

SHELVES AND QUATERNARY CLIMATIC CHANGES

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Abstract

This paper briefly reviews shelves and Quaternary climatic changes including relevant results of the International Geological Correlation Programme project no. 396 'Continental shelves in the Quaternary' (IGCP 396). In particular, up to five interglacial-glacial cycles have been identified on 'stable' shelves which is in agreement with the Vostok ice core in Antarctica. Long uplifted shelf sequences covering the last 3.6 Ma have been identified in New Zealand. Geochemical studies of corals in tropical shelves have provided records of sea-surface temperatures superior in resolution compared to oxygen-isotope (OI) stratigraphy of deep-sea cores.

During glacial periods, factors including the 'sparse' vegetation cover on the sub-aerially exposed shelves and the decline in coral reef growth are likely to cause a buildup of atmospheric carbon dioxide. Such a mechanism may be important in switching the earth from a full glacial mode into an interglacial mode.

Introduction

Shelves are defined as continental margins between the shoreline to a water depth of about 200 m. Unlike oxygen-isotope stratigraphy of deep sea cores used in the reconstruction of sea-level history, shelves provide direct record of Quaternary sea-level changes resulting from interglacial-glacial sea-level cycles. IGCP 396 is a 5-year project initiated in 1996 aimed specifically at filling the gap in knowledge on Quaternary shelves. This paper attempts to briefly review shelves and Quaternary climatic changes including relevant results of IGCP 396.

Importance of Drilling

The small role played by shelves to date in providing Quaternary climatic change information is attributed mainly to the lack of a major international initiative like the Ocean Drilling Program focused on shelves and the 'high' cost of offshore drilling. In the present millennium, due mainly to the shortage of land for development, the reclamation of shelves is expected to be increasingly common as a means of providing new land. The associated engineering site investigations to be carried out would be a valuable source of boreholes needed by researchers to study Quaternary climatic changes.

Drills for obtaining long continuous shelf sequences essential for studying Quaternary climatic changes are being improved. In Hong Kong where the seabed depth rarely exceeds 50 m, the wire-line vibrocoreing technique operating from barges was particularly successful for recovering cohesive sediments (Yim, 1999a). By inserting screw-on 6-m casings into the seabed, cores exceeding 6-m in length can be obtained. An Australian consortium comprises of the University of Sydney and the Australian Geological Survey Organization are currently undergoing sea trials to test a newly developed portable remotely

operated drill (PROD). This drill is designed for 100-m sub-surface penetration and water depths down to 2,000 m.

Quaternary Sequences on Shelves

Quaternary sequences on shelves possess advantages in the determination of chronology in comparison to terrestrial and deep-sea environments. The Holocene-Pleistocene boundary on shelves can usually be identified relatively easily because of the desiccation of the sub-aerially exposed shelves during glacial periods (Yim and Tovey, 1995). In siliciclastics-dominated shelves, Holocene marine deposits are readily recognizable by their high moisture content because they have never been subjected to sub-aerial exposure compared to their Pleistocene counterparts (Choy, 1997). Furthermore, the formation of palaeo-desiccated crusts (originally referred to as desiccated crusts but renamed after the 4th IGCP 396 Annual Conference held in Cape Town during 1999) formed by acid-sulphate soil development on the sub-aerially exposed marine deposits during glacial period(s) is useful as stratigraphic markers. Such palaeo-desiccated crusts may also be identified by using magnetic susceptibility (Yim *et al.*, 1998), microfabric properties (Tovey and Yim, 1996) and engineering properties including cone penetration testing (Yim, 1994).

On 'stable' shelves, the study of borehole sequences in Hong Kong has led to the recognition of five interglacial cycles dating back to OI stage 12 (Yim, 1994) (Table 1). This is in agreement with the five interglacial-glacial cycles identified in the Vostok ice core in Antarctica (Petit *et al.*, 1999) confirming that the Quaternary shelf deposits present in Hong Kong are controlled by eustatic sea-level changes.

Unit	Age
M1	Holocene/OI stage 1
T1	Last glacial/OI stages 2 to 4
M2	Last interglacial/OI stage 5
T2	Second last glacial/OI stage 6
M3	Second last interglacial/OI stage 7
T3	Third last glacial/OI stage 8
M4	Third last interglacial/OI stage 9
T4	Fourth last glacial/OI stage 10
M5	Fourth interglacial/OI stage 11
T5	Fifth last glacial/OI stage 12

Table 1. Classification of shelf deposits in Hong Kong. After Yim (1994) with modifications.

