Breakdown of mineral grains by earthworms and beetle larvae

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Abstract

Feeding experiments were conducted quantitatively to examine the breakdown of mineral grains by earthworm, *Eisenia feida,* and larva of beetle, *Protaetia lugubris insperata*. Crushed and sieved test minerals of K-feldspar and/or quartz were mixed with artificial humus that contained no mineral grains. The mixture was fed to the soil animals in the plastic containers. After 1-, 4- and 7-day experimental durations, the ingested mineral grains were collected from the casts excreted by the soil animals in each container. Even 1 day after feeding of mineral grains, the casts of soil animals contained finer, rounded mineral grains that were not included in the initial prepared mineral samples.

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1. Introduction

Weathering of minerals and rocks in natural environments has long been regarded mostly as abiotic processes. Recent environmental studies, however, elucidated the biotic processes that participate significantly in the chemical weathering. These biotic processes are alteration and dissolution of silicate minerals and rocks induced by higher plants (Drever, 1994; Alexandre et al., 1997; Augusto et al., 2000; Hinsinger et al., 2001), by lichen (Wilson and Jones, 1983; Wilson, 1995; Banfield et al., 1999; Chen et al., 2000) and by bacteria and fungi (Barker et al., 1997; Roger et al., 1998; Van Breemen et al., 2000; Santelli et al., 2001). These organisms contribute much to the soil formation through direct decomposition of silicate minerals in order to absorb the essential nutrients contained in them (Barker et al., 1997).

Earthworms play an important role in the improvement of soil conditions and many studies on earthworms have been conducted since Charles Darwin. Lee (1985) and Edwards and Bohlen (1996) summarized positive effects of earthworms on soil structure, such as formation of soil aggregates, pores and drainages for aeration. Geophagus soil animals including earthworms ingest large amounts of mineral grains with organic particles, and excrete them as innumerable soil aggregates. Microscopic observation indicated that the average grain size of minerals in the soil aggregates excreted by earthworms was generally smaller than that in the surrounding soil. Based on this observation, Bassalik (1913), Blanck and Giesecke (1924), Meyer (1943), Evans (1948), Shrikhande and Pathak(1951), Joshi and Kelkar (1952), and Basker et al. (1994)

proposed that the earthworms might mechanically break down mineral grains through ingestion and digestion of soil fractions. On the contrary, Toetia et al. (1950), Nye (1955), Lee (1967), Lee and Wood (1971), Watanabe (1975), Sharpley and Syers (1976), Bolten and Phillipson (1976), De Vleeschauwer and Lal (1981), Lal and Akinremi (1983), Hullgalle and Ezumah (1991) and Nooren et al. (1995) ascribed this phenomenon to selective ingestion of finer grains by earthworms. All of these studies addressing whether or not earthworms breakdown mineral grains were qualitative. This study aims to elucidate quantitatively the contribution of earthworms and larvae of beetle to soil formation by introducing a newly designed experimental system.

2. Materials and Methods

Approximately 15 l of autumn-tinted leaves was collected directly from trees of *Liriodendron tulipifera* L. and *Quercus variabilis* Blume. Fine mineral grains that might attach on the leaves were removed completely by tap water, then the leaves were put into a bucket with a lid. In order to accelerate decomposition of leaves, a handful of deadwood flakes and also a handful of pill bug, *Armadillidium vulgare,* and woodlice, *Porcellio scaber,* were mixed with leaves in the bucket. Special attention was paid so as not to contaminate mineral grains derived from the mixed deadwood and animals. After 6 months decay from January to June 2001 at room temperature, artificial humus, free from mineral grains, was obtained to be fed to soil animals.

Earthworms, *Eisenia feida* Savigny, and larvae of beetle, *Protaetia lugubris insperata* Burmeister (larva), were collected in the field soil at Asuke, Aichi Prefecture, Japan. An average length and an average wet weight of an earthworm were 6.87 cm (σ= 1.19) and 0.39 g (σ= 0.08), respectively. An average weight of a larva of beetle was

3.99 g (σ= 1.12).

A large K-feldspar crystal and quartz crystal were collected from Aichi and Fukushima Prefectures, respectively. Both crystals were separately crushed and sieved. Sieved grains were treated with ultrasonic vibration and washed with deionized water to remove the finer grains. These initial prepared mineral grains ranging 250 to 500 μm in sieved length (Fig. 1) were used in feeding experiments for earthworms, and grains ranging from 500 to 1000 μm for larvae of beetle.

The feeding experiments of mineral grains were carried out in the plastic container of 85 mm in diameter and 45 mm in depth. As precultures of soil animals, only the artificial humus was fed to them for several days in order to make preexisted mineral grains excrete from their digestive organs. No mineral grains were detected in their casts after 3 days for earthworms and after 7 days for larvae of beetle. Subsequently, the mixture of 1.00 g of mineral grains and about 6 g of artificial humus was fed to four earthworms in a container, and 2.00 g of mineral grains and about 10 g of artificial humus to one larva of beetle in a container. The plastic containers were covered with aluminum foil to shut out light. Three experimental durations, 1, 4 and 7 days, were adopted, and four containers were prepared for each duration. Laboratory temperature was optimized to 25℃ throughout the experiments, as was done by Graff (1953) and Haukka (1987). Casts in each container were completely collected, and ingested mineral grains were separated from the casts, as follows: (1) remove the non-ingested mineral grains attached on the cast surface under the binocular microscope with a pair of tweezers; (2) put casts into a 500-ml beaker and add 60 ml of 6% H_2O_2 solution; (3) decompose the organic fractions in the casts on the water bath; (4) rinse out impurities from the separated mineral grains with deionized water; and (5) dry in the oven at 105°C.

Grain size and roundness of mineral grains were measured using the Luzex Ⅲ-U image analyzer. In this study, grain size is different from the sieved length as shown in Fig. 1. We used maximum length given by image analyzer as grain size. Roundness of a mineral grain was calculated with the approximation by Hoshino et al. (1996): roundness index = $\{(\text{circumference} / 2\pi)^2 \times 100\pi\} / \text{area} - 100$. Rounder grain gives a smaller roundness index. As control experiments, the mineral grains not ingested by soil animals were also collected from each container and measured following the same procedure described above. The distribution patterns both of grain size and roundness of non-ingested grains in containers were almost the same as those of the initial prepared mineral grains. All data of distribution frequency of grains were represented as % in number of grains for each class of grain size and roundness index.

3. Results

3.1. Feeding experiment of mineral grains for earthworms, *E. feida*

Grain size distributions of K-feldspar before and after ingestion by earthworms were shown in Figs. 2a and b. Grains finer than 0.1 mm, though they were always observed microscopically in the samples of mineral grains separated from casts, were excluded from all data of the analytical results due to the limit of measurements. Grains finer than 0.3 mm were only trace in amount both in the initial prepared and non-ingested grains of K-feldspar in containers. On the contrary, the ingested grains of K-feldspar included a certain amount of fraction finer than 0.3 mm, especially the 0.1 - 0.2 mm fraction with a frequency of 10 - 20 %. The fractions coarser than 1.0 mm were trace in amount in all cases. Distribution patterns of grain size after ingestion for 1, 4 and 7 days were similar to one another.

