Ward, William Thomas (Bill) (1928–2011)

Geologist, Geomorphologist, Pedologist and Soil scientist

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Journal article Published: December 2006

Brisbane Airport: An alluvial landscape veiled by marine sediments

W.T. Ward and J.L.F. Hacker

Australian Journal of Earth Sciences, 53 (6): pp. 1001-1012

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At Brisbane Airport, the construction of a diversion channel for Kedron Brook exposed a former beach, low cliff and sand spit, which, with their associated sediments and acid sulfate soils, demonstrate a postglacial high sea-level 1.3 – 1.4 m above present mean sea-level. The beach appears to date from 4000 to 5000 y BP. It varies in level where it lies above soft ground; these variations, and sag depressions that follow buried streamlines, indicate sediment consolidation since withdrawal of the sea from the former shore. Most of the area consists of former estuarine deposits, mangrove and saline marshes, and stranded tidal flats on which acid sulfate soils are widely developed. The modern landforms mostly reproduce subsurface features, to the extent that the surface relief replicates the landscape transgressed by the sea 7000 years ago. A small rise of sea-level possibly to +0.65 m occurred about 2000 – 3000 years ago. Foredunes near the present shore that are related to a slightly lower level 1000 – 500 years ago (−0.25 m) are currently subject to wave erosion.

Journal article Published: February 2006

Coastal dunes and strandplains in southeast Queensland: Sequence and chronology

W.T. Ward

Australian Journal of Earth Sciences, 53 (2): pp. 363-373

https://doi.org/10.1080/08120090500507354

Parabolic dunes invade coastal strandplains and overlie prior blown dunes in southeast Queensland. These coastal dune landscapes were produced primarily by real changes in wind strength and frequency. Sand movement began in past glacial ages and in the most recent instance persisted into Holocene time. Four interglacial shores are identified with marine isotope stages 5, 7, 9 and 11, and allow estimation of the ages of the dune and beach sands, by correlation with the EPICA Dome C ice core, as follows: Triangle dune sand, n.d.; Garawongera dune sand, 65 ka; Woorim beach sand, 125 ka; Bribie beach sand, 245 ka; Bowarrady dune sand, 270 ka; Poyungan beach sand, 335 ka; Yankee Jack dune sand, 360 ka; Ungowa beach sand, 410 ka; Awinya dune sand, 430 – 486 ka; Cooloola dune sand, >486 ka.

Journal article Published: April 2004

Lead weight from Fraser Island compared with sources in France and China

W.T. Ward and B.L. Gulson

Archaeology in Oceania. 39 (1): pp. 52-53

https://doi.org/10.1002/j.1834-4453.2004.tb00558.x

A comparison of the isotope values of an ancient lead weight found in a stranded beach on Fraser Island, Queensland, with samples in a large global database showed that it resembled lead from mines in France (Ward et al., 1999).

Subsequent research has extended the database, including a substantial input from Dr Huang Bin, of the Chinese National Non-ferrous Metals Metals Corporation, Guilin (SIROTOPE, unpublished data).

We compared the new data with the isotope values for the lead from Fraser Island. The weight resembles lead from Beishan and Tonglin in China, but is highly unlikely to be from either source. Its best match is with lead mined in France.

Journal article Published: March 2001

Creation and interpolation of continuous soil layer classes in the lower Namoi valley

J. Triantafilis, W.T. Ward, I.O.A. Odeh, and A.B. McBratney

Soil Science Society of America Journal 65 (2): pp. 403-413

https://doi.org/10.2136/sssaj2001.652403x

The major errors associated with soil classification and mapping are due to subjective allocation of individuals to classes and incongruities between the classification system and the natural continuous variability of the soil mantle. Fuzzy clustering algorithms can be applied to resolve both errors.

In this study we numerically classified 1419 soil horizon samples using fuzzy k-means (FKM) and fuzzy k-means with extragrade (FKME) analysis. Each sample was characterized by 12 chemical and textural attributes that were used for the numerical classification. The fuzzy classes produced were mapped at various depths using a method that considered the unity of class membership and local kriging. The use of a confusion index enabled the representation of the continuous nature of membership between the classes mapped and highlighted areas where the collection of additional information may be appropriate. The resulting classes reflect sensible and practical groupings that are easily related to the natural structure of the landscape. Silt and clay contents were the most distinguishing attributes in identifying the various geological and geomorphic components. Differences in soil-forming process were well highlighted by organic C (Org. C), P, electrical conductivity (EC1:5), pH, and Cl− content.

We concluded that the fuzzy clustering algorithms and geostatistical techniques provide a worthwhile approach to soil classification and representation of the soil continuum.

Journal article Published: February 2001

Land suitability assessment in the lower Namoi valley of Australia, using a continuous model

J. Triantafilis, W.T. Ward, and A.B. McBratney

Australian Journal of Soil Research, 39 (2): pp. 273-289

https://doi.org/10.1071/SR99087

In an agricultural context, land evaluation is assessment for a specified kind of land utilisation. The final result of agricultural evaluation is a map, which partitions the landscapes into suitable and unsuitable areas for a particular land-use of interest. However, this approach may not represent the continuity of land. Land suitability could be better expressed by a fuzzy approach.

In this paper a fuzzy methodology is used to evaluate land suitability in the Edgeroi district for various crops including barley, dryland cotton, oats, pasture, soybean, sorghum, sunflower, and wheat. This is achieved using a membership function to derive a land-suitability membership score ranging from non-suitable (i.e. 0) to suitable (i.e. 1). We express this as continuous land suitability maps using punctual kriging. An expression for overall land suitability (i.e. its versatility) and its capacity with respect to suitability to particular rotations is introduced to highlight the most productive units of soil.

Conference paper Published: 2001

Cluster analysis of glass shards near Puketitiri, western Hawke's Bay

A.M. Hammond and W.T. Ward

Geological Society of New Zealand, Annual Conference: Advances in Geosciences, 27-29 November 2001, University of Waikato, Hamilton: Miscellaneous publication 110A p. 51

496 shards from a road cutting and pit that exposed Taupo, Waimihia, Kawakawa and Rotoehu ash in tephric loess, about 5 km NW of Puketitiri, were subjected to microprobe analysis by APH. A radiocarbon date and tephras indicated that the sampled interval recorded perhaps 45 ky (Hammond, PhD thesis, Massey University). Nine variables were determined.

Conference paper Published: 2001

Replicate means of rhyolitic tephras

A.M. Hammond and W.T. Ward

Geological Society of New Zealand, Annual Conference: Advances in Geosciences, 27-29 November 2001, University of Waikato, Hamilton: Miscellaneous publication 110A p. 52

The literature for New Zealand tephras provides mean electron-probe data for many ash beds. There is some duplication but for many beds slightly different averages are given. The different values are usually from different localities and are meant to enable correlation. Mostly there are two or three sets of values for single ash beds. For some beds, however, there are large numbers of replicates. For those who seek representative values, the data are difficult to evaluate, because the tephrostratigraphers have not indicated which averages, if any, should have precedence.

To clarify the relationships among the replicates, we have sorted them using two methods of cluster analysis. The first, fuzzy k-means (Ward et al., 1992), is a non-hierarchical method that seeks to identify similar groups in data. The second is a hierarchical clustering method (Wilkinson, 1987) that forms groups by joining similar individuals. Its results are normally displayed as a branched tree or dendrogram.

