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Radiocarbon ages of alpine humic soils samples from the Marcapata district in the Eastern Cordillera of the Peruvian Andes

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1. Introduction

In the study of Quaternary geomorphological and geological features, determining the numerical age is crucial to deriving information on geomorphic developments and environmental changes. In particular, the radiocarbon age dating of alpine soils serves as an important indicator for environmental changes (e.g., slope stabilization and successive vegetation invasion on slopes) in mountainous areas (e.g., Kariya, 2005; Kariya *et al.,* 2013).

In this paper, we present the ^{14}C dating results of 10 alpine soil samples collected from the Peruvian Andes. Glacial advances and retreats, and expansion and shrinkage of periglacial environments have occurred in the area since the late Pleistocene. The radiocarbon age data presented in this study will be useful to derive the paleoenvironmental conditions of the Central Andes.

2. Study Area

Our field survey was conducted in Marcapata District, located about 90 km east of the City of Cusco (Figs. 1 and 2). This alpine zone belongs to the Eastern Cordillera of the Peruvian Andes. Natural environmental conditions (e.g., climate, vegetation, and landforms) and traditional agro-pastoral activities in the area are

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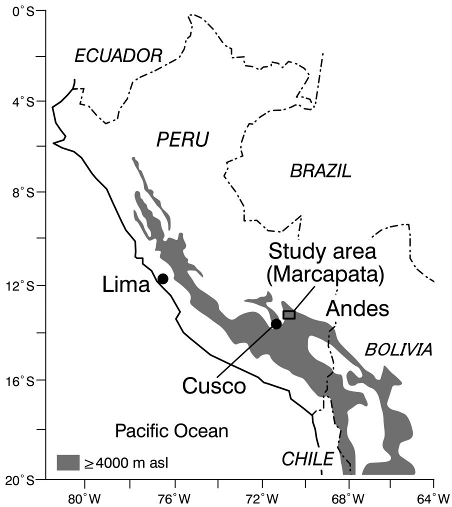

Figure1 Study area

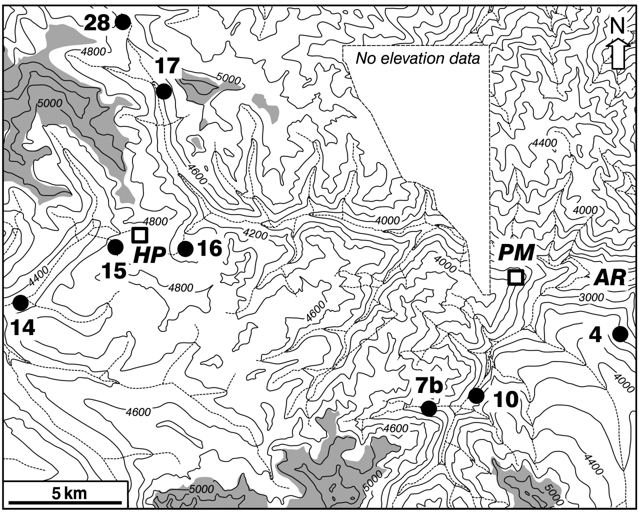

Figure 2 Location of the study sites

AR: Aras River, PM: Pueblo Marcapata (central settlement), HP: Hualla Hualla Pass. Grey areas show the location of perennial snow patches and glaciers.

described by previous authors (Yamamoto, 1980, 1992; Kariya and Sasaki, 2015).

3. Methods

Description of soil profiles of geological outcrops and in situ soil pits are presented in Fig. 3 and Table 1. Soil material for ^{14}C dating was carefully sampled and then analyzed in Japan. All samples were first sterilized and then dried at 200℃ for 2 hrs in the facilities at Chiba University. Chemico-physical pretreatment and ^{14}C dating were carried out in the Radiocarbon Dating Laboratory at Tohoku University and in the Institute of Accelerator Analysis Ltd. Chemical pretreatment consisted of acid-alkali-acid washing with 1N hydrochloric acid, 2% sodium hydroxide solution, and 6N hydrochloric

