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The imprint of tsunami in Quaternary coastal sediments of Southeastern Australia

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Keywords
tsunami, Holocene, coastal barriers, New South Wales, Australia, GeoQUEST

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The Imprint of Tsunami in Quaternary Coastal Sediments of Southeastern Australia

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Abstract

TL and 14C dating has revealed anomalous chronostratigraphies at two sites on the coast of southern New South Wales, Australia, where Pleistocene sands have been driven onshore over Holocene estuarine deposits. Lack of solar bleaching of the TL component which occurs in normal swash zones, an identical TL age obtained from pumice incorporated in the Pleistocene deposit, and boulders scattered through the sand are indicative of tsunami impact. These observations prompt reassessment of the strictly uniformitarian models of barrier emplacement during the Holocene transgression both in eastern Australia and elsewhere in the world where tsunami are a possibility.

Introduction

Despite an increased awareness of the significance of tsunamis as a geological process (e.g. Moore and Moore, 1984; Dawson et al., 1988; Young and Bryant, 1992; Bryant et al., 1992), their possible effect on coastal stratigraphy remains largely neglected. We argue that the shoreward transport of sand by tsunamis is recorded in apparent anomalies in recently developed Quaternary chrono-stratigraphies for sections of the coast of southern New South Wales. The examples presented here also demonstrate the scope offered by thermoluminescence (TL) analysis not only for establishing chronologies in coastal sediments, but also for reconstructing the mechanisms of deposition.
The deposition of sand on the beaches of New South Wales has been attributed to onshore transport during the Holocene transgression, with first sand arriving at about 6.5 ka when sea level reached its present height, and the last main input at about 3 ka (Thom and Chapelle, 1975; Royn and Thom, 1981). An alternate interpretation (Younget al., 1992) advances the peak of the transgression to about 7 ka at a height +2 m, which was maintained until about 1.5 ka when sea level dropped to its present height, and argues for the impact of several major tsunami during the Holocene. The evidence for tsunami includes boulders and eroded rock surfaces at heights up to 32 m above sea level (Younget al. and Bryant, 1994) and also highly bimodal beach deposits, disturbed middens and estuarine run-up deposits (Bryant et al., 1992). Two apparently anomalous stratigraphic sequences described here seem to indicate a very substantial tsunami impact during the final stages of the Holocene transgression along this coast.

Similarities between eastern Australian and the Bulgarian Black Sea coast can be found in some of this evidence for tsunami effects. Historical records of huge tsunami invasions on the latter shore (Christoskov and Tupkova-Zaimova, 1979) together with archeological and sedimentological evidence could well be explained by tsunami run-up rather than by the activity of normal sea waves or tides. The TL analysis presented in this paper could also be used in a similar manner to substantiate existing models for tsunami generation and their manifestations on the Bulgarian shoreline (Ranguelov et al., 1988).

Field sites and dating

The first anomalous stratigraphic section on the east coast of Australia is located behind the foredune at the northern end of Kioloa Beach (Fig. 1). At this site intensely weathered gabbro at an elevation of +1.4 m (all elevations are relative to Australian Height Datum which approximates mean sea level) is capped by 0.3 m of estuarine clay, 1.7 m of coarse beach sand cemented by humate and minor amounts of iron, 0.6 m of beach sand containing rounded pebbles and cobbles together with stringers of heavy minerals, and by 2.5 m of dune sand. The coarse clasts and the bedding highlighted by the layers of heavy minerals leave no doubt that wave action extended to an elevation of at least +3.8 m (Fig. 2).

As these sediments appeared at first sight to be another instance of the peak Holocene transgression above modern mean sea level reported elsewhere along this coast (Younget al., 1993), they were dated by TL analysis. The method of TL dating, carried out on the 90-125 micron quartz fraction, was the combined additive/regenerative technique of Readhead (1988), the accuracy of which has been demonstrated in coastal environment by check dating with ^14C and U/Th (Bryant et al., 1990; Younget al., 1993). The upper beach sand (W1663) yielded an age of 18.9±2.8 ka, the humate-rich beach sand (W1642) yielded an age of 25.2±3.9 ka, but the estuarine clay (W1664) beneath the sand yielded an age of only 8.7±0.8 ka (Table 1).