We have applied these methods to 76 tephra means revealed by an incomplete survey of the literature. The different strategies yield similar results. A few individuals appear to be borderline but the means mostly fall into five fuzzy groups. The separations of duplicates within groups could reflect inadequate sampling, or geographic variation. There has possibly been chance convergence of analytical results for stratigraphically distinct units. There could also be faults in our management of the number-crunching model. Of course, some variation might be due to human errors such as misclassification, or mistaken correlation. None of these factors is easily resolved.

Ward, A.W., Ward, W.T., McBratney, A.B., de Gruijter, J.J. (1992). MacFuzzy: A program for data analysis by generalised fuzzy k-means on the Macintosh. CSIRO Australia, Division of Soils, Divisional Report 116.

Wilkinson, L. (1987) SYSTAT: The system for Statistics. SYSTAT, Inc., Evanston, Illinois.

Journal article Published: June 2000

Palaeoecological transition in southwestern New South Wales: Ecosystem changes in pollen assemblages revealed by fuzzy analysis

M. Cupper and W.T. Ward

Quaternary Australasia, 18 (1): pp. 34-40

https://aqua.org.au/wp-content/uploads/2024/02/QA-Vol-18-June-2000-1-2.pdf

Fuzzy analysis, a numerical analytical technique, was used to elucidate vegetation changes expressed in pollen proxy data from Warrananga salt lake, southwestern New South Wales. Significant modifications of the structure and composition of plant communities occurred in this region during the Holocene. These included the development of casuarinaceous woodlands in the mid-Holocene and subsequent woodland-decline with the expansion of chenopod shrublands during the late Holocene. Eucalypts became more prominent and Casuarinaceae recovered prior to the European settlement phase. Significantly, fuzzy analysis also revealed phases of grassy open-woodlands between the woodland-shrubland transitions, suggesting a complex sequence of ecological succession. This study highlights the considerable potential of fuzzy analysis in interpreting fossil assemblages.

Journal article Published: February 2000

Sea-rafted pumice on the Australian east coast: Numerical classification and stratigraphy

W.T. Ward and I.P. Little

Australian Journal of Earth Sciences, 47 (1): pp. 95-109

https://doi.org/10.1046/j.1440-0952.2000.00763.x

Sixteen elements (Ca, K, Mg, Na, Al, Fe, Mn, P, Co, Cu, Li, Ni, Rb, Sr, Ti, Zn, determined by atomic absorption) were identified in 453 pumice fragments recovered from Holocene strandplains in southeast Queensland and New South Wales.

Eight pumice groups and 13 subgroups are recognised by numerical analysis. Some pumices record known eruptions. Others come from known centres in Tonga and Vanuatu. Several pumice eruptions have occurred from some centres, but there are instances of single episodes.

The numerical analyses, combined with carbon dating and soil identification, identify marker horizons in the development of the strandplains. These horizons provide a time-scale for soil development. Pumice that occurs in middens has an archaeological value. Coke was found with recent pumice. It conveniently identifies the modern industrial age.

Book Published: July 1999

Soils and landscapes near Narrabri and Edgeroi, NSW, with data analysis and using fuzzy k-means

W.T. Ward

CSIRO Land and Water Technical Report 22/99, Canberra, ACT (125 pages)

http://hdl.handle.net/102.100.100/213385?index=1

Narrabri lies by the Namoi River, near the Nandewar Range in north-west New South Wales, and Edgeroi rail siding, by the Newell Highway, is 24 km further north. The name Edgeroi is used also for the 1:50 000 topographic map that covers that district. The area is typical of the North-western Slopes and Plains of New South Wales and was studied to provide information on the regional soil pattern. It has a warm, dry subhumid climate with an annual rainfall near 700 mm, on the average, but with extreme variability. In this report the soils of the area are described, the soils at Edgeroi are mapped, and data are given for localities shown on the neighbouring Narrabri, Wee Waa, Bunna Bunna, and Pilliga topographic maps. Forests mostly occupy the hilly land and extend west into grassy plains, which once carried scattered wilga (Geijera parviflora) and myall (Acacia pendula). Woodlands border the rivers, and brigalow (Acacia harpophylla) occurs south of the Namoi. Attention is concentrated on surface geology and on the natural landscape because the soils vary mainly according to parent sediment and landform. To emphasize features of agricultural significance, detailed laboratory data for the surface soil are summarised and included in the soil classification using a new method of data analysis, fuzzy k-means.

Book Published: July 1999

The soils of the Agricultural Research Station at 'Myall Vale', near Narrabri, NSW, with data analysis by fuzzy k-means

W.T. Ward, G. McTainsh, D. McGarry, and K.J. Smith

CSIRO Land and Water Technical Report 21/99, Canberra, ACT (108 pages)

http://hdl.handle.net/102.100.100/213120?index=1

Cotton is the principal subject of study at 'Myall Vale'. The soils are mostly Grey Clays (Vertisols) on clayey loess that overlies a prior alluvial landscape. Grey Clays and Brown Clays occur on alluvium by the Namoi River. pH, electrical conductivity, chloride, nitrate, bicarbonate extractable P, exchangeable cations (Al, Ca, Mg, Na and K), calcium carbonate, organic carbon, silt and clay were determined on samples from standard depths at 19 sites. The cation and some other data are summarised by fuzzy k-means. Four soil groups are defined by cation and clay contents of the surface soils. Texture and soil drainage and especially slight differences in local relief are important. Slightly higher sites on clayey loess have more calcium whilst low sites have more magnesium. The alluvial soils have high values for potassium, sodium and magnesium. The soils of the research station are typical of the soils of the district but they have less clay and are more calcic than the clay-mantled landscape immediately to the north.

Journal article Published: April 1999

Ancient lead weight found with Loisels Pumice near Hook Point, Fraser Island, Queensland

W.T. Ward, I.P. Little, G.M. Roberts, B.L. Gulson, B.M. O'Leary, and D.M. Price

Archaeology in Oceania, 34 (1): pp. 25-30

http://hdl.handle.net/102.100.100/214804?index=1

A lead weight was recovered between 2.2 and 2.4 m depth in stranded beach sands at the southern end of Fraser Island. Its isotope values indicate a close affinity with lead from mines in France. Pumice found with the lead occurs elsewhere at sites dated 480±100 y BP and 520±75 y BP, and one fragment appears to be Loisels Pumice, for which a similar radiocarbon age has been reported from New Zealand. The data are difficult to assess but suggest that the lead weight could have reached this ancient beach between 1410 and 1630 AD.

Journal article Published: February 1992

Surface structure in grey clays of northwestern New South Wales in relation to micromorphology, cation suite and particle-size attributes

I.P. Little, A.J. Ringrose-Voase, and W.T. Ward

Australian Journal of Soil Research 30 (1): pp. 1-16

https://doi.org/10.1071/SR9920001

Considerable differences in surface structure (0-100 mm) were observed in the field in two adjacent areas of grey clays near Narrabri, N.S.W. The absence of any differences in clay mineralogy and granulometry of the sand fraction supported the field assessment that both types of soil were similar in provenance. A transect of soil profiles including seven with poor structure and five with well-structured surface horizons was examined. The field observations of structure were supported by photographs of the surface, and water entry after rain.

Micromorphological examination showed that closely spaced porphyric to adporphyric fabric in the poorly structured soils contributed to poor structure, highlighting the importance of textural attributes. The well-structured soils had a more widely spaced porphyric fabric. A measure of dispersibility depending on clay content and exchangeable plus soluble Na, Ca and Mg tallied very well with the field assessment of soil structure.

