

CHEVRON-SHAPED ACCUMULATIONS ALONG THE COASTLINES OF AUSTRALIA AS POTENTIAL TSUNAMI EVIDENCES?

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ABSTRACT

Along the Australian coastline leaf- or blade-like chevrons appear at many places, sometimes similar to parabolic coastal dunes, but often with unusual shapes including curvatures or angles to the coastline. They also occur at places without sandy beaches as source areas, and may be truncated by younger beach ridges. Their dimensions reach several kilometers inland and altitudes of more than 100 m. Vegetation development proves an older age. Judging by the shapes of the chevrons at some places, at least two generations of these forms can be identified. This paper discusses the distribution patterns of chevrons (in particular for West Australia), their various appearances, and the possible genesis of these deposits, based mostly on the interpretations of aerial photographs.

1. INTRODUCTION

The systematic monitoring of tsunami during the last decades has shown that they are certainly not low frequency events: on average, about ten events have been detected every year – or more than 1000 during the last century (Fig. 1, NGDC, 2001) – many of which were powerful enough to leave imprints in the geological record. Focusing only on the catastrophic events, we find for the last 400 years (Fig. 2, NGDC, 2001) that 92 instances with run up of more than 10 m have occurred, 39 instances with more than 20 m, and 14 with more than 50 m, or – statistically and without counting the Lituya Bay events – one every 9 years with more than 20 m run up worldwide. Considering at least 300,000 years of a high sea level during the Pleistocene epoch of more than 2 Mio. years, and assuming that the frequency of strong tsunami for those times was about the same as during the last centuries, the world's coastlines have been hit by about 30,000 tsunami with run up heights of more than 20 m during high sea levels of the Quaternary – and we know nearly nothing about their contribution to coastal forming. Strikingly, so far no systematic investigation of tsunami or paleo-tsunami imprints exists, and nearly all of their traces have been detected coincidentally. On the other hand, many attempts to prove historically documented mega events by finding their geological traces have failed. With this background in mind and referring to the state of the art of tsunami field evidences, we will discuss chevron forms along the Australian coastline with regard to their suitability as paleo-tsunami indicators, particularly because we urgently need more reliable indicators for tsunami events in the landscape. This regional-scale study for West Australia is based on aerial photograph interpretation. The aim is to differentiate the entire spectrum of morphological types of chevrons in different coastal environments covering a wide range of latitudes and deduce indicators of their age and genesis. However, this remote sensing approach has to be completed with a detailed sediment analyses and absolute dating techniques.

During the last years, several coastal forms and deposits have been identified that could be related to formerly unknown paleo-tsunami (Bryant *et al.*, 1996; Bryant, 2001; Mastronuzzi & Sanso, 2001; Kelletat & Schellmann, 2002; Scheffers, 2002, and others). On the one hand, there are huge dislocated boulders or groups of boulders appearing as significant landscape marks and as evidences for extremely high transport energies, and on the other hand, there may be

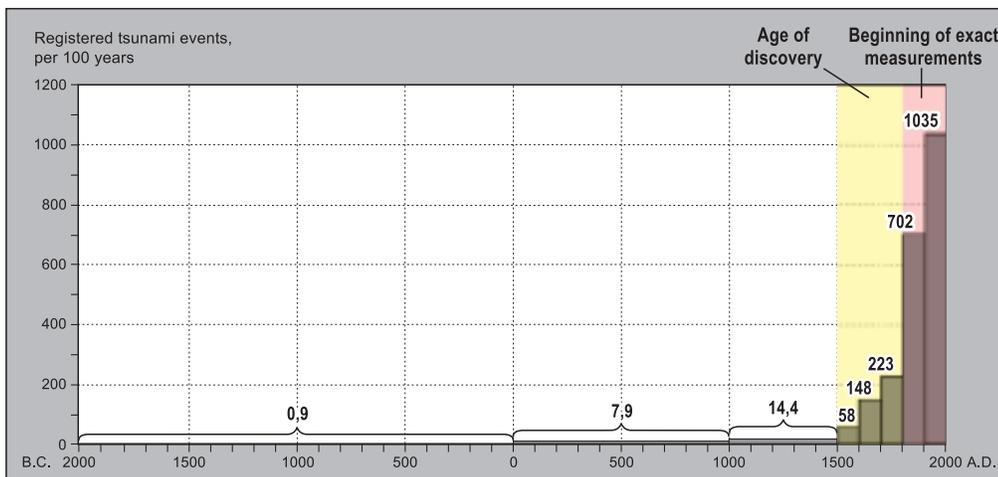


Fig. 1: Number of registered tsunami per century from about 2000 BC (NGDC, 2001).

