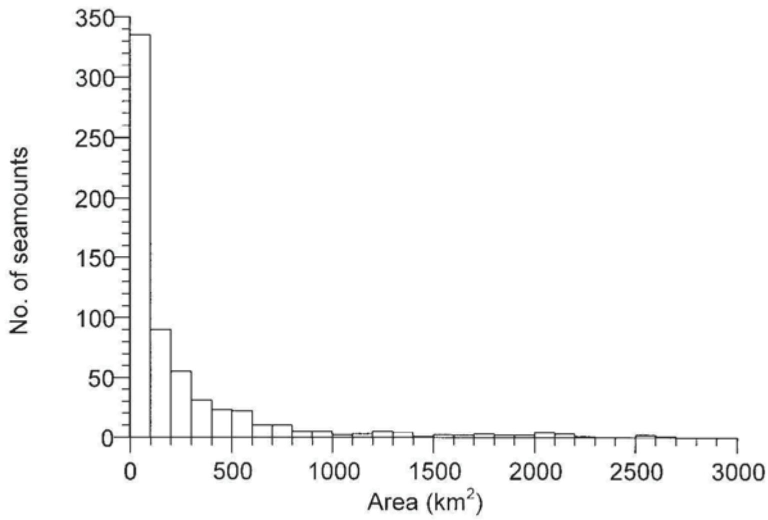


Fig. 4 Frequency of seamount area (km^2), in 100 km^2 groupings, for those seamounts less than 3000 km^2 in the New Zealand region.

general rises and plateaux like the Chatham Rise (Fig. 7A,B) whereas seamounts over 500 m are typically 200 km or more from the coastline, and associated with major bathymetric features like the Louisville Ridge, Colville and Kermadec Ridges, Three Kings Ridge, Macquarie Ridge, and Lord Howe Rise (Fig. 7C,D).

Seamounts are often visualised as steep-sided features, typically using a × 3 exaggeration of the vertical scale. However, at true vertical scale many have gradual or shallow slopes. Both methods used here to calculate slope show similar results (Fig. 8). The mean slope of most seamounts is <20°, with the most frequent slope being between 5° and 10°. Few slopes exceed 30°, although calculated mean slope can be over 50°. The distribution of maximum slopes is fairly unimodal centred on c. 20°, and extending to over 45°. Cross-sectional profiles of representative seamounts are shown in Fig. 9, which demonstrates the variability of size, shape, slope, and elevation of New Zealand seamounts. Mount Taranaki and One Tree Hill are also plotted to enable easy comparison with familiar New Zealand terrestrial forms.

