RESEARCH ARTICLES

MODERN DINOFLAGELLATE CYSTS FOUND IN SURFACE SEDIMENTS OF SANTA CRUZ ISLAND, GALAPAGOS

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SUMMARY

Modern dinoflagellate cysts in surface sediments collected on Santa Cruz Island, Galapagos, are described, along with other palynomorphs such as microforaminiferal linings, tintinnid loricae, copepod eggs and acritarchs including *Domasiella*-like micro-remains and *Halodinium* spp. The dinoflagellate cyst assemblages mainly consisted of *Spiniferites* cf. *scabratus* (gonyaulacoid) followed by *Brigantedinium* spp. and *Selenopemphix quanta* (peridinioids). No gymnodinioid cysts were found. No remarkable differences in cyst composition and densities were recognized between stations. The cyst assemblages were characterized by low species diversity and low cyst concentrations in comparison with the Pacific coast of Guatemala and Peru.

RESUMEN

Quistes de dinoflagelados modernos descubiertos en sedimentos de la isla Santa Cruz, Galápagos. Se describen los quistes de dinoflagelados colectados de sedimentos superficiales de Santa Cruz, en conjunto con otros palinomorfos, entre ellos las recubiertas de microforaminíferas, loricae de tintínidos, huevos de copépodos, y acritarcos incluyendo *Halodinium* spp. y micro-restos parecidos a *Domasiella*. Las asociaciones de quistes de dinoflagelados fueron compuestas en su mayoría de *Spiniferites* cf. *scabratus* (gonyaulacoide) seguido por *Brigantedinium* spp. y *Selenopemphix quanta* (peridinoide). No se encontraron quistes gimnodinioides. No hubo diferencias destacables en la composición ni en las densidades de los quistes entre sitios. Comparado con la costa pacífica de Guatemala y de Perú, las asociaciones se caracterizaron por tener baja diversidad de especies y baja concentración de quistes.

INTRODUCTION

The Galapagos Islands are famous for their unique biodiversity, and a great deal of biological research has been undertaken there. However, only a few studies on phytoplankton have been published, namely Kofoid (1907) on dinoflagellates, and Marshall (1972) and Rampi (1950) including diatoms, dinoflagellates, silicoflagellates and coccolithophorids. Further, no study on marine palynomorphs such as dinoflagellate cysts, microforaminiferal linings and others has been conducted so far. This paper describes the dinoflagellate cyst assemblage found in surface sediments collected at two locations on Santa Cruz Island.

The Galapagos Islands were created by late Cenozoic volcanic activity and have had no land connection to the continent. They are located *c.* 1000 km west of mainland Ecuador, and consist of several major islands, with numerous satellite islets. The main cluster of islands lies between 0°10′N to 1°25′S and 89°10′W to 91°40′W in the Pacific Ocean.

The islands are influenced by several major water currents, namely the cool, relatively oligotrophic Peru (Humboldt) Current, which turns west to become the South Equatorial Current, the warm North Equatorial Current and the Equatorial (Cromwell) Undercurrent (Shen *et al*. 1992). The cool (*c.* 13°C in its core), nutrient-rich Equatorial Undercurrent flows mainly from west to east, and wells up around the islands. During the warm season, the warm Panama flow (El Niño flow), from Central America, develops (Houvenaghel 1978). The islands are thereby divided into four major oceanographic zones: the coolest western zone, including the west of Isabela and Fernandina; the seasonally varying central zone, including the east of Isabela, Santiago and Santa Cruz; the relatively warm tropical zone, including Pinta, Marchena and Genovesa; and the cool southern zone, including Floreana, Espanola and San Cristóbal (Harris 1969). These zones are independent of the influence of South American continental coastal waters.

SAMPLING LOCATION AND METHOD

The selection of sample sites was initially based on the locations of mangrove zones along the coast. Unfortunately, the mangrove areas inspected (in San Cristóbal, Floreana, Santa Fe and Santa Cruz) were lacking muddy sediments, with the exception of two locations on Santa Cruz: the innermost part of Academy Bay (Stations 1, 2, 3), and Caleta Tortuga Negra (Station 5) (Fig. 1). The lack of mud at other sites is probably due to the strong coastal currents impeding the deposition of fine sediments. Indeed the mangrove trees there were growing directly on cracks within the basaltic lava.

