

Iron and spring water which have been ignored in material cycles in coastal marine ecosystems

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Material cycles in coastal areas can be calculated by freshwater and salinity budgets using a standardized method proposed by LOICZ (Land-Ocean Interaction in the Coastal Zones) Working Group if the targetted area is estuaries with an obvious salinity gradient. In the manual, material loads from spring water can be ignored in case no data are available. However, it is assumed that bottom spring water contains higher concentration of dissolved matter particularly minerals than that of river water, because it passes through the underground lithosphere. Eventhough the water volume is smaller than that of river water, it may contribute greatly to the material budget in coastal areas.

In enclosed coastal seas of Japan, the number of red tide occurrence has been decreased and the transparency has also significantly been increased by reduction measures of material loads from land. There are several areas in which the growth of fish and other organisms is depressed by nutrient depletion, which is called "oligotrophication".

Unexpectedly, the anoxic water mass is still formed in the bottom layer of coastal areas whereas the material loads was reduced. This evidenced that the anoxic water mass may be formed not only by decomposition of organic matter but also by chemical oxidation of hydrogen sulfide. This also suggests that depletion of iron which is an essential element for the growth of algae.

The author recently determined the concentration of dissolved iron from the upper area of the Ohta River which flowing into Hiroshima Bay to lower river and seawater of the bay. Iron and nutrient concentrations in a spring in the bay were also investigated. The author hopes the presentation would be a hook to promote material cycle study of coastal seas.

Keywords: nutrient, material cycle, iron, spring

Estimation of distribution and discharge flux of submarine groundwater using Rn-222 in the Yatsushiro Bay

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Continuous Rn-222 monitoring method has been developed around a decade ago, and with this method, evaluation of spatial distribution and flux of submarine groundwater discharge (SGD) in/along ocean coastal bay/line is becoming popular worldwide. In this presentation, we will introduce a case study in Yatsushiro Bay, describing distribution and flux properties of SGD, deduced by Rn-222 data collected during recent four years. We try to show and confirm the merit and limit of Rn-222 monitoring method and propose a new approach to solve several potential problems on Rn-222 study.

Yatsushiro Bay is one of the largest inland sea in Japan, surrounded by Kyushu mainland to the east and Amakusa Islands to the west. Its total area is around 1,200 km² with a total coastal line of around 220 km. The hinterland of this bay is composed of watersheds with various topographic and geological features. Therefore, Yatsushiro Bay should provide an ideal setting to understand the factors, i.e., watershed area, topographical gradient, presence of tidal flat, geological constituent materials and geological structure, controlling SGD distribution properties in wide scale coastal sea area. By summarizing these features, we can confirm interesting SGD distributing natures in coastal environments.

After analyzing Rn-222 samples of 61 flowing rivers into Yatsushiro Bay, we realized that river waters contain considerable Rn-222, which value cannot be ignored when interpreting Rn-222 signal in the sea. In order to evaluate the effect of river-originated Rn-222 in the coastal sea water, we developed sea water Rn-222 distribution model within whole Yatsushiro Sea, based on a previously constructed ocean circulation simulation model. The net SGD-originated Rn-222 concentrations were estimated by subtracting simulated river-originated Rn-222 concentrations from the observed towing Rn-222 monitoring data.

A total SGD flux within the Yatsushiro Bay was evaluated following traditional box model concept, by multiplying advection rate deduced from continuous Rn-222 monitoring results at mooring survey sites, and SGD patch area estimated by Rn-222 towing survey results. Consequently, it was concluded that 15% of the total water transported toward the Yatsushiro Sea from the land is SGD origin. Furthermore, we tried to understand the possible components contributing to Yatsushiro coastal water, FSGD, RSGD, river water, and sea water, with their contribution degree quantitatively. Our analysis also suggested interesting aspect that wind velocity on the coastal sea surface would be an important triggering factor of SGD.

As a result of our study, it was suggested within the Yatsushiro Sea that Rn-222 concentration could not play as a direct tracer of groundwater because the Rn-222 in the coastal sea water can be partially derived from rivers flowing into the bay. Although previous studies have not taken this effect into account in interpreting sea water Rn-222 observation results, our findings, and our solution idea, would be essential to be incorporated in a future study in an area of similar climate and topographical condition like Yatsushiro area. With this topic, we will propose distribution property, estimated flux, and discharging mechanism of submarine groundwater comprehended by a recent Rn-222 study in the Yatsushiro Sea.

