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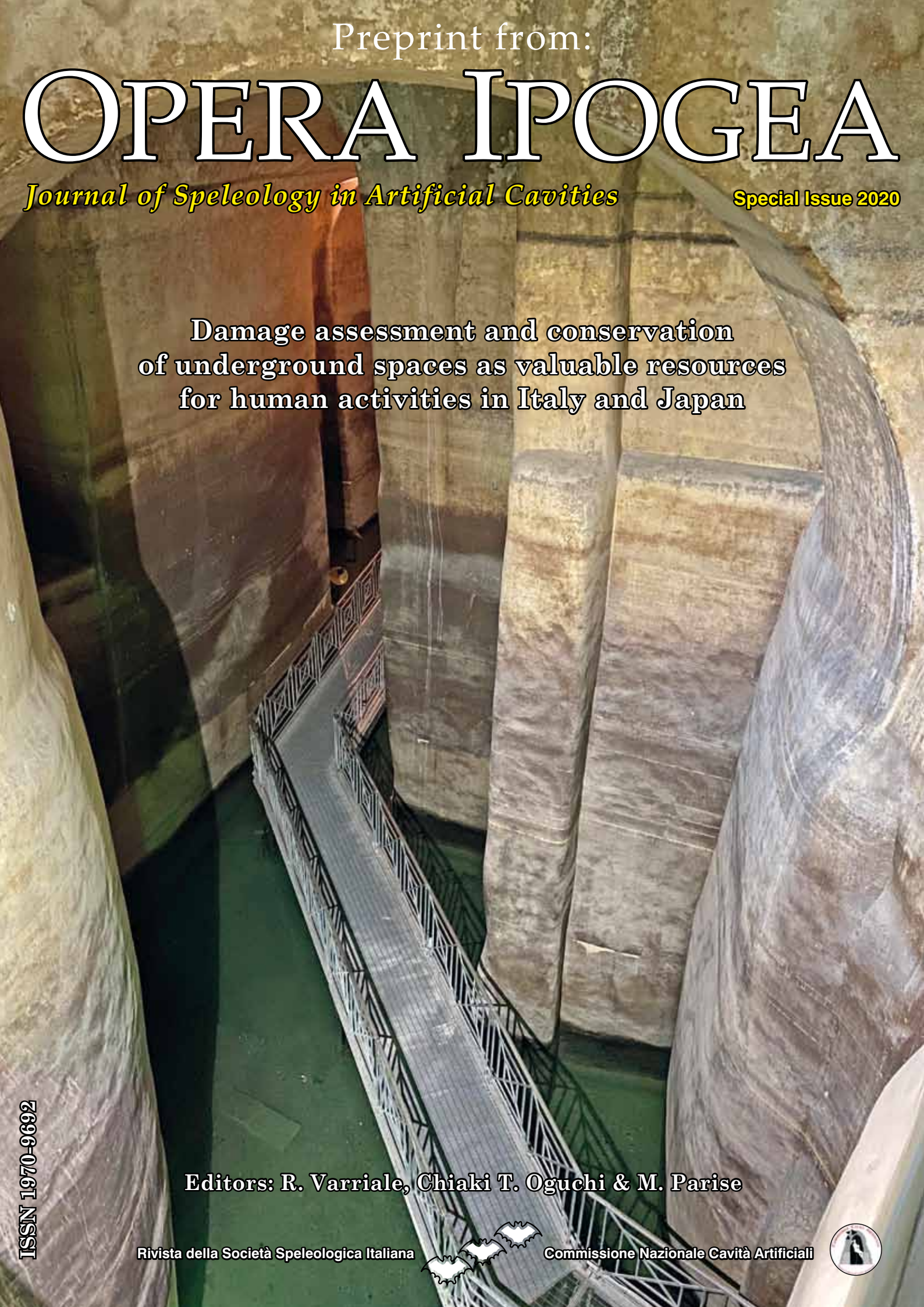

Damage assessment and conservation of underground spaces as valuable resources for human activities in Italy and Japan

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Indice

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Palombaro Lungo water tank in Matera, Basilicata, Italy (photo: Antros Archive – Matera)

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Chiesa K4c a Göreme, Cappadocia, Turchia (foto: Archivio Centro Studi Sotterranei – Genova)
K4c church in Göreme, Cappadocia, Turkey (photo: Centre for Underground Study Archive – Genoa)

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Non-destructive field measurement for investigation of weathered parts – Case study at the Taya Cave, Central Japan

Misure non invasive per l'investigazione di settori alterati nella Grotta Taya, nel Giappone centrale

Chiaki T. Oguchi[1], Kaisei Sakane[1], Yasuhiko Tamura[2, 3]

Abstract

Non-destructive measurements are useful methods for evaluating weathering degree without any damage on geoarchaeological sites. The present study aims to extract the deteriorated parts by using Silver Schmidt Hammer and ultrasonic pulse velocity tests on the Taya Cave in Yokohama city. It is a manmade cave excavated from Kamakura to late Edo periods. Many sculptures and reliefs were carved on the surface of the cave wall made of soft rock. The cave has a complex three-layer structure with a total length of 570 m. Firstly, distribution maps showing cracks and exfoliation parts were created. Then, the points showing low rebound values and slow ultrasonic pulse velocity were plotted on the same map. The results of these non-destructive on-site measurements shows that many dangerous parts were turned out within the worship route. Especially, the complex excavation point in the center of the cave found to be the place where collapse measures must be taken first.

