NOTE

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Submarine topography of Maldivian atolls suggests a sea level of 130 metres below present at the last glacial maximum

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Introduction

The Maldives is a linear atoll chain stretching north-south from approximately 7°N to 0.5°S along 73°E in the central Indian Ocean. The Maldivian atolls form the central and largest part of the Chagos-Laccadives Ridge. This Ridge is part of a still larger feature that stretches from the Late Cretaceous/Early Tertiary Deccan Traps of India (centred about 20°N) to the volcanically active island of Réunion at 21°S (Morgan 1981; Duncan and Hargreaves 1990). The Maldives themselves comprise an early Tertiary (50–60 Ma) volcanic basement overlain by approximately 2000 m of shallow-water carbonate (Purdy 1981; Duncan and Hargreaves 1990; Purdy and Bertram 1993, see also Glennie 1936).

The crest of the Maldivian carbonate ridge must have been exposed to subaerial erosion during periods of low sea level. The most recent sea level minimum was reached at the glacial maximum, dating around 18 000 radiocarbon years BP, perhaps 21 000 sidereal years BP (Bard et al. 1990). Although there are regional variations, the depth to which sea level dropped is often taken as 120 m (Fairbanks 1989).

This present study reports the results of an echo sounding survey around four Maldivian atolls which suggests that local sea level was reduced to about 130 m below current levels during the last glacial maximum. At that time present-day atolls would have been exposed as large, steeply cliffed islands.

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Methods

The echo sounding survey was carried out as part of a "Reef Fish Resources Survey" conducted by the Marine Research Section (MRS) of the Ministry of Fisheries and Agriculture (Anderson et al. 1992). Survey work was carried out aboard a 12.8 m wooden-hulled fishing vessel. The primary purpose of the echo sounding was to locate suitable areas for longline fishing on the outer reef slopes of four atolls: North Miladhunmadulu (Shaviyani), North Malé, Ari and Hadhdhunmathi (Laamu) (see Fig. 1). The echo sounder used was a Raytheon V900 with colour VDU and 200 KHz transducer. There was no recorder; rough sketches of transect profiles were copied from the VDU. Transects were run perpendicular to the outer atoll reef, usually between depths of 10 m or less (i.e. as close inshore as the captain felt prudent) to 200 m or more (i.e. to the operational limits of the echo sounder). Two to five runs were made at each site, with three being typical. During the first run the echo sounder was set with a full-scale display of 0–250 m. Subsequent runs were made with the echo sounder VDU set with a full-scale display of 50 m, centred on the depths of any slope breaks in order to fix such features more accurately. In most cases the breaks in reef slope appeared to be sharp, but in a few cases the cliff bottom appeared to run gradually into the reef slope below, presumably because of talus accumulation. In these cases the depth of the break in reef slope was estimated as the point of intersection of the two slopes.

The distribution of echo sounding sites was not random. This part of the fishing survey was carried out mostly during the south-west monsoon season (May to November), which limited operations on the western sides of atolls. Also, the large size of the cliffs outside eastern North Miladhunmadulu and northern Hadhdhunmathi made it difficult to locate suitable sites for fishing, thereby necessitating further echo soundings.

The precision to which depths were recorded was about 2 m. The echo sounder was not calibrated, so its accuracy is not known with certainty. However, the echo sounder always indicated depths compatible with those indicated by charts and fishing lines, suggesting accuracy to within about 3%. Readings were not corrected for tidal height, but this should have minimal effect on the results since tidal range is 1 m or less. Thus, echo sounder depth records are likely to be accurate to within ± 10 m.

Results and discussion

Echo sounder transects were recorded at eighteen different locations around four Maldivian atolls (Fig. 1).

Table 1 gives the approximate sizes of these cliffs. At every site the cliff was at least 30 m in height, dropping from 100 m to 130 m. At many sites the height of the cliff was considerably greater (Table 1). At ten out of eighteen sites the base of the cliff was at 125 m to 140 m, with a modal depth of 130 m (Fig. 2).

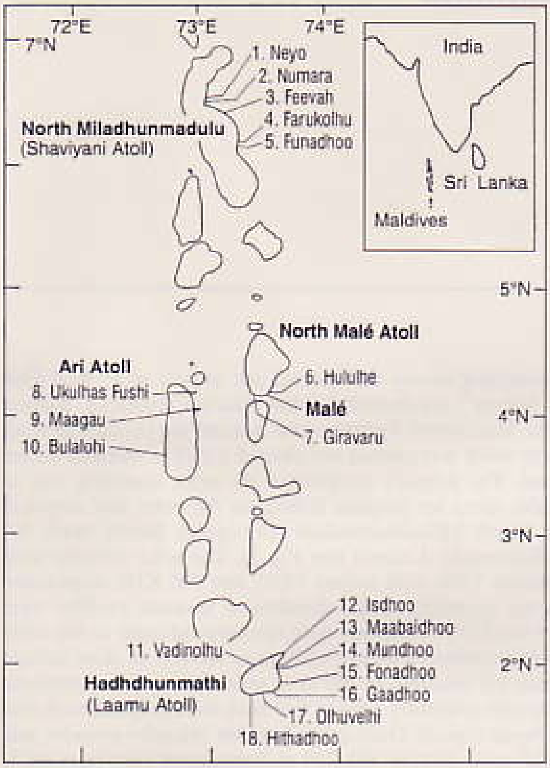

Fig. 1 Map of northern and central Maldives, showing locations of eighteen echo sounding sites

Although far from comprehensive, these results suggest the presence of major cliffs encircling some if not all of the Maldivian atolls. At all eighteen sites surveyed, the cliff bases were at 130 m or deeper. It is suggested that this 130 ± 10 m slope break marks the low stand of sea level during the last glacial maximum.

