Tunnel system made by the long-clawed shrew in a laboratory condition

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Running head: Tunnel system of the long-clawed shrew

Abstract. Tunnel construction by captive long-clawed shrews (*Sorex unguiculatus*) was investigated in an experimental cage designed for the observation of subterranean activity. Five subadult individuals were observed constructing tunnel systems in the experimental cage, but one newborn individual could not make a complex system. The tunnel system consisted of two parts: the main burrows at a depth of approximately 20–30 cm from the ground surface and surface runways at a depth of 3–7 cm. In a tunnel system, there were 2–4 permanent vertical passages with entrances to the ground surface and 3–5 blind chambers and burrows. To complete the tunnel system construction, a shrew usually spent 5–6 days. Two types of digging were recognized: (1) digging surface runways and short vertical passages and (2) digging deep tunnels.

Key words: burrow, digging, *Sorex unguiculatus*, subterranean activity.

Fossorial or semi-fossorial mammals rely on tunnels they dig for foraging and nesting (Swiderski 1991). There are many species adapted for burrowing activity, but direct observation of underground activity is usually difficult in the wild (Churchfield 1990; Guevara 2017). Among *Sorex* shrews (Soricidae, Eulipotyphla), the long-clawed shrew (*Sorex unguiculatus* Dobson, 1890) is one of the most adapted species for fossorial activity (Ohdachi 1995a, 1995b, 1997). The long-clawed shrew is a common species in the southern mainland part of the Russian Far East, Sakhalin, and Hokkaido (Dolgov 1985; Ohdachi et al. 2015). Abe (1983) ecologically classified the long-clawed shrew as "shrew-mole type". Sergeev and Ilyashenko (1991) also classified it as "burrowing type" based on skull, skeleton, and external morphology and ecology. Shrew species of semi-fossorial eco-type, including the long-clawed shrew, usually have a large body size, which provides them with a robust muscle system for the forelimbs and supplies sufficient energy for digging (Ohdachi 1995a). In addition, the long-clawed shrew has large forefeet with long claws, which are suitable for digging (Nesterenko 1999).

The burrowing habits of the long-clawed shrew were investigated by Yoshino and Abe (1984), Yokohata (1990), and Ohdachi (1995a); it was documented as a skillfull digger and burrower in soil when making underground tunnels. The long-clawed shrew appears to be a *Sorex* species capable of building tunnel systems among *Sorex* shrew species in Northeast Asia (Dolgov 1985; Nesterenko 1999). However, the tunnel structure and construction process have not been investigated by direct observation in the long-clawed shrew. The features of space use and underground behavior of this species can also provide information on niche partitioning for space among coexisting shrew species (Yajima et al. 2024). Herein, we report the process of tunnel construction by captive long-clawed shrews in an experimental cage designed for observing subterranean activity of shrews.

Materials and methods

Animals used

Thirteen long-clawed shrews were captured on 30–31 August 2000 in the experimental forest of Hokkaido Research Center, Forestry and Forest Products Research Institute (Toyohira-ku, Sapporo, Hokkaido, Japan), by use of 120 plastic pitfall traps (16-cm in diameter and 24-cm deep). The trapping procedure was described in detail by Ohdachi (1992). Captured shrews were moved to a laboratory at the Institute of Low Temperature Science, Hokkaido University (Kita-ku, Sapporo), where they were kept in a semi-open house under natural conditions of temperature and daylight. All animals were kept individually in plastic cages (35 cm L x 20 cm W x 25 cm H), containing a wooden nest box, an exercise wheel, and sawdust on the floor (Ohdachi 1994). Shrews were fed with mixed paste ration (Ohdachi 1994). The ingredients of the paste were: 400 g pork meat, 800 g pork liver, 680 g canned tuna for cats, 430 g canned dog food, and 100 g rabbit pellets (Ohdachi 1994). The frozen cubic pastes were preserved in a freezer. In addition to the artificial diet, living earthworms (Lumbricidae) were supplied occasionally. Among the 13 shrews captured, five subadult individuals (young of the year of birth) were used for the experiments of the present study. In addition, one new-born individual was used for an additional experiment (Table 1).