Surface sediment samples were collected using a TFO (University of Tokyo, Laboratory of Fisheries Oceanography) corer. In Caleta Tortuga Negra it was deployed from the shore at low tide on 19 December 1999 and in Academy Bay from a boat on 21 December 1999. Dinoflagellate cysts were extracted following the method of Matsuoka & Fukuyo (2000). The 8cm core from Station 1 was sampled every 2 cm and the 0–2 cm and 6–8 cm sections were analyzed. The upper 2 cm of sediment from each of the cores from Stations 2, 3 and 5 were also analyzed. One tenth of each concentrated sample was examined under a Zeiss Axiophoto optical microscope equipped with interference contrast.

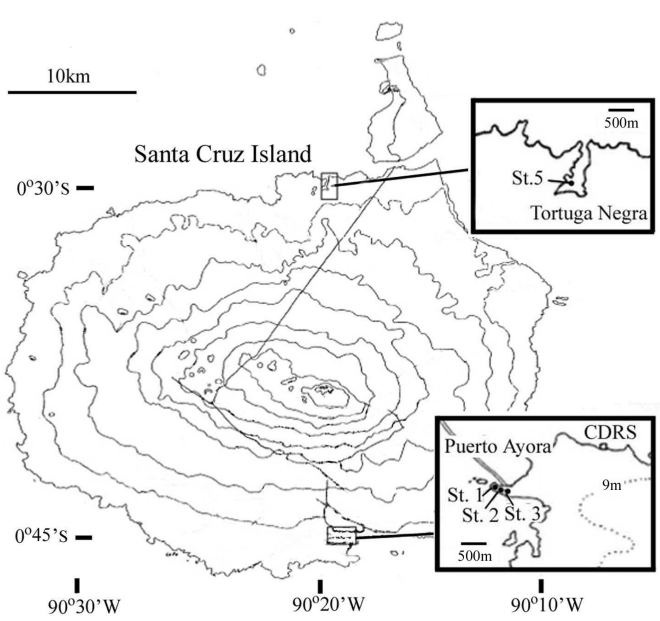

Figure 1. Sampling locations.

RESULTS

Marine palynomorphs composed of dinoflagellate cysts, microforaminiferal linings, tintinnid loricae, copepod eggs and acritarchs including *Domasiella*-like micro-remains were found in these samples (Table 1). Micro-remains, microforaminiferal linings and tintinnid loricae were the most common, followed by spiny copepod eggs. Dinoflagellate cysts consistently occurred in low numbers. The most common were *Spiniferites* cf. *scabratus*, followed by *Brigantedinium* spp. and *Selenopemphix quanta* (Fig. 2). No Gymnodinioid cysts were found. A few spherical and

Table 1. Occurrence of dinoflagellate cysts and other micro-remains in samples.

	Station:	**1 (0–2 cm depth)**	**1 (6–8 cm depth)**	**2**	**3**	**5**
Gonyaulacales cyst	**Plankton name**					
Spiniferites sp. cf. *scabratus*	*Gonyaulax spinifera* complex?	17	13	17	14	1
Spiniferites bulloideus	*Gonyaulax scrippsae*	1				
Spinferites cf. *delicatus*	*Gonyaulax* sp.			1		
Spiniferites hyperacanthus	*Gonyaulax spinifera* complex?		1			
Peridiniales cyst						
Brigantedinium cariacoense	*Protoperidinium avellanum*	1		1		
Brigantedinium spp.	*Protoperidinium* spp.		3	2	1	5
Selenopemphix quanta	*Protoperidinium conicum*		1	2	1	1
No name	*Protoperidinium americanum*			1		
Total cysts		**19**	**19**	**23**	**16**	**7**
Cyst concentration /ml		**101**	**101**	**122**	**169**	**37**
Acritarcha						
Domasiella? spp.		1	2	3	2	3
Halodinium spp.			1	2		
Tintinnid		56	19	25	8	1
Foraminifera						
Uniserial type		5		2	1	1
Biserial type		2	2	1	2	1
Coiled type		47	39	35	33	49
Copepod resting egg		24	15	51	5	1

ellipsoidal cysts also occurred. Dinoflagellate cyst concentration in the samples varied from 37 (Station 5) to 169 (Station 3) cysts per ml of sediment. There was no remarkable difference in cyst composition and densities between all stations. *Spiniferites* cf. *scabratus* was dominant in surface sediments collected from the innermost part of Academy Bay (Stations 1, 2, 3). Also no difference in species composition between the surface and bottom (6–8 cm depth) sediments of Station 1 was recognized. In the sediment of Caleta Tortuga Negra, round brown *Brigantedinium* spp., which are cysts of heterotrophic *Protoperdinium* spp., were relatively abundant.