Fig. 3 showed the size distribution pattern and the photographs of K-feldspar grains inside an earthworm's body. Grains finer than 0.3 mm were found in digestive organs of an earthworm (Fig. 3a). It was confirmed that K-feldspar grains were ingested with humus and were partly aggregated in the intestine (Fig. 3b,c). An earthworm excreted about 15 casts (about 0.06 g wet weight) per day.

Grain size distributions of quartz were similar to those of K-feldspar with respect to initial prepared, non-ingested and ingested mineral grains as shown in Fig. 4a and b. Finer grains ranging from 0.1 to 0.2 mm of ingested quartz attained to over 10%, and these frequencies were generally lower than the case of K-feldspar. The ingested quartz grains coarser than 1.0 mm were only trace in amount in the casts.

Roundness indices of initial prepared and non-ingested minerals showed similar distribution patterns to each other, having a mode of 12, corresponding to "rounded" according to the sedimentological roundness classification by Pettijohn (1957). While the mode remained the same, the roundness index category of 10 increased in casts of earthworms (Figs. 5a,b and 6a,b). Roundness index 10 corresponds to "well-rounded".

Grain size and roundness distributions of mixed minerals of K-feldspar and quartz were shown in Figs. 7a,b and 8a,b. In spite of exclusion of finer grains from the initial prepared mineral grains, the ingested mixed minerals contained grains finer than 0.3 mm. As for the result after 1 day, percentage of 0.1 - 0.2-mm fraction increased greatly up to 25 %, the highest of all experiments. Furthermore, grains with roundness index of 10 remarkably increased, and the distribution patterns shifted to more rounded than those of ingested K-feldspar or quartz alone.

3.2. Feeding experiment of mineral grains for larvae of beetle, *P. lugubris insperata* (larva)

Grain size distributions of K-feldspar and quartz before and after ingestion by one larva of beetle were shown in Figs. 9a-c and 10a-c. Grains finer than 0.5 mm were hardly detected both in the initial prepared and non-ingested minerals. However, casts contained grains finer than 0.5 mm even 1 day after ingestion. Especially 0.1 - 0.2 mm fraction of grains showed the maximum value, in the case of K-feldspar and quartz, up to approximately 60 % and 30 %, respectively. Roundness distributions of K-feldspar and quartz were similar to the results of earthworms. Ingested minerals mostly belong to “rounded” grains. The patterns of the distributions were similar to each other after ingestions for 1, 4 and 7 days. A larva of beetle excreted about 20 casts (about 0.23 g wet weight) per day.

4. Discussion

In the feeding experiments conducted under the newly designed methods, we quantitatively substantiated the possibility of breakdown of mineral grains by soil animal ingestion. We found that *P. lugubris insperata* (larva) exceeds *Eisenia foetia* in the ability of mineral breakdown. This suggests that the contribution of larvae of beetle is significant as producers a large amount of fine mineral grains in soils.

E. foetia and *P. lugubris insperata* (larvae) may select to ingest the smaller sizes from the initial prepared grains. Our work demonstrates that the mineral grains are clearly broken into finer particles. The crystallographic difference between K-feldspar and quartz should be mentioned. K-feldspar crystal has perfect (001) and (010) cleavages and its hardness is lower than that of quartz, which lacks cleavage. Therefore

K-feldspar grains must disintegrate more rapidly than quartz as shown in Figs. 2 and 4. This is indeed, analogous to the process of mechanical weathering of minerals in the Earth's surface.

The roundness indices of ingested mineral grains showed the "well-rounded", and the distribution patterns of the roundness totally shifted to the rounded shape. Postulating that the maximum pressure through the gut of *E. foetia* is insufficient to mechanically grind up mineral grains (Lee and Foster, 1991), the appendices of poorly rounded grains are chipped by the collision between grains. This is more probable in the case of beetle larvae; in addition to crush by mandible, harder quartz can abrade feldspar grains in the gut of the larvae.

Edwards and Bohlen (1996) stated that earthworms exhibit strong muscular actions of their body walls. The initial coarser mineral grains are evidently comminuted by the muscular action as they pass through the earthworm intestine. The process of breakdown of mineral grains by beetle larvae, however, may be different from earthworms; the ingested mineral grains are broken down by strong mandible of larvae of beetle. Therefore, the degree of breakdown of mineral grains by beetle larvae may be greater than that by earthworms in such a soil system as the larger density of beetle larvae.

The contributions of beetle larvae to soil-forming processes have hardly been reported so far. Our work shows that their influence should not be neglected. The role of geophagus soil fauna in soil forming process should be studies further. The experimental conditions adopted here are different from the natural environment, since natural soils form a complex system composed of various silicate minerals, clays, plant and animal detritus, humus, and microorganisms. Nevertheless, soil animal populations, such as earthworms and beetle larvae, may contribute far more to soil forming processes than is commonly expected.

Acknowledgements

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Figure captions

Fig. 1. Schematic diagram showing the relationship between the sieved length of a mineral grain and the grain size (maximum length) measured by image analyzer.

Fig. 2. Size distributions of K-feldspar grains. (a) Initial prepared mineral grains; (b) grains in casts of earthworms after 1 day.

Fig. 3. Mineral grains and humus in intestine of *E. feida*. (a) Size distribution of K-feldspar grains in intestine; (b) a photograph showing the inside of intestine with aggregated K-feldspar grains; (c) a photograph showing the inside of intestine with K-feldspar grains and artificial humus complexes.

Fig. 4. Size distributions of quartz grains. (a) Initial prepared mineral grains; (b) grains in casts of earthworms after 1 day.

Fig. 5. Roundness distributions of K-feldspar grains. (a) Initial prepared mineral grains; (b) grains in casts of earthworms after 1 day.

Fig. 6. Roundness distributions of quartz grains. (a) Initial prepared mineral grains; (b) grains in casts of earthworms after 1 day.

Fig. 7. Size distributions of mixed mineral grains of K-feldspar and quartz. (a) Initial prepared mineral grains; (b) grains in casts of earthworms after 1 day.

Fig. 8. Roundness distributions of mixed mineral grains of K-feldspar and quartz. (a) Initial prepared mineral grains; (b) grains in casts of earthworms after 1 day.

Fig. 9. Size distributions of K-feldspar grains. (a) Initial prepared mineral grains; (b) non-ingested grains in container; (c) grains in casts of one larva of beetle after 1 day.

Fig. 10. Size distributions of quartz grains. (a) Initial prepared mineral grains; (b) non-ingested grains in container; (c) grains in casts of one larva of beetle after 1 day.

Fig. 1.