To investigate the process of constructing tunnel system in the long-clawed shrew, an experimental cage was made for observating their subterranean activities (Fig. 1). Herein, a tunnnel system was defined as a complex burrow system with more than two entrances and some vertical and horizontal burrows. Three experiments were conducted. Experiments were carried out from 5 September to 19 November 2000 (Table 1) under natural conditions (light, temperature, and other conditions were not regulated).

Experiment 1

This was the main experiment to collect basic information of the subterranean activity of long-clawed shrews. Soil of 60 cm depth collected near the laboratory filled the experimental cage. The soil was tamped down evenly so that its hardness became approximately 1.5 kg/cm^2. Then, some litter and dead leaves collected around the laboratory were put on the soil surface. Small trays of food and water were put on the soil surface of the experimental cage. A grid lines were drawn on the front clear board to trace tunnels and locate some constructions made by shrews. Black plastic boards were attached in front of the clear boards to exclude light before observation. One individual was put in the experimental cage in the morning. Observations of the behavior of the shrew on the soil surface began immediately after it was placed in the cage. Subterranean observations began after dark. Before observations began, the black boards were gently detached. States of burrows were recorded 3–4 times per day for each experimental trial. In addition, activities and behaviors of shrews in soil were observed, and some activities were recorded by video and photographic cameras. The observation and records by photographs and videos were conducted for approximately 25–45 minutes per day. The numbers of animals used in this experiment were five subadults (three females and two males:Table 1). Every experimental trial lasted 11–15 days. Then, the shrew was removed from the cage, soil was changed, tamped down and this cage was used for next experimental trial.

Since width of the soil layer in the experimental cage was 6 cm, all pathways of underground passages made by shrews were visible through the transparent boards. This allowed us to sketch the structure of the tunnel systems in two dimensions (2D).

Experiment 2

To reveal the response to ready-made burrows by other individuals of the shrew, two trials of Experiment 2 were conducted (Table 1). One of the five experimental animals was placed in the cage with tunnels already dug by other conspecific individuals. Each trial lasted three days. The experimental conditions and the mode of observation of the shrew were the same as in Experiment 1.

Experiment 3

An additonal experiment was conducted for a newborn shrew. One of the captured adult females gave birth and three of six newborn individuals survived until their independence (Nesterenko and Ohdachi 2001). To test the digging ability of a newborn individual, one male newborn shrew was used for the observation. The newborn individual was placed in a plastic cage (65 cm L x 35 cm W x 35 cm H), filled with 20-cm soil of hardness of 1.5 kg/cm^2. No litter was put on surface of soil. Wooden house box, trays of the mixed paste diet and water were located in the cage. Then, this individual was put in the experimental cage (Fig. 1) with a ready-made tunnel system as for Experiment 2 for three days and behavior was observed (Table 1).

Results

Structure of tunnel system

All five subadult long-clawed shrews constructed tunnel systems in the experimental cage in Experiment 1. However, the one newborn individual could not construct a complex system.

All tunnel systems consisted of two parts. The first part was a complex of shallow surface runways and the second one was a complex of deep main burrows. There were 2–4 permanent entrance holes with mounds around them and 3–5 blind branches and chambers in each tunnel system (Fig. 2).

First, shrews began to dig some vertical holes of 5–7 cm deep (n = 12, mean = 6.0 ± 0.213 *SE*) (Fig. 3A), which were then connected by runways (Fig. 3B). Shallow runways were constructed at a depth of 3–7 cm (Fig. 2-b). These burrows had a diameter of less than 2 cm, although accurate size could not be measured as the walls of the burrows were loose and very friable. The friability of the top layer of soil was due to the soil and leaf litter mixing during the digging of vertical holes and surface passages (Fig. 3). There were no permanent exits to the ground surface from shallow runways and they were renovated daily. Exits often were clogged with soil after a shrew passed, but sometimes animals rebuilt exits at the same place.

