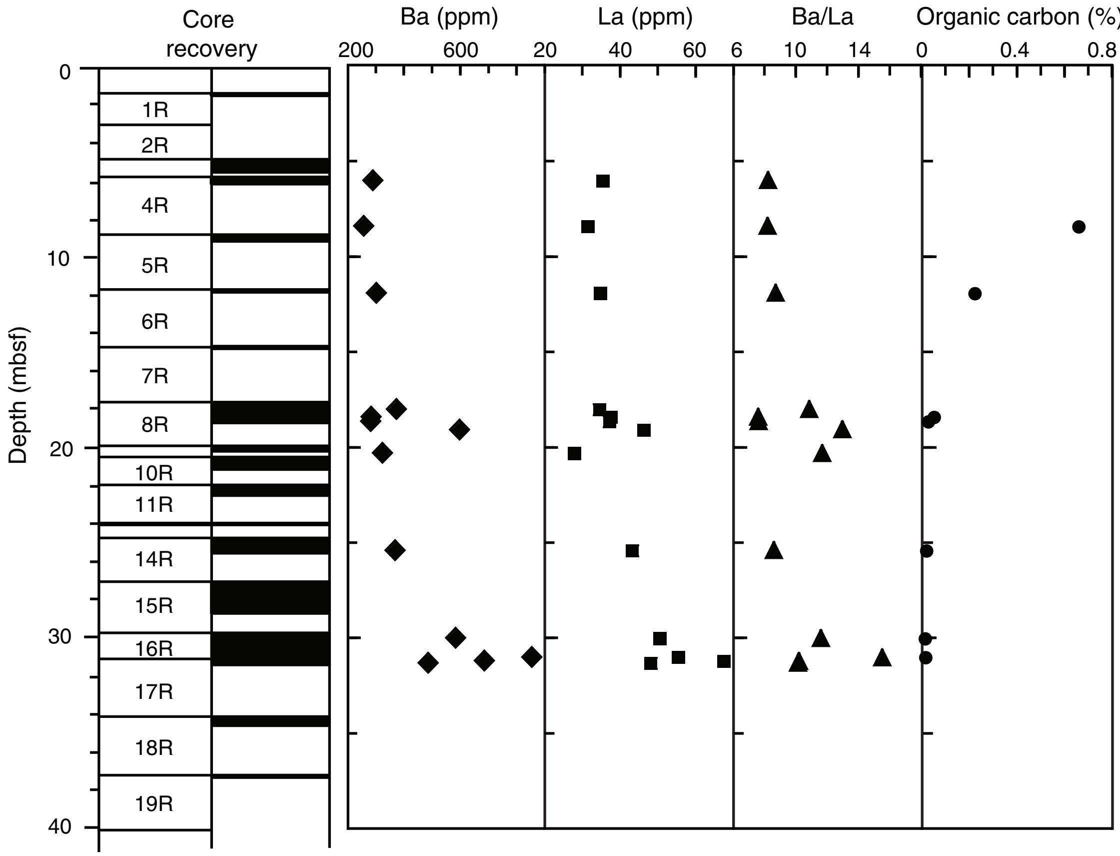

Table T1. Major and trace element analyses of volcaniclastic sediments. (See table notes.) (Continued on next three pages.)