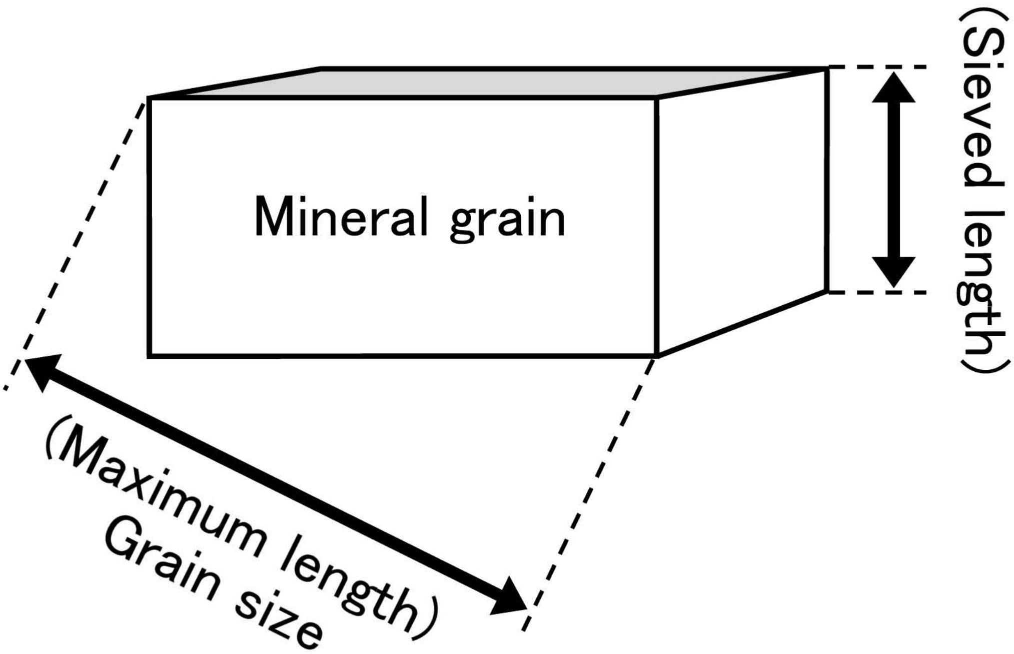
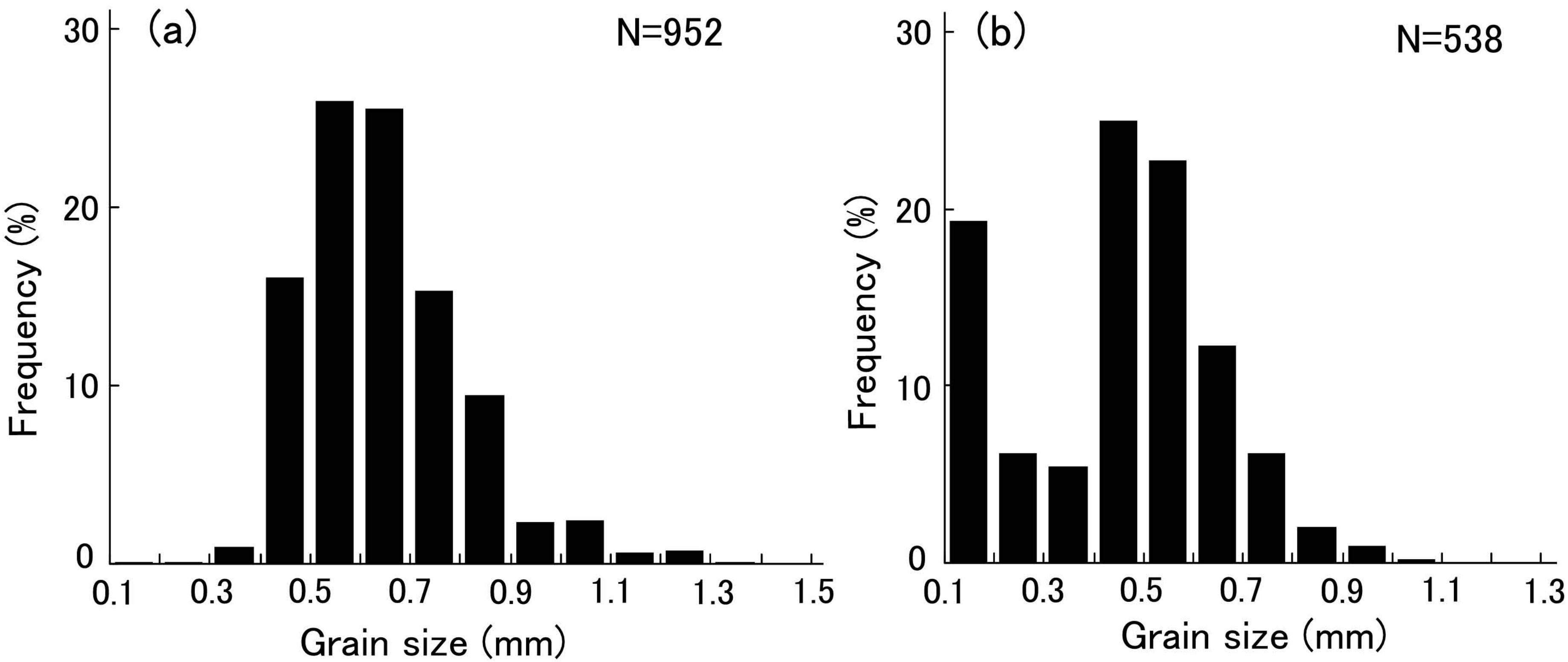


Fig. 2.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30
20
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0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
Grain size (mm)
(b)
N=538
Frequency (%)
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10
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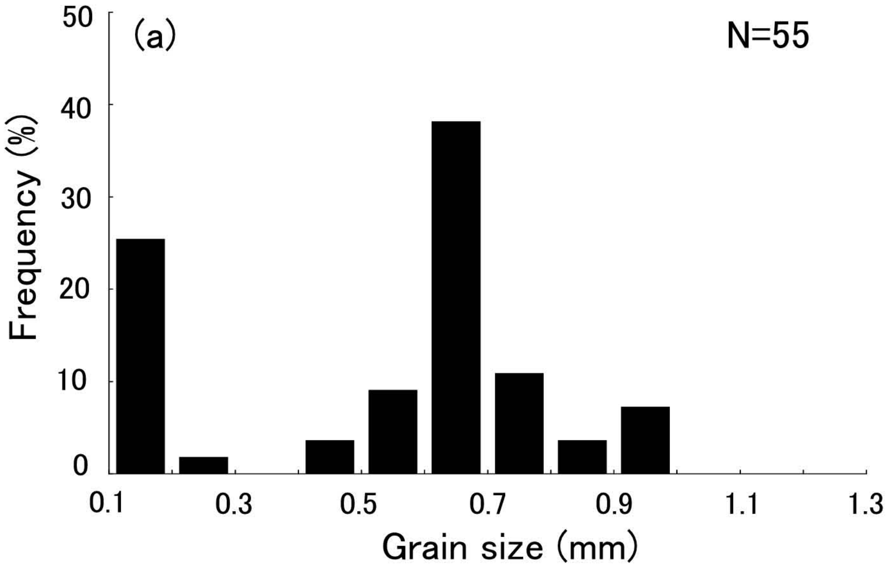
0.1
0.3
0.5
0.7
0.9
1.1
1.3
Grain size (mm)