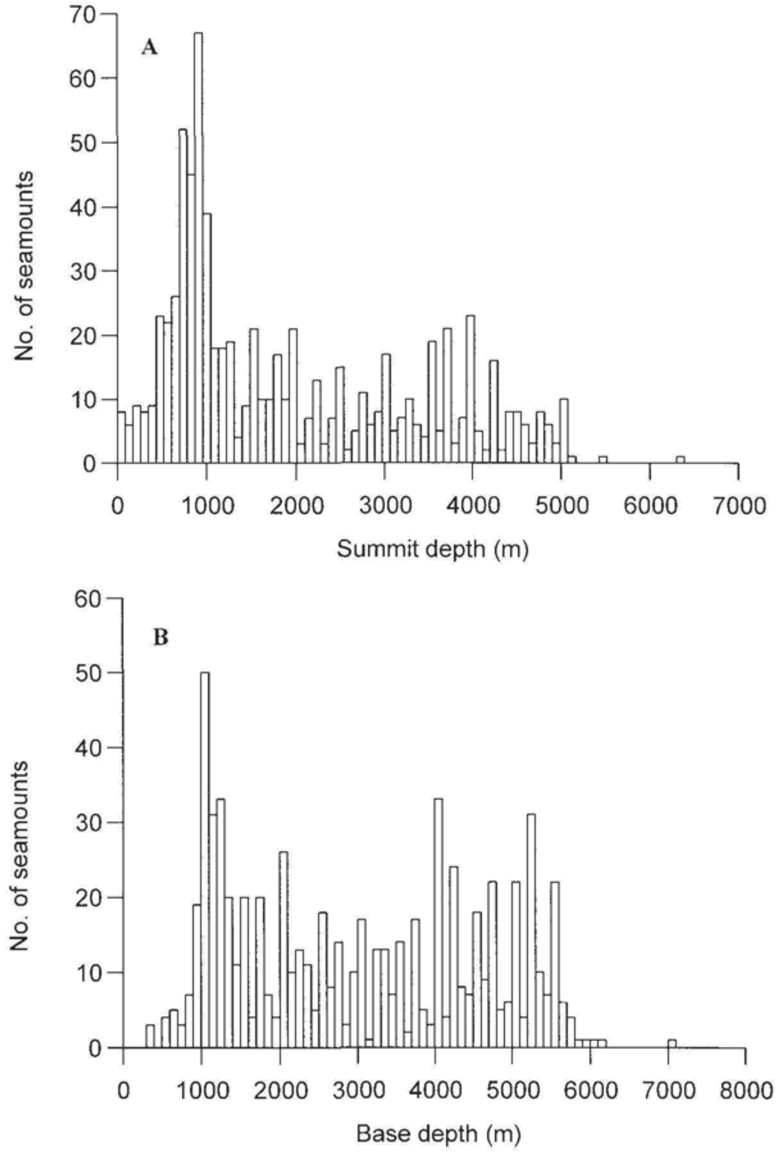
Seamount geology

There are approximately equal numbers of seamounts with continental and oceanic association (Fig. 10A). Continental seamounts are generally close to the coast, or around the edges of the extended shelf-slope, and include the Challenger Plateau, Lord Howe Rise, and Chatham Rise. Oceanic seamounts, such as those of the Louisville Ridge, are offshore from the coast, and surrounded by deep water. Over 100 seamounts are linked with elevated ridges (e.g., Macquarie Ridge, Kermadec Ridge).

Those seamounts that tend to have a continental association include continental rises, rifted continental blocks, and rifted margin volcanoes. Oceanic seamount features include hotspot volcanoes, oceanic plateau volcanoes, some mid-plate volcanoes, and arc volcanoes. Bollons and Gilbert seamounts are examples of large seamount blocks rifted from the main continental mass whilst the Louisville seamount chain is a series of hotspot volcanoes. An assessment of the number of seamounts for each of these geological origins is given in Fig. 10 B. Most have volcanic origin, with over 50% being mid-plate (e.g., Chatham Rise seamounts) seamounts, and over 100 seamounts formed by arc volcanism (e.g., Brothers, Rumble III) along the present-day Pacific-Australian plate boundary.

Data for seamount age are limited, but broadly speaking, seamounts within the New Zealand region have formed between: c. 100 and c. 80 million years ago (Ma), and associated with mid-plate or hot-spot volcanism of the deeper ocean floor; c. 90 and c. 70 Ma, and associated with break-up volcanism and tectonism of the New Zealand continental plateau (e.g., Bollons and Gilbert seamounts); and post 40 Ma, and associated with the evolving plate boundary, including arc volcanism, rifting, and oblique subduction.

Fig. 5 Frequency of seamounts in the New Zealand region by: **A**, depth at peak; and **B**, depth at base.



Surveys of seamounts associated with the southern Kermadec volcanic arc show good correspondence between the general backscatter from multibeam mapping, and the sediment type revealed by sea-floor photography (e.g., Rumble III seamount, Fig. 11). "Dark" backscatter represents areas of high acoustic impedance, which indicates hard rock substrate, whilst "light" backscatter imagery shows areas of low acoustic impedance and indicates the distribution of soft sediment.

Seamount classification

The results of the cluster analysis, illustrated as a dendrogram, indicate that 12 groupings of seamounts ($n = 475$) can be identified at the Euclidean distance measure of six (Fig. 12). Three seamounts were not classified at the level of similarity chosen to identify seamount groupings. The geographic distribution of the seamounts belonging to the identified classification groupings is shown in Fig. 13. The majority of the classified seamounts ($n = 136$) belong