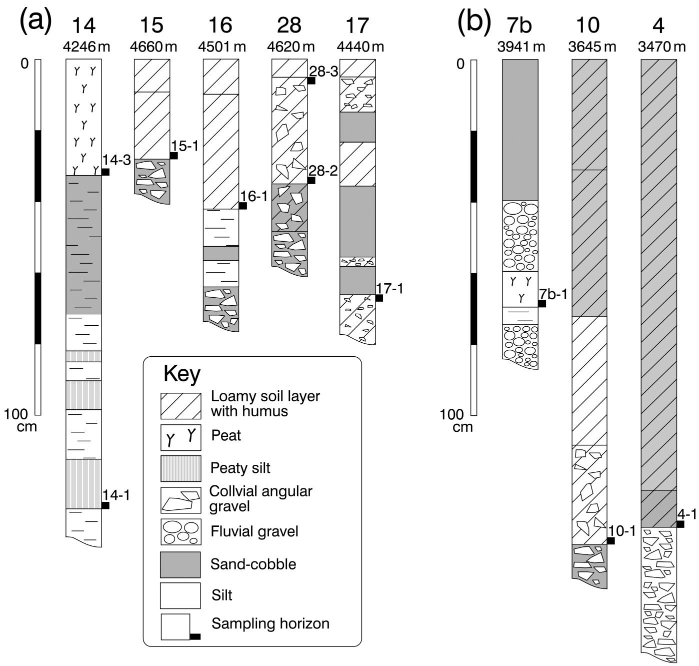

Figure 3 Soil columns of the study sites
(a) Western part of the study area and (b) eastern part of the study area.

Table 1 Geographic location of the study sites

Site	Latitude[1)]	Longitude[1)]	Altitude[1)]	Master landforms
4	13°36′40.08″S	70°56′57.47″W	3470 m	Landslide slip-plane
7b	13°38′36.65″S	71°01′23.29″W	3941 m	Floodplain of glacial valley
10	13°38′26.40″S	71°00′41.14″W	3645 m	Moraine in glacial valley
14	13°36′04.44″S	71°11′30.06″W	4246 m	Floodplain of glacial valley
15	13°34′41.26″S	71°09′15.84″W	4660 m	Moraine in cirque
16	13°34′48.88″S	71°07′31.21″W	4501 m	Moraine in cirque
17	13°30′50.90″S	71°08′15.94″W	4440 m	Moraine in glacial valley
28	13°29′53.32″S	71°08′49.43″W	4620 m	Side slope of glacial valley

[1)] Geographic position was determined using a handy GPS logger (Garmin Geko201).

Table 2 Radiocarbon dating results

Locality	ID	Material	^{13}C (‰)	^{14}C age (y BP, 1σ)	Calendar age (SHCal13 BP; 2σ) with probabilty distributions (%)		Lab. code
Site 4	4-1	Humus	−20.6	4086±85	4828-4344 (92.5)	4334-4295 (2.9)	IAA 614
Site 7b	7b-1	Peat	−26.8	3365±75	3818-3795 (1.5)	3724-3380 (93.9)	IAA 615
Site 10	10-1	Humus	−23.5	4681±97	5588-5046 (95.4)		IAA 616
Site 14	14-1	Peaty silt	n.d.	8610±60	9684-9465 (95.4)		TH 2067
	14-3	Peat	n.d.	2350±40	2459-2296 (71.7)	2268-2176 (22.9)	TH 2068
					2171-2161 (0.8)		
Site 15	15-1	Humus	−25.5	809±87	905-861 (4.8)	841-830 (0.8)	IAA 617
					820-556 (89.8)		
Site 16	16-1	Humus	n.d.	3460±40	3828-3787 (10.1)	3779-3569 (85.3)	TH 2064
Site 17	17-1	Humus	−24.0	1487±96	1565-1177 (95.1)	1128-1120 (0.3)	IAA 618
Site 28	28-2	Peaty silt	n.d.	3660±40	4085-3830 (95.4)		TH 2065
	28-3	Peaty silt	n.d.	2840±40	3020-3015 (0.4)	3005-2779 (95.0)	TH 2066

acid in RDL and acid washing with 1N hydrochloric acid in IAA. The half-life period of ^{14}C was referred as 5570 years.

The radiocarbon dates were corrected using the measured concentration of δ^{13}C. However, no correction for isotope fractionation was carried out on the data analyzed in the Tohoku University laboratories as no measurement of δ^{13}C concentration was carried out at TU. Furthermore, all of ^{14}C ages were calibrated to calendar ages by employing the OxCal 4.2 package (Bronk Ramsey and Lee, 2013) with SHCal13 calibration curve (Hogg *et al.*, 2013). Calibrated calendar ages were represented considering a 2-sigma error confidence interval (Table 2).

4. Study Sites

4.1. Hualla Hualla Pass Area

The Hualla Hualla Pass is located in the western part of Marcapata District (Fig. 3 and Table 1). This area is characterized by smooth glaciated slopes, valleys, cirques, and valley floors composed of glacial outwash debris.

Site 14: this site is located in the flood plain of the glaciated valley floor to the west of the Hualla Hualla Pass. The flood plain at this site is relatively wet and covered with short grass. The flood plain is used for livestock grazing (e.g., llama, alpaca, and sheep). The soil profile reveals an alternation of peat, silt, and peaty silt layers (Fig. 3).

Site 15: this site is located on a small moraine, in the proximity of a small glacial lake found at the cirque bottom. The slopes in the surrounding area are covered by short grass and used for pasture. The soil profile shows the presence of a thin humic loamy soil layer underlying glacigenic debris.