At seven of the eighteen sites, the cliff bases were at 160–170 m (Fig. 2). Whether this marks the depth of an earlier and deeper low-stand is not known. Alternatively, it may be significant that sites at which the cliff bases were deeper than 130 m were generally those that would probably have been exposed to the greatest wave action, if present wind patterns are any guide. The sites in question are those facing east in North Miladhunmadulu Atoll, west in Ari Atoll, and east or west in

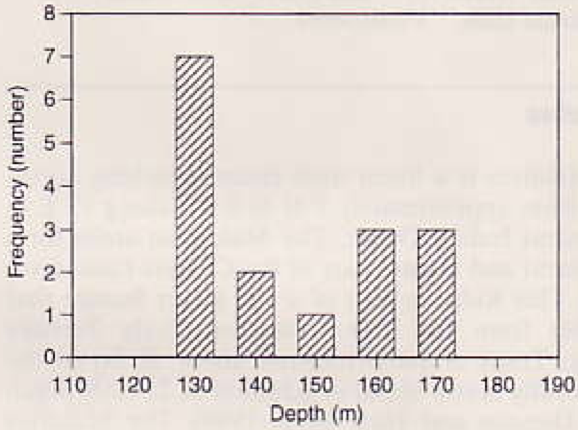

Fig. 2 Frequency histogram showing depth distribution of cliff bases on outer atoll slopes in the Maldives ($N = 16$; omits sites 12 and 5)

Table 1 Depths of cliffs on outer reef slopes at eighteen locations outside four Maldivian atolls

Site	Atoll	Nearest island	Depth of cliff top (m)	Depth of cliff base (m)	Aspect
1.	N. Miladhunmadulu	Neyo	75	170	E
2.	N. Miladhunmadulu	Numara	90	140	E
3.	N. Miladhunmadulu	Feevah	60–80	170	NE
4.	N. Miladhunmadulu	Farukolhu	100	150	E
5.	N. Miladhunmadulu	Funadhoo	80–90	140–170	E
6.	N. Malé	Hulhule	90–100	130	SE
7.	N. Malé	Giravaru	90–100	130–135	SW
8.	Ari	Ukulhas Fushi	100	130	NE
9.	Ari	Maagau	90	130	E
10.	Ari	Bulalohi	100	160	W
11.	Hadhdhunmathi	Vadinolhu	10–15	170	NW
12	Hadhdhunmathi	Isdhoo	20	(>200)	NE
13.	Hadhdhunmathi	Maabaidhoo	10–20	160	E
14.	Hadhdhunmathi	Mundhoo	20	160	E
15.	Hadhdhunmathi	Fonadhoo	<40	125–130	SE
16.	Hadhdhunmathi	Gaadhoo	100	130–140	S
17.	Hadhdhunmathi	Olhuveli	80–100	130–135	S
18.	Hadhdhunmathi	Hithadhoo	50–100	130	S

Hadhdhunmathi Atoll. It should be noted that the volcanic basement on which the Maldivian atolls stand has subsided about 2000 m over 50–60 Ma (Duncan and Hargreaves 1990; Purdy and Bertram 1993). This gives an average subsidence rate of about 3–4 cm ky^{-1}, although peak rates may have been three times higher (Purdy and Bertram 1993). There is no evidence of significant additional subsidence or uplift during the last 21,000 years.

A cliff of similar magnitude to the Maldivian ones reported here was noted off the deep fore reef of north Jamaica by Land and Moore (1977). They concluded that this "almost certainly represents a Pleistocene low-stand feature." At several locations in the Red Sea a distinctive steepening of reef slope has been noted at a depth of 100–130 m, with nickpoints at an estimated depth of 120 $\pm$ 10 m (Gvirtzman et al. 1977; Gvirtzman 1994). These were interpreted as the lowest erosional base level during the last glacial maximum (Gvirtzman et al. 1977; Gvirtzman 1994).

In the Maldives, a number of recent studies have indicated that atoll reefs were exposed by lowered sea levels during the last glacial maximum. Seismic studies have shown a strong reflector at about 15 m below the present reef surface, which is interpreted as a Holocene-Pleistocene unconformity resulting from subaerial erosion of exposed reef surfaces during glacial low-stand(s); this unconformity is very irregular, suggesting that it is strongly karstified (Dr. M. Risk, McMaster University, personal communication, August 1993). Purdy and Bertram (1993) suggested that subaerial erosion of exposed reefs formed karstic saucers on which were formed present-day faroes, the ring shaped reefs so characteristic of Maldivian atolls. Woodroffe (1992) showed that during the Holocene transgression reef growth on the Pleistocene antecedent foundation was predominantly vertical as reefs attempted to catch up with sea level, doing so at about 3000 y BP. Several reports have noted the numerous submerged reef terraces and caves within scuba diving depths (i.e. down to about 40 m), some interpreting them as constructional and erosional features resulting from low sea level stands (Hass 1961; Spencer Davies et al. 1971; Ciarapica and Passeri 1993; Morri et al. 1995; Bianchi et al. 1997).

This study is the first to provide data on the local sea level minimum at the last glacial maximum, suggesting that is was about 130 m below present. At the glacial maximum the Maldivian atolls would have been exposed as steeply cliffed islands with rugged plateaux tops. It should be noted that the present estimate of low-stand depth is approximate. A more accurate estimate would ideally require the use of calibrated equipment, evidence of wave-cut features, and due consideration of local eustatic changes.

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