Keywords: Taya Cave, Silver Schmidt Hammer, Ultrasonic pulse velocity.

Riassunto

Misurazioni non distruttive sono metodologie utili per valutare il grado di alterazione dei materiali, senza causare danni a siti geo-archeologici. Il presente contributo è indirizzato alla individuazione delle parti più degradate e alterate dell'ammasso roccioso nella Grotta Taya, nella città di Yokohama, mediante l'utilizzo dello sclerometro (Martello di Schmidt) e l'esecuzione di prove di impulsi ultrasonici di velocità. La Grotta Taya è una cavità artificiale scavata tra i periodi Kamakura e tardo Edo. Molte sculture e bassorilievi sono stati scolpiti sulla superficie delle pareti dell'ipogeo, costituito da roccia tenera. La cavità ha una struttura complessa, su tre livelli, per una lunghezza totale di 570 m. Per le attività del presente lavoro, inizialmente sono state realizzate carte della distribuzione di fratture e presenza di settori interessati da esfoliazione. Successivamente, sono stati riportati sulla stessa carta i punti che mostrano bassi valori di rimbalzo al Martello di Schmidt e bassa velocità degli impulsi ultrasonici. I risultati di queste misure non distruttive in sito mostrano che molte parti risultano degradate anche lungo il percorso di pellegrinaggio. In particolare, il settore centrale di scavo della cavità artificiale, risulta essere quello in cui effettuare altre misurazioni per controllare la possibilità di eventuali crolli.

Parole chiave: Grotta Taya, Martello di Schmidt, impulso ultrasonico di velocità.

Introduction

Geological heritage is typically less impressive when compared to the gorgeous cultural heritage, however, it is one of the important cultural properties that should be protected as human property to be passed on to future generations. In recent years, it has become necessary not only to preserve such a heritage, but also to consider its elements as public treasures. Especially for artificial caves, it is necessary to conduct a proper deterioration diagnosis as an object of mutual learning while conveying the excavated

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historical background to future generations, and to transfer the results in terms of maintenance and public release.

It is often discussed the problems of collapse of these artificial cavities. These caverns deteriorate with the time elapsed since the excavation, however, the time required for the deterioration depends on the geological characteristics of the land, as well as upon anthropogenic forces acting over the sites. In this study, we conducted a preliminary degradation diagnosis in Taya Caves in Yokohama. Taya Cave has been excavated continuously as a training place for Buddhist monks and has stunning Buddhist murals on the walls. At the site, there are the following restrictions: 1) adequate size of equipment to investigate the entire cave, 2) non-electronic apparatus for measurements, 3) no damages on cave walls, and 4) survey time conscious starting from 4 pm after closing, to avoid problems to visitors. Considering the above restrictions, the test equipments judged to be enabled to investigate the artificial cavity have been identified in a silver Schmidt hammer and an ultrasonic pulse velocity test.

Taya Cave

The Taya cave is located in the southernmost area of Yokohama city (fig. 1). Figure 2 shows the large-scale geology of this area and of its surroundings. The area consists of Quaternary deposits, mainly belonging to the Naganuma Formation and the Byobugaura Formation of the Sagami group in the hilly area which is equivalent to middle terrace. The Taya cave is excavated in the lower part of the Taya hill. Naganuma Formation is the lowest member of the Sagami Group, deposited about 700,000 to 150,000 years ago (Omori *et al.*, 1986; Ozawa & Tanaka, 2019). The lower layer