Not only does the age of the estuarine sediments differ markedly from the overlying sand, so do the TL characteristics of its quartz. The TL spectrum exhibited by the estuarine deposit at Kioloa (W1664) is dominated by a strong 325°C maximum which is characteristic of the quartz TL spectrum. The beach sand (W1663) and the humate (W1642) TL spectra are less affected by this maximum and proved far less TL sensitive. The beach sample displayed an additional pronounced TL shoulder at approximately 300°C which was not evident in the estuarine and humate samples. This is suggestive of a mix of sediments from different origins (Pricc, 1994).

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Fig. 1. Location of the study sites
A strikingly similar chronostratigraphic anomaly was encountered 170 km further north in an excavation behind the foredune at Bellambi Beach (Fig. 1). The sequence exposed at the northern end of the excavation consists of a highly oxidised sandy clay at an elevation of — 1.47 m, which is buried by 1.2 m of grey sandy clay, containing numerous estuarine shells, 0.9 m of orange sand, 0.2 m of sandy clay, and 4 m of grey sand in which bedding is indicative of beach deposition (Fig. 3). At the southern end of the exposure white sand separates the estuarine clays from the humate-rich sand, which here extends upwards from an elevation of about 1.8 m to 3.44 m. The southern section of the humate contains scattered, rounded sandstone boulders, up to 40 cm in diameter, at elevations of 2.8 m to 3.4 m, and part of it is overlain by a 20—30 cm layer of cobble-sized pumice clasts.
Table 1

TL analytical data...

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Site</th>
<th>Temperature Plateau</th>
<th>Paleodose (Grays)</th>
<th>% K</th>
<th>% Moisture</th>
<th>U + Th (Bq/kg)</th>
<th>Annual Dose (uGrays)</th>
<th>TLAge (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1213</td>
<td>Bellambi</td>
<td>350—500</td>
<td>31.0±3.7</td>
<td>0.63</td>
<td>19.3</td>
<td>31.5±4.0</td>
<td>1208±63</td>
<td>25.6±3.3</td>
</tr>
<tr>
<td>W1214</td>
<td>Bellambi</td>
<td>275—400</td>
<td>21.2±2.4</td>
<td>0.21</td>
<td>4.1</td>
<td>12.7±4.0</td>
<td>2867±74</td>
<td>7.4±0.8</td>
</tr>
<tr>
<td>W1295</td>
<td>Bellambi</td>
<td>300—500</td>
<td>19.4±1.6</td>
<td>0.37</td>
<td>3.8</td>
<td>17.8±4.0</td>
<td>884±74</td>
<td>22.0±2.6</td>
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<tr>
<td>W1296</td>
<td>Bellambi</td>
<td>275—500</td>
<td>24.4±3.4</td>
<td>0.18</td>
<td>6.5</td>
<td>40.9±4.0</td>
<td>1108±72</td>
<td>22.0±3.4</td>
</tr>
<tr>
<td>W1297</td>
<td>Bellambi</td>
<td>275—500</td>
<td>17.3±1.7</td>
<td>0.33</td>
<td>4.6</td>
<td>13.7±4.0</td>
<td>752±73</td>
<td>23.0±3.2</td>
</tr>
<tr>
<td>W1402</td>
<td>Bellambi</td>
<td>300—375</td>
<td>37.3±9.0</td>
<td>0.65</td>
<td>3.8</td>
<td>9.3±0.3</td>
<td>1477±70</td>
<td>25.2±6.2</td>
</tr>
<tr>
<td>W1298</td>
<td>Bellambi</td>
<td>275—500</td>
<td>151.0±14</td>
<td>0.9</td>
<td>2.6</td>
<td>51.6±4.0</td>
<td>2134±75</td>
<td>70.8±6.9</td>
</tr>
<tr>
<td>W1642</td>
<td>Kioloa</td>
<td>275—400</td>
<td>19.6±2.8</td>
<td>0.1</td>
<td>11.7</td>
<td>29.8±0.9</td>
<td>779±46</td>
<td>25.2±3.9</td>
</tr>
<tr>
<td>W1663</td>
<td>Kioloa</td>
<td>300—425</td>
<td>15.3±2.1</td>
<td>0.08</td>
<td>1.8</td>
<td>28.3±0.9</td>
<td>808±51</td>
<td>18.9±2.8</td>
</tr>
<tr>
<td>W1664</td>
<td>Kioloa</td>
<td>275—z400</td>
<td>7.1±0.5</td>
<td>0.95</td>
<td>30.3</td>
<td>41.5±1.3</td>
<td>821±40</td>
<td>8.7±0.8</td>
</tr>
</tbody>
</table>
Fig. 3. Quarry face at Bellambi showing 1. Holocene (6.6±0.8 ka) estuarine
muds capped by 2. Pleistocene (22.0±3.2 ka) beach sand, and 3. Holocene
(7.4±0.8 ka) beach sand. The top of the Pleistocene sand is +0.6 m above
mean sea level and the top of the estuarine mud is -0.27 m

