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GEOLOGICAL ENVIRONMENTS OF YAP ISLANDS, MICRONESIA

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Abstract

The Yap islands are characterized by the occurrence of metamorphic rocks of greenschist to amphibolite facies from oceanic tholeiite, and by the lack of raised coral reef. These geological features might be related to the slow ascending history of Yap island arc system. The lack of limestone might make Yapian people recognize the economic value on the stone money of stalactite. Also, strong hydrothermal alteration, associated with the eruption of the Tomil volcanics, plays a role in producing poor soils over a wide area of the Yap islands, where vegetation does not develop. However kaolinite is a predominant clay mineral in the alteration zone, which could be a useful resources for ceramics.

Sulfur isotopic ratios near the coast are generally low, and especially the samples from the channel close to the populated area show extremely low values. The ratio might be useful in the evaluation of the natural environment, as well as in the assessment of destructive impact on the environment by human activities.

Key words: amphibolite, greenschist, hydrothermal alteration, lagoon environment, raised coral reef, sulfur isotope, oceanic tholeiite

Introduction

Yap Islands are located in the western zone of Federated States of Micronesia, and comprise four main islands: Yap, Map, Tomil, and Rumong. Yap Islands are composed mainly of accretional metamorphic rocks and volcanic rocks, accompanied by coral sand and mangrove mud.

Yap Islands comprise an island arc system on the eastern convergent margin of Philippine Plate, connecting to the Palau island arc southward, and to Izu-Mariana arc northward.

There are many Micronesia islands in the east of Yap islands, such as Ulithi, Woleai, Satawal and Ifalik, which are located in the Pacific Ocean plate region, and are oceanic volcanics or atolls developed on the descending volcano.

The geology and its difference between each island might have played an important role in the development of culture and history of each island or region. In this study, the social homeostasis of small islands is considered from geological aspects, especially from the aspects of evolution of the Yap island arc, rock and mineral resources, and sediments on the lagoon floor.

Basement Rocks in the Yap Islands

The geological map in Fig. 1 is cited from JOHNSON et al. (1960). The pre-Quaternary rocks are divided into Yap formation, Map formation, and Tomil volcanics in order of formation age (TAYAMA, 1935). The Yap formation constitutes the basement and is exposed all over the four islands. The Yap formation is composed mainly of greenschist and amphibolite of basalt origin.