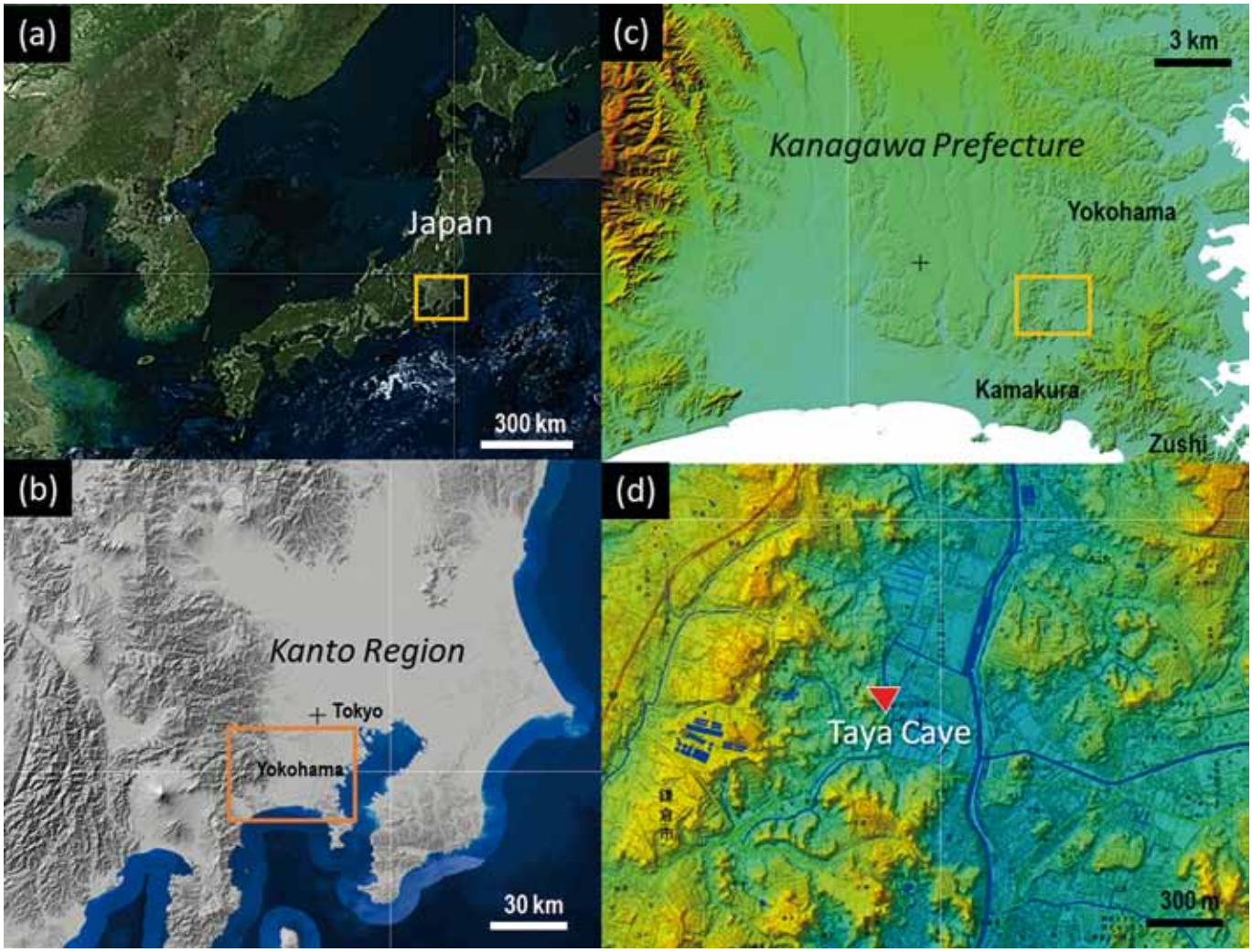


Fig. 1 – Location of the Taya cave (35°22' 03" N, 139°31'20" E), Japan, and surrounding area (a), Kanto Region, central Japan (b), Eastern area of Kanagawa Prefecture (c), and Taya Cave, located in Yokohama city (d) (modified from air photo and relief maps of Geospatial Information Authority of Japan, elaboration: C.T. Oguchi).

Fig. 1 – Ubicazione della Grotta Taya (35°22' 03" N, 139°31'20" E), Giappone, e aree circostanti (a), Kanto, Giappone centrale (b), zona est della Prefettura di Kanagawa (c), e Grotta Taya, a Yokohama (d) (modificata da foto aeree e carta digitale del terreno de Geospatial Information Authority of Japan, elaborazione: C.T. Oguchi).