In the Great Barrier Reef, reef development dating back to the Middle Pleistocene was indicated by drilling (Davies *et*

al., 1996). A 210-m long core obtained from the reef flat at Ribbon Reef 5 revealed 8 reef sequences separated by diagenetic boundaries (Webster and Davies, 1996). Sea-level oscillations with the diagenetic boundaries representing periods of low sea-level stands were attributed to be responsible.

Micropalaeontological study of borehole samples from the shelf provides information on Quaternary climatic changes. An example is the use of pollen record in the North Sea for palaeoenvironmental reconstruction during the Early Pleistocene by Ekman (1999). This led to the recognition of the Bavel Interglacial, the Linge Glacial and the Leerdam Interglacial.

Seasonal scale records can be obtained through the study of sequences in inlets. A 133-year sedimentary sequence in the Saanich Inlet of British Columbia was identified by Collins (1997) to offer insights into climatic controls during the years 1860-1993 AD.

Quaternary Sequences on Uplifted Shelves

Long Quaternary sequences have been obtained from the study of uplifted shelves. The Wanganui Basin in New Zealand was identified to contain one of the most complete late Neogene stratigraphic records in the world covering the last 3.6 Ma (Naish *et al.*, 1998). The 3-km thick basin fill comprises 58 shallow marine sedimentary cycles corresponding to 100 and 41 ka sea-level cycles since OI MG6. Within this sequence, OI stages MG6 to 5 are represented by marine cyclothem, whereas OI stages 17 to 4 are represented by a suite of coeval and younger uplifted marine terraces. The chronology proposed was based on radiometric ages on interbedded rhyolitic tephra, biostratigraphic data, palaeomagnetic polarity measurements, and, cycle correlations with the OI time scale.

Corals and climatic variability

In the last decade, high-resolution records of tropical climate variability from shelves are available for the first time through the study of coral skeletons. This method possesses the major advantage in being able to offer both the annual resolution and multi-century record length needed for quantification of seasonal-centennial changes in tropical surface ocean (Dunbar and Cole, 1999). A further advantage of this method is the superior resolution compared to OI stratigraphy of deep-sea cores including the possibility of calibration using instrumental records. For example, Wellington *et al.* (1996) demonstrated the relationship between $\delta^{18}\text{O}$ in coral, $\delta^{18}\text{O}$ measured in seawater, salinity measured in seawater and sea-surface temperature measured in seawater. The possible climatic indicators are summarized in Table 2. Based on Sr/Ca and $^{18}\text{O}/^{16}\text{O}$ ratios in corals, information on sea-surface temperature and surface-ocean water balance of the mid-Holocene was obtained by Gagan *et al.* (1998). More recently, seasonal and interannual variations in the radiocarbon of corals from the equatorial Pacific have been

linked to the redistribution of surface waters associated with the ENSO (Gagan *et al.*, 2000).

An exciting area being developed at present is the palaeo-climatological studies of pre-modern corals. Studies on dated corals from uplifted coral reef terraces such as Sumba in Indonesia (Pirazzoli *et al.*, 1993) should provide windows for examining longer palaeo-climatic well beyond the Holocene providing that the corals have not been influenced by recrystallisation.

Indicator	Climatic factor(s)
$\delta^{18}\text{O}$	sea-surface temperature, precipitation
$\delta^{13}\text{C}$	sunlight/cloudiness
$\Delta^{14}\text{C}$	sunlight/cloudiness (air-sea exchange)
Sr/Ca ratio	sea-surface temperature
Ba/Ca ratio	sea-surface temperature
Cd/Ca ratio	sea-surface temperature
F/Ca ratio	precipitation
U/Ca ratio	sea-surface temperature
Mn/Ca ratio	windiness, volcanic activity
Banding	seasonality
Fluorescence	precipitation

Table 2 Possible climatic archives in coral skeletons.

Tree rings and Climate Variability

Dendroclimatological archives of submerged forests on shelves particularly during glacial periods are largely an untapped. Tree rings work best in temperate regions at highly seasonal localities. However, in tropical regions the lack of annual growth rings in the tree species rules out its application.