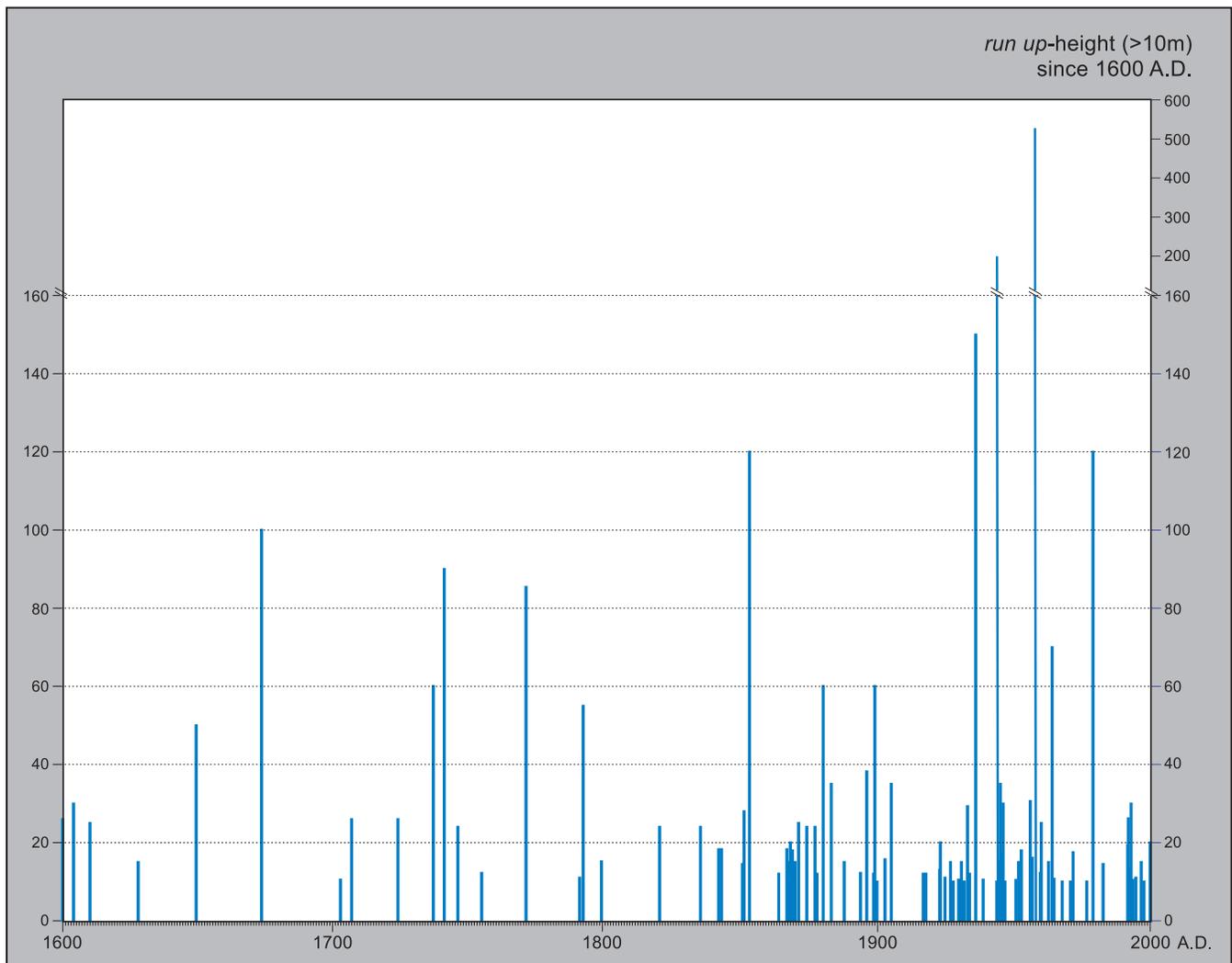


Fig. 2: High run up values during the last 400 years (NGDC, 2001).

smaller forms of rock sculpturing due to very strong tsunami currents, the latter, in particular, differentiated by Bryant (2001). But for even the largest dislocated coastal boulders (of more than 1000 t), some authors (Talandier & Bourrouilh-Le-Jan, 1988, for the Tuamotu-Archipelago, or Hearty *et al.*, 1998, for the Bahamas) prefer to believe that their genesis is caused by storm impact rather than tsunami. The chevrons (large sandy coastal deposits discussed in this paper), however, have not been proven in detail to be of tsunamigenic origin. To date, they have been mentioned in only a few papers (Bryant *et al.*, 1997; Bryant, 2001; Bryant & Nott, 2001, and Hearty *et al.*, 1998, Kindler & Strasser, 2000), and for only two regions (Australia and the Bahamas). Whereas the Australian examples have been described as tsunamigenic (from the Younger Holocene), the Bahamian features have been related to catastrophic storms from the last interglacial.

The intention of this study is to discuss whether the so-called chevrons may have a much wider distribution, and whether they may be clues for extreme tsunami impacts in a very extended area that have not yet been described.

2. CHEVRONS: DEFINITION, CHARACTER AND AGE

According to Hearty *et al.* (1998) chevrons are “*v-shaped, sublinear to parabolic, ribbon-like...depositional landforms*”, containing “*beach fenestrae*” and other “*water-made structures.*” On the Bahamas, where they can appear along 700 km of coastline, they are made by “*many waves acting over a short time interval*” or “*organized sets of large waves.*” Their average size there is 3 km long (max. 10 km!), a third of this as width, their ridges or ribbons may be 20 to 100 m wide, and they have a relative height of 8 to 25 m (max. 40 m) with the highest section in the distal parts. A central elongated depression is normally enclosed by the ridges. The chevrons are mostly sandy, but may contain pebble beds and clasts, often from aeolianite (on the Bahamas). They may be accompanied by huge boulders of up to 2000 t at 11 m asl. and 500 m distant to the shoreline, and have been dated on the last interglacial oxygen-isotope substage 5e at around 123,000 ± 5000 BP. The depositional forces should be extreme storms developed during a significant climatic revolution at the end of isotope substage 5e (Hearty *et al.*, 1998). The genesis of chevrons as water made structures, however, is still under debate. Kindler & Strasser (2000), who did not know of the 2000 t boulders accompanied with the Bahamian chevrons and did not find clasts in these features, interpret the forms as parabolic dunes from a lower sea level of isotope substage 5e in a phase of a dryer climate, and interpret the beach fenestrae in them as made by heavy rain.

Bryant *et al.* (1997), Bryant & Nott (2001), and Bryant (2001) described chevrons from SE- and W-Australia up to 30 km inland and 130 m high. They are often mapped as coastal dunes, because they sometimes resemble parabolic aeolian accumulations, but they may contain shell, clasts, and well rounded cobbles. At least in one place in West Australia, they have been dated to 1080 AD.

3. CHEVRON DISTRIBUTION ALONG THE AUSTRALIAN COASTLINES

According to Bryant (2001) and Bryant & Nott (2001), chevrons occur at Jervis Bay in New South Wales and around Point Samson near Port Hedland in the NW of West Australia.

In this section we will describe and interpret the very extended chevron distribution along Australia's coastlines on the basis of selected aerial photographs and topographic maps. Although sediment analysis has yet not been done, the various shapes, their relation to other coastal forms, their evidently older formation, their relation to the modern dominant wind patterns or to ancient dune systems, can be discussed, and some general conclusions regarding the age and forming processes can be given. None of the regions mentioned below have ever been analyzed regarding a tsunamigenic source of the chevron forms and sediments. Because of the extreme extent of Australia's coastline, the analysis presented in this paper has a lot of regional gaps, of course.

