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FORMATION OF THE PEDESTAL ROCKS IN THE TALIAO FORMATION, NORTHERN COAST OF TAIWAN

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ABSTRACT

In the northern coast of Taiwan, the Taliao Formation is well known for the occurrence of many bizarre hoodoo rocks cropping out at the Yehliu promontory and Peace Island. The pedestal rock is a kind of the hoodoo rocks with a cap-rock supported by a stalk. These pedestal rocks used to be interpreted as remnant rocks capped by concretions resulted by differential erosion. However, based on the occurrence and petrological analyses, many of the cap-rock, if not all, are rather encrusted only by a thin oxygenated layer formed under weathering processes.

Key words: pedestal rock, northern coast, Taiwan, Yehliu promontory, Peace Island

INTRODUCTION

The Miocene Taliao Formation is well exposed along the northern coast from Yehliu promontory to Keelung City (Fig. 1). The Yehliu promontory is located about 15 kilometers northwest of Keelung while the Peace Island situated in the northeast side of the Keelung City (Fig. 1). The Taliao Formation is composed of a lower mudstone, a middle sandstone (the Yehliu Sandstone Member, Ho *et al.*, 1964) and an upper thin sandstone and mudstone interbedded unit (Yen and Chen, 1953; Hong and Wang, 1988). The beddings of the Taliao Formation generally strike N48^{o}E and dip 20^{o} southeastward in the Yehliu promontory while strike N70^{o}E and dip 12^{o} southward in the Peace Island. This homoclinal nature of the strata results in conspicuous cuesta topography in both areas. Besides, as frequently being attacked and eroded by waves and winds, the northern coast of Taiwan is well known for its natural rocky coastal scenery. Spectacular and attractive wave-cut and erosional features, such as the vertical sea cliffs, benches, channels and many bizarre hoodoo rocks(**奇形岩**) are all over the coast.

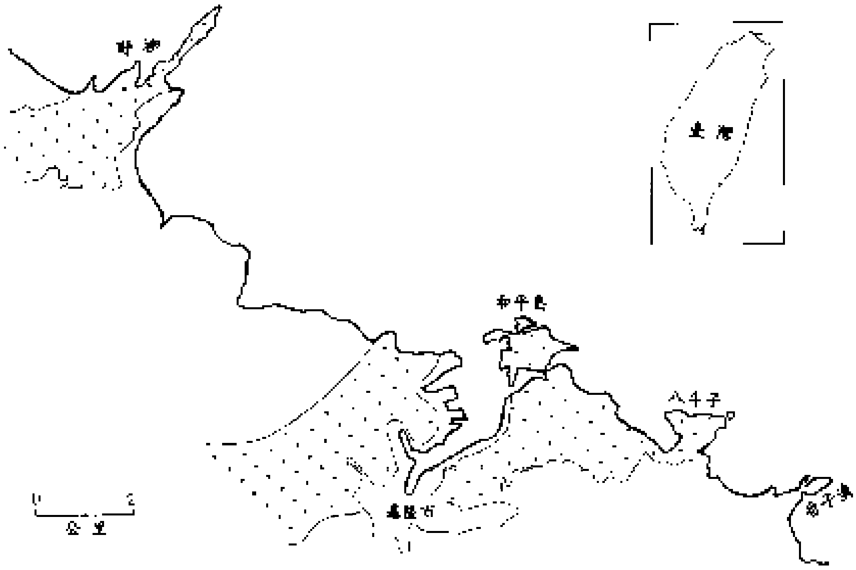

Figure 1. Location of the study area. The Taliao Formation is distributed in the dotted area.

The hoodoo rocks are well developed in the Yehliu Sandstone Member at the Yehliu promontory and the Peace Island. One type of the hoodoo rocks having a cap-rock supported by a stalk are pedestal rocks. In the Peace Island, these pedestal rocks are well known as 'Thousands-heads or Ten thousand tombs'. Meanwhile, in the Yehliu area the pedestal rocks are also called mushroom rocks(Hsu, 1964). One of the most famous mushroom rocks is the 'Queen's head'.

The head-like cap rocks of the pedestal rocks are used to be interpreted as concretions formed under diagenesis. Afterwards, under differential erosion, the pedestal rocks gradually stood out on the ground (Hsu, 1964). However, a few broken cap rocks were observed only encrusted with a thin weathering layer. Meanwhile, the rock inside the thin weathered crust looks like the rocks of the neck and the surrounding ground. Therefore, with detailed field observation on the occurrence of the pedestal rocks as well as petrological analysis, this study try to get better insight on the origin of these pedestal rocks.

PETROLOGICAL ANALYSIS

The middle Yehliu Sandstone Member of the Taliao Formation is composed of thick massive calcareous sandstone beds (Hsu, 1964; Hong and Wang, 1988). Vague layering structures were observed from this thick massive sandstone unit. These vague layers originally were mudstone laminations intercalated in sandstone beds. The thickness of the sandstone beds ranges from 2 to 15 cm while the mudstone laminations are less than 5 mm. in thickness. The obliteration of the beddings is mainly caused by strong bioturbation.