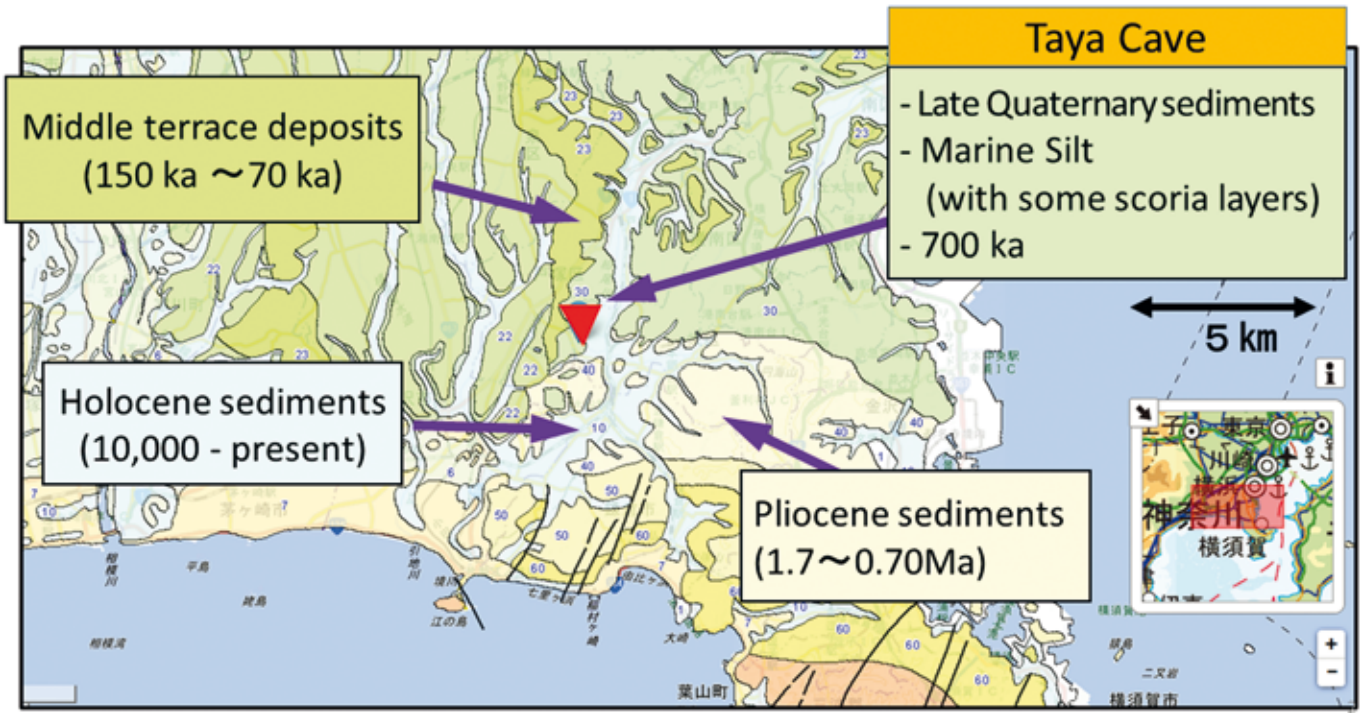


Fig. 2 – Large-scale geology map surrounding the Taya Cave (modified after 1:200,000 seamless geological map, elaboration: Akimoto).

Fig. 2 – Carta geologica a grande scala nell'area circostante la Grotta Taya (modificata dalla Carta Geologica 1:200·000, elaborazione: Akimoto).

(a) (b)

Fig. 3 – (a) Boundary between upper and lower Naganuma formations (photo: C.T. Oguchi) and (b) an example of shell fossil buried in the lower Naganuma formation (photo: Watanabe).

Fig. 3 – (a) Contatto tra i livelli superiore ed inferiore della formazione Naganuma (foto: C.T. Oguchi) e (b) un esempio di conchiglia fossile all'interno della formazione Naganuma inferiore (foto: Watanabe).

of the Naganuma Formation shows dark grey silts, including large shell fossils (fig. 3). The upper layer of the formation shows brown sandstones with fine to medium grain size in the upper layer. The boundary between the two layers can be observed inside the cave.

The Taya cave is inside the Josen-ji Temple, which originated in the 13th century. Many Buddhism reliefs had been excavated on the rock wall of the cave by monk trainees until the end of the 19th century. The rocks composing the Taya cave are represented by soft marine sediments.

The altitude of the cave is about 37 m above sea level, and the relative height is 13 m at the foot of the mountain. The length of the cave is approximately 570 m, and the cave is composed of three layers with a com-