3.1 Northern Territory

In the Roper River district near the mouth of the Rose river (i.e., the western section of the Gulf of Carpentaria) along a coastal stretch of at least 40 km, chevrons are developed in a low

coastal landscape. Their length may exceed 3 km, their altitude at least 33 m. Their axis is 135°-140°, which describes the direction of the forming forces. The chevrons are inactive and densely vegetated, evidently older than a beach ridge system that truncates their seaward basal parts.

3.2 Queensland (Fig. 3)

In the Cape Melville area (about 90 km SW of the cape) south of the mouth of the Jeannie River, a set of chevrons has developed along at least 10 km of coastline, formed from the SE (about 160°). All are inactive and densely vegetated. They start at beaches, as well as along low coastlines without sand. Clearly distinguishable are two different types of chevrons: an older one, hard to identify on aerial photographs, of up to 5 km in length, broad and partly eroded, and a strip of younger ones with clear contours, about 1 km inland, that are decorated by coastal swamps formed by the blocking of the run-off from the coastal plains.

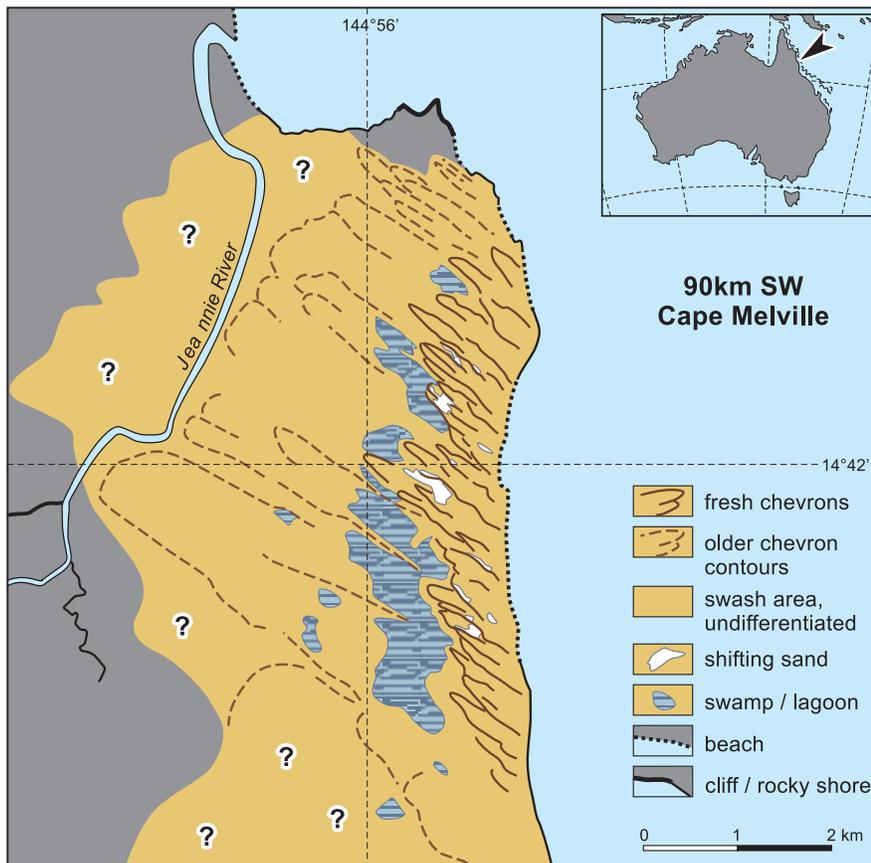


Fig. 3: Two generations of chevrons near the mouth of the Jeannie River, SW of Cape Melville, Queensland.

3.3 Victoria

Possible chevrons at Cape Bridgewater near Portland, extending across the broad tombolo of this cape, accumulated from the west, densely vegetated. Nearly 4 km long and up to 20 m high.

3.4 West Australia (along the south coast from E to W, and along the west coast from S to N)

a) Cape Arid National Park:

Along the bays W and E of the southernmost cape in the National Park, chevrons have accumulated from WSW, up to 6 km inland, and 40 to 60 m high in the western section. Vegetated, but the sand is partly mobilized again by strong winds.

b) Albany and environs (Fig. 4):

In the east and, in particular, to the west of Albany, the bays are decorated by leaf-like or lanceolate deposits along more than 30 km, extending inland for more than 3 km, some parts with heights of more than 100 m. They even appear on rocky headlands and along coastal sections without beaches or other sources of sandy material. Their general elongation is SSW to NNE, but in some places they start at the coastline from the south, bending to the east and back again to NE. This produces a flame-like form. Their outer contours are sharply marked, but in places, younger sand drift masks the contours. The chevrons are covered by vegetation including bushes and small trees, pointing to an active phase longer ago (at least centuries). Around headlands, clear refraction patterns of the chevrons can be detected. Another typical aspect in the Albany region is an exactly parallel inner pattern of smaller chevrons, repeated up to five times within the larger form, producing an overall, swash-like shape (Fig. 5).



Fig. 4: Extended chevrons near Albany with refraction patterns around headlands, curvatures, and well developed, even along rocky shorelines.

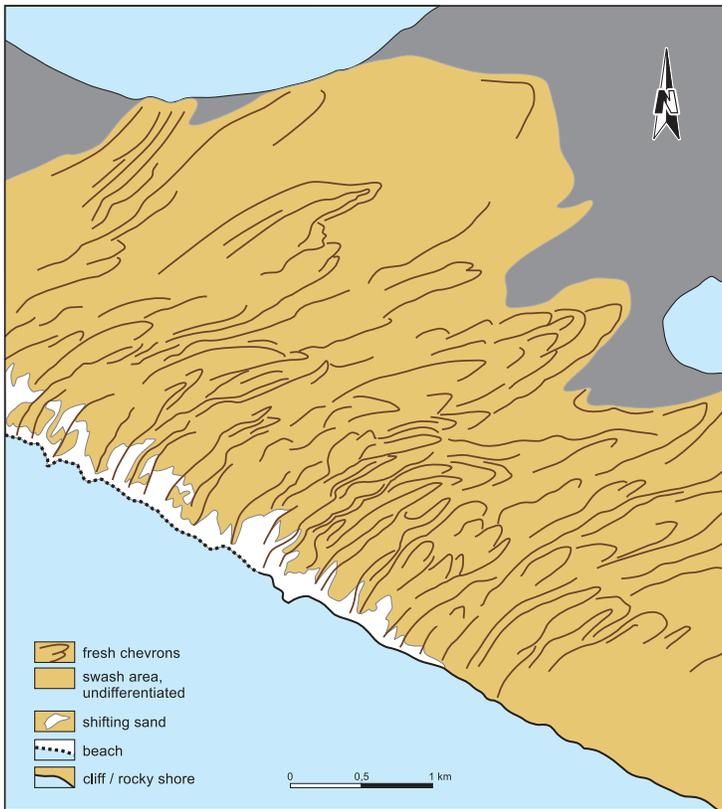


Fig. 5: Chevrons enclosed within larger forms from the Albany and Walpole area.