The deep tunnel usually was at a depth of 20–30 cm from the soil surface (Fig. 2-a). The maximum burrow depths in the five experimental trials were: 28, 30, 20, 25, and 30 cm (mean = 26.6 ± 1.887 *SE*). The walls of these main burrows were firm, and the burrow diameters were approximately 2.5 cm, but every deep horizontal tunnel had 2–3 areas widened to 3.0–4.0 cm diameters.

The main tunnel was connected to surface burrows by 2–3 vertical passages of 2.5 cm diameter (n = 13, all 2.5) (Fig. 2-c). Every vertical burrow had an enlarged entrance (Fig. 2-d) and the size of such an entrance chamber was approximately 5 cm long with a diameter of 3.5–4.5 cm (n = 12, mean = 4.0 ± 1.306 *SE*). Entrance holes had diameters of 4.0 cm deep (n = 16, mean = 4.0 ± 0.076 *SE*, range = 3.5–4.5). Shrews often rested in the entrance chambers, sometimes putting their snouts out.

Several burrows branched off the main tunnel. Branch burrows usually terminated in a dead end, but occasionally connected to form a loop (Fig. 2-e, Fig. 3D). A shrew continued to dig branch burrows even after it finished constructing the main tunnel. When a new branch burrow was made, the nearest old one was permanently plugged with soil.

Blind chambers were made in various parts of the tunnel system (Fig.2-f). Blind chambers were approximately the same size as entrance chambers: approximately 5 cm long with a diameter of 3.5–4.0 cm (n = 8, mean = 3.8 ± 0.183 *SE*). In the present study, we have not observed shrews, which rested in blind chambers. Shrews usually used extensions of the main tunnel and entrance chambers for resting sites.

Behaviors of digging soil

Two modes of digging soil were identified. The first mode was applied by shrews to make surface burrows. Shrews initially dug soil with the claws of the forefeet, passing the soil under the abdomen, then forcefully kicked it backward using the hind feet. This is a typical manner when digging the surface runways and vertical burrows. It is worthy to note that shrews dug downwards rotating around the long axis of their body as a screwdriver when digging vertical burrows.

Shrews applied the second mode of digging to make deep tunnels. When digging, the two hind legs were held wide open, not only to hold the body at fixed points in the burrow, but also to provide a forward propulsive force. When digging in the main horizontal burrow, a shrew pressed the excavated soil by the body on the wall of tunnel. In contrast to vertical digging, a shrew did not rotate along the long body-axis and did not turn over the body when making horizontal burrows.

When digging the first burrow, a shrew usually did not rest until the body was completely hidden under the ground. It spent 66–79 seconds (n = 5, mean = 72.0 ± 2.345 *SE*) for a shrew to completely hide its body underground. The minimum time to fully hide the body underground was 90 seconds including the tail. When constructing the second and subsequent vertical burrows, shrews often interrupted digging for a rest and sometimes resumed digging at another site.

Long-clawed shrews could turn around in any burrows and did not move back to front except when dragging a captured earthworm (“back-with-grip” type in Yokohata 1990) out of a burrow. Shrews moved one meter in approximately 5–6 seconds in the main tunnels (n = 7, mean = 5.6 ± 0.202 *SE*). During observations, shrews spent most of daytime underground, and came to the soil surface only to feed. The exit to the soil surface for feeding occurred at least once approximately every 40 minutes (n = 26). During daytime, animals actively moved in burrows, dug new passages, and repaired old ones. In most instances, the duration of digging was 3–5 minutes (n = 30, mean =

4.1 ± 0.159 *SE*), followed by 2–3 minutes resting or moving to another part of the tunnel network. Although the number of night observations was very limited ($n = 3$), the duration (minute) of digging was almost the same (mean = 4.3 ± 0.333 *SE*), as the daytime previously mentioned.

Procedure of constructing tunnel system

Immediately after putting a shrew in the experimental cage, it began to survey the ground surface and then tried to dig some ephemeral short holes. Later, the shrew abandoned these holes.