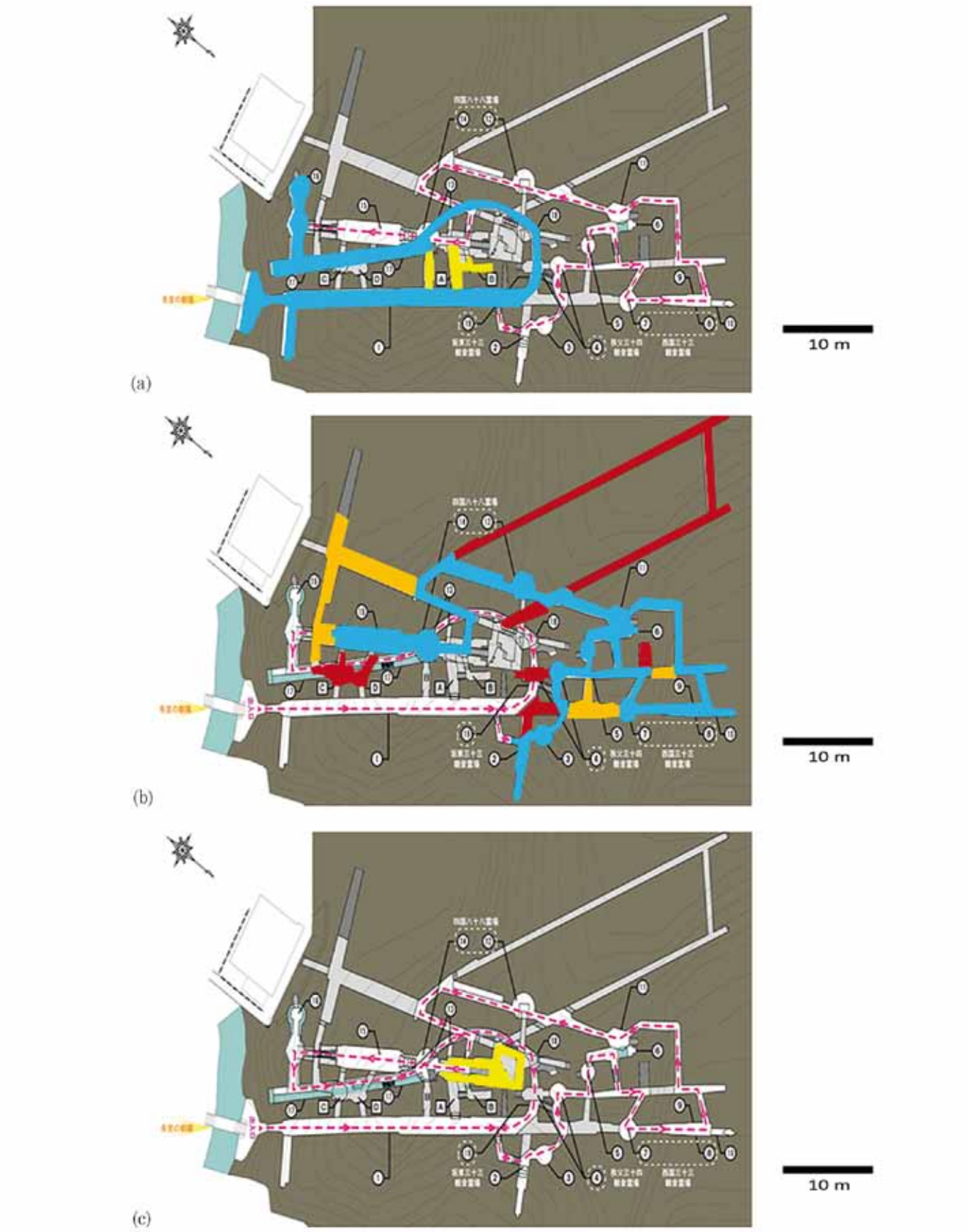


Fig. 4 – Plan map of the Taya Cave; (a) 1st level, (b) 2nd level, (c) 3rd level. Blue, yellow and red areas show accessible and observed paths, non-accessible but observed paths, and non-accessible and non-observed paths, respectively (elaboration by Sakane, modified after the base map drawn by ECPT).

Fig. 4 – Planimetria della Grotta Taya; (a) 1° livello, (b) 2° livello, (c) 3° livello. Le aree in blu, giallo e rosso indicano, rispettivamente, i percorsi accessibili e osservati, non-accessibili ma osservati, e non-accessibili e non-osservati (elaborazione di Sakane, sulla base della carta elaborata dall'ECPT).

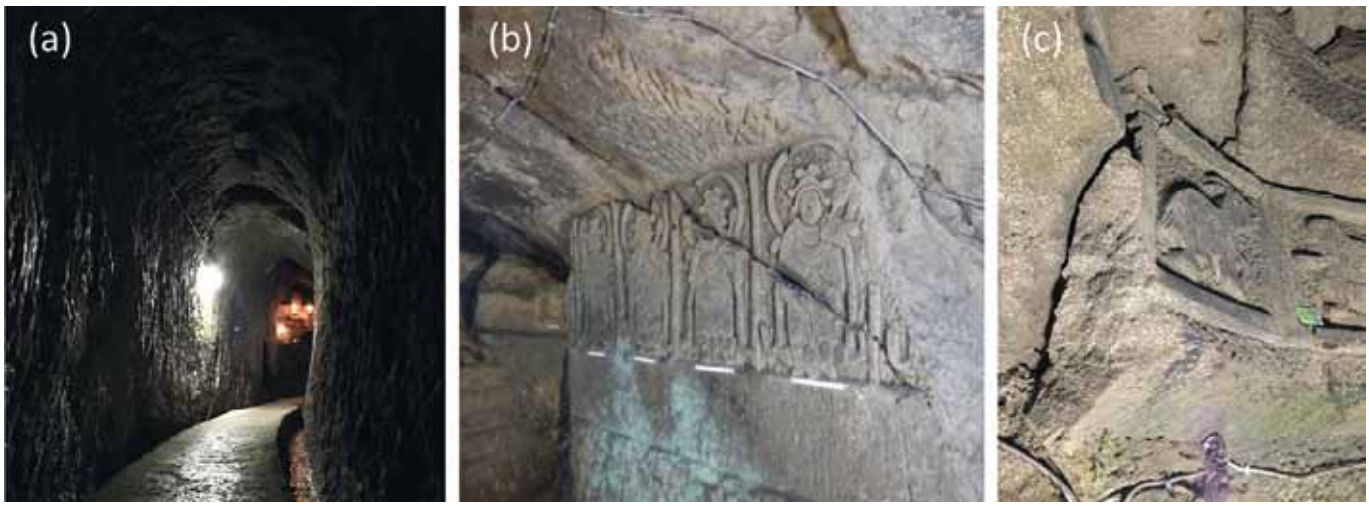


Fig. 5 – Inside of Taya Cave: (a) 1st floor path (photo: ECPT), (b) cracks on the 2nd level wall (photo: Shimizu), and (c) cracks on the 3rd level wall (photo: Shimizu).