Five groups were obtained from a euclidean distance/flexible sort strategy on the basis of cation suite, carbon content and particle size attributes. The groups identified areas of poor structure very well and the groups appear to be discriminated mainly on the basis of differences in Na, Ca and clay content. Treating the transect as a continuum of soils of very poor structure at site 1 grading to very good at site 12 showed that greater values for Ca, K, and clay were associated with good structure and greater values for Mg, C and silt were associated with poor structure. The sodium adsorption ratio and ionic strength of the soil solution were not on their own good predictors of structural behaviour possibly due to the independent contribution of Ca and Mg in this respect.

CSIRO Technical Report Published: 1992

MacFUZZY: A program for data analysis by generalised fuzzy k-means on the MacIntosh

A.W. Ward, W.T. Ward, A.B. McBratney, and J.J. de Gruijter

CSIRO Division of Soils, Divisional Report 116 (50 pages)

https://doi.org/10.25919/5cd478ba6cd88

MacFUZZY identifies similar records in data sets by using numerical pattern analysis. It tests a varied number of potential groups and indicates the number that best suits a particular data set. The program can be applied to any set of analytical data or other set of numerical observations natural or manufactured objects. It is a basic tool for data analysis and has potential applications in many disciplines. An example is given using soil data from Myall Vale, near Narrabri, New South Wales, Australia.

Book Published: 1989

Soil studies in the lower Namoi Valley: Methods and data. The Edgeroi data set

D. McGarry, W.T. Ward, and A.B. McBratney

CSIRO Division of Soils

http://hdl.handle.net/102.100.100/637188?index=1

Journal article Published: December 1988

Reply to discussion: History of coastal dunes at Triangle Cliff, Fraser Island, Queensland

W.T. Ward and K.G. Grimes

Australian Journal of Earth Sciences 35 (4): pp. 583-587

https://doi.org/10.1080/08120098808729474

The differences in viewpoint that Ward and Grimes (1987) try to reconcile relate to carbon dating of Bed T and to the relationships of Bed T to Triangle Cliff dune sand and Wathumba beach sand. Their conclusion is that Triangle Cliff dune sand and Wathumba beach sand are in part contemporary. Coventry proposes another explanation but obscures the issue by devoting most of his text to a discussion of problems he associates with recognizing morphostratigraphic units and sea levels in relation to dune and beach sands. His arguments here are with Ward (see references below), although Grimes is under fire simply because the authorship of table 1 in Ward and Grimes (1987) was not clearly indicated. The more general topic is discussed first.

Conference paper Published: January 1987

Coastal geology of the area between Rainbow Beach and Inskip Point

W.T. Ward

In Field Conference: Gympie District (eds. C.G. Murray and J.G. Waterhouse), Geological Society of Australia, Brisbane: pp. 99-105

https://www.academia.edu/4687603/1987_Gympie_District

The coast of southeast Queensland between Brisbane and Fraser Island is formed mostly of dunes, sandy plains and peaty swamps lying between a few headlands of hard rock. The coastal deposits preserve a record of sea-level and climatic fluctuations that is without parallel elsewhere. The great thickness of the deposits, the changes in shoreline position, the evident changes of sea level, the extent of weathering, and the advanced stage of geomorphic degradation of the older sands all imply that sand accumulation commenced a very long time ago. The classification of the sands given in Table 1 is based on study of coastal exposures, physiographic expression, correlation of unconformities in strand plains and dune sequences, facies interpretation, and observed similarities of weathering.

The nine dune sand units recognised by the writer and listed in Table 1 are not necessarily equivalent to the eight dune systems of Thompson and Moore (1984) and Thompson (this volume).

Journal article Published: 1987

History of coastal dunes at Triangle Cliff, Fraser Island, Queensland

W.T. Ward and K.G. Grimes

Australian Journal of Earth Sciences 34 (3): pp. 325-333

https://doi.org/10.1080/08120098708729414

Triangle Cliff, at the western shore of Fraser Island, has been formed by marine erosion, mostly of parabolic dunes that were blown to their present position by southeast trade winds and fixed in place by vegetation. The section exposed at the shoreline shows that the blown sands (Triangle Cliff dune sand) lie on stranded foredunes (included with the Wathumba beach sand) developed when the present sea level was first attained. At the eastern shore of Fraser Island, the Triangle Cliff dune sand was formed before the Wathumba beach sand. It is inferred that the dune sands had begun to move before the sea attained its present level, but did not reach the present position of Triangle Cliff until the middle Holocene. By this time conditions that initiated sand movement had possibly ceased to prevail.

Radiocarbon dates from material exposed in Triangle Cliff appear to be in reversed order of age but are capable of simple explanation. The dated sediments are time-transgressive; however, the youngest carbon date is from material that may have intruded older deposits.

The new data allow a better placement of the Pleistocene-Holocene boundary in relation to the coastal sands. We recognize a maximum postglacial sea level of perhaps slightly more than + 1 m and a possible minor fall in sea level at about 3400-4000 years BP.

CSIRO Technical Memoir Published: 1986

Soil landscapes of the Edgeroi district: Geomorphic development of the sandstone ridges

W.T. Ward

CSIRO Division of Soils, Technical Memoir – –/86

CSIRO ONLY (No public access)

CSIRO Technical Memoir Published: 1986

Descriptions of ten soil cores from near Roma bore, Edgeroi, NSW

W.T. Ward and R.A. Dickson

CSIRO Division of Soils, Technical Memoir – –/86

CSIRO ONLY (No public access)

CSIRO Technical Memoir Published: 1986

Site procedure and data dictionary for describing locations and morphology of 10 cm soil cores from the Edgeroi sheet

W.T. Ward, M.A. Korevaar, A.B. McBratney, A.W. Moore, G.M. Roberts, and E. Veldhuis

CSIRO Division of Soils, Technical Memoir 14/86

CSIRO ONLY (No public access)

Journal article Published: September 1985

Correlation of east Australian Pleistocene shorelines with deep-sea core stages: A basis for a coastal chronology

W.T. Ward

Geological Society of America, Bulletin 96 (9): pp. 1156-1166

https://doi.org/10.1130/0016-7606(1985)96<1156:COEAPS>2.0.CO;2

A review of recent attempts to relate emerged shorelines to deep-sea core stages indicates that correlations based on radiometric ages must be treated carefully, for stratigraphic control is often lacking. Radiometric ages help field interpretation, but some authors question the geology before questioning the dates.

The view that oxygen-isotope values in deep-sea sediment cores reflect changes in ocean volume is used to interpret sequences of stranded shorelines in Gippsland (Victoria), southeast Queensland, New Zealand, South Carolina (United States), and Morocco. As a basis for study, it is accepted that all of the shorelines in the areas compared result from global changes of sea level superimposed on continuously emerging land masses that have been rising uniformly, but at different rates, in the different localities.

Five stands of the sea, ending at the last interglacial maximum, are recognized and correlated with dated deep-sea core stages as follows: G11 (Gippsland) = Woorim (Queensland) = Awatuna 1 (New Zealand) = Silver Bluff (South Carolina) = Ouljian (Morocco) = core substage 5e, 125,000 yr; G26 = Bribie (Qld) = Karoro (NZ) = Princess Anne = Harounian = core stage 7,220,000 yr; G37 = Poyungan (Qld) = Albion 113 (NZ) = Pamlico = Anfatian (G2) = stage 9,330,000 yr; G65 = Ungowa (Qld) = Albion 165 (NZ) = Bethera = stage 11, 430,000 yr; G70 = Albion 183 (NZ) = Talbot = Anfatian (Thomas quarry) = stage 13,480,000 yr. Implied rates of uplift are used to date and correlate six earlier shorelines: G125 = Penholoway = late Maarifian = 1.02 m.y.; G160 = Wicomico = Maarifian = 1.18 m.y.; G260 = Okefenokee = Haj Salah = 1.43 m.y.; G360 = Sunderland = Sidi Messaoud = 1.64 m.y.; G420 = Coharie = Bouchaib bel Kamel = 1.80 m.y.; A600 = Orange-burg = Fouaratian = 2.35 m.y.