Fig. 3.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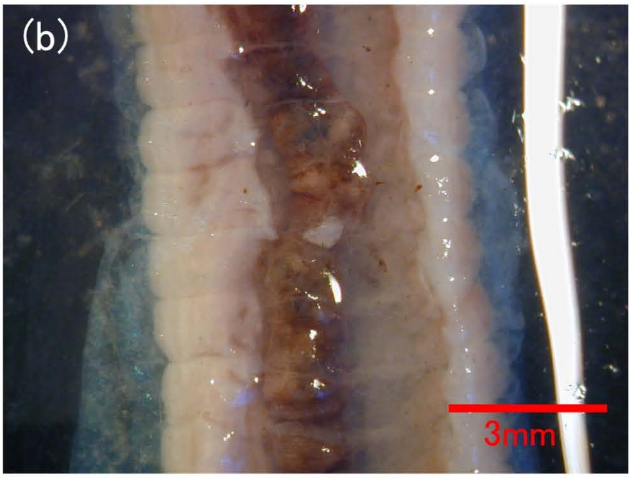
1.3
Grain size (mm)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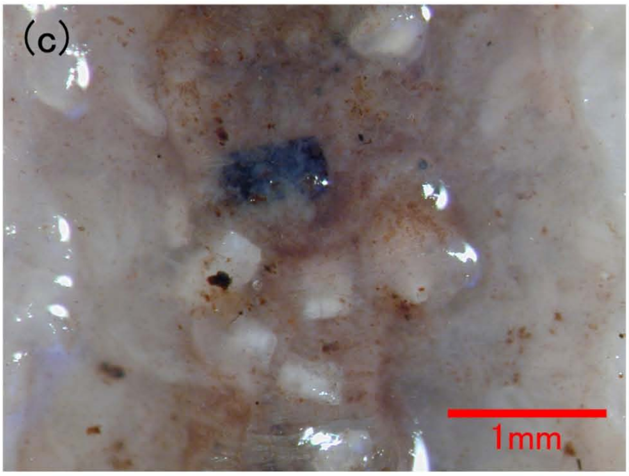
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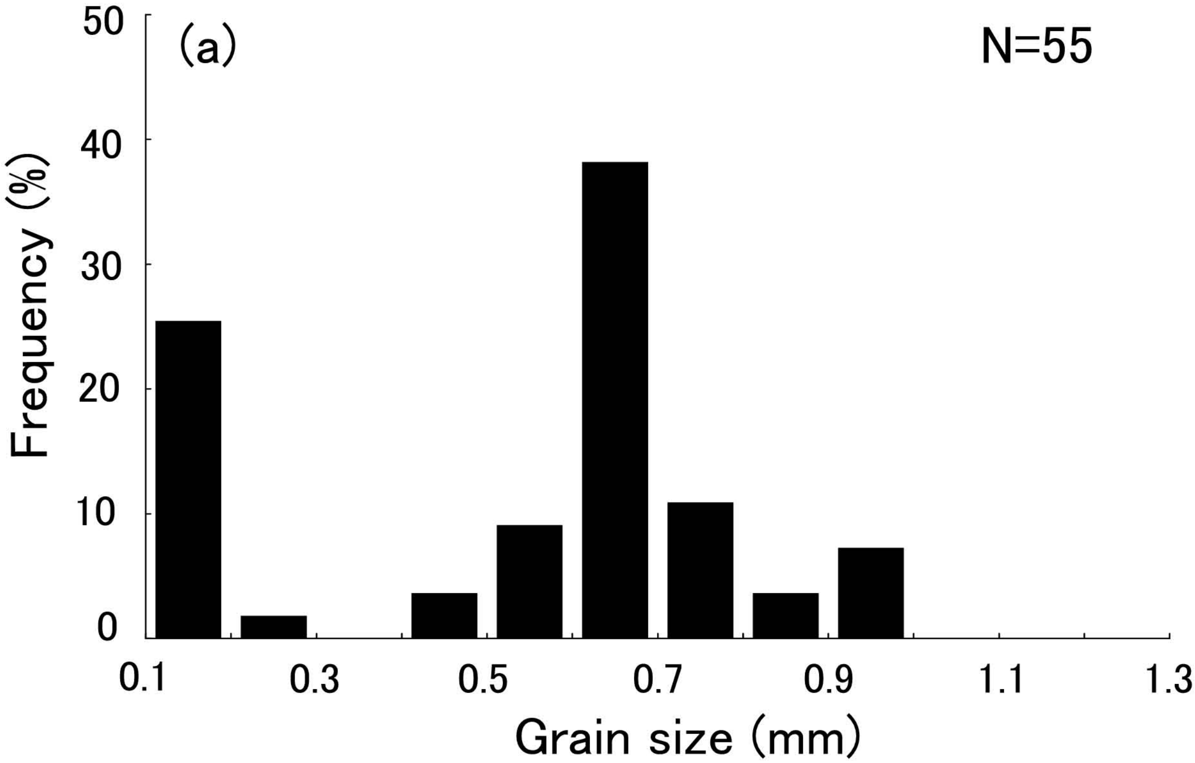
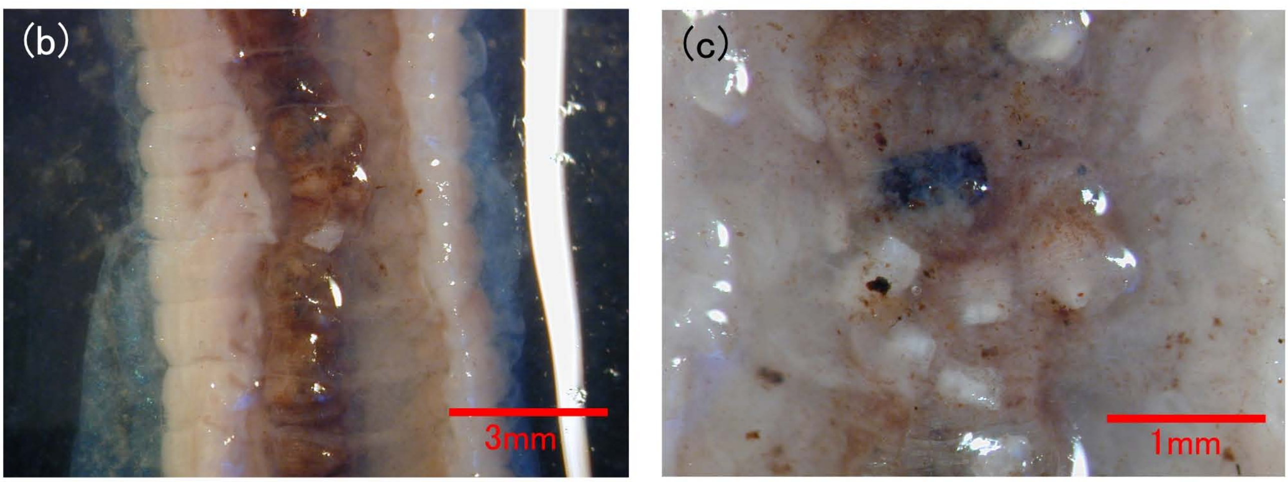