Keywords: SGD, Rn-222, simulation, tidal flat, discharge rate, distribution

Analyses of submarine groundwater discharge based on Radon-222 concentrations of the coastal water in Japan

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Radon-222 is one of the useful tracers for evaluating submarine groundwater discharge (SGD), because the groundwater has extremely high concentration in ²²²Rn compared with surface water. In this study, we attempted to compile and compare radon data observed in ten study areas in Japan, with SGD observed by seepage meters as well as local environmental parameters such as precipitation, gradient, permeability, basin area, tidal range, and others. We used geographical information system (GIS) and digital elevation model (DEM) to evaluate the characteristics of the basin. The highest ²²²Rn concentrations was recorded in Yuza (Northwestern Tohoku area) in Japan, where the highest SGD by seepage meter was observed. ²²²Rn concentrations increases with precipitation within the study areas of four bays in Yuza and four bays in Otsuchi. Multivariable analyses of driving factors of submarine groundwater discharge were performed in the ten study areas.

Keywords: submarine groundwater discharge, Radon, coastal groundwater

The origin of submarine groundwater discharge in the coastal zone of Hiji, Oita prefecture

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It is believed that groundwater discharges from the seabed of the coastal zone of Hiji, Oita prefecture. The marbled sole which lives around this submarine groundwater discharge (SGD) is called the "Shirosita Karei", and is held in high regard by the local community. From ancient times, local people have believed that this Shirosita Karei grows because of SGD. However, the ecological link between marbled sole and SGD has not been well established. Moreover, although it is clear that there is SGD in the area, there is almost no information about the origin and dissolved components of the SGD. In this study, we directly collected SGD and analyzed its chemical composition and water stable isotopes. Additionally, we analyzed the chemical composition and water stable isotopes of the inland cold spring water. We considered the origin of the SGD by comparing the result of the SGD analysis and the inland cold spring analysis. Since we expected that the temperature of SGD would be different than seawater, we used a thermometer for the identification of the discharge location. We inserted a stainless steel pipe in the identified location and collected SGD water. The sodium concentration from the collected SGD water was 12.1 mg/l, indicating fresh water. The isotopic composition of the SGD water resembled that of the inland cold spring water. The recharge area of the inland cold spring water is at an elevation of 200 m or more. These results suggest that the SGD water comes from an elevation of 200 m or more. It indicates that the origin of SGD is water recharged in the forest area of the mountain slope, and that the water moves under the plain and is discharged at the seabed.

Keywords: Submarine groundwater discharge, Stable isotope, recharge area, Hiji

Submarine groundwater discharge and nutrients state of around coastal seawater

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In recent years, the importance of nutrient input to the coastal seawater through submarine groundwater discharge (SGD) has been pointed out in several studies. The coastal area of Hiji town in Oita Prefecture, it is known that there is a submarine groundwater discharge. However, the effects of SGD-derived nutrients has not yet been clarified in this area. Therefore, we investigated the spatial distribution of SGD using radon-222 isotope as a groundwater tracer and assessed the impact on the nutrient (DIN and DIP) concentrations of surrounding seawater. In May 26-30, 2014, we monitored ²²²Rn and nutrients along the coast of Hiji. In addition, we collected the spring water on the land and the spring water of a salt water mixture discharged on the coast. As a results, ²²²Rn concentrations was clearly highest on SGD point. Nutrients concentrations around the SGD point were higher DIP concentrations than elsewhere and the N/P ratios lower than the Redfield ratio. These results imply that SGD is main source of DIP in coastal area of Hiji.

Keywords: Submarine groundwater discharge, ²²²Rn, Nutrients, Primary production

The influence of groundwater discharge on primary production in a shallow coastal sea, Obama bay, Japan

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Submarine groundwater discharge (SGD) often influences on biogeochemical properties in coastal seas. We observed spatial and temporal variations in SGD using ²²²Rn and seepage meter along the shoreline of Obama bay, Japan. The results showed SGD exists even in the shallow sea adjacent to the small water catchment area (~1 km²), where the range of the tide is relatively small (10 ~30 cm). The spatial and temporal variations in chlorophyll observed at the same time suggest that the SGD influences on primary production.

Keywords: land-ocean interaction, submarine groundwater discharge, coastal ecosystem, primary production

Location estimation of submarine groundwater discharge from Mt. Fuji in Suruga Bay (II)

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Around the foot of Mt. Fuji, the main flow passages of groundwater are thought to be in the Younger Fuji volcano, which consists of the pervious basaltic lavas in new volcanic stage. Especially, the Fujikawa-kako fault zone, which stretches south to north in the southwestern side of Mt. Fuji, has a potentially effect on the local groundwater flow system into Suruga Bay. Therefore, precipitation at Mt. Fuji have been considered to be discharging partly from seabed in Suruga Bay and making a great impact on the biological production at the coastal sea area.