There is an important advantage concerning the application of dendroclimatology on shelves during glacial periods where information is particularly sketchy. The temperate regions in both the northern and southern hemispheres expanded towards the equator making the applicable geographical areas even more extensive than in the present day. An example of a presently tropical shelf where temperate wood specimens suitable for tree-ring work can be found is the Pearl River mouth off Hong Kong (Yim, 1999b). At this location, the dredging of offshore sand and gravel deposits has provided wood specimens in pre-last interglacial terrestrial deposits confirming that more temperate conditions once existed at the site during glacial periods.

Record of Storms

Shelf sedimentary sequences may provide a record of cyclones (known as typhoons in east Asia and hurricanes in north America). In Australia, shelf sediments collected immediately before and after Cyclone Winifred permitted documentation of the formation of a storm bed (Gagan *et al.*, 1988). The resultant storm bed was more than 11 cm

thick, covering an area exceeding 1,200 km², and extending more than 30 km offshore to water depths exceeding 40 m. Foraminiferal diversity is useful in the identification of storm beds in the Pearl River Estuary off Hong Kong (Huang and Yim, 1998). Table 3 provides a summary of native and exotic foraminifers present in Holocene storm beds of a vibrocore located in the Pearl River Estuary. The co-existence of native and exotic foraminifers in storm beds was attributed to the introduction exotic foraminifers into the normally estuarine area during typhoons. This is also supported by the close resemblance of mean size between the foraminiferal tests and the inorganic sediment particles. The greatest number of storm beds found in the Holocene sequence of boreholes over a time scale of ca. 8 ka was 17 (G. Huang, 1999, personal communication). This represented perhaps only 10 % of the major storms.

Native	Exotic
<i>Ammonia annectens</i>	<i>Ammonia compressiuscula</i>
<i>A. beccarii</i> vars.	<i>Bolivina robusta</i>
<i>Elphidium advenum</i>	<i>Brizalina</i> spp.
<i>E. hispidulum</i>	<i>Bulimina</i> spp.
<i>Hanzawaia nipponica</i>	<i>Cibicides</i> spp.
<i>Quinqueloculina lamarckiana</i>	<i>Epistominella naraensis</i>
<i>Q. seminulum</i>	<i>Eponides procerus</i>
	<i>Fissurina</i> spp.
	<i>Globigerina</i> spp.
	<i>Heterolepa dutemplei</i>
	<i>Hopkinsina pacifica</i>
	<i>Lagena</i> spp.
	<i>Nonionella</i> spp.
	<i>Pyrgo</i> spp.
	<i>Rosalina bradyi</i>
	<i>Schackoinella globosa</i>
	<i>Textularia</i> spp.

Table 3 Summary of native and exotic foraminifers present in Holocene storm beds of a vibrocore located in the Pearl River Estuary adjacent to the new Hong Kong International Airport. After Huang and Yim (1997) with modifications. The presence of exotic foraminifers is explained by their shoreward transport from the open shelf during typhoons.

Shelves and the Global Carbon Cycle

The contribution of shelves to the global carbon cycle is a subject of great importance for the study of future global changes. A study of the inner shelf off Hong Kong indicated that the release of fossil methane from shelves should be taken into account in the global carbon budget (Yim, 1999c). In order to quantify this, areas of acoustic turbidity detected using high-resolution boomer seismic profiles can be mapped for determining the proportion of the present day shelves affected.

Extensive mangrove development is associated with periods of marine transgression while very diminished mangrove occurs during marine regressions (Grindrod *et al.*, 1999). The 'sparse' vegetation cover on the sub-aerially exposed shelves and the decline in coral reef growth during

glacial periods are likely to result in a buildup of atmospheric carbon dioxide. This is considered to be a mechanism important in switching the earth from a full glacial mode into an interglacial mode.

Future Work

Seven areas of future work have been identified:

- (1) Record of the Younger Dryas on shelves.
- (2) Record of Heinrich events on shelves.
- (3) Coral palaeo-thermometry as an independent means of checking sea-surface temperatures obtained from OI stratigraphy of foraminifers.
- (4) Climatic information during periods of low sea-level stands.
- (5) Contribution of shelves to the global carbon cycle particularly during periods of low sea-level stands.
- (6) Use of shelf sequences for land-sea correlation.
- (7) The further development of coral palaeo-climatology as a multi-proxy approach.

Acknowledgements

IGCP 396 receives seed funding from UNESCO and the International Union of Geological Sciences. I would like to thank the participants from the 38 countries for their support and their scientific contributions.

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