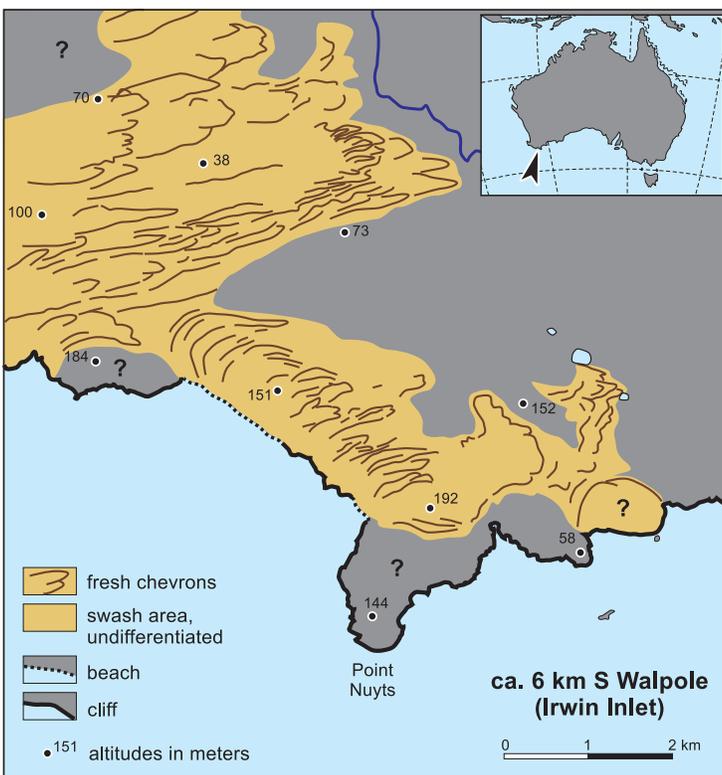


Fig. 6: Refraction and curvatures of chevrons, and their development, even along cliff shorelines near Walpole.

c) *Irwin Inlet, about 6 km S of Walpole (Fig. 6):*

Chevrons on both sides of the inlet, from SW and WSW, up to 5 km inland and up to 150 m high. Mostly along a rocky shoreline, from about 250°-260°, vegetated, with refraction patterns around headlands.

d) *Northcliffe:*

Chevrons at least 7 km long, some more than 100 m high, mostly along a steeper coast or cliffs without beaches, vegetated, from the west (250°-270°).

e) *White Point E Augusta:*

This bay E of Augusta near Cape Leeuwin is decorated by chevrons along its entire length of >30 km, in the eastern part around 2 km inland, in the western part up to 3 km, with heights of 30 to 40 m. Along the eastern part of the bay, chevrons top cliff sections, in the western part they start along beaches. Their long axis changes from WSW in the east to S to SSE in the west, showing a clear refraction pattern that does not correspond to the main wind directions. Despite some active blowouts, the chevrons are inactive forms again.

f) *Cape Leeuwin area (Fig. 7):*

The rocky western coast of this cape shows chevrons extending 4 km inland from the west. To the north, they bend a little toward 280°-290°. Their height is about 40 m to more than 100 m asl.. Some of the chevrons widen to their distal parts, giving the shape of oak leaves. Characteristic are gaps in the chevron formation, which are not orientated to headlands or rocky shores.

g) *Bunbury:*

Smaller chevrons along sandy beaches, but inactive and covered by vegetation, reaching about 1 km inland and mostly 20 to 30 m high.

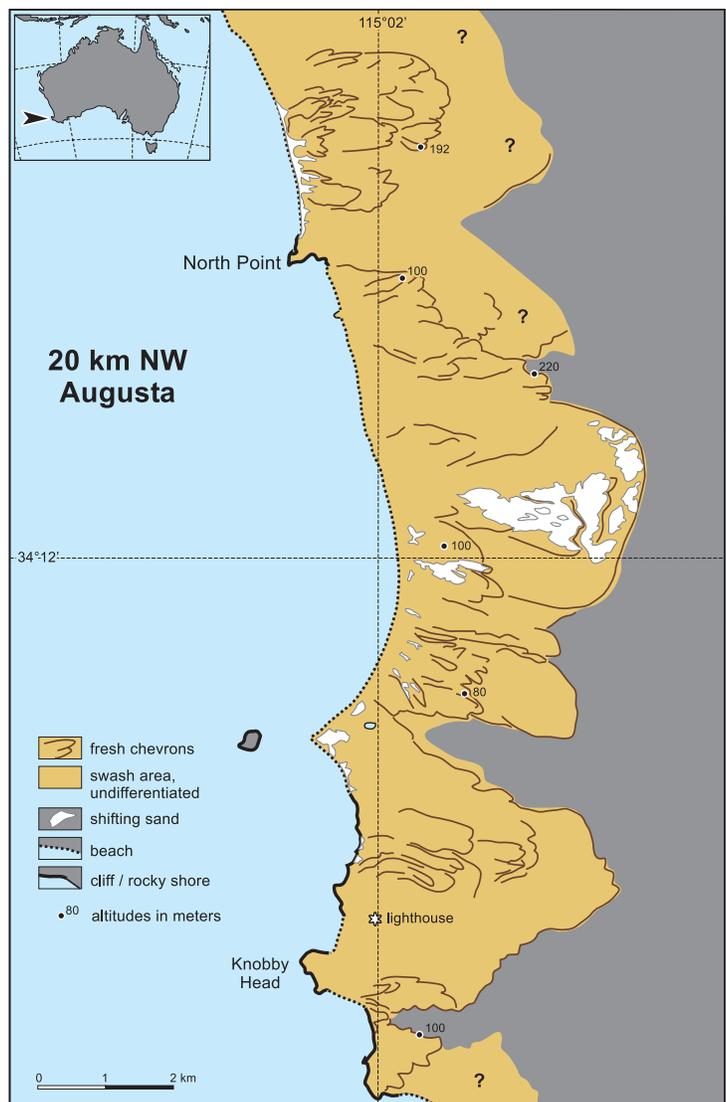


Fig. 7: The Cape Leeuwin Peninsula is widely decorated by large chevrons from the west.