DISCUSSION

The dinoflagellate cyst assemblage from surface sediments of Santa Cruz Island consisted of three *Spiniferites* species of the Gonyaulacales, more than four species of the Peridiniales and no Gymnodiniales. This assemblage is characterized by low species diversity and low cyst density. In comparison, dinoflagellate cyst concentration in surface sediments off the Pacific coast of Guatemala was approximately 650 cysts per ml of sediment (Rosales-Loessener *et al*. 1996). The low cyst concentration in Santa Cruz may be due to strong coastal currents sweeping out the fine muddy particles from the shallower sea-floor areas. Marshall (1972) listed more than 17 dinoflagellate species, including a few species of *Gonyaulax* and *Protoperidinium*, around the Galapagos. However, none of these species has ever been known to produce a resting cyst. The motile form of *Spiniferites* cf. *scabratus* is not known from the plankton so far. Motile forms of *Selenopemphix quanta* (= *Protoperidinium conicum*) and *S. nephroides* (=*P. subinerme*) were not reported by Marshall (1972). Such differences between

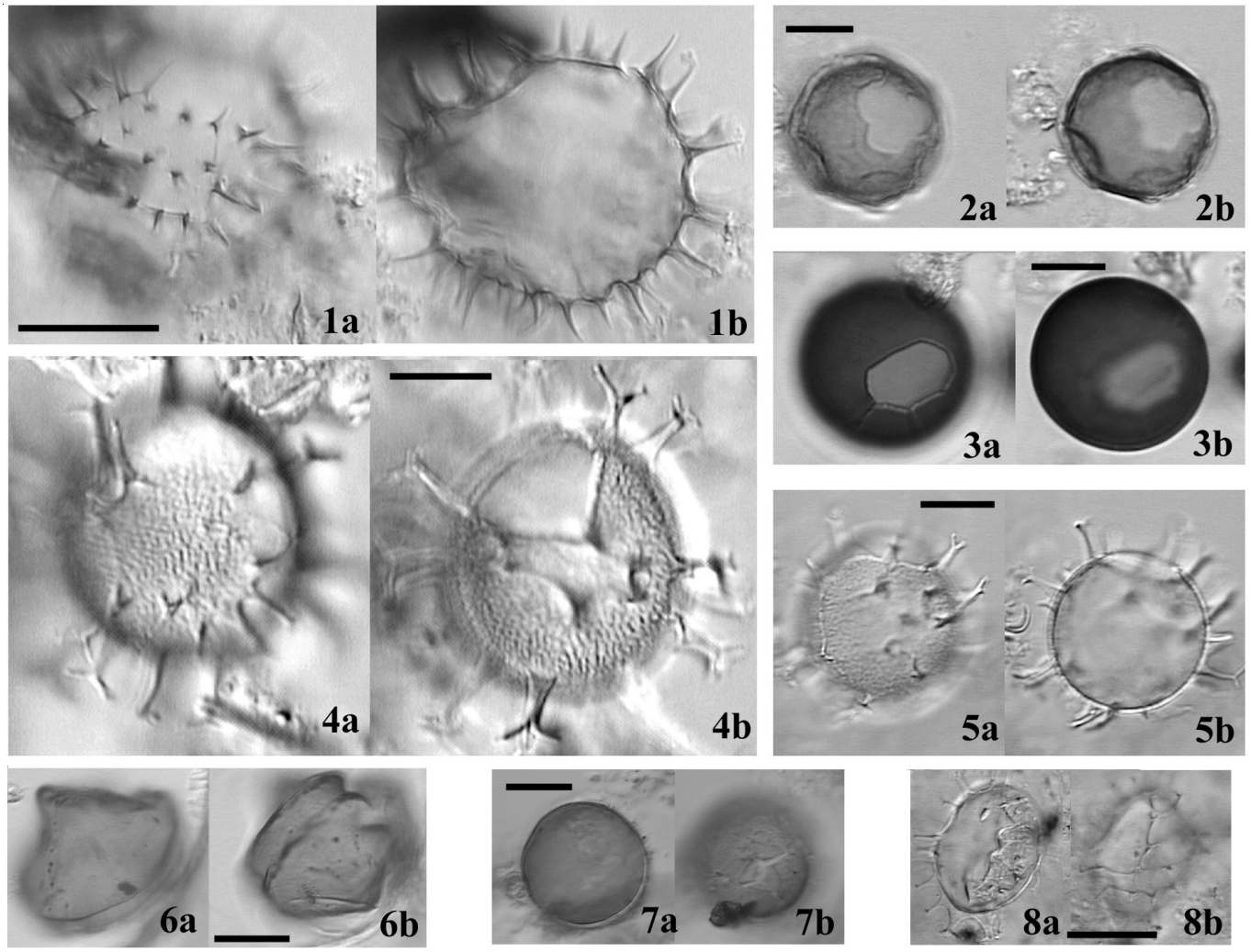

Figure 2. Dinoflagellate cysts found in surface sediments of the Galapagos Islands: 1 *Selenopemphix quanta* (Bradford) Matsuoka (= cyst of *Protoperidinium conicum* (Gran) Balech; 2 *Protoperidinium americanum* (Gran & Braarud) Balech; 3 *Brigantedinium cariacoense* (Wall) Reid (= cyst of *Protoperidinium avellanum* (Meunier) Balech or *P. punctulatum* (Paulsen) Balech); 4, 5 *Spiniferites* sp. cf. *scabratus* (Wall) Sarjeant; 6 *Selenopemphix nephroides* Benedek (= cyst of *Protoperidinium subinerme* Paulsen); 7 *Brigantedinium* sp. indet. (= probably cyst of *Protoperidinium* sp.); 8 *Spiniferites bulloideus* (Deflandre & Cookson) Sarjeant (= cyst of *Gonyaulax scrippseae* Kofoid. Scale bar is 20 μm.

plankton and benthic cyst communities suggest that more intensive surveys are needed. In addition no gymnodinioid cysts were observed, and the gymnodinioid plankton species such as *Gymnodinium oceanicum*, *Gymnodinium* sp. and *Gyrodinium* sp. listed in Marshall (1972) were very rare.