Core, section: Interval (cm):	310-M0008A-4R-1 22–28	310-M0008A-5R-1 15–20	310-M0008A-6R-1 5–9	310-M0008A-7R-CC 4–13	310-M0008A-8R-1 42–51	310-M0008A-8R-1 61–80
Sample	Gray sand/silt	Gray sand/silt	Gray sand/silt	Boulder	Boulder	Cobble
Major element oxides (wt%)						
SiO_2	32.79	29.86	40.32	42.15	42.68	42.32
TiO_2	2.97	2.83	3.66	3.15	3.13	1.77
Al_2O_3	13.22	11.92	11.67	15.56	15.83	8.51
FeO*	11.72	10.91	12.82	10.94	11.03	9.75
MnO	0.15	0.14	0.17	0.16	0.17	0.17
MgO	9.99	9.67	10.44	4.98	6.04	16.76
CaO	7.63	9.12	10.15	9.58	9.98	*12.02*
Na_2O	1.98	1.79	2.16	1.79	2.65	1.21
K_2O	0.81	0.71	1.11	1.21	1.07	*0.44*
P_2O_5	0.30	0.26	0.36	0.69	0.66	0.14
LOI	10.36	11.56	6.45	1.90	2.18	1.88
Trace elements by XRF (ppm)						
Ni	241	248	244	50.9	54.1	381
Cr			732			
Sc			30			
V			327			
Ba	100	211	282	398	319	125
Rb	23.2	21.4	24	22.8	22.5	11.1
Sr	432	544	473	675	662	258
Zr			262			
Y			25			
Nb			38.7			
Ga			18			
Cu	54.1	61.2	58	93.9	88.2	45.2
Zn	104	97	127	95	94	*68*
Pb			2			
La			36			
Ce			62			
Th			2			
Nd			35			
U			5			
Trace elements by ICP-MS (ppm)						
Rb	26.1	21.9	23.4	9.6	16.0	4.5
Sr	570	636	504	365	770	185
Y	26.9	25.4	28.6	4.9	26.9	7.1
Ba	288	255	300	258	372	97
La	35.11	31.26	34.52	4.53	34.34	6.00
Ce	73.83	65.87	73.95	44.67	81.04	18.46
Pr	10.41	9.51	10.87	1.35	10.40	2.02
Nd	42.61	39.18	44.45	5.82	42.65	9.23
Sm	8.88	8.26	9.34	1.17	8.90	1.96
Eu	2.69	2.53	2.77	0.36	2.81	0.53
Tb	1.15	1.04	1.13	—	1.16	—
Dy	5.98	5.55	6.08	0.94	6.06	1.57
Ho	1.02	0.93	1.02	—	1.06	—
Er	2.44	2.32	2.53	0.31	2.64	0.48
Tm	0.34	0.31	0.34	—	0.37	—
Yb	1.87	1.83	2.07	0.15	2.13	0.21
Lu	0.29	0.26	0.28	—	0.31	—
Pb	3.5	2.8	3.7	5.4	3.5	2.0
Th	3.4	2.6	3.2	0.5	2.8	0.4
U	5.5	2.6	2.3	1.3	1.3	0.4
La/Sm_N	2.55	2.45	2.39	2.51	2.49	1.98
Carbon (wt%)						
Total	1.00	1.36	0.37			
Organic	0.68	0.66	0.22			
Inorganic	0.33	0.70	0.15			

Table T1 (continued). (Continued on next page.)

Core, section: Interval (cm):	310-M0008A-8R-1 84–89	Duplicate	310-M0008A-8R-1 107–111	Duplicate	310-M0008A-9R-CC 0–5	310-M0008A-10R-1 27–30	310-M0008A-14R-1 0–10
Sample	Gray sand/silt		Brown sand/silt		Pebble	Pebble	Pebble
Major element oxides (wt%)							
SiO_2	41.23	41.42	41.26		41.01	37.80	*44.03*
TiO_2	3.95	3.97	3.86		3.46	2.90	*4.07*
Al_2O_3	10.97	11.06	11.27		15.87	9.69	*16.50*
FeO*	14.71	14.57	14.55		11.14	11.61	9.29
MnO	0.15	0.15	0.15		0.18	0.17	*0.13*
MgO	10.82	10.90	11.57		4.33	14.22	*3.07*
CaO	6.17	6.21	6.84		8.96	9.12	*8.89*
Na_2O	2.02	2.00	1.72		3.19	1.56	2.14
K_2O	0.96	0.96	0.77		1.45	0.95	2.01
P_2O_5	0.29	0.29	0.31		0.51	0.25	*0.90*
LOI	8.22	8.22	7.46	7.35	3.83	9.74	5.77
Trace elements by XRF (ppm)							
Ni	403	405	448		66.1	453	*90.9*
Cr	862	875	778				
Sc	32	31	32				
V	320	326	308				
Ba	256	256	255		503	320	*750*
Rb	18	18	14		30.9	23.2	40.1
Sr	307	304	323		646	414	*754*
Zr	242	236	246				
Y	23	24	25				
Nb	40.8	40.3	42.4				
Ga	18	19	19				
Cu	65	64	52		113	67.8	*51.1*
Zn	145	147	129		99	98	*89*
Pb	1	3	2				
La	35	34	37				
Ce	63	68	66				
Th	3	9	3				
Nd	35	37	39				
U	2	1	1				
Trace elements by ICP-MS (ppm)							
Rb	15.0		10.9		45.3	18.1	17.5
Sr	369		357		887	419	612
Y	30.8		28.4		34.1	15.9	12.0
Ba	282		281		595	323	648
La	37.34		36.98		45.96	27.65	14.13
Ce	81.74		81.42		103.00	59.17	31.86
Pr	11.56		11.62		12.88	8.34	4.40
Nd	46.34		47.60		52.13	33.87	18.43
Sm	9.83		10.11		10.62	6.93	3.78
Eu	3.00		3.09		3.35	2.12	1.24
Tb	1.17		1.19		1.45	0.89	0.62
Dy	6.38		6.50		7.66	4.41	2.50
Ho	1.05		1.05		1.36	0.73	—
Er	2.67		2.62		3.39	1.61	0.90
Tm	0.35		0.34		0.48	0.24	—
Yb	2.12		2.04		2.78	1.18	0.58
Lu	0.29		0.28		0.41	0.19	—
Pb	3.2		2.9		5.3	2.6	5.5
Th	3.7		3.6		4.2	1.8	1.5
U	1.9		1.1		1.8	1.0	1.0
La/Sm_N	2.45		2.36		2.80	2.58	2.42
Carbon (wt%)							
Total	0.07		0.03	0.03			
Organic	0.05		0.02	0.02			
Inorganic	0.02		0.01	0.01			