CSIRO Technical Memoir Published: 1985

Diagnostic-table method for field texture identification

W.T. Ward, M.A. Korevaar, and E. Veldhuis

CSIRO Division of Soils, Technical Memoir – –/86

CSIRO ONLY (No public access)

Conference paper Published: May 1984

The farmer and the dust bowl

W.T. Ward

In Proceedings of the National Soil Conference, Brisbane, Queensland, 13-18 May 1984, Australian Society of Soil Science, pp. 227-232

The literature relating to wind erosion of agricultural and pastoral lands does not clearly distinguish the separate effects of land management and natural climatic variation. The erosion is regarded either as an everyday hazard that must be endured, or as the inevitable consequence of unwise cultivation and overgrazing. The great drought of the 1930s, for instance, with its associated wind erosion was a natural hazard that could happen at any time and might best be described in terms of probabilities, like floods. Others take the view that the erosion was due to heavy overgrazing by sheep and disturbance of the soil by agriculture, which was overly-extended at that time of economic depression.

The editors of "Nature" (138: 1039, 139: 580) favoured the belief that desiccation followed man's actions. Ploughing had destroyed humus and had allowed the soil to dry out. Wasteful development had lowered water tables, and the weakened topsoil became prey to the ordinary variation of the wind. CSIR studies (Pamphlets 64 and 70, see also F.N. Ratcliffe, "Flying Fox and Drifting Sand") that had attributed the social and economic disaster to the unprecedented drought and to overstocking and rabbit infestation were belittled. No space was found for Ratcliffe's letter protesting the unfair criticism. But by this time the drought had broken. The world, too, was distracted from natural events by the imminent war. The controversy ended.

In a larger time frame, one has the clear association of prehistoric human occupation with blowing sand on Fraser Island. Had occupation weakened the vegetative cover and permitted wind erosion? The blowouts are merely the last of a long series, however, which probably began before the advent of man in Australia.

A different view of the cause of the drought is given by a consideration of the morphology of South Point on Bribie Island, near Brisbane. South Point had a stable shoreline until 1928. The shore was then rapidly built forward and when the RAAF first photographed it in 1942 it had acquired its present form; its stability had returned.

South Point is sensitive to southeasterly winds and is built forward when these winds increase. Meteorological data for Brisbane confirm the geomorphic record. The changes in wind strength and frequency give evidence of an extraordinary change in the zonal winds in the 1930s and suggest a possible long-term periodicity. The recorded rainfalls provide further support: in the years of severe drought in the south, that is, in persistent anticyclonic weather, the Queensland coast received unusually good rains from the frequent onshore winds. The observed changes in the wind and rain explain wind erosion in Australia in the 1930s. However, clearing and grazing in the arid zone had weakened the vegetation that protected the soil so that the erosion occurred first and was worst on farmed land. It appeared that farming had caused the erosion. For that reason, the farmer received the blame, and the natural change that was primarily responsible went unrecognized.

Book Published: 1984

The Capricornia section of the Great Barrier Reef: Past, Present and Future

eds. W.T. Ward and P. Saenger

Proceedings of a symposium sponsored by of the Royal Society of Queensland and Australian Coral Reef Society, Kindler Theatre, Queensland Institute of Technology, 1984 (181 pages)

Search: National Library of Australia

Article Published: 1984

Coastal evolution during the last million, the last 10,000, and the last 200 years in southeast Queensland

W.T. Ward

In 'Geological and Environmental aspects of coastal management programs' (ed. A.V. Arakel), Department of Applied Geology, Queensland Institute of Technology, Brisbane. pp. 172-176

Book chapter Published: July 1983

Sequence of soil formation on coastal lands and the effects of sea-level changes

W.T. Ward and W.M. McArthur

In Soils: An Australian Viewpoint (CSIRO Division of Soils/Academic Press) pp. 101-105

http://hdl.handle.net/102.100.100/285287?index=1

'Sequence of soil formation on coastal lands and the effects of sea-level changes' is the title of Chapter 8 of 'Soils: An Australian Viewpoint' (CSIRO Division of Soils/Academic Press), 1983.

'Soils: An Australian Viewpoint,' draws upon 50 years of soil research, and the experience of 67 authors — many pioneers in their field with international reputations as leaders in soil science — to make this the definitive work on the processes that have shaped Australian soils, the relationships to the rest of the world, and aspects of land use in Australia. This book presents a vigorous scientific effort to understand the soils of a country that extends from near-equatorial to subantarctic latitudes and includes deserts, semi-arid savannas, sclerophyll forests, tropical and temperate rainforests, farmlands and urban areas. (928 pages)

Conference paper Published: May 1982

Formation and development of the shoreline near Tangalooma Point, Moreton Island

W.T. Ward

In Proceedings of the Royal Society of Queensland, 1982, 93: pp. 11-20

Although it consists of loose sands freely exposed to wave action on Moreton Bay, the coast near Tangalooma Point has been more-or-less stable since it was formed a few thousand years ago. However, it is subject to natural erosion now, and its forested cliffs could soon become bare sand. Some erosion is associated with wrecks lying at the shore but most appears to be an effect of changes in wave action induced by changes in wind direction and frequency since the 1930s.

Newsletter article Published: 1982

Sedimentation and soil development at Brisbane Airport

W.T. Ward and J.L.F. Hacker

Sedimentology Newsletter 11: p. 54 (Australian Sedimentologists Group, Geological Society of Australia)

This paper by W.T. Ward and J.L.F. Hacker details the geological history and soil development of the Brisbane Airport site. It is primarily known for highlighting how the construction of the Kedron Brook diversion channel exposed former coastal landforms (e.g., beaches and spits), helping to document postglacial sea-level changes in the region.

Journal article Published: May 1981

Chemical and mineralogical trends in a chronosequence developed on alluvium in east Gippsland, Victoria

W.T. Ward and I.P. Little

Geoderma 25 (3-4): pp. 173-188

https://doi.org/10.1016/0016-7061(81)90034-3

Soil profiles developed on a set of six alluvial terraces formed at intervals from Middle Pleistocene to modern times, on sediments drawn from the same source, were examined to discover what chemical and mineralogical changes had occurred with the passing of time. The youngest soil was textually uniform, with light textures throughout. The next youngest had light textures at the surface and somewhat heavier textures at depth.

The four oldest profiles had sandy A horizons with well-developed clayey B horizons. The initial phase of soil development seems to have involved some enrichment with clay from sediments now removed and appears to have been complete after about the first 20,000 years. Soils older than this showed a marked texture break between A and B horizons but there was also a level in the subsoils below which systematic associations of the elements K, Mg, Zn, Co, Ni, Rb and Li with clay ceased. The depth of this level differed with age in an approximately linear fashion, reaching 165 cm with the oldest soil. Thus, it appears to mark the depth to which significant weathering has extended after the early developmental stage.

Changes related to age had also occurred in the upper zones of the oldest profiles. As this zone became deeper it also weathered so that the regression coefficients for the relationships between the elements noted above and clay contents change progressively with age, indicating that these elements are less abundant in the older soils. Cu, Ca and P also follow this trend although they are not related to the amount of clay.

