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Age, source, and distribution of Holocene tephra in the southern Kurile Islands: Evaluation of Holocene eruptive activities in the southern Kurile arc

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ABSTRACT

We identified 32 distinct layers of Holocene tephra in the southern Kurile Islands on the basis of petrological features and ^{14}C ages of soils beneath or above the tephra layers. Three layers were derived from the volcanoes of Kunashir Island: one from Mendeleev volcano (ca. 2.6 cal ka) and two from Tyatya volcano (1420 cal. BP and AD 1973). Fourteen widely distributed silicic tephra layers were derived from four volcanoes in Hokkaido: Mashu, Rausudake, Tarumai, and Hokkaido-Komagatake. A widespread tephra was derived from Baitoushan volcano, between China and North Korea. Fourteen tephra layers have unknown source volcanoes: 1 silicic medium-K ash, 2 silicic low-K ash, and 11 scoria/pumice ash layers. Except for the medium-K ash, these tephra are presumed to be derived from the volcanoes in the Kurile Islands. It has been known that caldera-forming eruptions occurred at Mashu (Hokkaido) and Lvinaya Past (Iturup) volcanoes in the early Holocene (ca. 12–8 ka). However, we did not find any tephra from Lvinaya Past volcano. Our results provide evidence of the temporal and spatial evolution of eruptive activity in the southern Kurile arc. We conclude that the level of the eruptive activity in the southern Kurile Islands (especially Kunashir Island) has been lower than that in eastern Hokkaido since 8 ka. The islands produced mainly vulcanian and strombolian eruptions of mafic magma, whereas eastern Hokkaido produced plinian eruptions of silicic magma repeated at intervals of 1000–2000 years.

1. Introduction

Tephra layers are useful time markers in sedimentary sections in outcrops and deep-sea cores, because they are synchronous over large areas. For this purpose, it is essential to correlate the tephra layers from different localities on the basis of age data and petrological features such as mineral assemblages, shapes and refractive indexes of glass shards, and glass and mineral chemistry. It has been reported that glass chemistry is a powerful tool for correlation (e.g., Smith and Westgate, 1969; Larsen, 1981; Westgate and Gorton, 1981). The precise correlation method using glass chemistry has been also adopted in recent many cases (e.g., Santacroce et al., 2008; Wulf et al., 2008). Moreover, tracing tephra layers to their source volcanoes has allowed researchers to construct an eruptive history for these volcanoes as well as evaluate the activity of volcanic fields (Hasegawa et al., 2009, 2011; Marra et al., 2014; Tomlinson et al., 2014).

The Kurile arc is one of the most active volcanic zones in the world (Gorshkov, 1970), extending from Hokkaido (Japan) to Kamchatka (Russia) (Fig. 1). Its activity includes major caldera-forming eruptions during the Holocene (Melekestsev et al., 1988; Braitseva et al., 1994, 1995). Although many tephra layers exist on each island of the arc, the fundamental research focusing on their source volcanoes for stratigraphic and chronologic purposes has been adequate only for Chikurachki and Fussa volcanoes in the northern Kurile Islands (Belouzov et al., 2003; Hasegawa et al., 2011) and Tyatya (Chachadake) volcano in the southern Kurile Islands (Nakagawa et al., 2002). Although there is research about tephrostratigraphy in Holocene deposits in the southern Kurile Islands (Razzhigaeva et al., 1998; Nakamura et al., 2009), it could not identify source volcanoes for many tephra layers due to the limited survey area as well as inadequate information on possible source volcanoes.