Fig. 5 – Interno della Grotta Taya: (a) percorso al primo livello (foto: ECPT), (b) fratture sulle pareti del secondo livello (foto: Shimizu) e (c) lesioni sulle pareti del terzo livello (foto: Shimizu).

plex structure (fig. 4). In detail, the cave consists of an arched passage (fig 5a) and nine domes. There are about 200 excavated sculptures and reliefs on the wall (fig. 5b and 5c), which are supposed to be re-sculpted repeatedly until the late Edo period (18th century). Because of this unique characteristic, this cave is included as a registered regional cultural property of Yokohama city.

However, weathering and deterioration are currently progressing, and the walls and ceiling are interested by exfoliation processes (fig. 5c). For this reason, the damage assessment of this cave is necessary, and the Taya Cave Preservation Committee was established in 2017 at this aim, and has been working to preserve the cave since then.

Visual mapping of dangerous points in the cave

In order to grasp the current situation in the cave, we first observed the parts that seemed more susceptible to collapses. Three types of deterioration were recorded on the map, inside and outside the route for visitors in the cave: cracks, wall peeling, and ceiling exfoliation. Although there is an electric light in the cave, the overall environment is quite dark. We always went around the cave with multiple people to prevent incorrect mapping by personal judgment. The following conditions were set in order to distinguish from the pattern on the wall: 1) cracks with a length of 1 m or more or running over the ceiling, and 2) exfoliation or peeling on wall of ceiling with continuously 1 m or a size of 30 cm x 30 cm or more.

The places with cracks on the 1st level are distributed near the entrance and the U-shaped passage (fig. 6). In the 2nd floor, cracks are concentrated where the

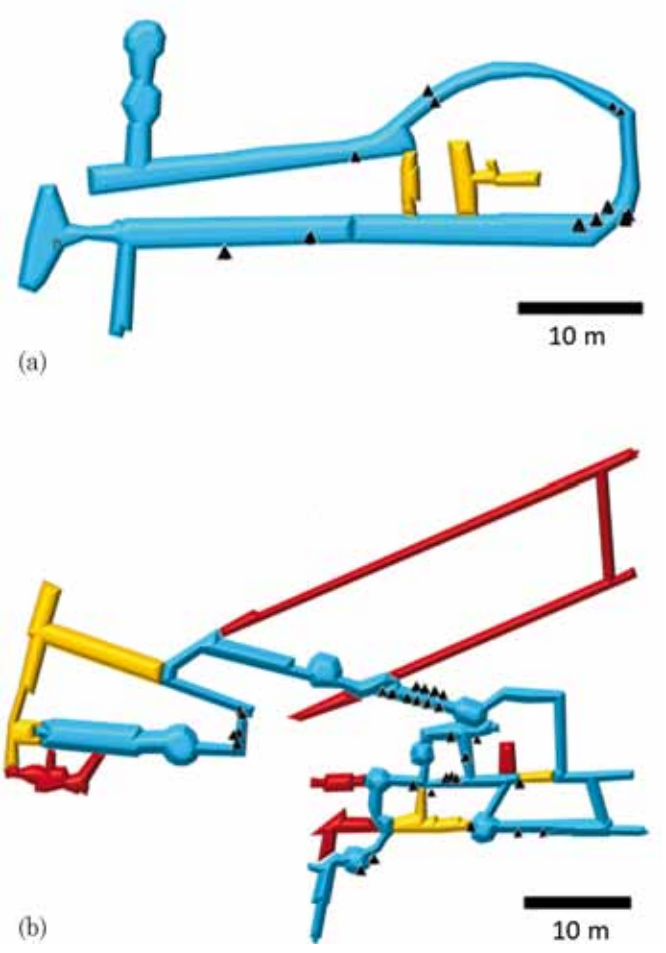


Fig. 6 – Locations of cracks: (a) 1st floor, (b) 2nd floor. Triangle symbol indicates cracks (elaboration: Sakane).

Fig. 6 – Ubicazione delle fratture (indicate dai triangoli): (a) 1° livello, (b) 2° livello (elaborazione: Sakane).