50
40
30
20
10
0
(a)
N=55
Frequency (%)
0.1
0.3
0.5
0.7
0.9
1.1
1.3
Grain size (mm)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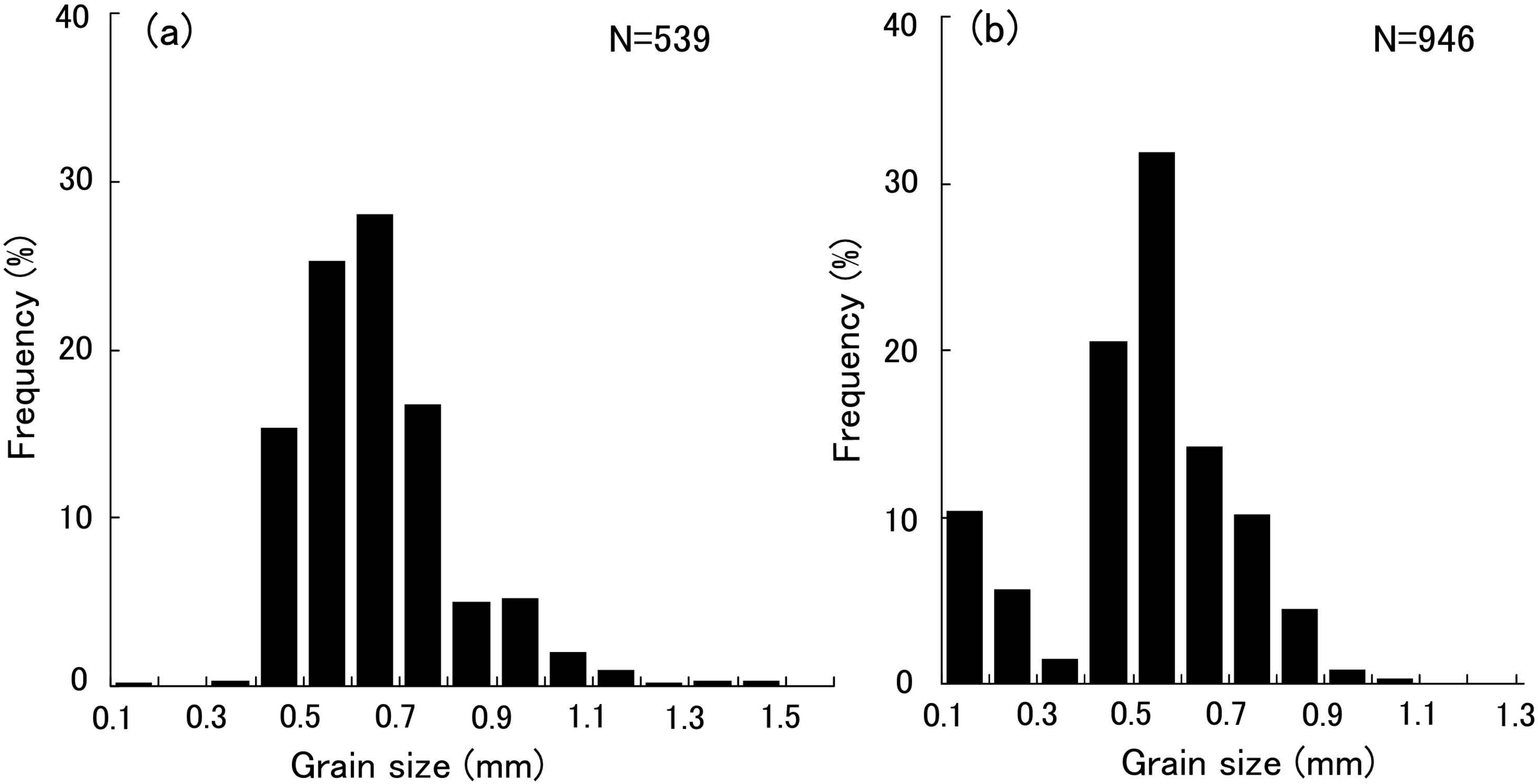
3mm
(c)
1mm

Fig. 4.