Rock specimens representing the cap rock, neck and surrounding grounds are collected for petrological analysis. For each specimen, part of the rock sample was thin-sectioned for petrographic study; the other part was grounded into powder and examined by the X-ray diffractometry.

Description of hand specimens

The hand specimens collected from the field can be divided as fresh and altered (weathered) parts. The weathered outer layer of the cap rock is dark brown in color while that of the neck and surrounding rocks is yellowish. The inner fresh part of the rock specimens, including inside the caps, necks and the surrounding ground, is light gray in color. The thickness of the weathered part of the cap rock is in general less than 3 mm, while that of the neck and surrounding ground form only a veneer (less than 1mm.) which is difficult to be examined petrologically. Therefore, only the outer layer of the cap rock is treated as the altered part for petrological analysis. Both of fresh and altered rock specimens give effervescence when treated by hydrochloric acid indicating calcareous content.

Petrographic study

Thin sections are made from (1) outer (weathered or altered) layer; (2) inner fresh parts (including the cap rock, neck and surrounding ground); and (3) the intersection of (1) and (2) of the cap rock. Under the polarized microscope, the rocks all are composed of various clastic materials disseminated in a fine-grained matrix. The clastic materials are predominantly as quartz, plagioclase, calcite, fossils, rock fragments and a minor amount of muscovite, chlorite and opaque minerals. Most of the clastic materials are angular to subangular with an average grain size less than 50 μm. Fossils are frequently replaced by opaque minerals. The grain size of the matrix is too small for identification under the microscope. The major difference between thin sections (1) and (2) is the existence of pellets in (2) but hardly observed in (1). A calcite veinlet occurs among the mineral grains in thin section (1). It is believed to be formed after the weathered products such as hematite and limonite are formed. Although the boundary between fresh and altered part of the hand specimen can be clearly distinguished by their difference in color, it is by no means distinguishable under the microscope.

It is noted that thin sections made from the fresh part of the cap rock, the neck and the surrounding grounds are identical petrographically. Therefore, the cap rock and neck are all genetically related to their surrounding grounds.

X-Ray diffraction examination

The altered layer (of the cap rock) and fresh part of the rocks (include the cap rock, the neck and the surrounding ground) are ground to powder separately and examined by the X-ray diffractometry. The CuKα is used as X-ray source and the operating condition is 40 KV and 30 mA. The diffraction patterns of the powder are identified to contain quartz, plagioclase, calcite and some clay minerals. No significant difference for the constituting minerals between the fresh and altered rocks is observed. There is a minor difference in relative abundance of calcite between the two rock types. Although the altered part may contain pigments such as hematite or goethite which cause the yellowish tint of the rock specimen, no iron oxide are identified by the diffraction method.

In short, the results of our petrological analysis of the rock specimens strongly indicate that the rocks composed of the cap, neck and surrounding ground are similar in mineralogical content. They are, as a whole, generally considered as calcareous sandstone in the literature (Ho, 1975). They are covered by a thin layer of weathered products such as hematite and limonite forming a yellowish surface. The cap rock has a relatively thicker weathered layer that may sometimes form cracks and be filled by secondary calcite veinlets.

Field Observation

Detailed field observations on the occurrence of the pedestal rocks were carried out in the Yehliu promontory and the Peace Island. Three lines of field evidence were observed that are evidently against the concretion origin as follows:

1. The characteristics of the rock in the neck are gradually changed through the lower boundary and into the cap rock.
2. The same trace fossil tubes can be traced from neck through the entire cap rock.
3. Cracking and spalling off of the outer weathering crust were observed from a few cap rocks. The inner rock beneath the weathering crust can thus be observed from the cracks and the spalling scars. These newly-cropped-out inner fresher cap rocks are light gray in color and look like those of the neck and the surrounding ground. Besides, through the petrological analysis described above, there is no significant differences found between these fresh rocks sampled from the inner cap rock, neck and the surrounding ground.

Furthermore, six developing stages of the pedestal rocks (Fig. 2) were observed from the field and described as follows:

A. Stage I

Since the Yehliu Sandstone Member is strongly bioturbated, the mottled rock is inhomogeneously mixed with sand and mud. Therefore, when the exposed rock attacked by waves and other weathering processes, different sizes and shapes of swales occurred on the ground surface. These swales sometimes accumulate seawater or rains; sometimes heated and dried by the sun. Under repeated wetting and drying, the surface of the swales was gradually chemically altered and oxidized to form a resistant thin brownish weathering layer. Formation of the weathered layer may persist to stage III.

B. Stage II

Since the surface of the swale is more resistant to erosion, a shallow peripheral furrow were formed under the differential erosion occurred at the edge of the swales. In many cases, the peripheral furrows occur along local joints. It is likely that the joints developed during the upheaval of the region also played an important role in the formation of these peripheral furrows.

C. Stage III

The peripheral furrows were gradually deepened. Water was repeatedly gathered and then dried in the furrow. As a result, the inner walls of the furrows were gradually weathered and oxidized again to form the thin brownish weathering layer. Without being able to keep water to promote forming weathering crust, the surrounding ground is continually lowered by erosion. Under these processes the cap rocks have been gradually isolated and formed.