For the purpose of contribution to make sense of the rich coastal ecosystem in Suruga Bay, we conducted a survey for submarine groundwater discharge (SGD) in Oku-Suruga Bay: from the mouth of the Fuji River, at which the fault is found, to Tagonoura, where the lavas of the Younger Fuji volcano are distributed from 100 to 200 m below sea level. We are trying to estimate some locations of SGD from bottom topography, condition of seabed and geological structure by using multibeam sonar, side scan sonar and sub-bottom profiler, respectively. We also use a remotely operated vehicle (ROV) for photographing for the image of the extrapolated spring points. In this presentation, we introduce our works noted above.

Keywords: submarine groundwater discharge (SGD), Mt. Fuji, multibeam sonar, side scan sonar, sub-bottom profiler, remotely operated vehicle (ROV)

Effects of submarine groundwater discharge on coastal fishery production: emphasizing on fish community

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Biotic and abiotic surveys were conducted at four sites in Japan, where submarine groundwater discharge has been confirmed. In order to evaluate the contribution of nutritional input from the terrestrial ecosystems to production of fishery resources in coastal areas, sampling for fish and their prey organisms were conducted. Number of fish species, fish abundance and biomass were compared between areas of different levels of Radon concentration at each site.

Keywords: coast, water-food NEXUS, Fishery resources, biodiversity, submarine ground water, biological production

The evaluation of the effectiveness of the $\delta^{13}\text{C}$ signature in bivalve shells as proxy for environment of SGD

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Submarine groundwater discharge (SGD) is often characterized by high concentration of nutrients and documented as an important pathway between land and sea contributing to the biological productivity in coastal waters. However, to our knowledge, no scientific information about the relationship between environmental conditions of SGD and the extent of biological productivity of the primary consumers is available. The carbon stable isotope composition of dissolved inorganic carbon ($\delta^{13}\text{C}\{\text{DIC}\}$) is generally different between SGD (low $\delta^{13}\text{C}_{\text{DIC}}$) and sea water (high $\delta^{13}\text{C}_{\text{DIC}}$). Bivalves record chemical and biological environment-signal in their shell. In this study, to examine whether the $\delta^{13}\text{C}$ of bivalve shell ($\delta^{13}\text{C}_{\text{SHELL}}$) reflect the $\delta^{13}\text{C}_{\text{DIC}}$ of the ambient water or not, we conducted the rearing experiments of Manila clam *Ruditapes philippinarum* under laboratory and field conditions. Manila clam was reared at three different salinity in the laboratory; 100% sea water (100 % SW), 80% sea water + 20% underground water (80 % SW) and 60 % sea water + 40% underground water (60 % SW). Water temperature of three salinity groups was maintained at 25 °C and the same amount of diet (*Chaetoceros gracillis*) was fed every day during experiments (3 months). There was a high positive correlation between $\delta^{13}\text{C}_{\text{DIC}}$ and salinity ($r^2 = 0.997$, $n = 32$, $p < 0.001$). Although the significant difference among 100 % SW, 80 % SW and 60% SW was not found (ANOVA, $p > 0.05$), the $\delta^{13}\text{C}_{\text{SHELL}}$ of 80 % SW and 60 % SW was tend to be lower than that of 100 % SW. The field experiment was carried out at 6 sites under different SGD condition in Obama Bay, Japan from July to August 2013. Manila clam was reared in the small containers with bottom sand, which were kept at the depth of 2 m under natural condition. There was a high negative linear relation between $\delta^{13}\text{C}_{\text{SHELL}}$ and Radon 222 (^{222}Rn) concentration at surface layer of each rearing site, which is a useful tracer of SGD ($r^2 = 0.920$, $n = 6$, $p < 0.01$). Thus, it seems that the $\delta^{13}\text{C}_{\text{SHELL}}$ shows some possibility of being proxy for environmental reconstructions of submarine groundwater discharge. However, the value of the $\delta^{13}\text{C}_{\text{SHELL}}$ was lower by about 5 ‰ than that of the $\delta^{13}\text{C}_{\text{DIC}}$ of ambient water in the laboratory experiment. It was the possible reason that isotopically light metabolic carbon, derived from food, is incorporated into shell carbonated.

Keywords: Dissolved inorganic carbon, metabolic carbon, bivalve shell, carbon stable isotope ratio, submarine groundwater discharge

The application of regional groundwater flow model to the underground dam in the ryukyu limestone aquifer

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The underground dam was construction in the Ryukyu limestone aquifer and groundwater is used to agricultural water. Water quality change of groundwater and that affect to sea water quality through submarine groundwater discharge to be expected due to agricultural use.