(a)
N=539
Frequency (%)
0
10
20
30
40
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
Grain size (mm)
(b)
N=946
Frequency (%)
0
10
20
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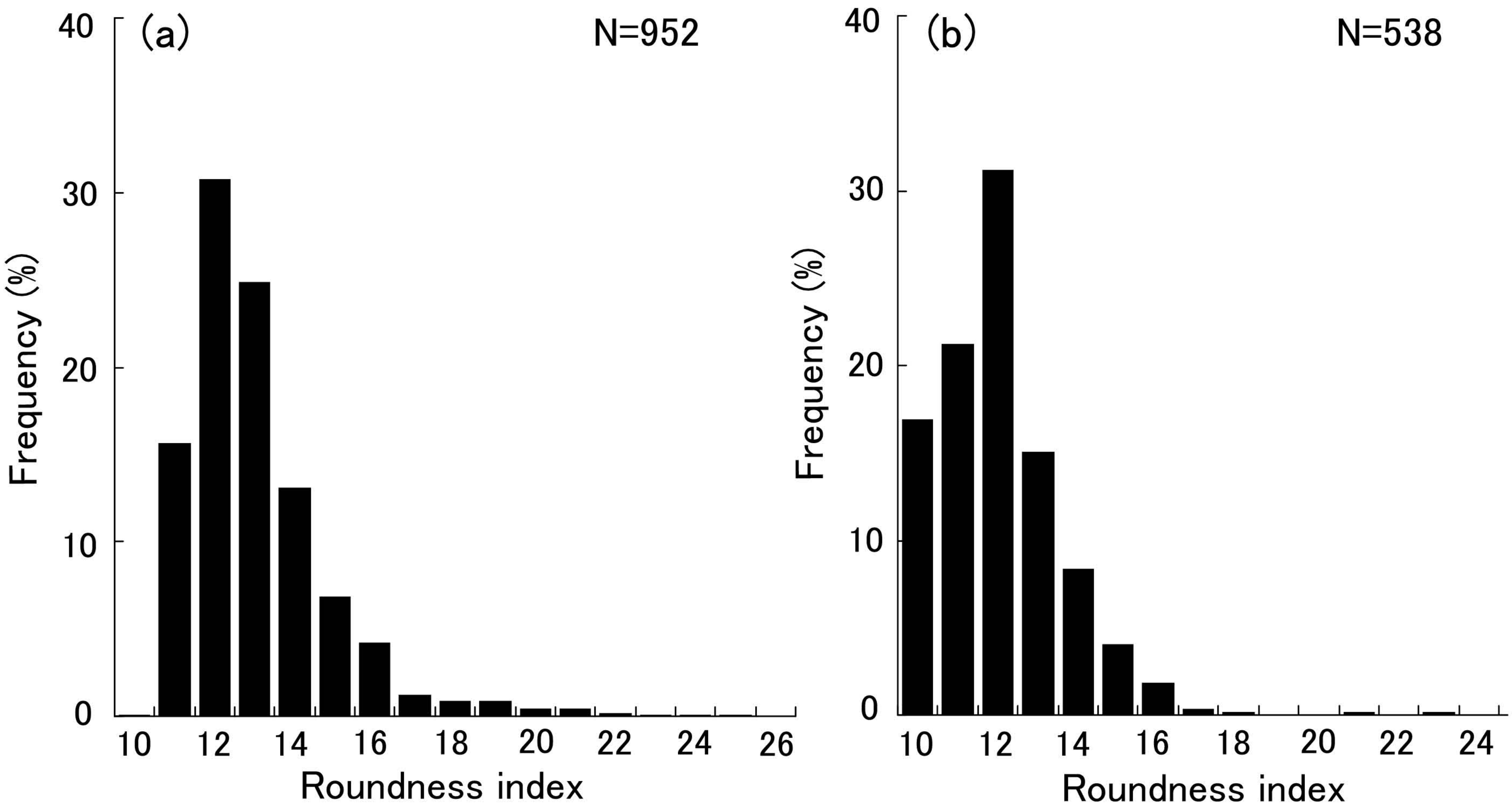
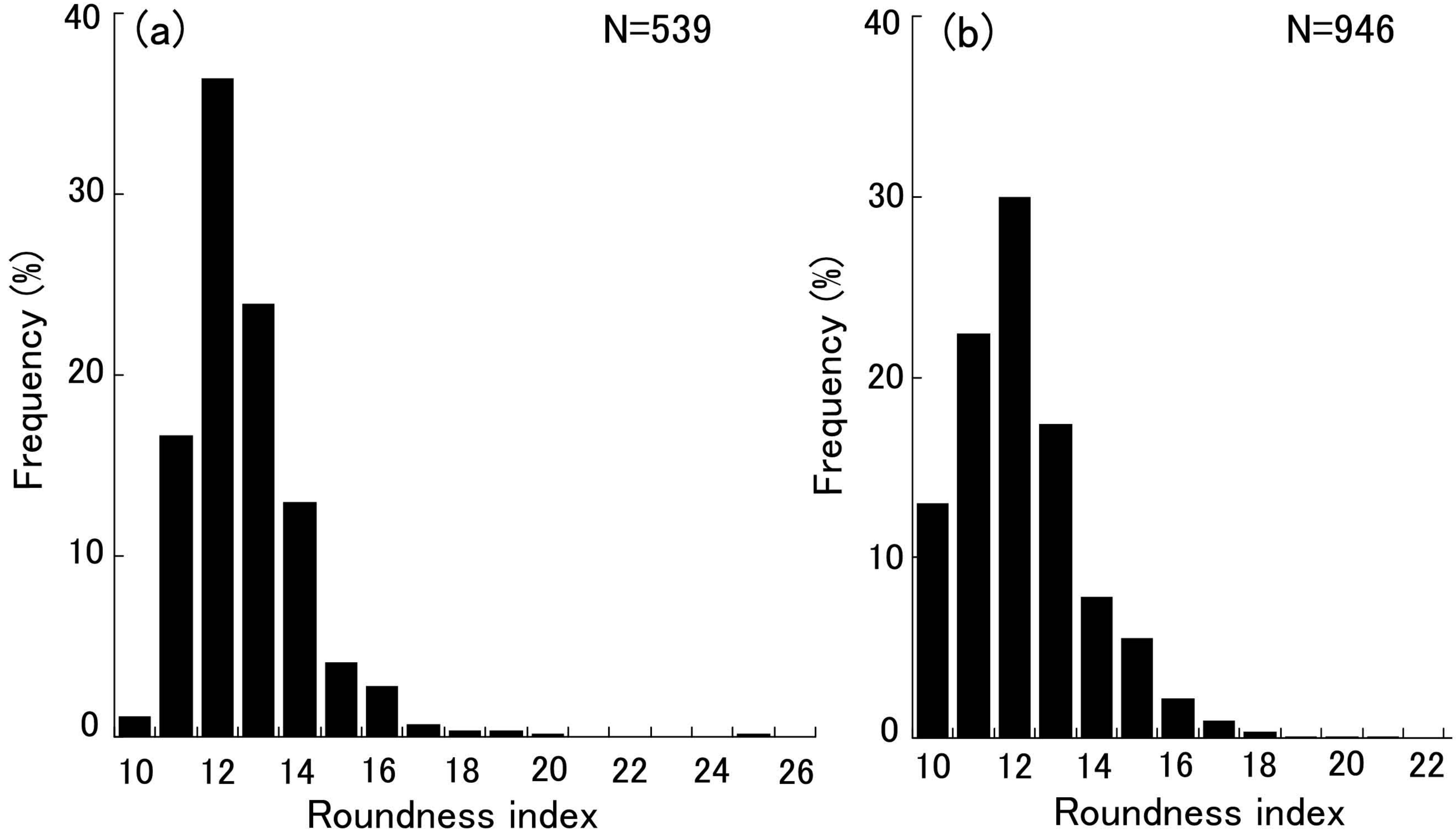
0.3
0.5
0.7
0.9
1.1
1.3
Grain size (mm)

Fig. 5.



(a)
N=952
Frequency (%)
Roundness index
(b)
N=538
Frequency (%)
Roundness index

Fig. 6.



(a)
N=539
Frequency (%)
40
30
20
10
0
10
12
14
16
18
20
22
24
26
Roundness index
(b)
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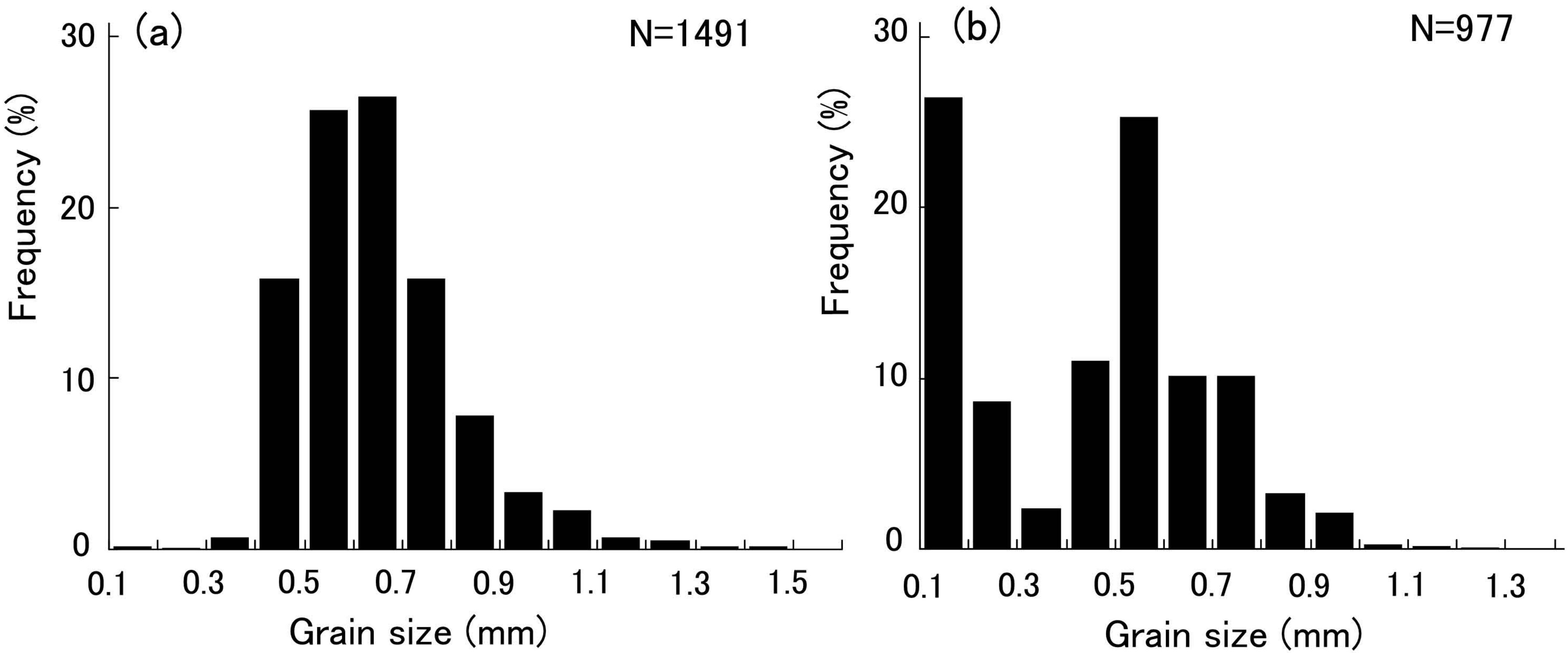
Frequency (%)
40
30
20
10
0
10
12
14
16
18
20
22
Roundness index