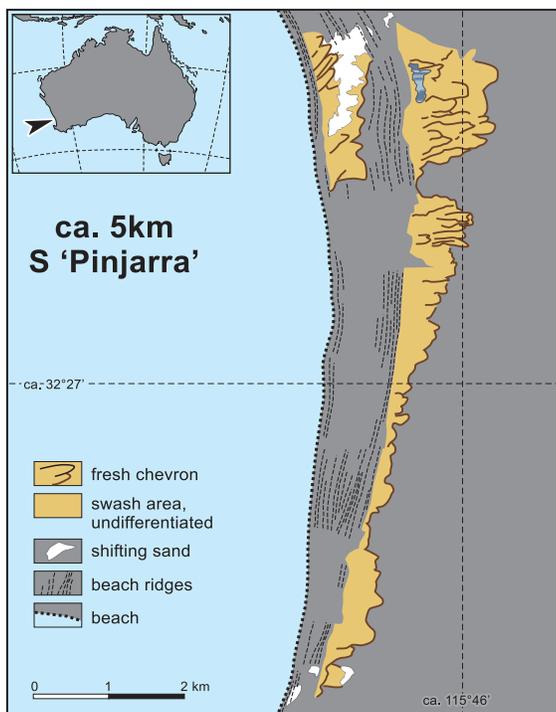


Fig. 8: Although fine sediments are available, chevron development was followed by beach ridge formation during the Younger Holocene near Mandurah and Pinjarra south of Perth.

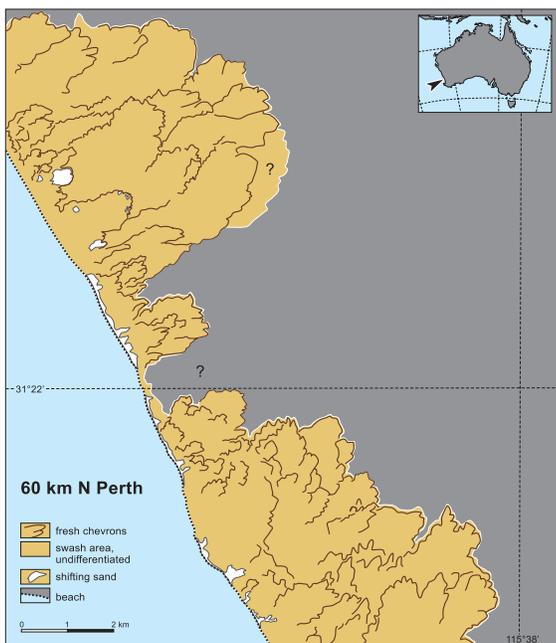


Fig. 9: Many chevrons north of Perth show an oak leaf appearance.

h) Mandurah/Pinjarra:

Shorter chevrons (about 1 km in length), extending at least 30 km along sandy beaches, formed from westerly directions, partly destroyed by younger drifting sands, vegetated, heights up to 40 m. Their coastal sections may be truncated by younger beach ridge sequences (Fig. 8).

i) North of Perth (Fig. 9):

Chevrons up to 5 km inland, from the west, along at least 60 km of narrow beaches, highest around 40 m, from about 250°-270°. Older forms further inland are mostly destroyed, and a younger set is clearly marked in spite of vegetation cover. In contrast to other areas, the chevrons show an “oak leaf” appearance.

j) Beagle Island N Perth:

Steep coast with small beaches. Chevrons several kilometers long and 30 m high, from 190°-200°, i.e., in a small angle to the coastline. Here they resemble inactive parabolic coastal dunes.

k) Dongara S Geraldton:

The chevrons accompany a low cliff for about 30 km directly north of Dongara, further north they follow a narrow beach, reaching 2 km inland, mostly 20 m high, max. 60 m, formed from the south (180°-200°). In the southern portion, they resemble inactive parabolic dunes.

l) Geraldton:

North and south of the town, chevrons have been formed from southerly directions (180°-190°, i.e., in an angle to the coastline), partly with drifting sand, up to 40 m high and less than 2 km long.

m) Edel, Tamala and Denham:

West of Shark Bay, chevrons decorate the outer peninsulas, crossing them for several kilometers, but are never developed on peninsulas protected from the open ocean. Up to 80 m high, forms are very similar to terrestrial elongated and parabolic dunes. Formed directly from the south.

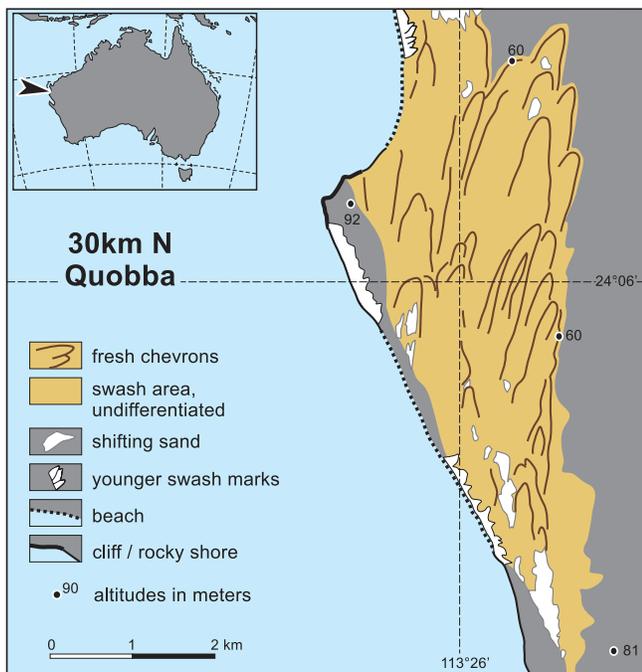


Fig. 10: Chevrons near Point Quobba are very similar to parabolic dunes.