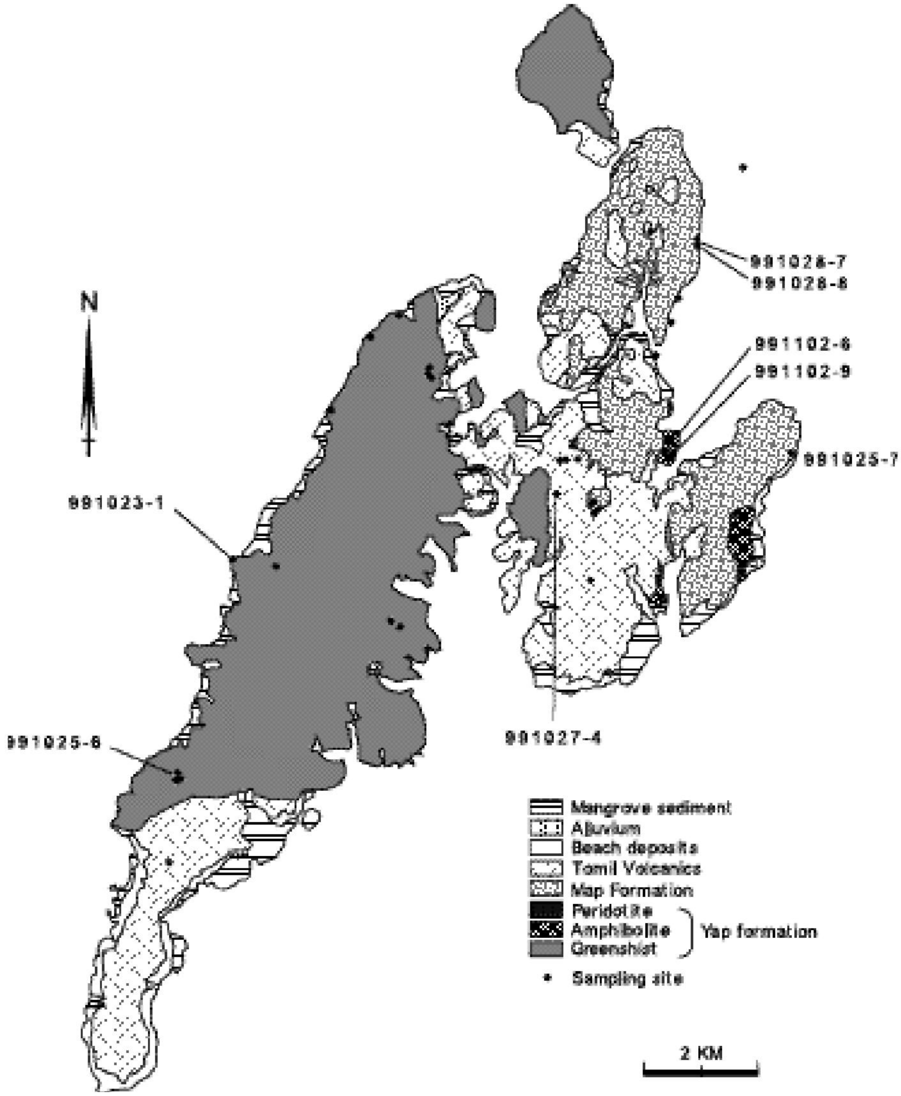

Fig. 1. Geological map of Yap Islands, indicating the location of sampling points of rocks (after Johnson et al., 1960).

The metamorphic grade increases eastward from greenschist facies (western coast of Yap island) to amphibolite facies (eastern coast of Tomil island). Among three island arcs; Izu-Mariana, Yap and Palau, the metamorphic rocks occur only on the Yap arc. Both tholeiite and calc-alkaline rock series common in island arc region are observed in the Palau arc, but no metamorphic rocks (NEDACHI et al., 1996). The Yap formation is derived from melange trapped in the Yap trench. Ultramafic rocks intrude into the amphibolite. The rock is clinopyroxinite to olivine websterite, and the main rock-forming mineral is clinopyroxene, associated with olivine, orthopyroxene, plagioclase and magnetite. The rocks are not metamorphosed and the serpentinization is so weak.

Table 1. Chemical compositions of volcanic, metamorphic and ultramafic rocks from the Yap islands.

	991023-1 Yap F.	991025-6 Yap F.	991025-7 Map F.	991027-4 Yap F.	991028-7 Map F.	991028-8 Map F.	991102-6	991102-9
	greenschist	greenshist	breccia of amphibolite	amphibolite	breccia of gabbro	breccia of gabbro	websterite	websterite
SiO_2	43.67	49.68	45.37	50.85	49.36	50.47	50.81	51.44
TiO_2	1.65	2.34	1.78	2.29	2.44	2.27	0.12	0.14
Al_2O_3	9.78	12.99	10.92	13.40	14.65	15.35	2.40	4.46
Fe_2O_3	12.45	10.60	12.91	11.94	11.54	11.42	6.03	5.74
MnO	0.17	0.16	0.19	0.19	0.15	0.15	0.12	0.12
MgO	16.90	7.71	15.02	7.00	6.61	4.94	21.11	18.58
CaO	9.47	10.99	10.18	10.21	9.91	9.92	18.22	19.55
Na_2O	1.35	3.79	1.76	3.05	4.31	4.40	0.21	0.19
K_2O	0.14	0.19	0.14	0.14	0.40	0.43	0.02	0.02
P_2O_5	0.14	0.21	0.15	0.28	0.20	0.22	0.00	0.00
Total	95.72	98.66	98.41	99.34	99.58	99.56	99.03	100.24
FeO/MgO	0.66	1.24	0.77	1.54	1.57	2.08	0.26	0.28