Table T1 (continued). (Continued on next page.)

Core, section: Interval (cm):	310-M0008A-14R-1 24–28	310-M0008A-16R-1 55–60	310-M0008A-16R-1 115–120	310-M0008A-17R-1 0–5	310-M0008A-17R-1 10–15	310-M0008A-17R-1 18–23	310-M00010A-1R-1 22–26
Sample	Brown sand/silt	Brown sand/silt	Brown clay/sand	Pebble	Pebble	Pebble	Gray sand
Major element oxides (wt%)							
SiO_2	41.44	38.90	31.37	43.59	45.15	47.06	37.88
TiO_2	3.22	3.39	3.84	3.33	3.69	3.64	2.91
Al_2O_3	12.04	14.80	13.88	14.85	14.96	16.66	11.12
FeO*	14.20	14.44	14.93	10.96	10.51	10.25	11.06
MnO	0.16	0.21	0.36	0.15	0.16	0.16	0.14
MgO	4.96	5.15	2.95	5.59	4.48	5.08	10.50
CaO	1.36	1.60	1.44	9.37	7.63	9.98	12.77
Na_2O	1.91	1.97	2.02	1.57	3.36	2.46	2.14
K_2O	0.73	0.76	0.84	1.48	2.04	1.81	1.01
P_2O_5	0.05	0.23	0.32	0.58	0.88	0.88	0.32
LOI	21.07	16.98	21.72	2.13	2.38	1.37	10.30
Trace elements by XRF (ppm)							
Ni	230	305	286	100	30.8	73.3	243
Cr							646
Sc							29
V							266
Ba	288	279	324	361	523	480	262
Rb	35.8	29.6	37.5	31.2	56.8	40.5	22
Sr	287	370	422	609	808	722	782
Zr							223
Y							21
Nb							33.7
Ga							17
Cu	51.3	66.0	70.6	69.1	72.7	69.0	43
Zn	113	124	122	103	120	116	103
Pb							1
La							31
Ce							60
Th							2
Nd							33
U							3
Trace elements by ICP-MS (ppm)							
Rb	45.9	37.7	45.7	13.4	78.6	45.1	23.8
Sr	357	474	656	281	1166	773	803
Y	35.2	39.2	42.7	8.0	46.6	36.3	21.5
Ba	367	581	852	192	684	484	258
La	42.93	50.21	55.05	9.22	67.17	47.85	27.81
Ce	89.93	114.58	112.55	21.13	148.39	104.19	57.87
Pr	13.12	14.92	16.51	2.70	21.42	14.77	8.38
Nd	52.45	59.42	64.94	11.24	81.78	58.43	34.56
Sm	11.00	12.14	13.23	2.28	15.83	11.65	7.20
Eu	3.29	3.76	4.14	0.65	4.87	3.59	2.18
Tb	1.29	1.40	1.51	0.45	1.70	1.34	0.93
Dy	7.24	7.79	8.55	1.56	9.75	7.39	4.80
Ho	1.20	1.28	1.38	0.35	1.49	1.19	0.83
Er	3.16	3.40	3.66	0.54	3.95	3.03	2.03
Tm	0.41	0.44	0.47	—	0.48	0.39	0.29
Yb	2.58	2.81	3.03	0.33	3.17	2.44	1.57
Lu	0.34	0.37	0.39	—	0.39	0.32	0.24
Pb	4.3	4.4	4.6	3.8	6.2	4.0	2.6
Th	4.3	5.5	5.7	1.2	5.8	4.6	2.5
U	1.9	2.9	6.2	1.4	1.9	1.7	1.9
La/Sm_N	2.52	2.67	2.69	2.62	2.74	2.66	2.50
Carbon (wt%)							
Total	0.01	0.03	0.01				1.20
Organic	0.01	0.01	0.01				0.19
Inorganic	0.00	0.02	0.00				1.01