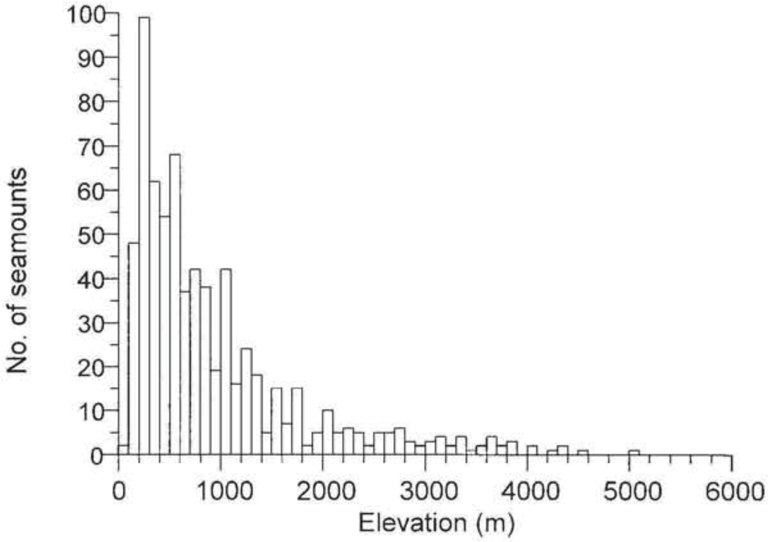


Fig. 6 Frequency of seamount elevation in the New Zealand region.

to Group 11 and are widely distributed throughout the New Zealand region in deep basins. Group 12 seamounts, the second largest grouping (n = 115), are associated with the Kermadec, Colville, and Three Kings Ridges in the north of the region. Group 10 seamounts (n = 23) are almost entirely restricted in distribution to the Hikurangi Plateau, whereas those of Group 9 seamounts are associated with the slopes of the Chatham Rise (n = 70), Bay of Plenty (n = 10), and Challenger Plateau (n = 4). Seamounts of Group 8 (n = 26) are more widely dispersed, occurring in relatively deep water north and south of the eastern end of the Chatham Rise (n = 15), in a trough on the western edge of the Lord Howe Rise (n = 2), at the head of the New Caledonia Trough (Telecom, Aotea seamounts), and on the slope of the Campbell Plateau near Auckland Island (n = 7). Group 7 seamounts are either closely associated with the Louisville Ridge (n = 18) or the Lord Howe Rise (n = 8) in the north of the region, whereas Group 5 (n = 16) and Group 2 (n = 6) are both associated with the Macquarie Ridge in the south of the region. Group 6 contains four seamounts along the Resolution Ridge System, four features clustered together on the slope at the southern end of the East Coast Ridge, the region's two largest seamounts (Bollons and Gilbert), two seamounts north of Gilbert seamount in the Tasman Basin, and other single isolated seamounts at the southern end of the Colville Ridge (Colville Knoll), on the Hikuranki Margin (Ritchie Hill), on the Northland Plateau (Cavalli seamount), and on the West Norfolk Ridge (seamount No. 447). Groups that contain only a small number of seamounts are situated in the Emerald Basin (Groups 4 and 3) and the slope of the Campbell Plateau (Group 1) in the extreme south of the region.

The Euclidean distance similarities of the seamount groups and the biologically meaningful variables that contribute the most to such similarities are detailed in Table 2. The similarity values for the identified seamount groups ranged considerably, with seamounts belonging to Group 9 and Group 6 being the most and least similar, respectively. The variables depth at base, depth at peak, elevation, and distance from continental shelf were consistently ranked as the top four contributing variables to the similarity observed for each seamount group. The contribution to the within-group similarity by any other of the variables used in the analysis was always negligible (<0.01%). Depth at base was the variable that in the majority contributed the most to the observed within-group similarity (for Groups 12, 9, 8, 6, 5, 2, and 1), otherwise it generally ranked third in overall contribution (5.86–54.22%). Although the variable depth at peak was deemed the most important variable for four of the seamount groupings (Groups 11, 10, 7, and 3), generally this variable was the second in its overall contribution (15.95–49.57 %) to the observed similarity. The variable elevation, which contributed between 3.6% and 63.41%, was either the third or second (6 and 5 instances out of 12, respectively) highest contributor, only once contributing the most to the observed within-group