Fig. 7.



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Frequency (%)
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0.3
0.5
0.7
0.9
1.1
1.3
1.5
Grain size (mm)
(b)
N=977
30
20
10
0
Frequency (%)
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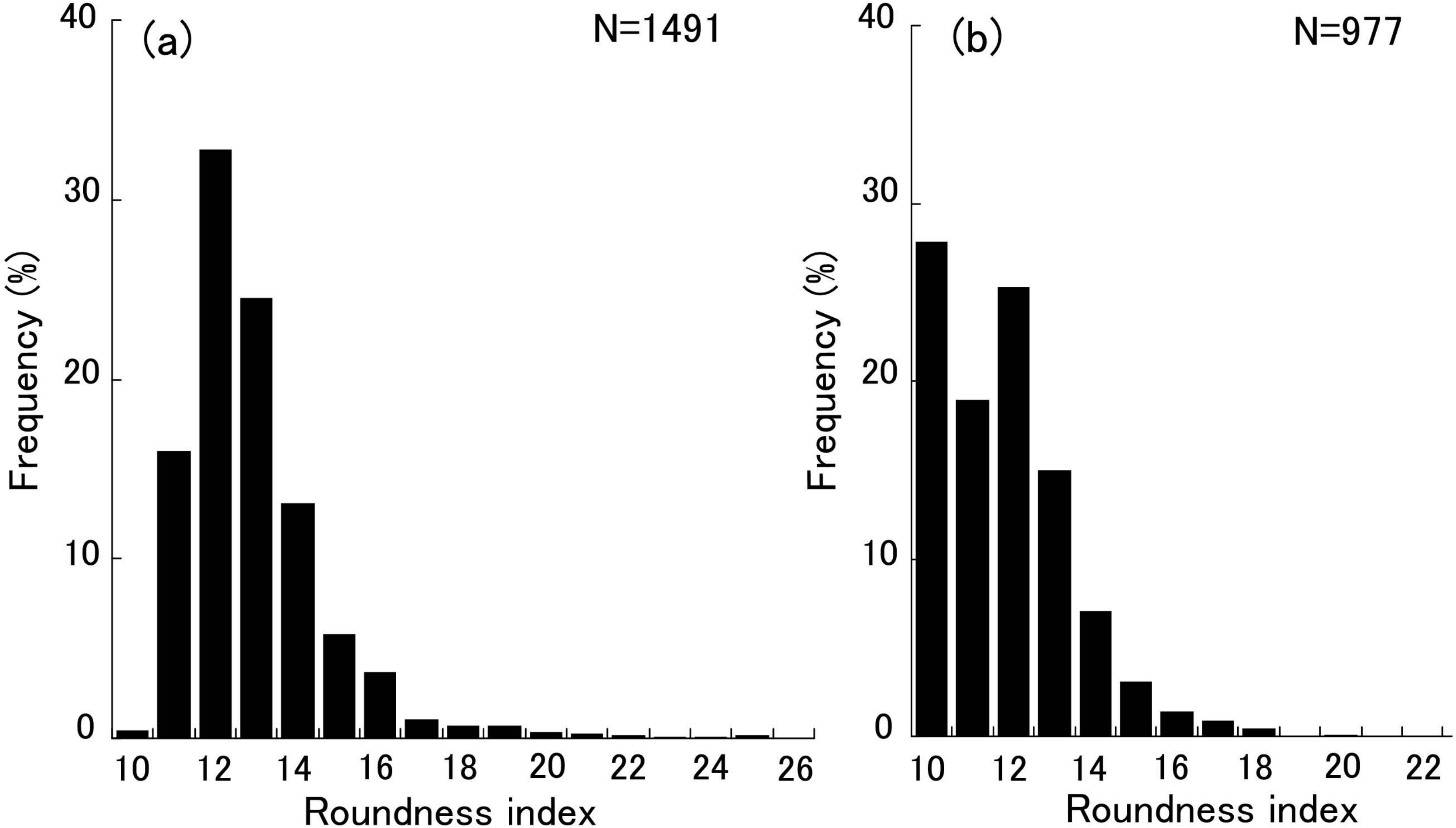
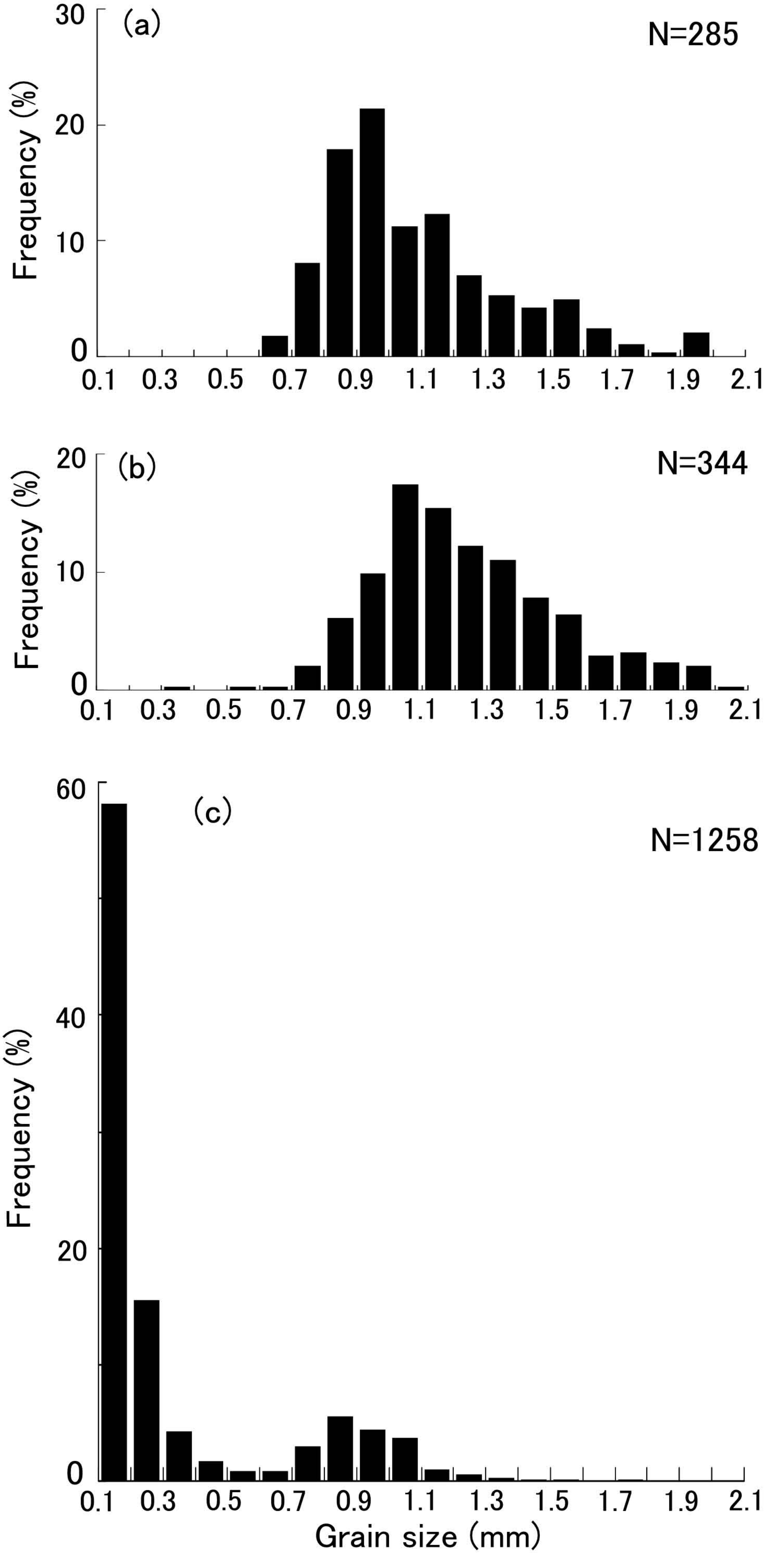
0.3
0.5
0.7
0.9
1.1
1.3
Grain size (mm)