The procedure of the construction of a tunnel system of the long-clawed shrews followed a consistent pattern. First, the shrew made some sloped vertical burrows of 6–7 cm depth. Among the entrances of these burrows, the mixture of the litter and soil were placed (Fig. 3A). Then, in the loose litter-soil layer, the shrew made temporary surface runways of 3–4 cm depth and extended 2–3 vertical passages to the depth of 15–30 cm (Fig. 3B). The next step was to start digging a main tunnel in deeper position and connecting it to the vertical passages (Fig. 3C). This procedure usually lasted about five days: in four out of five trials of Experiment 1, shrews finished building the tunnel system on the fifth day, and one male (2KSU-2) completed the construction of a main burrow on the sixth day. After finishing the construction of the main tunnels, all shrews made additional branch burrows and blind chambers (Fig. 3D) but did not make more new main passage during the experiment.

Shrews also repaired any vertical burrows that sometimes collapsed due to soil shedding. In two of five experimental trials, a new vertical passage was built next to the old one that was clogged with soil excavated when the new passage was dug. In these instances, a part of the waste soil was thrown onto the ground surface, and a rough mound was formed near the entrance hole.

Use of the tunnel systems made by other individuals

In two trials of Experiment 2, the shrews did not build a new main tunnel, but used deep burrows made by other individuals at the first time. However, the entire peripheral part of the underground system was rebuilt. The shrew dug shallowly, and all surface burrows were rebuilt. Then, the shrew made new entrance holes and new vertical burrows. New burrows were constructed along the ready-made vertical passage in such a way that the excavated soil was thrown into the old burrows, which were finally completely plugged. Then, after connecting vertical burrows with the unreconstructed main tunnel, old branch burrows from the main tunnel and chambers were completely destroyed by filling soil and new branch burrows were built.

Digging ability of newborn individual

After the newborn shrew (3NSU-1) was separated from the mother and siblings at 29 days-of-age and put into a cage with soil, it immediately started digging soil. The newborn shrew made only simple holes or short shallow burrows of 3–5 cm depth but did not build a tunnel system. It most commonly ran on the ground surface and spent most of its time in a wooden house on the soil surface. However, when this shrew was placed in the cage with the tunnel system made by another individual, it used the ready-made burrows and even tried to dig new branch burrows from the ready-made vertical passage.

Discussion

Although Adams (1912) found the common shrew (*S. araneus*) to be an active burrower and Hamilton (1931) reported that the northern short-tailed shrew (*Blarina brevicauda*) constructed subterranean tunnels, little is known about the burrowing ability and behavior in most soricine species. A large part of digging behaviors by shrews was based on speculation or the imagination of researchers (Skoczen 1958) as the observation of underground activities was difficult.

Churchfield (1980) found that *S. araneus* could not construct an extensive burrow system but could only make surface runs between the ground and litter and shallow burrows of 3-cm depth. Based on skull, skeleton, and external morphological and ecological features, Sergeev and Ilyashenko (1991) categorized *S. unguiculatus*, *S. isodon,* and *S. daphaenodon* as "burrowing type", although little was known regarding subterranean habits for *S. daphaenodon* at that time. Okhotina (1974) reported that *S. isodon* had digging abilities similar to *S. araneus,* suggesting *S. isodon* can make only shallow burrows. The giant shrew (*S. mirabilis*) appeared to have excellent burrowing ability judging from ecological and morphological evidence (Okhotina 1969, 1974; Nesterenko 1999). Thus, the long-clawed shrew and the giant shrew can be considered as semi-fossorial inhabitants, or the "shrew-mole" type proposed by Abe (1983) among Palearctic soricine shrew species studied so far. In this study, we clearly demonstrated that long-clawed shrews possess the ability to construct a tunnel system.

There has been scarce information about the structure of the burrows of long-clawed shrews before the present study, except that the diameter of holes was about 2.5 cm (Abe 1968; Yokohata 1990) and the deepest depth of burrow was 20–30 cm (Yoshino and Abe 1984; Ohdachi 1995a). Yoshino and Abe (1984) also indicated that there were two types of digging behavior: surface digging and burrowing in deep soil. These findings were confirmed in the present study. According to the present study, the difference of behavior between the two types was revealed. When digging surface and vertical burrows, shrews throw away the soil with their hind legs, whereas when digging main tunnels, they press the soil against the burrow walls. The shrews made some blind chambers in a tunnel system (Fig. 2). In the present study, the function of the chambers has not been revealed. The long-clawed shrew may use them as excretion sites (Sagara et al. 2008).