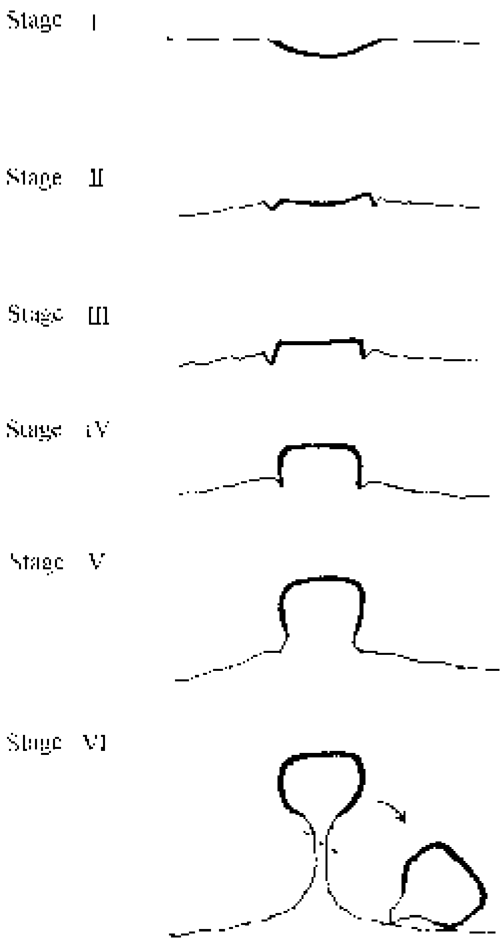

Figure 2. Six developing stages of the pedestal rocks.

D. Stage IV

As eroded faster than cap rock, the surrounding ground is much lowered. The peripheral furrow continuously deepened, enlarged and finally breached. After breaching, the furrow is no longer able to hold water to promote alteration and oxidization. Therefore, the development of thin weathering layer is stopped. The formation of the cap rock is now completed.

E. Stage V

Afterwards, under differential erosion the stalk begins to be engraved. A stubby stalk right below the cap rock are mainly developed in this stage.

F. Stage VI

The stalk is getting longer and slimmer, as the surrounding ground continuously eroded down. Whenever the stalk is too slim to support, the cap rock will finally fall down to the ground.

CONCLUSION

According to the model proposed above, the head-like cap rock of the pedestal rocks is interpreted as being formed by the action of the weathering processes. These pedestal rocks were used to be interpreted as diagenetic concretions which under different erosion, stood out on the ground (Hsu, 1964). However, in the field, a few broken cap rocks observed to be encrusted with a thin weathering outer layer. On the basis of the petrological examination in this study, we found that the head, the neck and the surrounding ground are all composed of the same type of rock. We also found that there is no significant mineralogical difference between the altered and fresh part of the cap rock. The only difference is the outer appearance that is more reddish color of the outer altered rock, due to staining of iron oxides such as hematite and/ or limonite on the rock (Pl. 1). The oxides were formed during the weathering processes. The oxidized layer may be accompanied by the formation of calcite vein (Pl. 2) which fills cracks of the rock during formation of the pedestal rocks at a later stage. Therefore, the origin of the pedestal rocks in Yehliu promontory and Peace Island is reinterpreted as the encrustation of the oxides and carbonates on the surface of "normal" rock rather than as formed by differential erosion on the remnants of "concretion" in the strata.

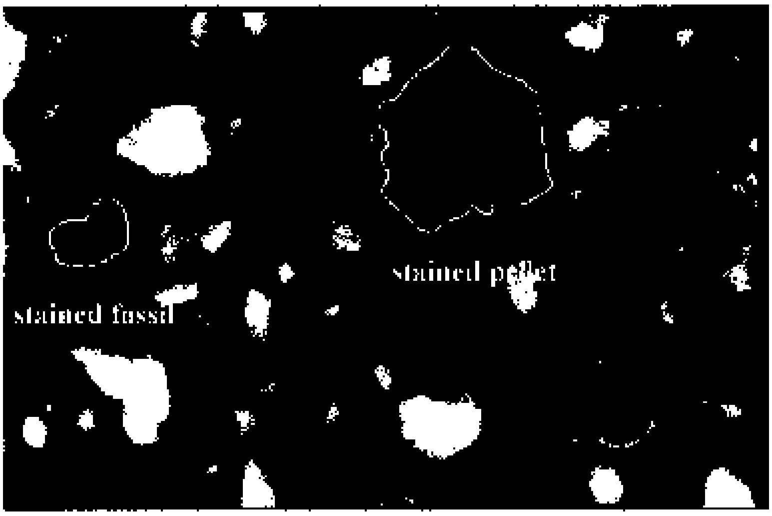

Plate 1. Photomicrograph (x100) of the thin section of the altered crust of cape rock as viewed under open nicol. The stained pellet and stained fossil are outlined. The major clastic constituents include quartz, plagioclase, fossils and pellets. The clastic components are inbedded in a matrix of clayey of unknown composition.

Plate 2. Photomicrograph (x100, open nicol) of the thin section of the altered crust of cape rock shows the secondary calcite veinlet formed during the weathering process.

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