Book Published: 1981

Public information: Your right to know

eds. W.T. Ward and M.M. Bryden

Proceedings of a symposium sponsored by the Royal Society of Queensland, Brisbane, 1981 (62 pages)

Search: National Library of Australia

Journal article Published: September 1980

Winds in southern Queensland and rain in Australia and their possible long-term relationship with sunspot number

W.T. Ward and J.S. Russell

Climatic Change 3: pp. 89-104

http://hdl.handle.net/102.100.100/294075?index=1

Wind records at Brisbane indicate past changes in ambient weather systems that appear to be confirmed by observed changes in Australian rainfalls. Both wind and rainfall data support geological field evidence of a climatic change in southeast Queensland in the 1930s.

At Brisbane the numbers of calms observed in January and July declined from 1887 to 1935, and then increased again. This variation was associated with changes in wind patterns, particularly in winter (July) from 1933 to 1937 and afterwards, but also in summer (January) during the 1930s.

The changes in circulation were enough to explain the movement of beach and dune sands at that time. The changes in windiness show a close connection with the 80-year trend in sunspot number: the initial period of below average sunspot number coincided with increasing wind strength and more southeasterly winds. Rainfall trends show similar associations with sunspot trends, but the direction of rainfall change is different in different regions. In southeast Australia, changes in rainfall are positively correlated with trends in sunspot number over the last 80 years, while the opposite holds for the far southwest and Cape York Peninsula. On the north coast, negative correlations occur in summer, and positive correlations in winter, but in Queensland and western New South Wales the correlations are positive in summer and negative in winter. It is too soon to tell whether the connection between sunspots and weather is accidental or functional.

CSIRO Technical Memoir Published: 1980

Shoreline erosion on the west coast of Moreton Island

W.T. Ward

CSIRO Division of Soils, Technical Memoir

CSIRO ONLY (No public access)

CSIRO Technical Report Published: 1980

Use of chemical data for classification of pumices from sandy beach deposits in southeastern Queensland

I.P. Little and W.T. Ward

CSIRO Division of Soils, Divisional Report No. 48 (14 pages)

https://doi.org/10.25919/5c7eb92a339d3

Pumice samples collected from a series of Holocene beach ridges on Fraser Island and a chenier plain at Broad Sound, Queensland, were analysed chemically for a suite of 16 elements. There were 244 pumice samples and the data obtained were subjected to statistical analysis in the hope that the pumices would fall into groups related to their composition.

Eight groups could be discriminated. However they could not be related in a simple way to the dated Broad Sound chenier sequence and there was a large “residual” group of individuals which did not fit into any of the 8 major classes.

Journal article Published: March 1979

Stratigraphy of two sandrocks at Rainbow Beach, Queensland, Australia, and a note of humate composition

W.T. Ward, I.P. Little, and C.H. Thompson

Palaeogeography, Palaeoclimatology, Palaeoecology 26: pp. 305-316

https://doi.org/10.1016/0031-0182(79)90153-6

Two intervals of coastal sandrock development are proved by the occurrence of sandrock boulders in a fossil beach that is itself preserved in sandrock. The fossil beach also contains driftwood, and carbon dates obtained by previous workers indicate that its age is greater than 40,000 years. The ancient beach rises 3 m above the present ocean beach and is the highest Pleistocene shoreline recognized on Queensland's southern coast. It is therefore likely to represent the warmest interval of the last two million years. Several lines of evidence indicate that the fossil beach is hundreds of thousands of years old. This is in agreement with tentative correlations with other Pleistocene events described in a previous paper where an age of 400,000 years was attributed to it.

Large amounts of aluminium can be extracted with alkaline ammonium citrate from the two sandrocks, which are composed of quartz sands cemented with organic matter. Gibbsite is present in the older sandrock and in the boulders of older sandrock in the fossil beach. There is much less C relative to Al than in the younger sandrock. This is possibly due to decomposition of Al-humate by loss of organic matter, leaving Al in situ. If the rate of decomposition could be calibrated, by for example radiocarbon dating of the younger sandrock, it might be possible to use the C/Al ratios to date the older sandrock.

Conference paper Published: 1979

Geological development of northern Moreton Bay

H. Hekel, W.T. Ward, M. Jones, and D.E. Searle

In 'Northern Moreton Bay Symposium' (eds. A. Bailey, N.C. Stevens), Proceedings of a Symposium held at the Abel Smith Lecture Theatre, University of Queensland, 23-24 September 1978, Royal Society of Queensland, pp. 7-18

Article Published: October 1978

Notes on the origin of Stradbroke Island

W.T. Ward

University of Queensland, Department of Geology, Papers 8 (2): pp. 97-104

The fixed dunes which form Stradbroke Island rest on a prior land surface and are surrounded on most sides by a post-glacial strand plain. The island did not grow from an offshore bar or spit, and is not therefore a barrier island, as has been supposed. It was formed by drowning, and appeared when interglacial seas flooded over lands that included high areas of blown sand.

Article Published: March 1977

Sand movement on Fraser Island: A response to changing climates

W.T. Ward

University of Queensland, Occasional Papers in Anthropology 8: pp. 113-126

https://espace.library.uq.edu.au/view/UQ:1dac35b

Fraser Island is built of sand blown into dunes by the southeast trade winds. The main periods of blowing are associated with times of glaciallylowered seas, but there have been three relatively small episodes of wind erosion in recent times, during the present interglacial. The first and second had occurred before Cook surveyed the coast, for he described the dunes which the second episode produced. The third probably occurred since European settlement but it is not well dated. Similar histories of postglacial deposition occur in Victoria and New Zealand.

The long history of glacial low seas and southeasterly winds alternating with interglacial high seas and relative calm, and the repetition, albeit on a smaller scale, of the inferred glacial-age wind pattern in postglacial time makes this record especially important to the development of climatic models.

In glacial ages the southeast trades were stronger because the temperature gradients between the equator and poles were larger. In the present interglacial changes in the vigour of the atmospheric circulation caused the surface winds to waver above and below sand-moving speeds. The present time is one of relatively calm weather and stability.

Book Published: 1977

Geomorphology and soils of the Stratford-Bairnsdale area, East Gippsland, Victoria

W.T. Ward

CSIRO Division of Soils, Soils and Land Use Series No. 57 (67 pages + 1 map)

https://doi.org/10.25919/5e3076d447b37

The soils of the Stratford-Bairnsdale area are varied, although there are few differences in parent material and relief. A knowledge of the past history of the soils is needed to understand soil development, and the results of field investigations with this purpose are described here. Soil genesis is shown to be closely related to landscape history. Many of the present-day soils are developed on prior soils that are now partly eroded or buried.

The prior soils were made relict by a climatic change estimated at 3-400 000 yrs ago. Soils formed since then show a progressive sequence of weathering stages, according to age of soil formation. Weathering has resulted in the development of texturally differentiated (duplex) profiles, with clay subsoils beneath porous sandy topsoils. This change in the soil interferes with drainage and occurs at various depths. This has occurred in all soils except those formed on modern flood-plains and young aeolian sands.

On the lowlands near the coast formed in the last 4000 years soil development is slight and is complicated by recent changes of ground-water level. The 20 soil associations shown on the accompanying map are closely related to a series of 14 marine terraces and a less complete sequence of matching alluvial terraces bordering the major rivers. Sedimentation during periods of high sea level produced the greater part of the marine and alluvial plains of the area and at these times conditions would have been like those prevailing now. By contrast, the fertile East Sale plain was formed in cold and arid glacial times.