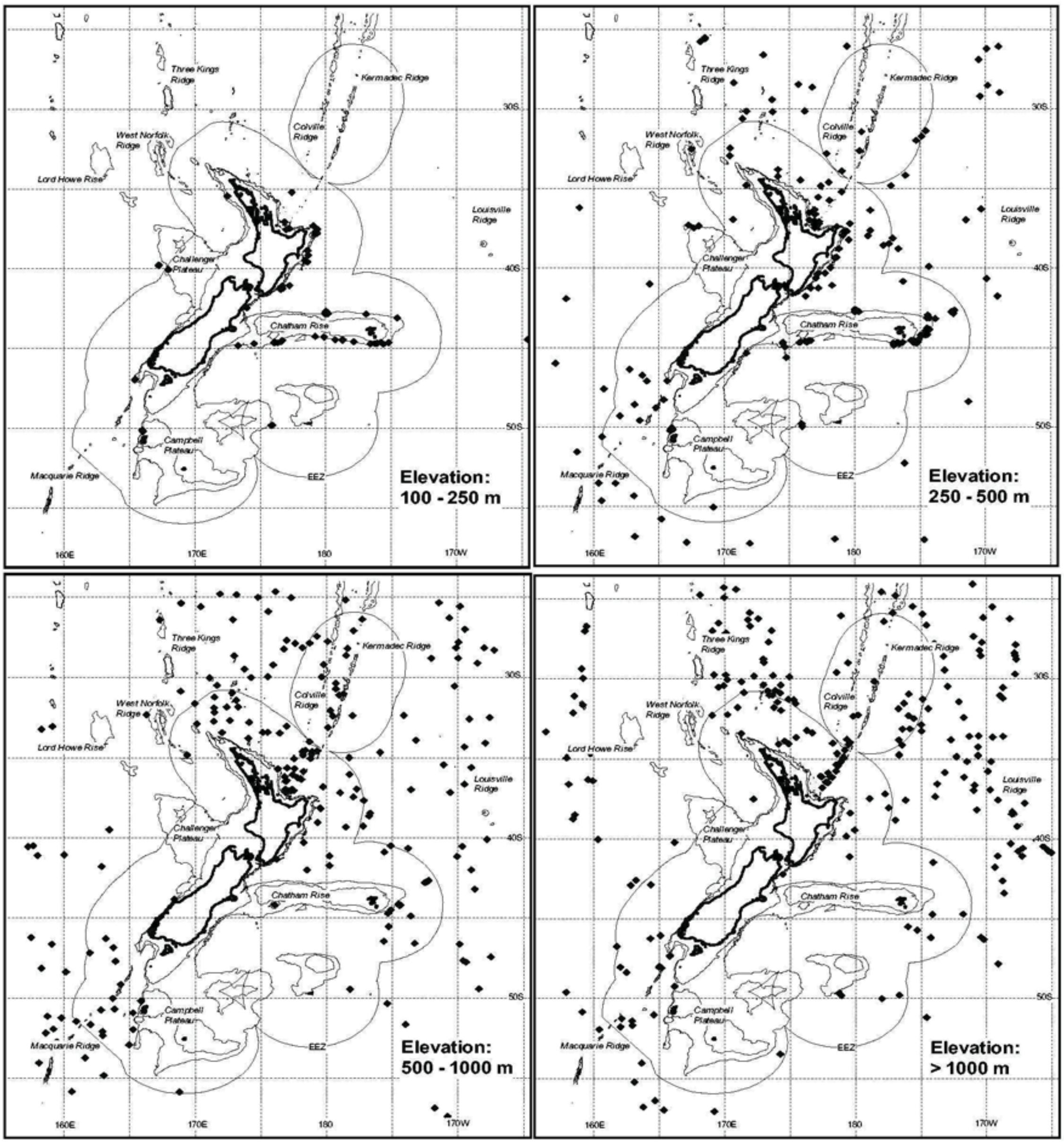


Fig. 7 Distribution in the New Zealand region of seamounts by elevation (4 categories: <250 m; 250–499 m; 500–999 m; ≥1000 m). Filled diamonds indicate position of seamount peak.