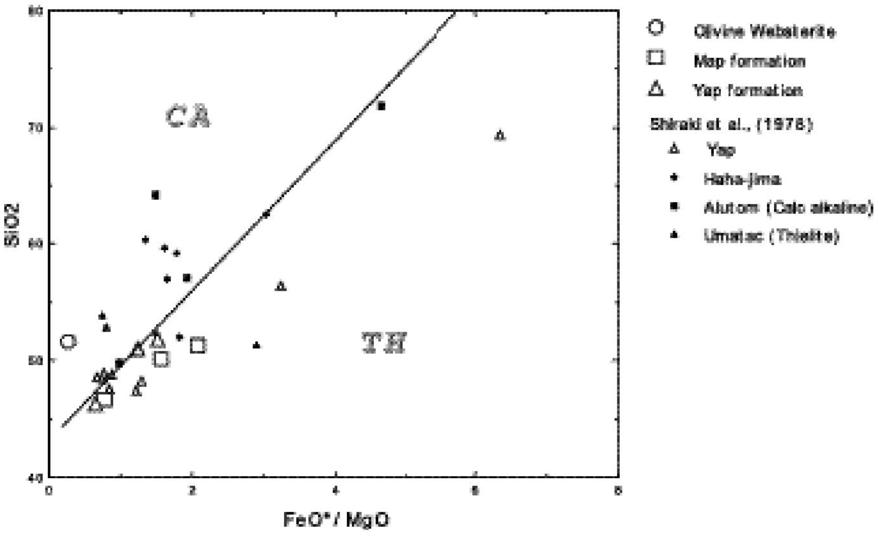

Fig. 2. SiO_2 versus FeO*/MgO ratio of greenschist, amphibolite and websterite in the Yap formation, and gabbro of fragment in the Map formation. FeO* means FeO content assuming that all iron is ferrous.

The Map formation postdates the Yap formation and is composed mainly of tectonic breccia with the fragments of metamorphic rocks of the Yap formation and other igneous rocks. COLE et al. (1960) described foraminifera in the sandstones and siltstones of Map formation, suggesting Miocene as the formation age. JOHNSON et al. (1960) thought that the igneous fragments in the Map formation were of Miocene melange, but the metamorphic grade of these fragments is far lower than that of the Yap formation. Even if the formation might be accretional member, the thrusting mechanism is different from that of the Yap formation.

The major chemical compositions of mafic and ultramafic rocks were estimated using the XRF. The results are in Table 1 and illustrated in Fig. 2, which suggest that the basalt is an oceanic tholeiite. SHIRAKI (1971) and SHIRAKI et al. (1978) thought that these mafic and ultramafic rocks are MORB in origin.

The Tomil volcanics are exposed over a wide area of Tomil and Map Islands, and in the southern area of the Yap island. The volcanics are composed mainly of agglomerate, breccia, tuff and lava. SHIRAKI (1971) pointed that the composition is andesitic, which is mineralogically and geochemically similar to varieties of andesite on the Mariana and Palau arcs. He thought that the Tomil volcanics belonged to the calc-alkaline or island arc tholeiitic series on the continental side of the Andesite Line.

Hydrothermal Alteration on the Tomil Volcanics

Previous workers have reported that the Tomil formation was deeply weathered. We confirmed strong and wide alteration by hydrothermal solution, although the rocks were overprinted by weathering. At almost all area of the four islands, we observed the network veins of hydrothermal argillization. Kaolinite is dominant, and in some places alunite can be detected. The fluid inclusions of quartz in the hydrothermal vein are homogenized at the temperature less than 200℃. RYTUBA and MILLER (1989) reported the gold mineralization at the northeastern end of the Tomil island, which might have been produced by a series of hydrothermal activity.

The hydrothermal alteration play a role in accelerating the strong weathering, which differ slightly from ordinary laterite, characterized by the depletion of Fe_2O_3, Al_2O_3 and SiO_2, and by soil poor in nutrients. These soil materials generally are not suitable for vegetation and agriculture, but kaolinite is used for ceramics. Hence a highly concentrated area of kaolinite might be a mineral resource.

Lack of Raised Coral Reef

Island arc along convergent boundary of plates often repeat to rise and descend. Then raised coral reefs are well developed in tropical and sub-tropical zone. However, it is a unique characteristic that there is no big raised coral reef nor big limestone in the Yap islands. Recent raised coral reef of small scale is observed in the offing, and 2 meters top of coral reef is exposed at low tide. As it is unrealistic that raised coral reef has been completely eroded, an unprecedented geological history is suggested for the Yap islands. The people of the islands have a culture of stone money, and numerous stone monies of various sizes are in or around their houses and other living area. Generally the bigger stone money is made from limestone, and small one is from crystalline stalactite or stalagmite. It is said that these rocks have been imported from neighboring island arc countries; mainly from Palau, and also from Guam and the Philippines. The traditional values of the Yapian culture for stone money is inevitably connected to the lack of raised coral reef. In other words, the unprecedented geological history of the Yap islands might be related to the culture of stone money.