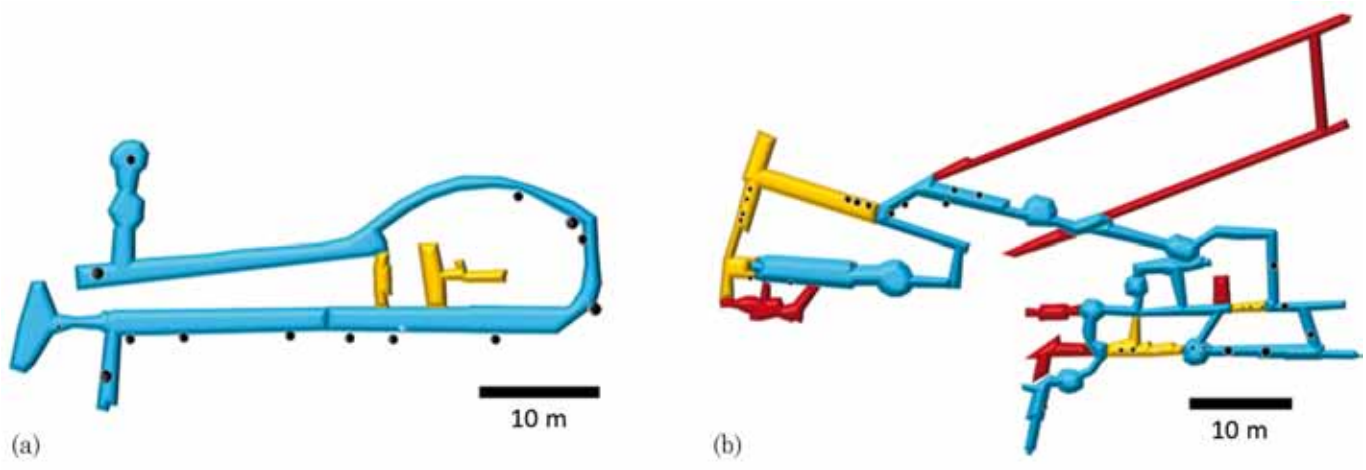


Fig. 7 – Locations of exfoliations: (a) 1st floor, (b) 2nd floor. Solid circles indicate the exfoliations observed (elaboration: Sakane).

Fig. 7 – Ubicazione delle esfoliazioni (indicate dai pallini neri): (a) 1° livello, (b) 2° livello (elaborazione: Sakane).

cave passages. This area has the vents passed from the 1st to the 2nd level as well.

As concerns exfoliation, this is often observed on the wall edge at the conjunction of paths. Newly opened sub-entrance in the south of the cave might affect the exfoliation (fig. 7).

Silver Schmidt hammer test

Silver Schmidt Hammer (fig. 8) is a non-destructive testing machine, also called a rebound Hammer. The ratio of the rebound speed to the striking speed of the internal spring (rebound speed ratio: Q value) is calculated using the same principle as the echo chip hardness tester. Since it is rechargeable, and does not require correction based on the striking angle, it could be used without inconvenience even in a narrow cave.

Measurements at 8 domes were made and the results are summarized in figure 9. Red circle and arrows show the rebound values below average, indicating low strength and the most vulnerable parts.

Fig. 8 – Silver Schmidt hammer (photo: Sakane).

Fig. 8 – Martello di Schmidt (foto: Sakane).

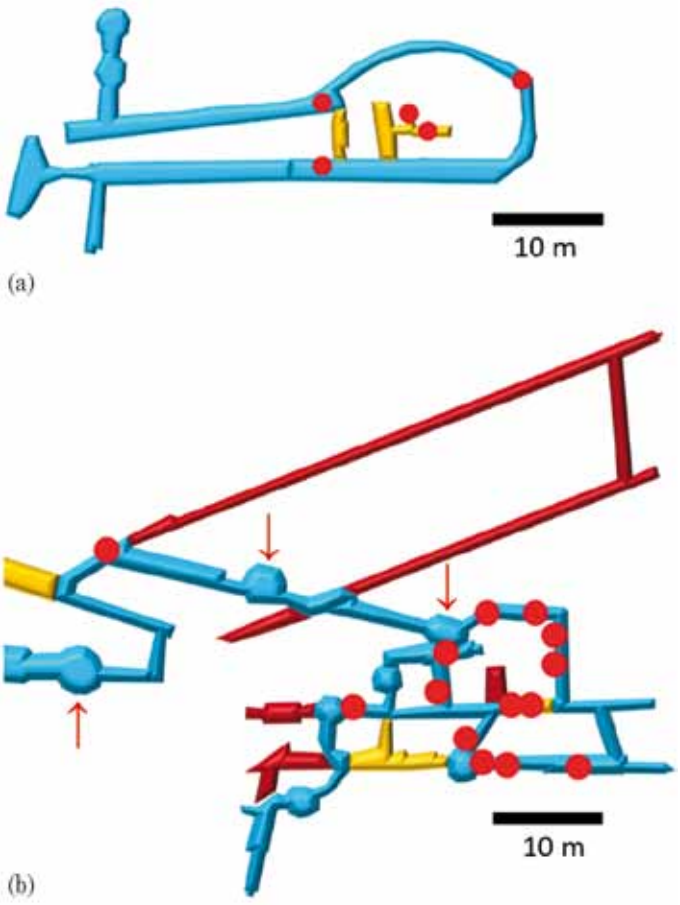


Fig. 9 – Measurement points and results of silver Schmidt Hammer tests less than average, indicating red circle for cave wall and arrows for domes. The average, maximum and minimum values are 18.4, 23, and 15, respectively. (a) first level, (b) second level (elaboration: Sakane).