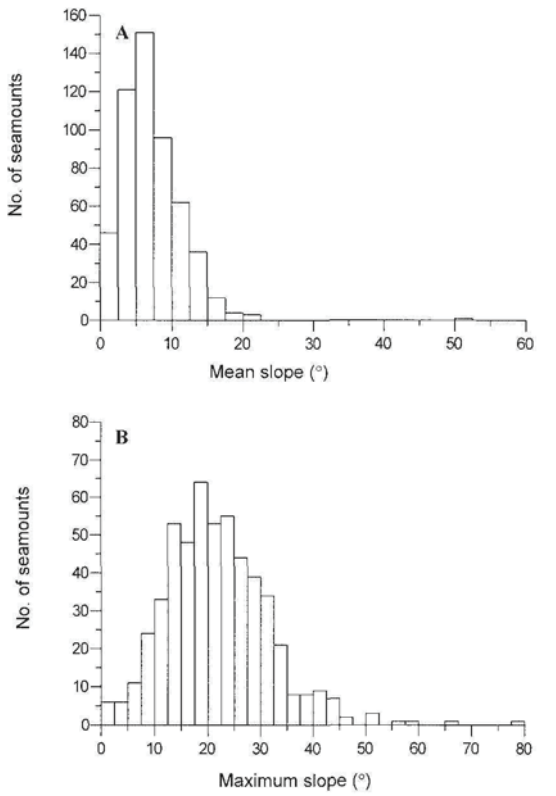


Fig. 8 Frequency of seamount slopes in the New Zealand region. **A**, mean slope calculated from area and elevation; and **B**, maximum slope measured from the detailed bathymetry.

similarity (for Group 4). Of the four most important variables, distance from the continental shelf always contributed the least (0.01–4.72%) to the observed within-group similarity.

DISCUSSION

The results of the present study clearly demonstrate that c. 800 known seamounts in the New Zealand region have very diverse physical characteristics. Seamounts span a wide range of sizes, depths, elevation, geological associations and origins, and occur over the latitudinal range of the region, lying in different water masses of varying productivity, and both near shore and off shore. As such, it is difficult to generally describe New Zealand seamounts, as there is no typical feature. Thus, seamounts provide a wide variety of habitats, and this is potentially important for structuring the diversity of the faunal assemblages associated with the seamounts of the region.

The number of known seamounts considered by the present study is almost certainly an underestimate for smaller seamounts that are in the order of 100–500 m high. Recent multibeam swath-mapping of regions of the Kermadec Ridge (northeast of the North Island) indicates that seamounts as large as 10–20 km basal diameter can remain undiscovered (Wright et al. in press). Thus it should be noted that the sea-floor area of currently unknown features may increase the present estimate of seamount area considerably (only c. 7 % of the region is mapped with multibeam surveys). For larger seamounts a comparison of regional bathymetric data (CANZ 1997) and satellite altimetry data (Smith & Sandwell 1994, 1997; Ramillien & Wright 2000) suggests that most are identified. The present assessment of seamount distribution is in part an artifact of the latitudinal/longitudinal distribution of bathymetric data (Smith 1993), some of which reflects fishery-related research effort (e.g., seamounts on the Chatham Rise which are commercially fished for orange roughy and oreo), but is in part real owing to a greater number of seamounts associated with boundary or hotspot volcanism to the north.

Data on substrate type for seamounts in the region are very limited. However, the apparent agreement between the distribution of substrate interpreted from the backscatter and pattern of sediment and rock substrate derived from the seabed photographs (for Rumble III) provide clear evidence for the existence of highly heterogeneous substrate composition over spatial scales of 10–1000 m for at least the Kermadec arc seamounts. Extrapolation of results from multibeam/camera substrate surveys of active seamount volcanoes to New Zealand-wide seamounts is currently difficult to assess. However, a new technique provides a promising avenue to directly derive objective substrate maps from backscatter data (Le Gonidec et al. in press) and thereby improve understanding of substrate distribution on/between seamounts.

Although some data indicate that physical characteristics can be important in influencing the composition of the fish fauna of some New Zealand seamounts (Clark & Field 1998; Tracey & Fenaughty 1997; Clark et al. 2001; Tracey et al. 2004), there are currently no comparable studies for benthic macroinvertebrates. Studies are under way to quantify the diversity of benthic fauna for New Zealand seamounts and to examine the spatial