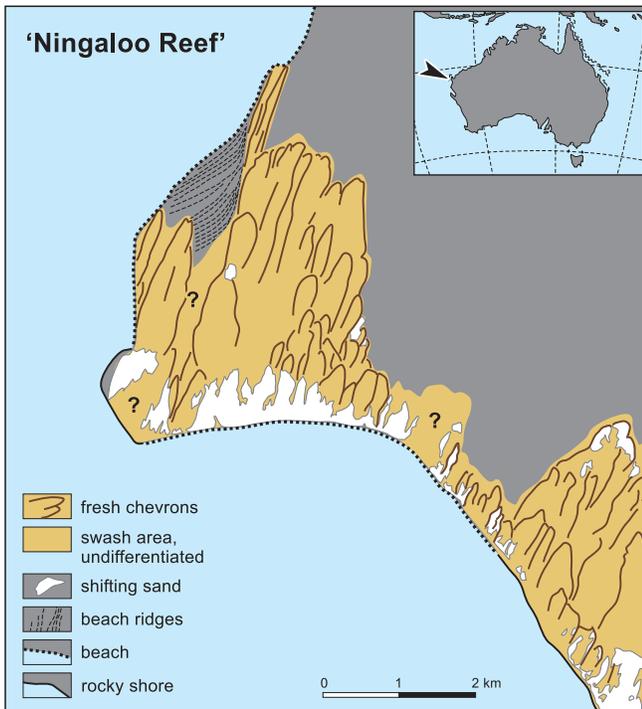


Fig. 11: Chevrons close to the Ningaloo reef may originate along beaches or cliff lines, and partly cover older Holocene beach ridge systems.

n) Carnavon:

North of the town, broad beach ridges with remnants of older and truncated chevrons behind, changing about 18 km north of the town into parabolic forms directly contacting the beaches. Length is about 1 to 3 km, height 10 to 28 m.

o) Quobba (Fig. 10):

Around Red Bluff, about 40 km N of Point Quobba, chevrons from 190°-200°, at Point Quobba more towards 180°, i.e., parallel to the coastline. It seems that they continue inland in a field of parabolic and elongated older dunes. Chevrons some kilometers long, on top of cliffs, some more than 100 m asl.

p) Ningaloo (Fig. 11):

Similar appearance to point Quobba: from the south (180°-210°), some kilometers long, changing into a parabolic dune field inland, height more than 20 m. Partly active blowouts and sand drift. The chevrons may partly cover a system of small beach ridges.

4. GENERAL CONCLUSIONS FROM THE MORPHOLOGIC ASPECTS AND DISTRIBUTION AS ARGUMENTS FOR A TSUNAMIGENIC ORIGIN OF CHEVRONS

Based on the distribution patterns of the chevrons, their orientation to the coastlines, their relation to other coastal forms (such as cliffs, headlands, or beach ridges), the source of loose material (in particular sand), geomorphic aspects, freshness of forms, and vegetation cover, it is possible to draw some general conclusions:

a) Chevrons of one to several kilometers in length and heights of 10 m to more than 120 m are distributed around the coastline of Australia (i.e., Gulf of Carpentaria, Cape York Peninsula, New South Wales, south and west coast of West Australia), with a clear dominance in the west of the continent.

b) Chevrons may be formed perpendicular to-, parallel to-, or in angles to the coastline.

c) They usually have a straight axis, but at some places they can bend in two directions and change their main direction by up to 90° (Fig. 5 and 12).

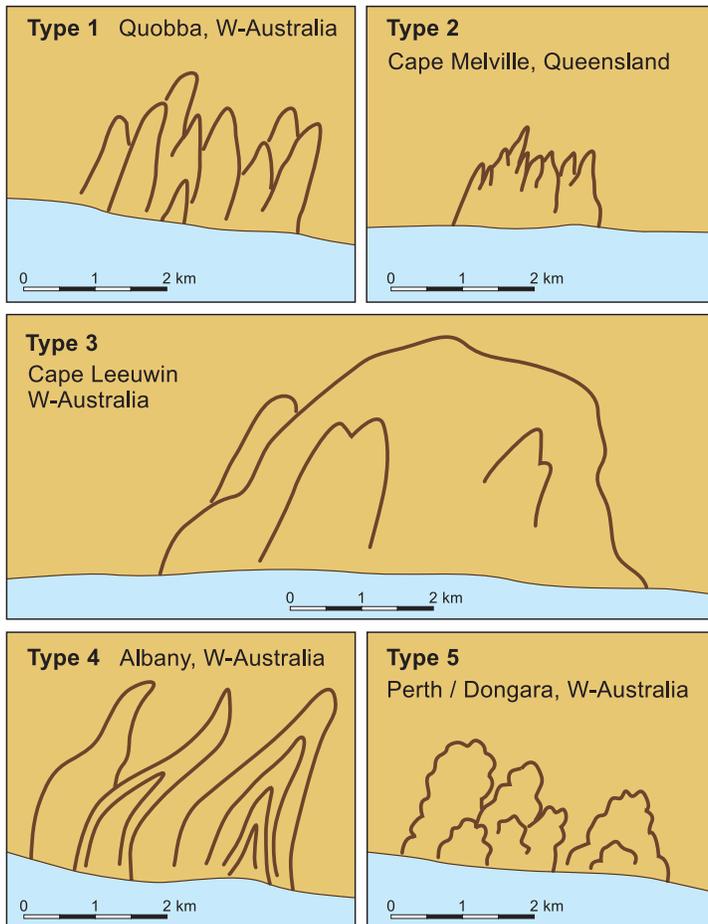


Fig. 11: Chevrons close to the Ningaloo reef may originate along beaches or cliff lines, and partly cover older Holocene beach ridge systems.