The Environment of Sea Floor in the Coral Reef

To consider the role and effect of the natural environment in the life style of the inhabitants, we collected the lagoon sediments; granule, sand and mud transported from coral reef and land area. Sampling from the 35 sites in the lagoon, also included measurement of temperature of sea water, pH, Eh, content of dissolved oxygen, dielectric constant and salinity. The results are

Table 2. Sulfur isotopic compositions of the sediments and the feature of sea water from the lagoon of the Yap islands

Site	Sediments					Sea water						
	Depth to bottom (m)	fragment	type*	S (ppm)	δ34S (‰)	Depth of sample (m)	pH	Eh (mV)	Temp. (℃)	DO** (mg/l)	DC*** (μS)	Salinity (‰)
1	12.0	coral sand	1	1530	10.7	0.0	8.41	-92	32.8	2.94	49.7	32.2
1						7.0	8.47	-96	34.9	2.82		
2	7.0	muddy sand	2	2000	-9.5	0.0	8.23	-81	32.2	3.56	59.1	33.7
2						7.0	8.27	-84	32.5	3.41	31.4	33.0
3	1.3	lateritic sandy mud	3	197	-4.5	0.0	7.62	-47	29.7	1.37	55.9	33.4
4	1.0	organic mud	3	1230	-4.7	0.0	7.98	-67	29.8	1.81	57.1	34.0
5	1.1	sand-mud				0.0	8.19	-79	30.6	1.75	58.1	34.3
6	8.0	coral sand	1	1690	8.5	0.0	8.28	-84	31.3	2.72	58.5	34.2
6						6.0	8.29	-85	30.7	2.85	51.3	33.0
7	1.5	coral sand				0.0	8.51	-97	31.0	3.30	58.5	34.5
9	0.8	sand-mud	3	1480	-10.7	0.0	7.66	-73	30.4	2.92	57.3	33.4
10	1.0					0.0	7.93	-88	30.3	3.19	57.8	34.4
11	1.0	coral				0.0	7.97	-90	30.1	3.04	57.8	34.4
12	17.5	muddy sand	2	2480	-3.3	0.0	8.00	-93	32.1		59.1	34.4
12						7.0	8.05	-95	30.9		59.1	34.6
13	10.0	mud	3	6100	-21.1	0.0	7.97	-90	30.4	2.70	57.3	34.0
13						7.0	7.98	-90	29.9	3.21	57.2	34.2
14	34.5	sandy mud				0.0	8.06	-95	29.0	2.86	57.2	34.4
14						7.0	8.02	-93	28.8	2.98	56.7	34.4
15	1.6	Coral sand	1	1180	18.9	0.0	8.04	-94	30.0	2.85	57.9	34.5
16	2.0	pebble-granule	2	1340	-5.3	0.0	7.61	-69	30.6	1.85	52.6	30.7
17	1.5	lateritic sand-mud	3	2240	-20.6							
18	2.5	pebble-sand	2	3140	-16.4	0.0	7.67	-63	29.0	1.97	57.1	34.4
19	9.0	sand				0.0	7.98	-86	29.7	2.98	57.7	34.6
20	2.8	sand				0.0	8.00	-86	28.9	2.85	57.0	34.7
21s						0.0	8.16	-95	29.9		57.8	34.5
21m	24.0	silt	3	1350	4.1							
23	31.5	coral sand	1	1420	8.1	0.0	8.19	-96	29.9		58.8	34.8
24m/25s	1.3					0.0	8.15	-96	30.8	3.07	58.7	35.0
25m/26s	1.5	coral sand	1	1060	10.7	0.0	8.12	-93	30.8	2.17	58.9	34.8
27	6.5	reddish coral sand	1	951	14.9	0.0	8.08	-90	31.1	1.90	59.4	34.7
29	41.5	coral sand	1	1510	8.3	0.0	8.07	-90	31.2	2.60	58.5	34.6
30	13.5	Fragment	3	2740	-22.9	0.0	8.06	-90	32.1	2.29	59.1	34.3
30						7.0	8.02	-87	31.4		58.8	34.5
32	37.5	mud	3	2650	-18.6	0.0	8.09	-92	32.6	2.39	59.1	34.4
33	37.0	sandy silt	3	1390	-1.0	0.0	8.09	-92	32.7	2.41	59.7	34.5
34	33.0	coral sand				0.0	8.09	-92	32.9	2.59	59.7	34.5
35	14.5	sandy mud	3	1720	-1.2	0.0	8.10	-92	32.4	2.95	59.6	34.6

*type1: coral fragment, type 2: coarse grained fragment of basement rock, type 3: fine grained fragment mainly of basement rock ** DO: Dissolved oxygen *** DC: dielectric constant

shown in Table 2. In the laboratory, heavy minerals and clay minerals were analyzed using XRD, and sulfur isotopic composition were measured by mass spectrometer; VG Optima.