Groundwater model for understanding and predicting hydraulics and contaminant transport in aquifer make assumptions about the distribution and hydraulic properties of geologic features that may not always apply to karst aquifers. In this study, a finite difference groundwater model (MODFLOW-NWT) was applied to construct an equivalent single layer two-dimensional mathematical model of the Ryukyu limestone aquifer, which is located a southern part of Okinawa main islands. In order to handle problems at regional scale groundwater model in the aquifer, automated parameter estimation method (PEST) and coupling the conduit flow process was used in this model. Groundwater level measurements collected in 1994 were used to calibrate a steady state model of the study area. This study shows the ability of MODFLOW-NWT and PEST to simulate regional groundwater flow in highly karstified aquifer such as Ryukyu limestone aquifer, which is important for water resource and groundwater management in the area.

Keywords: Underground dam, groundwater flow, conduit flow, PEST, submarine water discharge

Analysis about the condition of sea water intrusion to Yodo River estuary by the fluid model

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Red tide of *Alexandrium tamarense* occurred in Yodo River estuary in recent years. *A. tamarense* is marine phytoplankton and causes shellfish poisoning. Sea water intrusion to Yodo River is one of the reasons of marine phytoplankton survive. We investigated the distribution of the sea water intrusion by in-situ observation, then reproduced it by the fluid model. Fluid structure of Yodo River estuary consists by the runoff of fresh water, the estuary circulation, the tidal current and the wind driven circulation. These had contributed at almost same rate to sea water ascension.

Keywords: Yodo River, sea water intrusion, Red tide, shellfish poison, fluid model

Diurnal variation of pH in Oshoro Bay, Hokkaido: A monitoring study assessing and projecting impacts of ocean acidification

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Coastal marine species have already been experiencing a low pH environment (<7.9) that is not predicted until 2100 in open oceans in a high CO₂ world. To properly assess impacts of ocean acidification on them inhabiting wide ranges of diurnal variation of pH, we need to conduct long-term and high-frequency monitoring measurements of environmental parameters. In this study, to investigate the diurnal variation of pH in subarctic region, which is less known than tropical and subtropical regions, we conducted monitoring measurements of pH, seawater temperature, and salinity in Oshoro Bay, Hokkaido from 2013 to 2014. Mean, maximum, and minimum pH values obtained by a pH meter were 8.02, 8.47, and 7.33, respectively. Although ranges of diurnal variation of pH were different with season, increases in pH during the day and decreases during the night were found in all periods. There are no statistically significant relationships between the variation of pH and that of seawater temperature or salinity except in some cases. These results suggest that observed diurnal variations of pH may be driven by photosynthesis and/or respiration in resident organisms in Oshoro Bay.

Keywords: subarctic region, ocean acidification, coastal ecosystem, diurnal variation

Ongoing stress of transboundary pollution: Assessment of atmospheric N deposition influence by means of nitrate isotopes

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Anthropogenic emissions of reactive nitrogen (N) due to fossil fuel combustion and modern agriculture practices have dramatically increased in global scale. In the Japanese watershed along the Sea of Japan, large amounts of reactive N emitted from northeastern Asia have deposited onto forest ecosystems, and thus N concentrations in rivers and groundwaters have been increased year to year. Remotely modified N concentrations of terrestrial waters in local watersheds would affect coastal ecosystems. However, quantitative influence of N deposition on the watershed along the Sea of Japan is still unclear. In this study, we assessed the influence of atmospheric reactive N deposition on the watershed in Wakasa Bay by means of the ¹⁷O anomaly ($\Delta^{17}\text{O}$) in nitrate, which is an alternative tracer for atmospheric nitrate ($\text{NO}_3^-_{atm}$). As a result, fractions of $\text{NO}_3^-_{atm}$ in stream waters of the Kita River observed in 2014 changed from >10% in winter to 6% in summer. This seasonal variation corresponded to monthly changes in reactive N (= NO_3^- , NH_4^+ and others) deposition rates onto the watershed. However, most of NO_3^- in stream water was derived from remineralized NO_3^- by nitrification ($\text{NO}_3^-_{re}$) within the watershed. Apparent nitrification rates estimated by $\Delta^{17}\text{O}$ were significantly higher than total N deposition rates. Although fractions of $\text{NO}_3^-_{atm}$ in groundwater and spring water (mean \pm SD = 4.3 \pm 0.3%), which was dated from 2001 to 2009 by SF₆, were significantly lower than that in stream water, yearly variation in $\text{NO}_3^-_{atm}$ fractions showed exponential increasing trend in the recent decade. These results imply that atmospheric reactive N deposition would affect severe influence on not only the forest ecosystem but also the coastal ecosystems.

Keywords: transboundary pollution, atmospheric nitrogen deposition, triple oxygen isotope, nitrogen saturation, retrospective analysis, Sea of Japan