d) Their outer contours are relatively sharply marked, particularly the parts that are furthest inland. These parts may be the highest.

e) Chevrons continue from the coastline to heights of more than 120 m, even in a rocky environment without sandy sources. The forming forces have been strong enough to reach several kilometers inland, as well as high up on steep slopes.

f) Many chevron formations show simple contours (i.e., only single ribbons or ridges framing a central depression), but others have up to five enclosed ridges that are smaller but strongly parallel (Fig. 5). This is due to several waves, not to several forming generations differing in time.

g) Most chevrons are narrower to their landward side (Fig. 12), but some widen inland, resembling oak leaves (Fig. 9).

h) The chevrons have a swash-like appearance that differs from that of coastal dunes. Typically, chevron formations can have smaller gaps without chevrons, and this appearance differs markedly from coastlines with shifting dunes (which do not have such gaps).

i) Along curved beaches in rounded bays, the direction of the chevron axis may change, corresponding to the normal wave approach in bays, which is always perpendicular to the beaches.

j) On opposing sides of a headland, the chevrons may have different directions due to refraction.

k) The sources for the chevron material may be beaches, but chevrons also occur often at locations where there is no beach, but instead, cliffs or steeper coastal slopes. At these locations the material can only derive from the foreshore environments.

l) All chevrons are inactive forms, covered by vegetation and soil, even in the dry western environments. Their relation to the active coastline, however, proves their Holocene maximum age.

m) In some regions, at least two generations of Holocene chevrons can be detected. The older, landward chevrons are much more eroded and often difficult to detect on aerial photographs (Fig. 3).

n) An older Holocene age is shown by the existence of sequences of younger beach ridges seaward of the chevrons, which have destroyed or reworked the chevron's basal parts (Fig.8). At other places, chevrons have covered older Holocene beach ridge patterns.

o) Areas of chevron development are sometimes not suitable for coastal dunes because of the lack of sand, the presence of mangrove fringes or other dense coastal vegetation (Fig. 3 and North Queensland), or seaward dominant wind directions.

p) Because of their similar appearance and clearness of form, at least the younger chevron generation along the south and west coast of West Australia seems to be from the same event at least some 100 years ago. This is in contradiction to an origin as coastal dunes, because they developed successively over a longer time.

q) The direction of the chevrons in some places coincides with predominant regional winds or the fossil dune patterns of terrestrial Australia (see Fig. 13), but in other places, this is not the case.

r) All chevron patterns can be explained by one or two extreme tsunamis. For West Australia, the source of the tsunami cannot be Réunion Island with the collapse of the Piton de la Fournaise volcano in 4200 BP (see Labazuy, 1996), because from this distance, the wave pattern should be more or less parallel from the west along the entire coastline. At the southern coast, however, waves from west to southwest with a refraction pattern to southerly directions appear around Cape Leeuwin, along the central western coast the dominant direction is west, and in the northern parts of West Australia they change to the southerly direction. This can be explained by a tsunami source at a nearer distance (e.g., about 1000 km to reach coastlines along more than 2000 km of the continent) near the latitude of Perth (see Fig. 14). The origin may be a large submarine slide or a meteorite.

s) There are evidences that West Australia (and other coasts such as northern Queensland or New South Wales) have been affected by extremely strong tsunami in the past. They have transported sand, shell, and cobble up to 30 km inland, and up to 60 m, or even 130 m, in height

(Bryant *et al.*, 1997; Bryant & Nott, 2001, Bryant, 2001), and have decorated several places along the coastline (Quobba, Cape Leveque, New South Wales, etc.) with large boulder fields > 30 m asl..