Since semi-fossorial shrews nest in burrows (Churchfield 1990; Swiderski 1991), the construction of their tunnel systems should differ not only between adults and subadults, but also between males and females. Tunneling patterns in adult long-clawed shrews have not yet been studied, but we did not observe any obvious differences in tunnel structure between the sexes in subadults. The observations on two males and three females in the present study are clearly insufficient to draw a firm conclusion about the absence of such differences. However, the results of our experiments suggest the existence of individual differences, at least in the timing of tunnel construction: one of the experimental males completed construction one day later than the other four individuals. While there could be many reasons for differences in the duration of tunnel construction in the wild (differences in soil hardness, season, weather conditions, population density, and many others), the main cause seems to be the physiological characteristics of a particular individual.

Soricine species usually establish intraspecific territories, and such territoriality seems to be maintained by aggressive behavior (Crowcroft 1957). In experiments, long-clawed shrews exhibited antagonistic behavior whenever two conspecific individuals encountered each other (Ohdachi 1997). However, it remained unknown whether long-clawed shrews could use burrows made by other individuals. The present study illustrated that long-clawed shrews used tunnel systems made by other conspecific individuals and they modified the ready-made burrow structures.

Churchfield (1980) also reported that *Sorex* shrews utilized the tunnel system constructed by more adept burrowers such as *Apodemus* mice, that made a tunnel of 25-cm depth (Crowcroft 1957). Long-clawed shrews are known to use the burrows made by other animals. For example, in Hokkaido, Japan, it may use tunnels constructed by some rodents, such as the gray red-backed vole *Myodes* (= *Craseomys* or *Clethrionomys*) *rufocanus* (Yokohata 1990). In the Russian Far East, long-clawed shrews often use tunnel networks of the Ussuri mole (*Mogera robusta*) (Nesterenko

1999). Ussuri moles construct tunnel system of two deep layers at a depth of 30 and 60 cm, respectively (Okhotina 1966). Such tunnel system is maintained for many years and probably long-clawed shrews use such long-lasting tunnels. It is not yet known whether the long-clawed shrews modify the burrows made by other larger species.

We were only able to compare the subterranean behavior of three females and two males of subadults in fall and early winter. Thus, age, sex, and seasonal differences in subterranean activity were not detected in the present study. In the next step, such differences in subterranean activity of long-clawed shrews should be considered.

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Figure legends

Fig. 1. The experimental cage designed for the observation of subterranean activity of shrews.

Fig. 2. Schematic drawing of the tunnel system constructed by long-clawed shrew (2KSU-1). a: deep tunnels. b: shallow runway. c: vertical passages. d: entrance chambers. e: branch burrow. f: blind chambers.

Fig. 3. An example of the procedure of the construction of tunnel system by a long-clawed shrew (2KSU-7) in the experimental cage. A: making vertical holes of 6–7 cm depth (observed on 22 October 2000). B: burrowing temporary surface runway of 3–4 cm depth and vertical passages to a depth of 15–25 cm (23 October 2000). C: construction of main tunnel and connecting it to vertical passages (25 October 2000). D: making branch burrows and blind chambers in the rectangle area of C (27 October 2000). The dotted parts indicate the loose layer of mixture of litter and soil.