The apparent Pleistocene age of the oxidised sandy clay at Bellambi is
supported by a TL determination of 70.8±6.9 ka (W 1298). A Holocene age of the
grey sandy clay which overlies this Pleistocene deposit is demonstrated by a $^{14}$C
determination of 6.6±0.08 ka (Beta 43951) for estuarine shell (Tapes watlingi,
Plebidonax deltoides). A Holocene age is also indicated for the grey sand at the top
of the sequence by a TL determination of 7.4±0.8 ka (W1214), an age
indistinguishable from the $^{14}$C determination near the bottom of the section. However,
TL determinations of 23.0±3.2 ka (W1297), 22.0±3.4 ka (W1296), 22.0±2.6 ka
(W1295) and 25.6±3.3 ka (W1213) indicate a late Pleistocene age for the sand lying
between the basal Holocene estuarine deposit and the grey upper sands. Moreover, a
TL determination of 25.2±6.2 ka (W1402) indicates a Pleistocene age for a clast in
the pumice layer which caps part of the humate-rich sands. In short, the TL and $^{14}$C
ages indicate that a body of Pleistocene sand was carried onshore during the early
Holocene and that it was then buried under Holocene sand.

Both sites are also problematic in that the sands which occur on or immediately
adjacent to the modern shoreline are of last glacial age, when the sea was far below
its present height. Indeed sands of glacial and interstadial age also occur at similar
elevations at seven other sites along the coast of New South Wales (Bryan et al.,
1994), but those instances do not lie on a Holocene substrate.
Reliability of dates

On several counts the chronostratigraphic anomalies seem to be real, rather than just artifacts of the dating techniques employed. First is the very pronounced clustering of dates within stratigraphic units at particular sites and between apparently similar units at different sites. The four TL determinations from the humate-rich sands at Bellambi fall within the same narrow range (22.0±3.4 ka to 25.6±3.3 ka, and also overlap with the TL determinations for the similar unit at Kioloa (18.9±2.8 ka to 25.2±3.9 ka). Perhaps even more important is that the TL ages determined by the additive/regenerative analysis of quartz sand are supported by virtually identical ages determined for other materials by different techniques. The Pleistocene TL ages obtained from the sand at Bellambi are indistinguishable from the TL age of 25.2±6.2 ka determined for the pumice clast layer lying on these sands. The age of the pumice sample was determined by means of the fine grain additive technique (Atkin, 1985), using the 1—8 micron polymineral grain size fraction. The similarity between the ages determined for the heat zeroed pumice and the solar zeroed host sediments lends considerable confidence to the reliability of these ages. The same conclusions can be drawn for the Holocene estuarine deposits because the ages ranging only from 7.4±0.8 ka to 6.6±0.08 ka were obtained both by TL and \(^{14}C\) analysis.

As the determined ages seem reliable, it appears that at about 7 Ka substantial quantities of Late Pleistocene sand were transported shoreward and deposited on top of Late Holocene estuarine muds and bedrock outcrops along at least 200 km of this coast. The extent and synchronicity of the remnants point to a regional rather than localized mechanism of transport.

Transport mechanism

The Pleistocene age of the sand leaves little doubt that it was moved very rapidly in a catastrophic wave event and not by normal wave action as sea level rose gradually during the Holocene transgression. The normal transport and exposure of sand on beaches results in almost the complete bleaching of residual TL. The maximum residual TL detected by us in modern beach sand along this coast corresponds to an age of ~1.6 Ka, and at these sites the 90—125 micron grains used for TL analysis were probably being selectively winnowed when exposed above the coarser grains comprising the great bulk of the sand (Bryan et al., 1992).