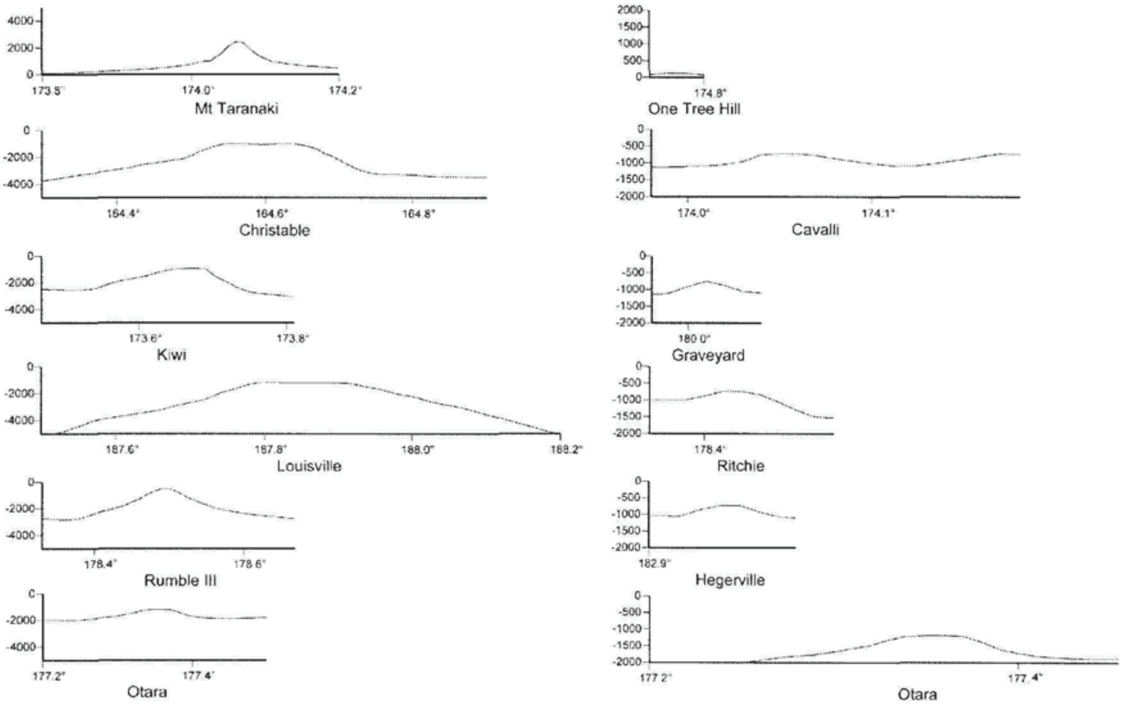


Fig. 9 Profiles of selected seamounts of the New Zealand region (and terrestrial features Mt. Taranaki and One Tree Hill for comparison).

pattern of assemblage composition, both within and between seamounts of the region (Clark et al. 1999a). However, presently such an analysis will be fairly restricted (so far 40 seamounts have been specifically sampled with a limited number of direct sampling gear deployments on each feature) and is likely to be incomplete for some time (complete identification of certain taxa will take many years). Considering the need to more efficiently document the biodiversity of seamounts, which are costly to sample, and the need for such information to underpin issues of conservation and sustainable use of the seamount environment (e.g., fishing, mining) (Johnston & Santillo 2004; Morato & Pauly 2004), it seems prudent to produce a biologically meaningful classification of New Zealand's seamounts. Such a classification is consistent with recent recommendations from the seamount scientific community (Stocks et al. 2004).

The adoption of simple classification procedures, and the resultant interpretations, potentially provide a greater scientific underpinning for environmental management (e.g., Valesini et al. 2003). The results of this classification analysis indicate that New Zealand region seamounts can be placed into 12

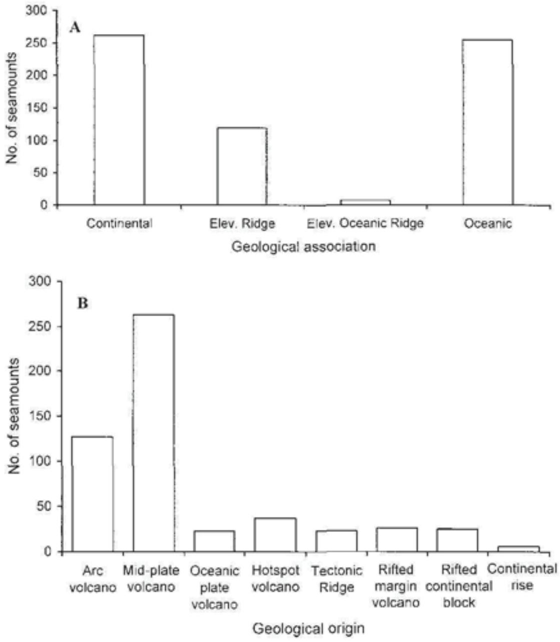


Fig. 10 Geological association of seamounts in the New Zealand region with: **A**, continental or oceanic systems; **B**, and frequency of seamount classes based on interpreted geological origin.