Table 1. Characteristics of the long-clawed shrews used in the experiments and the terms of the experimental trials

Individual Code	Age and sex	Body mass (g)	Experiment date		
			Experiment 1	Experiment 2	Experiment 3
2KSU-1	subadult female	8.7	5 Sept.–17 Sept. 2000	18 Oct.–20 Oct. 2000	–
2KSU-2	subadult male	9.7	18 Sept.–28 Sept. 2000	4 Nov.– 6 Nov. 2000	–
2KSU-3	subadult male	9.8	6 Oct.–18 Oct. 2000	–	–
2KSU-7	subadult female	9.7	21 Oct.– 4 Nov. 2000	–	–
2KSU-10	subadult female	8.4	7 Nov.–19 Nov. 2000	–	–
3NSU-1	newborn male	9.5	–	–	3 Oct.– 5 Oct. 2000

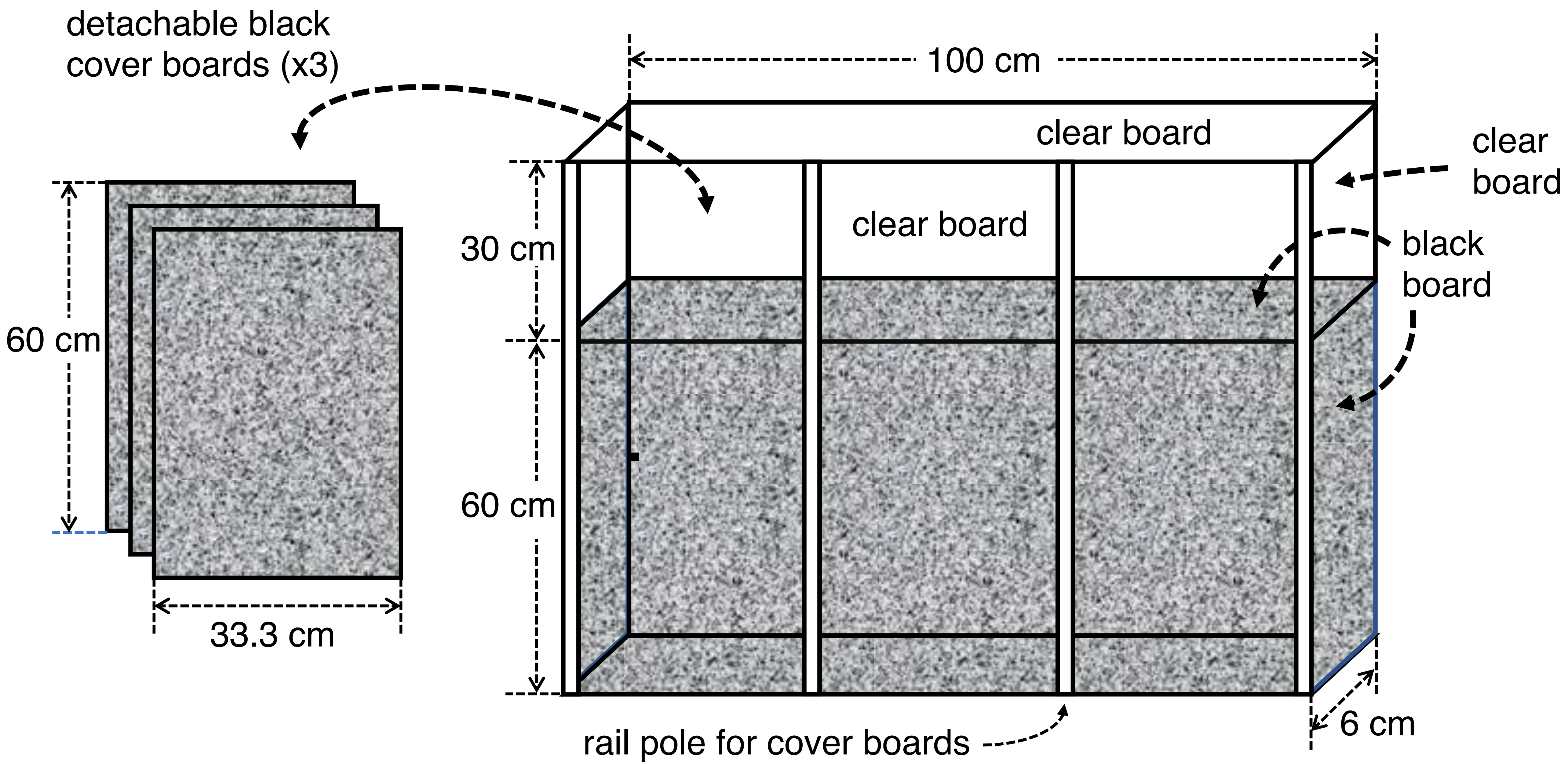

Fig. 1. Nesternko & Ohdachi

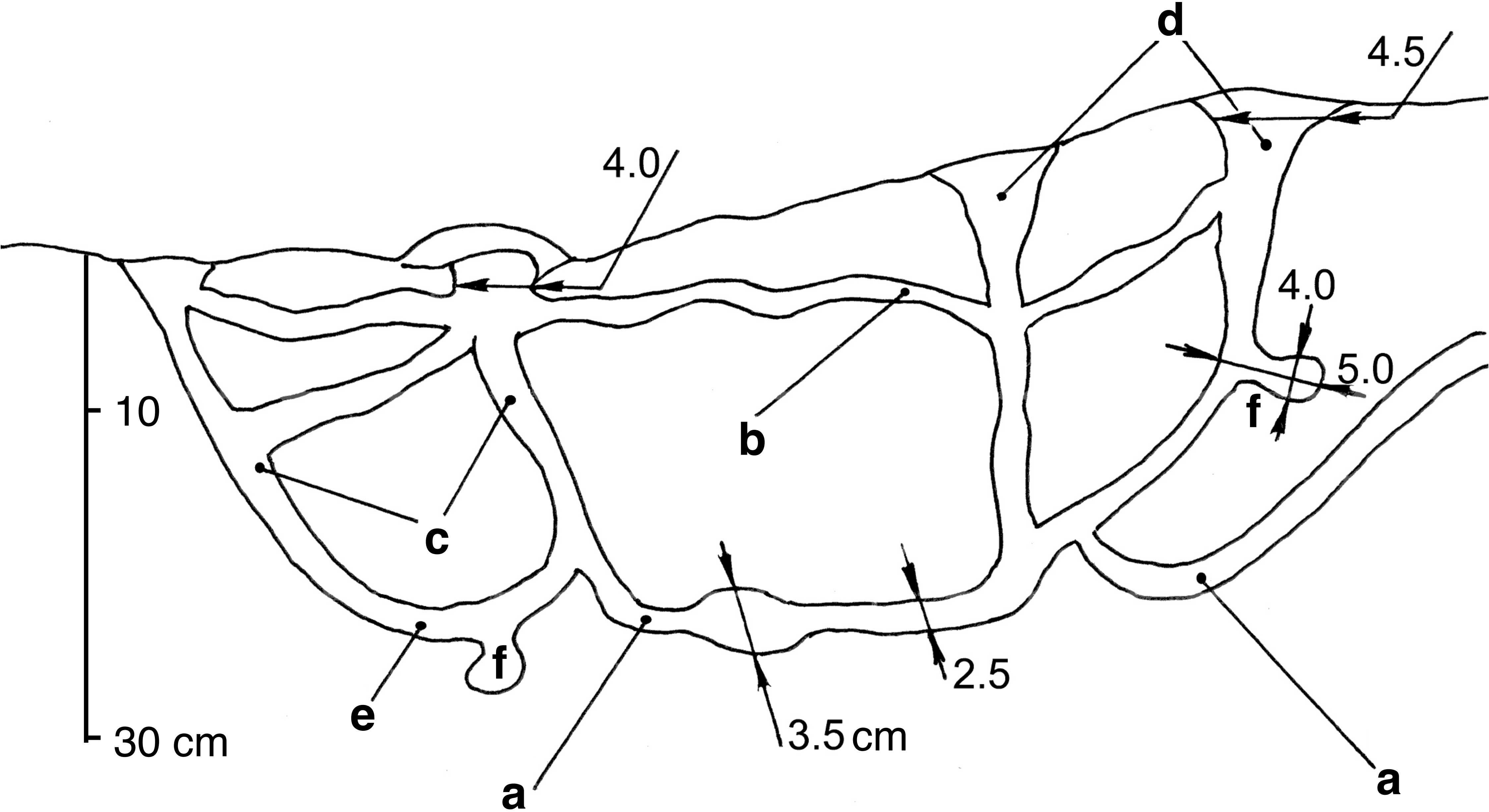

Fig. 2. Nesternko & Ohdachi

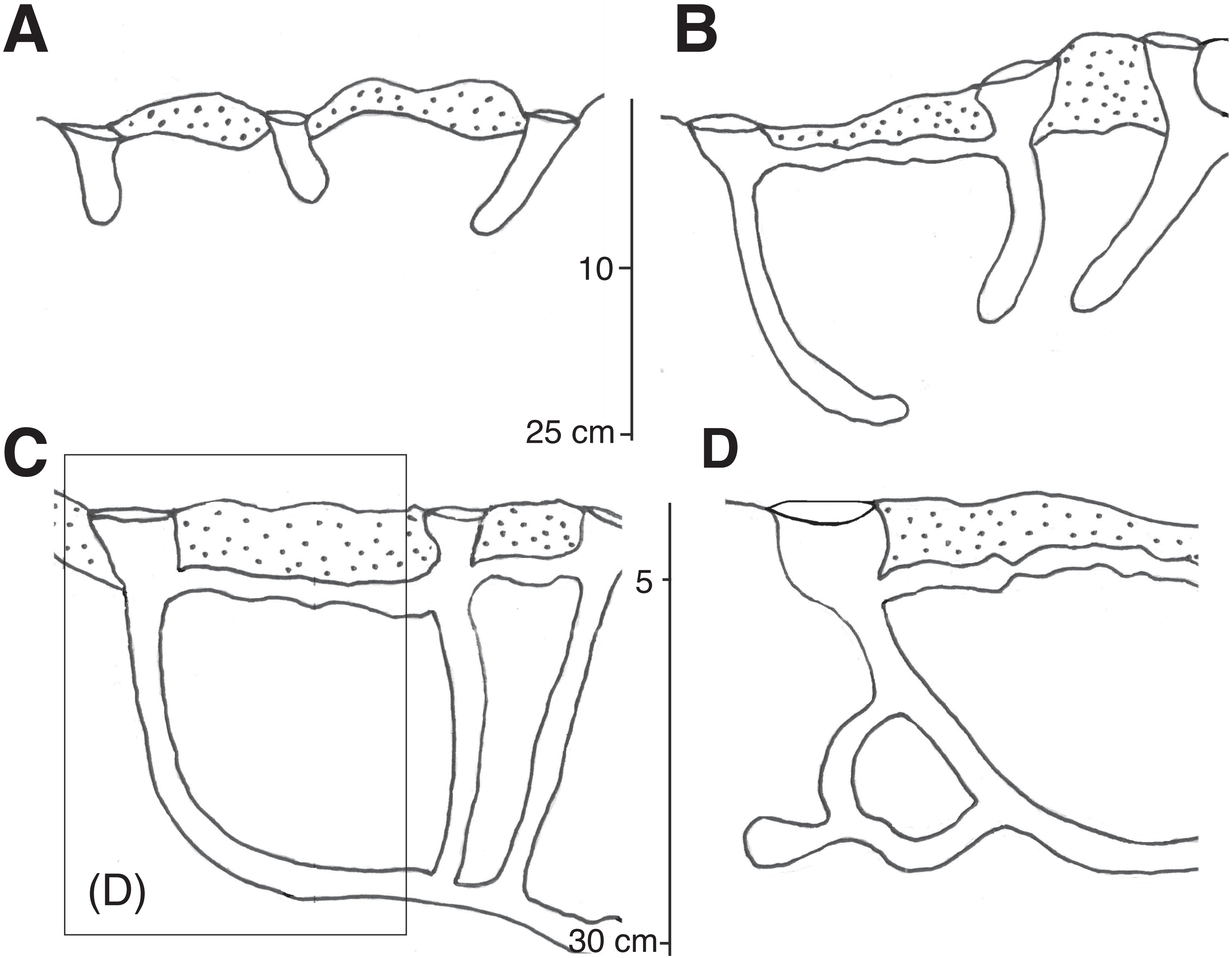

Fig. 3. Nesternko & Ohdachi