Conference paper Published: 1977

Brisbane's north coast and Fraser Island from the air

W.T. Ward

In Field Conference: Lady Elliot Island, Fraser Island, Gayndah, Biggenden (Handbook), 11-13 June 1977 (ed. R.W. Day), pp. 14-30. Geological Society of Australia, Queensland Division (96 pages + map)

Conference paper Published: 1977

Quaternary geology and geomorphology of Fraser Island

W.T. Ward

In Field Conference: Lady Elliot Island, Fraser Island, Gayndah, Biggenden (Handbook), 11-13 June 1977 (ed. R.W. Day), pp. 61-64. Geological Society of Australia, Queensland Division (96 pages + map)

Conference paper Published: 1977

Field excursion from Orchid Beach to Triangle Cliff and Lake Bowarrady

W.T. Ward

In Field Conference: Lady Elliot Island, Fraser Island, Gayndah, Biggenden (Handbook), 11-13 June 1977 (ed. R.W. Day), pp. 65-71. Geological Society of Australia, Queensland Division (96 pages + map)

Journal article Published: October 1975

Geology of coral terraces, Huon Peninsula, New Guinea: A study of Quaternary tectonic movements and sea-level changes: Discussion and reply

W.T. Ward

Geological Society of America, Bulletin 86 (10): pp. 1482-1486

https://doi.org/10.1130/0016-7606(1975)86<1482:GOCTHP>2.0.CO;2

The stranded coral reefs of the Huon Peninsula occur on a coast subject to rapid uplift and must therefore record times when sea level was rising faster than was the land. Full interglacial conditions or episodes of marked global warming can be inferred. More than 40 uranium-thorium ages for 11 terraces were provided by Chappell (1974a) and Bloom and others (1974). These compare well with identifications of times of high sea level elsewhere for example, in Barbados (Broecker and others, 1968). Three of the Huon coral terraces (III, IV, and VI) provide ages like those estimated by Ward and others (1971) for the Silver Buff, Princess Anne, and Pamlico shorelines of South Carolina and for their proposed Australian correlatives, G11, G26, and G37. The agreement is particularly good and supports the earlier estimates of times for high sea levels in Australia and South Carolina, especially when allowance is made for dating error and the effect of different rates of uplift on the timing of transgressive maxima.

The high rates of uplift have carried fringing reefs developed near present sea level well above the zone subject to wave attack and have brought into view shorelines usually concealed elsewhere by the postglacial transgression. Chappell (1974a) attempted to distinguish the separate effects of tectonic movement and sea-level change. He used ratios of shoreline elevations as a guide to the history of uplift, and he made certain assumptions about some positions of past sea level; more or less steady uplift in the interval covered by reliable dates was accepted. Chappell found that his curve of sea-level changes strongly resembles the generalized curve for Caribbean ocean-surface paleotemperatures (Emiliani, 1966). Considerable support was thus enlisted for his eustatic trace. Too much should not be made of this, however, for the paleotemperature time scale has been revised recently (Emiliani and Shackleton, 1974).

Conference paper Published: March 1975

Soil landscapes of North Stradbroke Island

C.H. Thompson and W.T. Ward

In Proceedings of the Royal Society of Queensland 86: pp. 9-14

Eleven soil landscapes are presently recognized on North Stradbroke Island and are briefly described. Podzols and humus podzols are the dominant soils developed in the silica sands which form most of the island. Profile development of the podzols increases with increasing age of the parent sands, ranging from shallow profiles less than 60 cm thick on young sands to giant podzols on the old sands where soil profile development may exceed 15 m.

Exhibit Published: 1975

Nutrient-element levels in some coastal sands and the possible effects of sandmining on their distribution

W.T. Ward

Fraser Island Environmental Enquiry, Transcript of Proceedings, unnumbered exhibit

Exhibit Published: 1975

Geology and geomorphology of Fraser Island

W.T. Ward

Fraser Island Environmental Enquiry, Transcript of Proceedings, Exhibit 226. (The map from this report is printed in the Final Report, Commission of Inquiry, 1976, p. 20)

This submission summarises observations made on Fraser Island during current research on landscape dynamics in the coastal fringe of south-east Queensland. The geological research is being done as a basis for other earth-science studies.

Article Published: 1975

Times of coastal sand accumulation in south-east Queensland

W.T. Ward and I.P. Little

In 'Managing Terrestrial Ecosystems' (eds. J. Kikkawa and H.A. Nix), Proceedings of the Ecological Society of Australia (1975) 9: pp. 313-317

http://hdl.handle.net/102.100.100/307709?index=1

SUMMARY

This article by W.T. Ward and I.P. Little established a chronology for the massive coastal sand accumulations in south-east Queensland. The authors link the age of coastal dunes and beach sands to fluctuating Quaternary sea levels and past interglacial periods. By analyzing strandplains and dune sequences (such as the Woorim, Bribie, Poyungan, and Ungowa sands), they successfully correlate them with past ocean levels and corresponding deep-sea marine isotope stages. The paper provides crucial chronological data that supported broader studies on soil landscapes and podzol development sequences across giant coastal dunes.

Journal article Published: July 1974

Correlation of Pleistocene shorelines in Gippsland, Australia, and Oahu, Hawaii: Discussion (H.T. Stearns) and Reply (W.T. Ward)

W.T. Ward

Geological Society of America, Bulletin 85 (7): pp. 1189-1190

https://doi.org/10.1130/0016-7606(1974)85<1189:COPSIG>2.0.CO;2

Journal article Published: January 1974

Rattling iron concretions from the Waikato coal measures

C.W. Childs, W.T. Ward, and N. Wells

New Zealand Journal of Geology and Geophysics 17 (1): pp. 93-101

https://doi.org/10.1080/00288306.1974.10428478

Two iron-rich concretions from the Waikato Coal Measures are described. Each has a hard iron oxide shell with a weathered outer surface. In one case there is a solid siderite-rich interior; in the other the shell encloses a void which contains a clay rattle. Concentrations of Fe, Al, Ca, K, Si, P, S, Mn, Ti, Mo, Mg, and Cu, in various parts of the concretions have been measured and the dominant minerals in these parts have been determined. The concretions are considered to represent different stages in a process which begins when iron mobilised by decomposing organic matter is precipitated under reducing conditions as siderite in sediments. Subsequent oxidising conditions produce a series of “boxes” each with a dense ferric oxide shell. The shell thickens as the enclosed ferrous ions are oxidised and eventually a void is created within the concretion. The kaolin rattle represents the weathered remnant of the host sediment.

Conference paper Published: 1974

Computer storage of soil data: Use of a generalized file management system

A.W. Moore, W.T. Ward, and C.H. Thompson

Transactions of the 10th International Congress of Soil Science, Moscow, 12-20 August 1974: pp. 684 -691

http://hdl.handle.net/102.100.100/309902?index=1

The growing need for rapid data handling in the commercial world has led to the development of generalized file management systems for business use. These systems have broad application and are likely to be useful for the processing of scientific data, in particular that associated with resource surveys.

Several soil data storage and retrieval systems have been developed for scientific use, e.g. the Belgian (Leenheer et al., 1968) and British Columbia (John et al., 1969) Soil Survey files, and the soil micromorphology file used in CSIRO (Norris et al., 1971). The latter is also used as an index to the CSIRO Division of Soils collection of soil thin-sections. These three file management systems are all specific, each being written to do one particular job. As an alternative approach, we have experimented with a generalized file management system designed for commercial use. This takes advantage of the fact that the cost of developing the system is amortized over a large number of users. Eight files have been established, all dealing with soil and vegetation data.