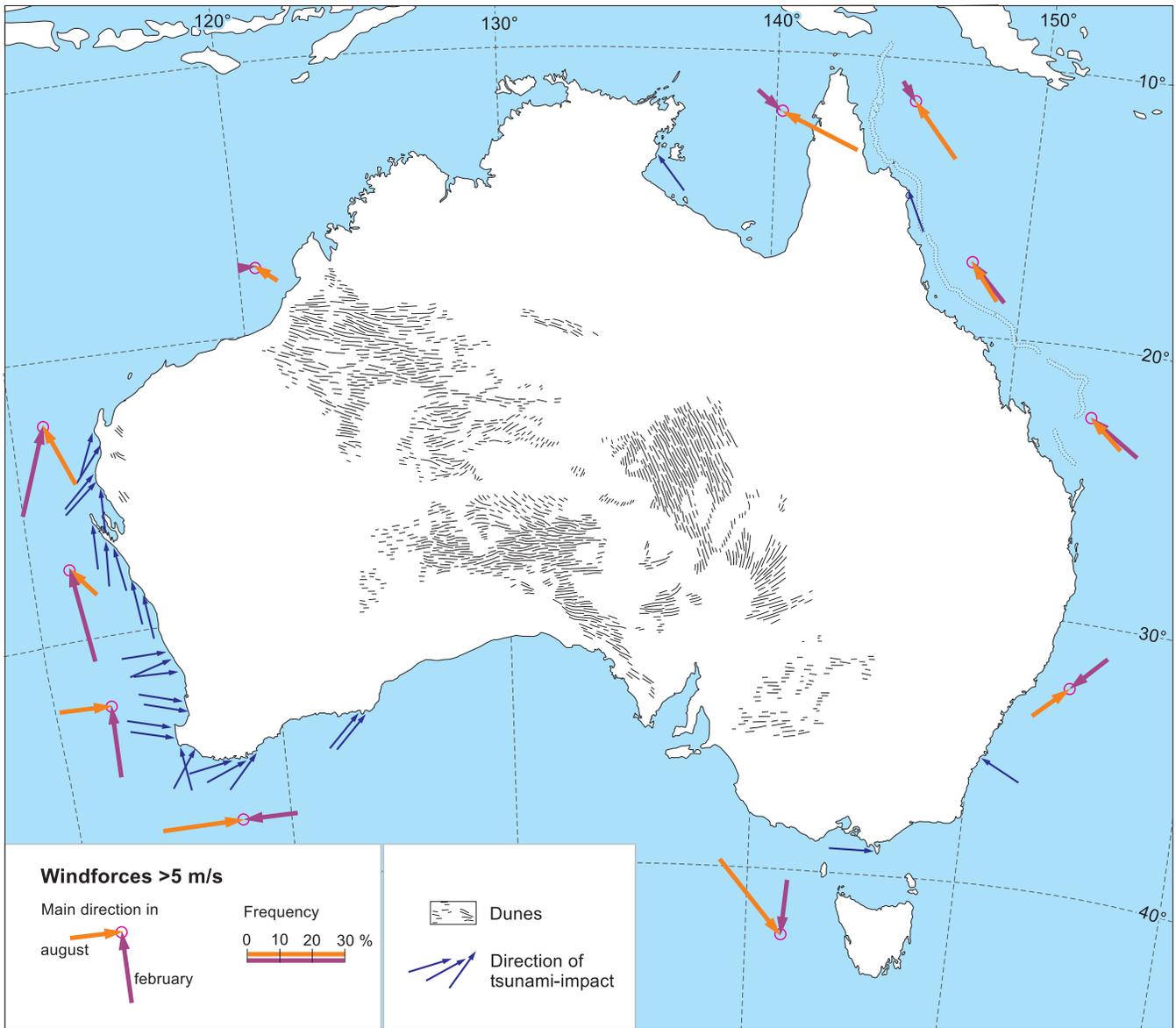


Fig. 13: Direction of chevron axes, fossil dune patterns, and modern wind systems.

5. CONCLUSIONS

Of course, the hypothesis that chevrons are swash forms from tsunami must be proven in the field with more evidence than is known today, in particular, by analyzing their sediments and by dating. On the other hand, it would be difficult to explain all of the chevrons presented here as coastal dunes, because to do so would require a rather complicated evolutionary history consisting of at least:

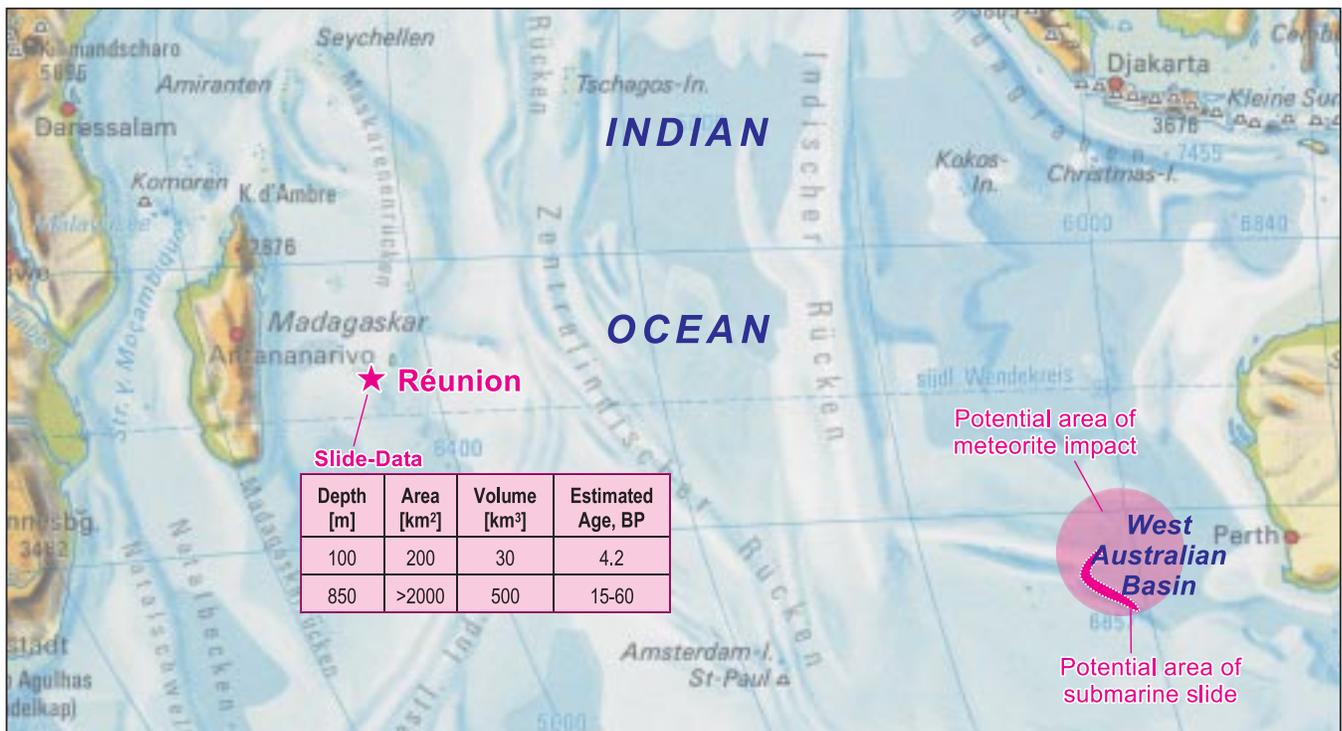


Fig. 14: Possible origin of the West Australian chevrons: not from the distant Réunion volcanic collapse, but from a nearer submarine slide or meteorite impact.

a) A first phase of coastal dune development during the middle Holocene with a sea level lower than today's to expose sand for blow out in foreshore regions of modern cliffs and submerging slopes, and with a wind pattern different from today's.

b) A phase without coastal dune development for several thousand years, but with beach ridge formation at places where sand was available.

c) A second phase of coastal dune development, rather short, about 1000 years ago, again with a lower sea level to mobilize fine sediments from foreshore regions, and again with a wind pattern different from today's.

d) No significant coastal dune development for the last several hundred years, and the establishment of the modern coastal wind systems.

Obviously, this evolutionary history contradicts – besides other evidences – the sea level curve for the Younger Holocene as has been developed by our Australian colleagues.

There can be no doubt that the chevrons along the Australian coastlines are special forms worthy to be investigated more intensively. What should be done in the near future is to investigate whether these chevrons contain sediments too coarse for aeolian transport, and to find out, by more radiocarbon dating, whether they were really accumulated during the same event. If their genesis from giant tsunami can be confirmed, we have a new instrument for identifying these impacts along other coastlines of the world.

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