Site 16: this site is located on a small moraine at the valley head cirque, east of the Hualla Hualla Pass (Fig. 4). Slopes around this site too are used for pasture and are covered with short grass. A thick humic layer of soil is observed in the profile.

4.2. Quico Valley

The Quico Valley is an elongated valley formed by the Pleistocene and Holocene glaciations; it represents the uppermost tributary valley of the Aras River, which runs through Marcapata District. The Quico Valley is situated north of the Hualla Hualla Pass.

Site 28: this site is located on the side slope of a glaciated valley.

Figure 4 Soil pit at site 16
Photographed in July 2004.

The site and surrounding areas are used for pasture. Ground surface is covered with short grass and is used for livestock grazing. Thin humic soil layers containing angular gravel are observed.

Site 17: this site is located on a lateral moraine surrounded by pasture land. Short grass covers extend widely over the slopes and the surrounding areas. Humic soil layers containing angular gravel are also observed at this site.

4.3. Chumpi Valley

The Chumpi Valley is the tributary of the right bank of Aras River. The uppermost part of the Chumpi Valley reaches the northern face of the Ausangate Massif.

Site 7b: this site is situated on the flood plain of a meandering river, which runs in the glaciated valley. Slopes around this site are used for pasture and are covered with short grass. The flood plain is mainly composed of fluvial sand and gravel; thin peat layers between sand and gravel layers occur.

Site 10: this site is located on the lateral moraine of the central part of the Chumpi Valley. In this area, potato cultures are cultivated. A humic soil with intercalating sand and gravel characterize the vertical profile.

4.4. Eastern Pueblo Marcapata

Two broad ridges are found in eastern side of the Pueblo Marcapata settlement. These were eroded by glaciation and periglaciation during the late Quaternary period.

Site 4: this site is located on the upper part of a landslide-slip surface, found on the side of a broad ridge. Potato and corn are cultivated in the area. A thick humic soil is observed at this site. This soil covers an angular gravel layer, derived from talus deposits.

5. Results and Preliminary Interpretation

Radiocarbon ages are listed in Table 2. Interpretation and implications from radiocarbon data at each site are briefly discussed.

Site 14: the estimated age of sample 14-1 (9684-9465 cal BP) indicates that genesis of the peaty soil occurred in the early Holocene. This soil type genesis reveals that slope stabilization and subsequent vegetation invasion took place before this age range. The age of sample 14-3 (2459-2161 cal BP) corresponds to an onset of peat accumulation that occurred during the middle Holocene.

Site15: the age of sample 15-1 (905-556 cal BP) indicates the invasion of vegetation on slopes and successive soil genesis in the cirque. Conversely, the slopes around site 15 would have been covered with perennial snow or ice before this period.

Site 16: the age of sample 16-1 (3828-3569 cal BP) corresponds to that of vegetation invasion and soil genesis at the cirque, which occurred in the earliest part of the late Holocene. Similar to site 15, slopes in the proximity of site 16 were blanketed by a perennial snow patch, or by an ice body, until ca. 4000-3500 cal BP.

Site 28: the age of sample 28-2 (4085-3830 cal BP) relates to geomorphic stabilization of the deglaciated valley slopes and subsequent invasion of vegetation on slopes. Whereas the age estimated for sample 28-3 (3020-2779 cal BP) reveals that mass-movement of debris from the surrounding slopes continued. After this period, such slope movements had probably ceased.

Site 17: the age of sample 17-1 (1565-1120 cal BP) is linked to late Holocene slope destabilization on the moraine slopes. Evidence from the soil profile suggests that the debris movement might have occurred three times at this site.

Site 7b: the age of sample 7b-1 (3818-3380 cal BP) indicates decreasing fluvial debris transport in time and successive peat accumulation. The peat layer appears to be buried by the subsequent deposition of debris, possibly due to more recent fluvial action.

Site 10: the age of sample 10-1 (5588-5046 cal BP) indicates invasion of vegetation on the top and side areas of the moraine slopes and subsequent soil genesis during the middle Holocene. Immediately after this time, movement of rock clasts, along the ground surface and shallow subsurface appears to have continued for a short period until slope movement ceased.

Site 4: the age of sample 4-1 (4828-4295 cal BP) is linked to debris deposition, possibly due to head scarp landsliding occurred before this time. This age also indicates that landslides occurred before this and the onset of soil genesis under stabilized slope condition occurred after this.

6. Concluding Remarks

In order to estimate the timing of soil genesis and the change in pedo-environments in the Eastern Cordillera of Peruvian Andes, radiocarbon dating of 10 alpine soil samples was carried out. Dating results demonstrate that all of the 10 soil samples date back to the Holocene epoch. These data allowed estimation of the temporal occurrence of glacial fluctuations, periglacial environments, slope stabilization, and invasion of vegetation on the slopes and proximal areas.

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