Generalized file management systems have been developed following the recognition that there are many procedures common to the processing of data, regardless of its nature. The large number of generalized file management systems available commercially (Codasyl Systems Committee, 1969) vary considerably in sophistication, reliability, price and dependence on particular computer hardware.

Journal article Published: September 1973

Correlation of Pleistocene shorelines in Gippsland, Australia, and Oahu, Hawaii

W.T. Ward

Geological Society of America, Bulletin 84 (9): pp. 3087-3092

https://doi.org/10.1130/0016-7606(1973)84<3087:COPSIG>2.0.CO;2

Differences in elevation of stranded shorelines in Gippsland and Oahu are explained by regular uplift of one area relative to the other. Both areas are rising with reference to Mangaia, Cook Islands, which is presumed to be stable. The mean long-term rate of rise for Oahu in the Pleistocene, after Pliocene subsidence and late Pliocene to Pleistocene marine transgression through at least 185 m, is estimated to be 1.6 cm per 1,000 yrs.

Ages derived from an earlier comparison of Gippsland shorelines with others on the Atlantic Coastal Plain in South Carolina are in agreement with K-Ar analyses of basalt associated with the Hawaiian shorelines.

Journal article Published: May 1973

American emerged shorelines compared with levels of Australian marine terraces: Discussion

W.T. Ward, P.J. Ross, and D.J. Colquhoun

Geological Society of America, Bulletin 84 (5): pp. 1835-1838

https://doi.org/10.1130/0016-7606(1973)84<1835:AESCWL>2.0.CO;2

Few coastal plains preserve as many ancient shores as the Atlantic seaboard of the United States. For South Carolina, eleven separate stands of ocean level are recognized (Colquhoun, 1965). Most are part of a sequence that has been known for several years mainly from the work of C. W. Cooke* whose reports drew together prior observations and supported them, over a space of nearly fifty years, with a vast body of new detail.

Cooke's predecessors attributed the stranded shorelines of the Atlantic Coast to the occurrence of earth movements. It appeared to them that the sea had held its level while the land was periodically uplifted, on occasion after subsidence. Cooke's mapping showed that the old shores were sensibly horizontal over their entire length from Maryland to Florida and west into Louisiana (Cooke, 1966). This convinced him that earth movements were to be denied, and he advanced and held firmly to the new view that the shorelines recorded changes of sea level against a stable land. Because younger shores lie at elevations below those formed in earlier times, it seemed that a progressive lowering of ocean level had been imposed on the changes in shoreline position that resulted from changes in size of the continental ice caps. It followed from his thesis (Cooke, 1930) that global correlation of Pleistocene events in lands free of contemporary earth movements was made possible by comparison of stranded shoreline heights.

It is now known that there are few coasts where former shorelines are developed at the same altitudes as on the Atlantic littoral. A similar sequence of levels is reported from Hawaii (Stearns, 1935), and the lowermost American levels were matched with southwest African shores by Hoyt (1967).

Cooke was of the opinion that shoreline levels observed in Gippsland, Australia (Ward and others, 1971), could also be correlated on a direct height-for-height basis with those of the Atlantic plains. We disagree on this point. Our view is that the ancient shorelines of the Atlantic Coastal Plain result from glacio-eustatic changes of sea level against a steadily rising land, and we regret that our present comments on Cooke's (1971) published argument did not reach him before his death.

* Wythe Cooke died on 25 December 1971.

CSIRO Technical Memoir Published: 1973

Soils inspection of Narayen airstrip, 16 August 1973

W.T. Ward

CSIRO Division of Soils, Technical Memoir 56/73

Conference paper Published: 1973

Effect of uplift on altitude of Pleistocene shorelines

W.T. Ward

International Union for Quaternary Research (INQUA), 9th Congress, Christchurch, New Zealand, 2-10 December 1973, extended abstracts, pp. 393-394

Although levels are uniform over wide areas, the stranded shorelines of the so-called stable coasts must result from earth movements combined with real changes in sea level, because different shoreline elevations are found in different places. The implied earth movements may be intermittent, or continuing. The second of these possibilities resembles the explanation long accepted for areas of glacial rebound, where studies of raised beaches reveal the history of uplift.

In areas such as Scandinavia plots of shoreline height against distance from centre of uplift commonly display a proportionality between the stranded shoreline levels, or at least between several levels of a sequence. Localities equally distant from a centre have similar rates of earth movement, and their stranded shorelines occur at similar elevations. Unknown shores can be identified by their height above a recognized reference level. Shoreline plots like these cannot be used where observations are dispersed around the world, because the relation between distance and rate of uplift does not hold. Similar diagrams can be produced where shoreline ages in a single locality can be estimated, however, and where the effects of different rates of movement can be calculated using appropriate models. The figure shows the heights that shores in Gippsland, Australia, would have for various rates of movement. It is assumed that uplift has continued regularly throughout the period of shoreline development. Predicted height equals observed height in Gippsland plus rate of uplift times shoreline age. Shoreline ages proposed by Ward, Ross and Colquhoun (Palaeogeography, Palaeoclimatology, Palaeoecology, 9: 77, 1971) are used for calculation. Different ages or different heights would change the predicted levels, but the shoreline pattern shown in the figure must resemble the true situation, if the basic premises are correct.

The earliest formed shoreline is the highest only where rates of uplift are high the time of maximum transgression varies according to rate of movement. As rates of uplift increase, new shores are raised into view. Thus the true amplitude of a sea level rise is not well shown by observed shoreline altitude. The figure suggests that river terraces graded below present ocean level might not be of glacial age, especially where signs of high shorelines are few or absent.

The plotted data points test the hypothesis that regular movements are responsible for the varied heights of observed Pleistocene shores. Radiometric ages allow calculation of rates of movement for localities A - E. Rates for F and G follow from prior correlations with B. The positions of HK are decided arbitrarily, by pairing the lowest shore in each locality with the lowest Gippsland level. Except for J (Majorca) and K (southern France), observed shoreline levels confirm predicted heights. They therefore support the ages proposed for the Gippsland shores, as do localities with higher rates of uplift not shown here (Malibu coast, U.S.A.; Pentecost, New Hebrides). The lowest shores in Majorca and southern France are consistent with regular uplift, but predicted and observed positions of higher shores do not agree. These field observations are not adequately explained by the hypothesis, and a varying rate of uplift is probable (Ward, Bull. A.S.E.Q., no 33-34: 33, 1972).

Very high shorelines in Gippsland suggest upheaval, and subsidence of Mururoa is accepted. Stable coasts must lie somewhere between these extremes but the figure implies that shoreline evidence is insufficient to decide the question. Ward, Ross and Colquhoun (op. cit.) have suggested that Mangaia might present a true eustatic record because constant shoreline levels there, and on nearby islands, prove that the moat-and-arch structure beneath the Cook Group was rigid during the Quaternary. Nevertheless, a general uplift without deformation might be shown by the occurrence of G11 above present sea level. This shore coincides with an interstadial and its true level is therefore likely to be below the modern one, Past ocean temperatures like the present relate to earlier shores. If similar sea levels are implied, the point of zero uplift could lie near -0.10 m per thousand years relative to Gippsland.