Fig. 9 – Punti di misura e risultati dello sclerometro (Martello di Schmidt), eseguiti sulle pareti dell'ipogeo (cerchi rossi) e sui domi (frecce). I valori medi, massimi e minimi sono 18.4, 23, e 15, rispettivamente. (a) primo livello, (b) secondo livello (elaborazione: Sakane).

(a) (b) (c)

Fig. 10 – Ultrasonic velocity measurement: (a) apparatus pandit lab (Fuji Bussan Co. Ltd.) (photo: Sakane), (b) distance measurement at the site (photo: C.T. Oguchi) and (c) wave velocity test (photo: C.T. Oguchi).

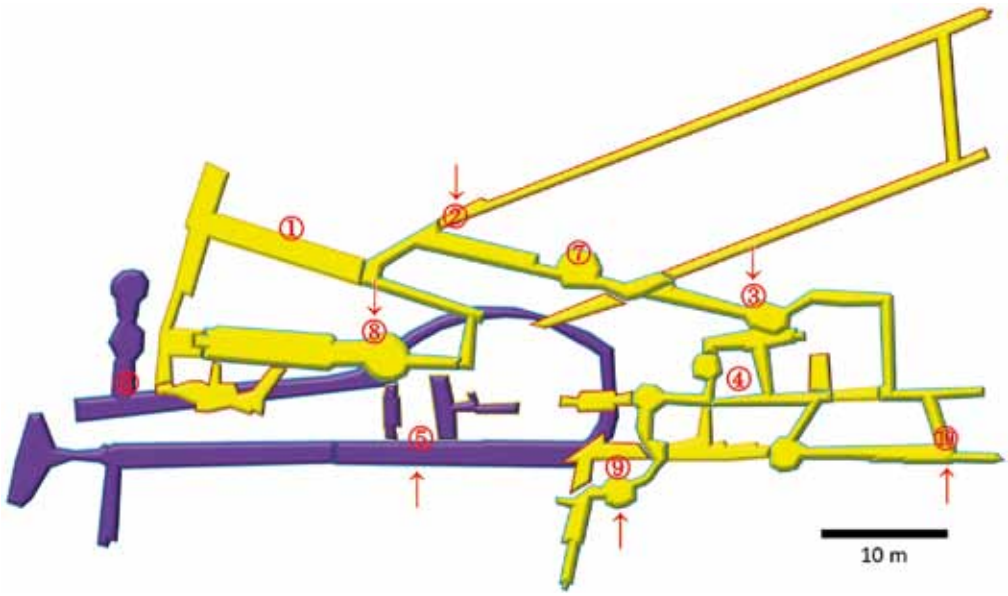
Fig. 10 – Misure ultrasoniche di velocità: (a) apparato pandit lab (Fuji Bussan Co. Ltd.) (foto: Sakane), (b) misura della distanza in sito (foto: C.T. Oguchi) e (c) prova di velocità dell'onda (foto: C.T. Oguchi).

Ultrasonic pulse velocity test

Ultrasonic pulse velocity measuring device (fig. 10) is a non-destructive measurement. It is easy to carry out by means of a silver Schmidt hammer. Internal transmission velocity was measured from the ultrasonic transmission time over a certain distance. Preliminary tests were carried out in the conditions of measurement distances of 10 and 20 cm, with transmission grease and non-grease, with wet wall condition, and without visible crack parts. After confirming these condition, 10 measurement points were selected (fig. 11) and measured 5 times at each point.

Table 1 shows the results of the average data. Although the values range from 285 to 404 μs/m, these are extremely low values compared to general rocks. The points 2, 3, 4, 5, 8, and 10 show rather low values. These points are characterized as high dense corridor area of the cave.

Point	velocity
No. 1	404
No. 2	*313*
No. 3	*285*
No. 4	*312*
No. 5	*289*
No. 6	345
No. 7	330
No. 8	*311*
No. 9	343
No. 10	*297*
average	374



On the left: Table 1 – Result of ultrasonic pulse velocity measurement. On the right: Fig. 11 – Location of the ultrasonic velocity measurement. Red arrows show the points below average values (elaboration: Sakane).

A sinistra: Tabella 1 – Risultati delle misure di impulso della velocità ultrasonica. A destra: Fig. 11 – Ubicazione delle misure di velocità ultrasonica. Le frecce rosse indicano i punti con valori al di sotto della media (elaborazione: Sakane).

Concluding remarks

The vulnerable parts of the Taya cave were turned out by using non-destructive measurements of silver Schmidt hammer and ultrasonic pulse velocity. The results obtained from these measurements are integrated by visible observations to detect cracks and exfoliation. These damaged parts are located around the curved passage on the first level of the cave. On the second level, these parts are concentrated in the main route on the north side of the cave. On the third level, cracks were found on the east side, and low values of Silver Schmidt on the west side. The entire corridor is considered to be in danger condition on the third level. From these investigations, it is cleared that this is the portion that needs the most urgent protection in the Taya Cave.

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