Table T1 (continued).

Core, section: Interval (cm):	310-M0010A-2R-1 23–27	310-M0021B-18R-1 32–33	310-M0021B-18R-1 55–58	310-M0021B-19R-1 11–13	310-M0021B-20R-1 83–85	310-M0021B-20R-1 116–118
Sample	Gray sand	Gray sand	Calcareous sand	Gray sand	Light brown sand	Light brown sand
Major element oxides (wt%)						
SiO_2	38.12		7.91			
TiO_2	3.10		0.79			
Al_2O_3	11.04		2.41			
FeO*	11.22		2.77			
MnO	0.15		0.04			
MgO	10.20		5.07			
CaO	12.82		43.23			
Na_2O	2.13		0.62			
K_2O	1.02		0.22			
P_2O_5	0.32		0.13			
LOI	9.42	35.23	36.92	25.75	16.98	22.10
Trace elements by XRF (ppm)						
Ni	230		47			
Cr	656		140			
Sc	30		7			
V	277		74			
Ba	260		49			
Rb	23		9			
Sr	751		3571			
Zr	232		68			
Y	21		5			
Nb	34.1		9.6			
Ga	16		3			
Cu	44		14			
Zn	106		26			
Pb	1		1			
La	28		1			
Ce	54		7			
Th	2		5			
Nd	33		7			
U	3		3			
Trace elements by ICP-MS (ppm)						
Rb	25.7	7.8	4.8	10.5	13.2	14.7
Sr	877	1893	2238	1435	580	751
Y	22.2	3.4	4.2	4.6	9.8	11.2
Ba	283	20	26	38	98	126
La	30.82	2.82	3.34	4.95	11.21	10.64
Ce	64.49	5.98	7.12	10.47	24.77	23.92
Pr	9.34	0.84	1.00	1.46	3.37	3.20
Nd	38.47	3.87	4.50	6.33	14.04	13.53
Sm	7.96	0.74	0.90	1.23	2.81	2.89
Eu	2.42	0.14	0.21	0.28	0.78	0.84
Tb	1.02	—	—	—	0.52	0.54
Dy	5.40	0.65	0.77	0.95	1.99	2.10
Ho	0.92	—	—	—	—	—
Er	2.26	0.12	0.20	0.24	0.72	0.77
Tm	0.31	—	—	—	—	—
Yb	1.79	—	0.02	0.04	0.46	0.52
Lu	0.26	—	—	—	—	—
Pb	2.8	0.8	0.7	1.5	2.1	2.1
Th	1.4	0.5	0.5	0.5	1.5	1.5
U	2.5	2.2	1.7	1.9	2.0	2.6
La/Sm_N	2.50	2.46	2.39	2.59	2.58	2.38
Carbon (wt%)						
Total	1.23	11.46	5.99	7.31	3.83	4.18
Organic	0.17	0.20	0.96	0.19	0.05	0.13
Inorganic	1.06	11.26	5.02	7.12	3.78	4.05

Notes: LOI = loss on ignition, XRF = X-ray diffraction, ICP-MS = inductively coupled–mass spectrometry. — = below detection limit, empty cells = not analyzed.

Table T2. Clast ages.

Hole, core, section, interval (cm)	Clast type	Data type	Age (Ma)	± (Ma)
310-				
M0008A-7R-CC, 4–13 cm	Boulder	Weighted plateau	0.66	0.03
M0008A-8R-1, 42–51 cm	Boulder	Weighted plateau	0.69	0.03
M0008A-17R-1, 18–23 cm	Pebble	Normal isochron	0.64	0.06
M0010A-20R-1, 8–14 cm	Pebble	Weighted plateau	0.33	0.04