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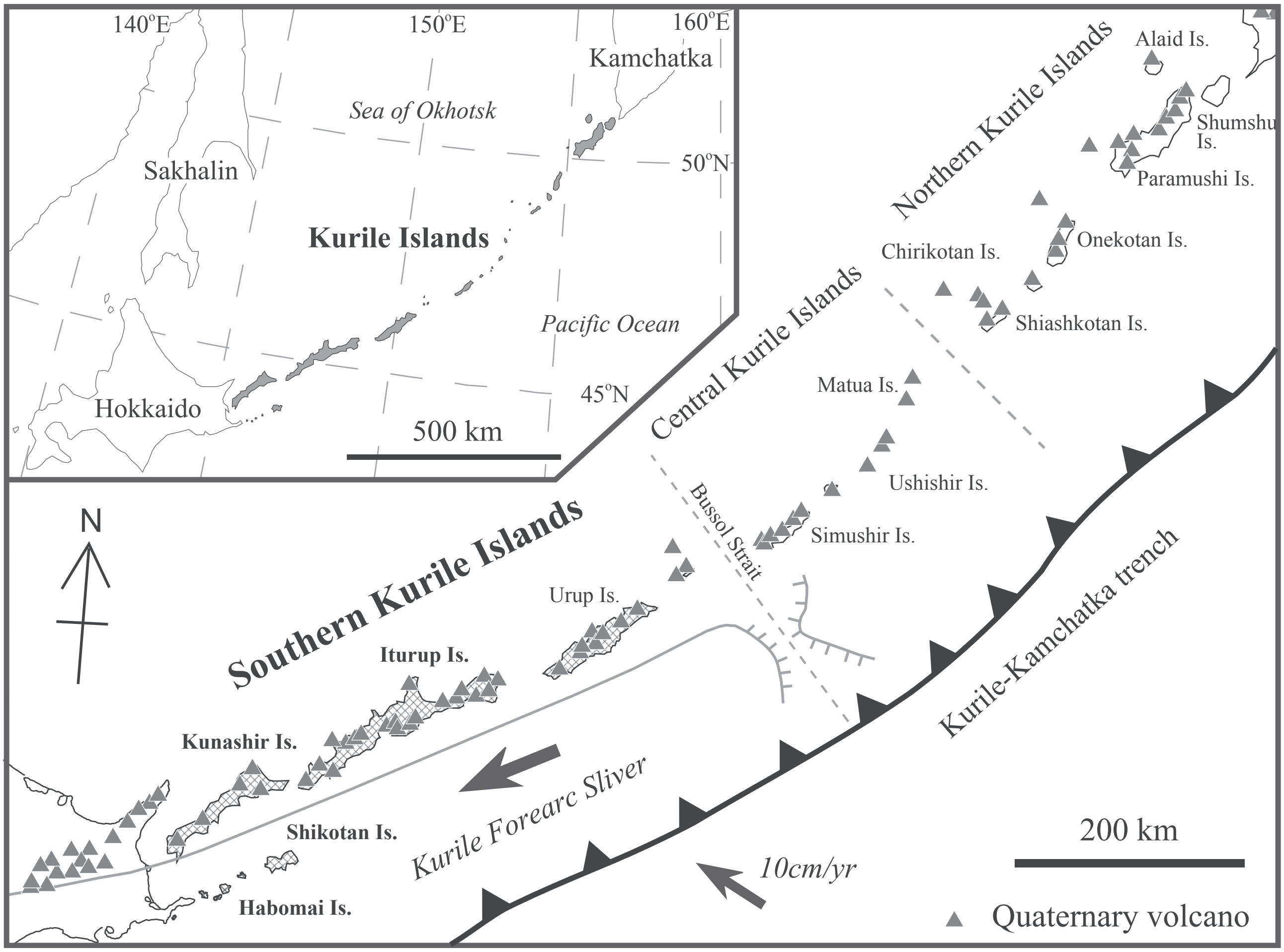

Fig. 1. Map of the Kurile arc. The tectonic setting (Kimura, 1986) and Quaternary volcanoes (Gorshkov, 1970; Zhuravlev et al., 1987) are also shown. Inset map exhibits the Kurile arc locality.

Recent studies have elucidated the stratigraphy of Holocene deposits of the southern Kurile Islands, such as Iturup (Etorofu), Kunashir (Kunashiri), Shikotan, and the Habomai group (Fig. 2) using biostratigraphic methods (pollen, diatoms, botanical analysis) and radiocarbon (^{14}C) dating (Korotky et al., 2000; Razzhigaeva et al., 2002, 2008, 2009). These deposits also contain many tephra layers, but neither their correlation among investigated sites nor their source volcanoes are well understood. In this study, we determined the ages and sources of these tephra layers on the basis of ^{14}C dates and glass chemistry to construct a Holocene tephrostratigraphy for the southern Kurile Islands. This outcome was made feasible by recent tephrostratigraphic research in Hokkaido adjacent to our study area. We used this new information to evaluate the eruptive activity in the southern Kurile Islands and compare it with that in Hokkaido and the southern Kurile arc.

2. Tectonic setting and general geology around the southern Kurile Islands

The detailed tectonic setting of the Kurile arc has been documented by Gorshkov (1970) and Kimura (1986). Kimura (1986) divided the arc into the northeastern and southwestern Kurile arcs, separated by the trough of Bussol Strait (Fig. 1). These arcs differ in their arrangement and geomorphic features. The dip angle of the subducting Pacific plate is 48–55° in the northeastern arc and 38–46° in the southwestern arc (Avdeiko et al., 1991). This study focused on the southwestern Kurile arc (called “southern Kurile arc” hereafter).

The Kurile arc consists of two sets of islands, the Lesser Kurile and Greater Kurile chains (Gorshkov, 1970). The Lesser Kurile chain is a short extension of the Nemuro Peninsula of easternmost Hokkaido and includes the Habomai Islands and Shikotan Island as well as the submarine Vityatz Ridge. It consists mainly of igneous rocks of Cretaceous and Paleogene age (Lelikov et al., 2008). The Greater Kurile chain extends for 1150 km from Hokkaido to Kamchatka, and has more than 30 Quaternary volcanoes (Fig. 1). In the southern Kurile arc, this chain includes Urup, Iturup, and Kunashir Islands. Many volcanoes in this area have had historical eruptions, and some of them are under intense fumarole activity at present (Gorshkov, 1954; Simkin and Siebert, 1994). The largest eruptions in the southern Kurile Islands occurred in the Late Pleistocene: on Kunashir Island, Golovnin (Tomariyama) and Mendeleev (Rausu-san) volcanoes have occurred caldera-forming eruptions (ca. 38–40 ka BP: Melekestsev et al., 1988). The largest Holocene eruption occurred at Lvinaya Past (Moikeshi) volcano on Iturup Island (9400 ± 60 BP), forming a large caldera, which is flooded now by sea (Melekestsev et al., 1988; Braitseva et al., 1995).

3. Previous studies about the southern Kurile Islands

Tephrostratigraphic studies in the southern Kurile Islands using ^{14}C ages, biostratigraphy, and whole-rock glass chemistry in tephra layers were carried out by Razzhigaeva et al. (1998). However, the correlations of the tephra layers were tentative because few data were available for the widespread tephra layers