Based on field observations, the results are as follows:

1) The detrital material transported from the land area is not so abundant. Mangrove forest could have played an important role in precipitating detrital material from the land area. Almost all fragments from the outer zone of the lagoon are coral materials. The intense deposition of

fragments from basement rock is observed in some places. Rather deep (20-50m) sea floor of small hollow lagoon near the western coast of the Yap island is occupied by thick mud layer transported from basement rock. The reason might be that the transportation by the current of sea water is very low, and that large fragments may not have been transported from both land and reef. On the other hand, pebble, granule and sand are predominant in the channels near Colonia harbor, and man-made channel between Yap and Tomil islands. The amount of organic material increases in the channel closest to the coast.

2) Even in the channel near the coast, the activity of sulfate reducing bacteria is not so strong, and there is no stench of hydrogen sulfide. Under the microscope, framboidal pyrite can be observed in the mud samples in the channel near the coast.

3) Clay mineral assemblage of sediments reflects directly the geology in the land area. Chlorite and smectite are predominant in the surrounding lagoon of the Yap and Map formations, and kaolinite and gibbsite are frequently recognized around the Tomil volcanics.

Sulfur Isotopic Ratio as an Indicator of Environment

The sediments contain sulfur up to about 6000ppm. The sulfur isotopic ratios were measured. The preparation procedure is as follows. The sample of 5 g was crushed by auto-mill for 5 minute, and 500ml distilled water is added and stirred for one day. The sample was washed several times by 1M HCl solution, using centrifugal separator to remove SO_4^{2-} ion. Anhydrite and gypsum are also removed if they exist in the sample. The sample is dried and is put into Kiba solution to be extracted sulfur as H_2S, which is trapped as ZnS precipitate in zinc acetate solution. ZnS is converted to Ag_2S, and Ag_2S is oxidized to SO_2, by mixing with Cu_2O in the furnace at 1000℃. SO_2 gas is injected into mass spectrometer, VG-Optima, to measure the $\delta^{34}S$. The re-

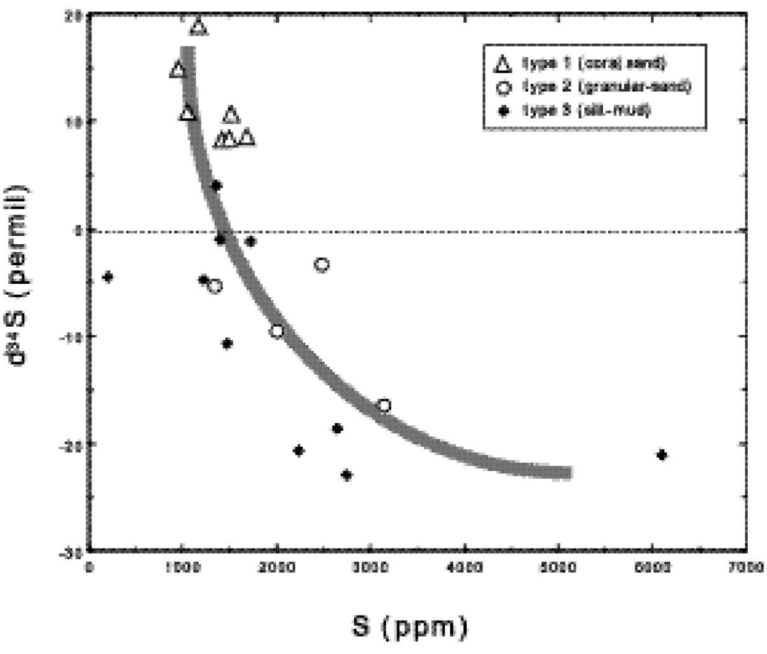

Fig. 3. Sulfur isotopic ratio against S content of the lagoon sediments around the Yap islands.