The assemblages of dinoflagellate cysts in surface sediments off the Pacific coast of Guatemala, documented by Rosales-Loessener *et al*. (1996) were more diverse in gymnodinioid, gonyaulacoid and peridinioid cysts, and more abundant. The dinoflagellate cyst assemblage off Peru (Wall *et al*. 1971) was more abundant and diverse, and contained more gonyaulacoid cysts. It is also of interest that the Galapagos assemblages lacked any specimens of the tropical dinoflagellate *Polysphaeridium zoharyi* (=*Pyrodinium bahamense*) which occurs off the Pacific coast of Guatemala (Rosales-Loessener *et al*. 1996) and Peru (Wall *et al*. 1971). This may be an effect of the cool Peru Current.

The occurrence of dinoflagellate cysts around oceanic islands, isolated from continental coastal biological communities, leads to the question of how dinoflagellates might extend their geographical distribution. The Galapagos Islands have never been connected to the continent and ages of the existing islands range from <1 to 5.6 million years (Geist *et al*. 1985). At emergence of the first islands, coastal marine organisms, including dinoflagellates, would not have been present. Thereafter, the coastal biocommunity was presumably transported to the islands as drifting planktonic organisms. Some dinoflagellates can produce a resting cyst as part of their life cycle, especially when they encounter unfavourable conditions, become transported to oceanic islands, and then germinate and repopulate the plankton once environmental conditions become favourable again. Oceanic islands are key places where dinoflagellates can expand their habitat across oceans. In the cyst assemblage of the coastal sediments of Guatemala reported by Rosales-Loessener *et al*. (1996), some gymnodinioid species, such as *Polykrikos* cf. *kofoidii* and *Cochlodinium ? polykrikoides*, were associated with *Speciferites bulloideus*, *Brigantedinium* spp., *Selenopemphix quanta* and others. The lack of gymnodinioid coastal species in surface sediments around Santa Cruz may simply mean that no cysts of these species have reached the islands yet, rather than that environmental conditions there are unfavourable for them.

This transport model could be important when considering the spread of cyst-producing harmful microalgae such as dinoflagellates. As a result of tourism in the Galapagos, ports such as Puerto Ayora and Puerto Baquerizo Moreno have been constructed. Coastal currents weaken in such areas, allowing the deposition of fine muddy particles containing dinoflagellate cysts. This may similarly allow non-native organisms, transported in ballast waters of cargo vessels, to colonise and flourish in these areas.

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