The inclusion of the boulders in the sand at Bellambi, together with the lag of Pleistocene pumice which partly covers this sand, provides independent evidence of the rapid transport and deposition with minimal reworking. So too does the inclusion of cobbles, which are dominantly of a different lithology to the shoreline outcrops, in the Pleistocene sands at Kioloa. Although the shoreline at Kioloa is cut entirely in gabbro, the cobbles embedded in the Pleistocene sand are metamorphic. About 200 m to the northeast a beach of cobbles, approximately 90% of which consists of well-rounded metamorphic clasts, overlies the gabbro at an elevation of 4.5 m, indicating that this low headland has been completely overwashed by wave action. As these clasts have been derived neither from the shoreline, nor from nearby relict alluvium in which clasts are almost entirely reworked vein quartz, they were apparently moved onshore by the same catastrophic event which emplaced the sand.

It seems unlikely that storm waves were the transporting mechanism, because they would almost certainly result in extensive reworking and sorting of the
sediment. Furthermore, although large storm waves do occur along this coast, the largest storm for at least 80 years led to no comparable onshore movement of sand (Bryan and Kidd, 1975; Bryan, 1988).

We conclude that relict marine sand was transported from the inner shelf to the present shoreline by tsunami. These deposits closely resemble those laid down by modern tsunami, especially in that many such modern deposits consist primarily of extensive sheets of sand which rise inland as tapering sedimentary wedges (Dawson, 1994). As the boulders interbedded with the sand occur near the top of the deposit at Kioloa, it seems that several waves were required to carry them onshore.

Conclusion

The evidence from Kioloa and Bellambi demonstrates the versatility of TL analysis not only for identifying chronostratigraphic anomalies in coastal sands, but also for indicating the mechanism of transport and deposition. The fact that Pleistocene sand was carried onshore without significant reworking and bleaching by exposure to sunlight, and was then deposited on top of Holocene sediments seems at odds with the accepted view of a dominantly gradual shoreward transport of sand by normal wave processes over thousands of years during the middle to late Holocene. The Pleistocene age of the sand which was notreset by exposure to sunlight, the Pleistocene age of pumice clasts identical to that of the sands on which they lie, the scattering of boulders through the sand, and the strong sedimentary indications of deposition by three main waves provide compelling evidence of tsunami imprint. Moreover, as Bellambi and Kioloa are 179 km apart, the imprint is likely to be recorded at other sites scattered along the coast of New South Wales. It may well explain, for example, the extremely rapid build up of sand at Broulee and Moruya, where Thoms et al. (1981) noted that approximately 70% of the width of Holocene barriers accumulated prior to about 6 ka. And, as we have pointed out previously (Bryan et al. 1992), the virtual termination of sand input on many barriers along this coast at about 3 ka coincides with the apparent impact of a tsunami recorded in sandy estuarine run-up deposits at Cullendulla Creek on the north side of Batemans Bay. Moreover, as the east Australian coast seems far removed from the influence of tsunamis, the imprint revealed here should prompt a reassessment of models of marine deposition along other coasts subject, even tenuously, to such a hazard.

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References


Цунами отложения в кватернериных седиментах Юго-восточной Австралии

P. Янг, E. Брайант, M. Прайс, E. Спасов

(Резюме)

Термolumинисцентные (ТЛ) и углерод-14 (14С) датирования показали аномальные хроно-стратиграфии двух объектов на берегу южной части Ново- го Южного Уэлса, Австралии, где пески Плейстоцена напластованы на берег над отложениями Холофна в устьях рек. Факты, свидетельствующие о воздейсствии цунами это отсутствие солнечного отбеливания ТЛ-компоненты, которое происходит в нормальных зонах прибоя, идентичная ТЛ-эпоха, полученная от пумиса (вулканическая лава), включенная в отложения Плейстоцена, а также как и щебень разбросанный в песках. Эти наблюдения показывают, что нужно сделать переоценку строго унифицированных моделей местоположения барьеров во время голоценовой трангрессии и в Восточной Австралии и пов- сюду в мире, где возможно возникновение цунами.