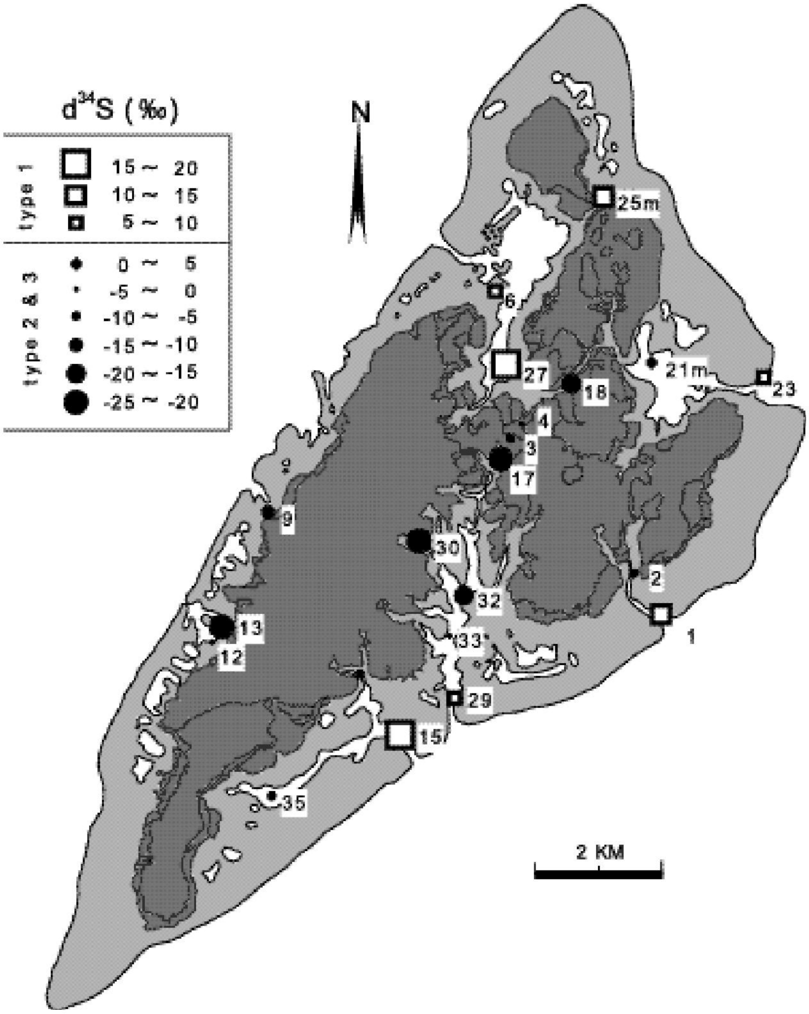

Fig. 4. Sulfur isotopic composition of the sediments in the lagoon around the Yap islands.

sults are shown in Table 2 and Fig. 3. The δ^{34}S values vary from -21 to +20 permil. As shown in Fig. 3, δ^{34}S decreases with increasing S content of the sediment. It is said that the value of the SO_4^{2-} ion in sea water is usually +20 permil, that the value of sulfate precipitate from sea water is usually +20 permil, and that biogenic pyrite produced by sulfate reducing bacteria shows low δ^{34}S value such as -20 to -30 permil. The relationship between δ^{34}S and S content suggests that S is fixed by bioactivity; sulfate reducing bacteria, as pyrite in detrital sediments. On the other hand, the values of coral sand are similar to that of sea water +20 permil. Although we could not confirm the S species in the coral sediments, it can be pointed that sulfate reducing bacteria does not survive in the reef zone and coral sand. Fig. 4 shows the distribution of δ^{34}S values in the lagoon. Clearly sediments in the channel near the coast line show lower δ^{34}S value, due to biogenic pyrite. Notably, the chlorite-smectite-organic matter mud in the small depression on coral near Tageegiin Village show -21 permil as δ^{34}S value. The S content is 6100ppm.

Although the content of dissolved oxygen of sea water is not low, the bottom of the hollow might be suitable reducing environment for sulfate reducing bacteria to survive actively. As the human population is not so high, the natural environments might be suitable for bioactivity. Low $\delta^{34}S$ values are also obtained from the channel near Keeng and Makai, and the southern entrance of artificial channel between Yap and Tomil islands. Many people are living near these areas, and the sediments contain abundant organic matters, which maintain the reducing environment. The $\delta^{34}S$ value and S content might be good indicator of impact caused by human activity. On the other hand, sulfate reducing bacteria does not survive in the outer zone of the lagoon.

Conclusion

The Yap islands are composed mainly of metamorphic rocks of greenschist to amphibolite derived from oceanic tholeiite, and a lack of raised coral reef. These geological features might be related to the slow ascending history of Yap island arc system. The lack of raised coral reef might be related to the culture of the stone money. Strong hydrothermal alteration is observed everywhere, and might have played a role in producing poor soils for vegetation or for other agriculture. However kaolinite might become a useful resources for ceramics if high concentration areas would be discovered.

Sulfur isotopic ratio might be useful to evaluate the natural environment, or to determine the anthropogenic impact on the environment.

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