Fig. 8.



(a)
N=1491
Frequency (%)
40
30
20
10
0
10
12
14
16
18
20
22
24
26
Roundness index
(b)
N=977
Frequency (%)
40
30
20
10
0
10
12
14
16
18
20
22
Roundness index

Fig. 9.


(a)
N=285
Frequency (%)
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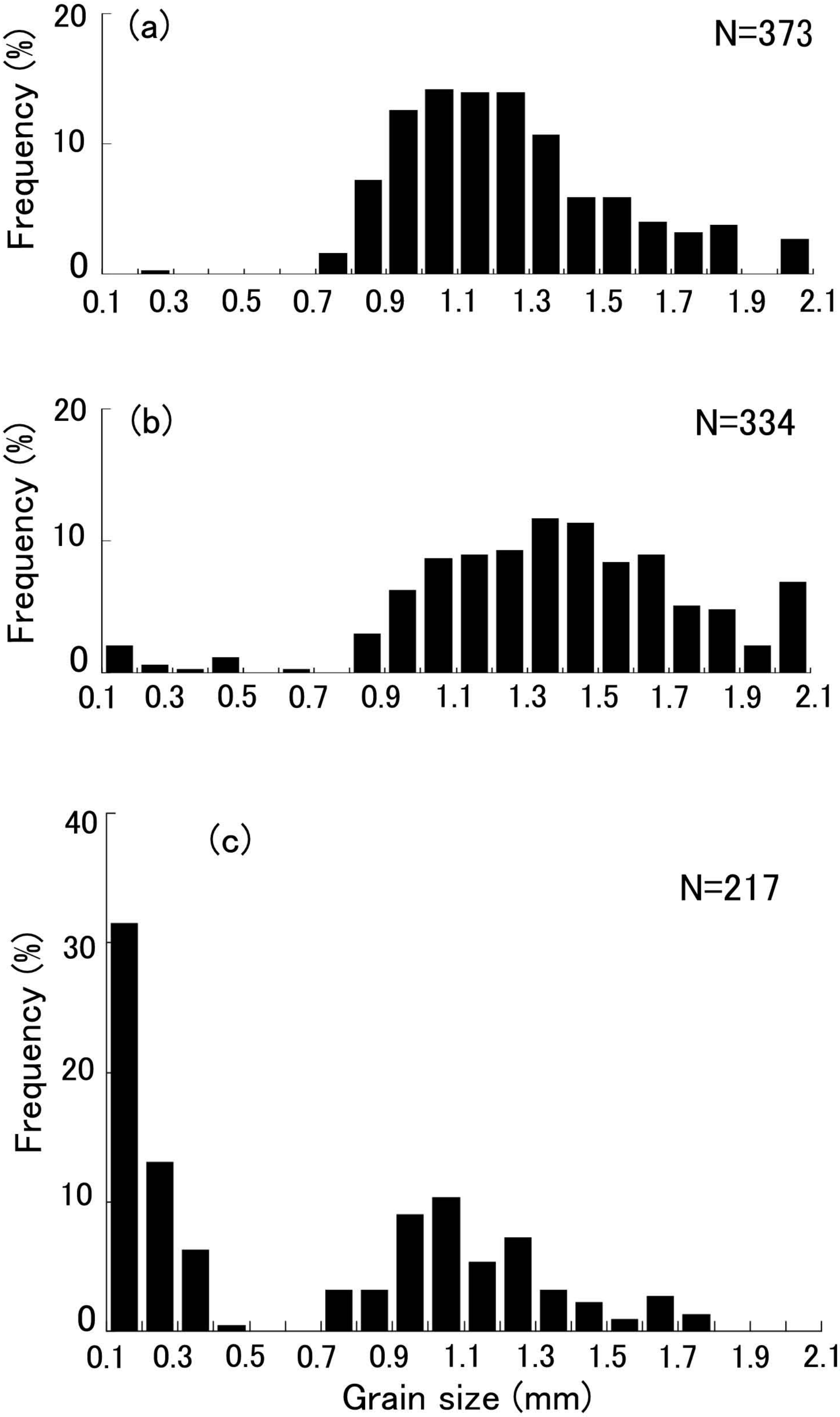
20
10
0
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
(b)
N=344
Frequency (%)
20
10
0
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
(c)
N=1258
Frequency (%)
60
40
20
0
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
Grain size (mm)

Fig. 10.



(a)
N=373
Frequency (%)
20
10
0
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1
(b)
N=334
Frequency (%)
20
10
0
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1
(c)
N=217
Frequency (%)
40
30
20
10
0
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1
Grain size (mm)