Journal article Published: December 1972

Pleistocene ash in the Waikato basin: Ages implied by changes in sea level

W.T. Ward

New Zealand Journal of Geology and Geophysics 15 (4): pp. 678-685

https://doi.org/10.1080/00288306.1972.10423993

Ages implied for the stranded shores of northern New Zealand by their present correlation with supposed Australian equivalents indicate that the Waiterimu and Hamilton ash beds are between c. 400,000 and c. 750,000 years old. This estimate is consistent with K-Ar ages obtained for Franklin Basalts, which appear from stratigraphie exposures to be much the same age as the Waiterimu ash. A possible correlation with ash beds B (= Waiterimu) and C (= Hamilton) in deep-sea cores east of New Zealand is suggested.

Journal article Published: June 1972

Numerical analysis of soils: A comparison of three soil profile models with field classification

A.W. Moore, J.S. Russell, and W.T. Ward

Journal of Soil Science 23 (2): pp. 193-209

http://hdl.handle.net/102.100.100/313678?index=1

Fourteen field and laboratory attributes of 49 south-east Queensland soils were examined by numerical analysis. Three different models were used for description: the soils were viewed (1) as arrays of layer-attributes, (2) as sets of depth functions (orthogonal polynomials) each of which describes an attribute, and (3) as sequences of layers of soil material. Dendrograms derived from Euclidean distance similarity matrices were constructed for the 49 profiles. Very similar dendrograms were obtained using (a) layer-by-layer comparisons (with layers weighted by an exponential depth function) and (6) orthogonal polynomials, with equal weight given to profile mean (size parameter) and five coefficients (shape parameters). The dendrogram derived from sequential analysis differed markedly from the others and seemed less meaningful; the divisive approach that had to be adopted to delineate groups of profile-layers may have resulted in a sub-optimal classification.

An independent field study which related the soils to geomorphic units and to differences in parent material provided a further, separate classification. The groups derived by numerical analysis, using models 1 and 2, agreed well with the field classes even though the strategies used were different and independent. It is concluded that existing techniques of numerical analysis can provide immediate useful support in field surveys.

Journal article Published: June 1972

Correlation of shorelines affected by earth movements

W.T. Ward

Association Sénégalaise pour l'Étude du Quaternaire de l'Ouest Africain (ASEQUA), Bulletin de Liaison, Senegal 33-34: pp. 33-54

The elevations of stranded shores in Gippsland, Australia, are compared with others reported from Sudan and Arabia; from the Pacific coast of Shikoku, Japan; from Majorca; and from southern France. Comparisons are also made with periods of coral growth produced by variations in level of the sea at Mururoa, Tuamotu Archipelago.

The results suggest that the stranded shores in all localities record eustatic changes in level of the sea. The observed differences in altitude are reasonably explained by epeirogenetic uplift (or subsidence, in the case of Mururoa). For the periods represented by the stranded shores of the Sudan, Arabia, and Mururoa, earth movements seem to have proceeded continuously and regularly. For Shikoku, the observations are consistent with rates of uplift increasing to the present day. In Majorca and southern France there may have been significant variations in rates of movement.

Radiometric ages from Mururoa appear to be consistent with ages speculatively attributed to the stages of high sea level.

SUMMARY

This paper explores the methodologies and models used to trace and correlate ancient shorelines and coastal terraces, particularly in areas complicated by tectonic shifts, regional uplift, and glacial-interglacial sea-level changes.

Ward's research models how both sea-level fluctuations (eustasy) and ground deformation (earth movements/uplift) contribute to the varying elevations of stranded beaches.

Using available geochronology (like radiocarbon or uranium-series dating), his methods allow geologists to pair specific shorelines from different regions and estimate their ages, despite vertical earth movements, helping to map past climates and coastal tectonic histories.

Journal article Published: March 1971

Interglacial high sea levels: An absolute chronology derived from shoreline elevations

W.T. Ward, P.J. Ross, and D.J. Colquhoun

Palaeogeography, Palaeoclimatology, Palaeoecology, 9 (2): pp. 77-99

https://doi.org/10.1016/0031-0182(71)90034-4

The heights of some stranded shores in Gippsland, Australia, greatly exceed the level to which the ocean would rise if all present-day ice were to melt, and uplift is thus implied. Differences in level shown by comparison of these interglacial shorelines with others in South Carolina may therefore be the result of movement of one area relative to the other. Contemporary shorelines in the two localities can nevertheless be recognized from certain physiographic similarities and from the meagre measured age data presently available. We believe, furthermore, that there is sufficient information to permit estimation of the average rate of relative movement, and we attempt to analyse the field observations by applying a simple model that relates shoreline elevation to implied rate of uplift. This model is based on the supposition that the earth movements actually experienced were continuous, or can be reasonably represented as small fluctuations about a regular long-term trend. Use of the model permits estimation of absolute ages (calculated from differences in altitude of correlated levels) for each high sea level stage that is recognized. Although the calculated or “altimetric” ages derived in this way are quite speculative, they agree with radiometric ages of Alaskan transgressions, interglacial littoral faunas, and warm intervals identified in deep-sea cores, and seem therefore to be verified by these comparisons. Particular correlations between high sea levels and warm core stages are implied: if these pairings are accepted, the altimetric ages can be re-estimated using the ages of the core stages. Predictions which use the calculated ages also provide tests of their value.

Study of the data from Gippsland and South Carolina, supplemented by observations from New Zealand, Mangaia (Cook Islands), Morocco and Lebanon, suggest that six high sea levels occurred in the last 250,000 years, and two about 400,000 years ago. Other stages of high sea level are dated at 0.76, 1.43, 1.66, and 1.97 million years. The occurrence of regular earth movements at coastal localities seems therefore to provide a means for dating sequences of marine terraces that span the entire Pleistocene. Application to the important Quaternary sequence of New Zealand suggests that the last three major glaciations experienced in that country occurred during the last 145,000 years.

The implied rates of long-term earth movement relative to Mangaia are shown by comparison of shoreline elevations to be 2.40 ft. per thousand years for the West Coast of New Zealand, 0.214 ft. per thousand years for Gippsland, Australia, 0.073 ft. per thousand years for South Carolina and 0.059 ft. per thousand years for Morocco and Lebanon. These relative values for uplift become absolute rates if Mangaia has been free of earth movements in Quaternary times as the observations suggest.

Conference paper Published: 1971

Hydrogeological aspects of littoral salting

W.T. Ward, J.A. O’Shea, and P.H. Walker

Symposium on Salinity Problems, 29 March to 2 April, 1971, Mildura, Victoria: Working Papers (ed. P. A. Muecke): 3-9/25

Search National Library of Australia

Journal article Published: 1971

Postglacial changes in level of land and sea

W.T. Ward

Geologie en Mijnbouw 50 (5): pp. 703-718

https://drive.google.com/file/d/0B7j8bPm9Cse0OE43VnlVbVlQM0U/view?resourcekey=0-gFXFKEZ-N1CZtSHqjGoT1Q

Four postglacial high sea levels, separated by intervals of low water, are recognized at 7.5 ft, 4.5 ft, 3.0 ft and 1 ft above present mean sea level in East Gippsland, Victoria, Australia. Direct estimation of shoreline age is made impracticable by an absence of datable material in the stranded beach sediments, but a few dates are available for lagoonal beds. These dates, and correlations with New Zealand made possible by the common occurrence of similar sequences of coastal dunes resulting from changes in postglacial climate, suggest that the four stages of high sea level occurred about 4,700, 3,000, 1,500 and 750 calendar years ago. In particular the East Gippsland shoreline sequence is similar to that observed in the Firth of Thames, New Zealand.

The stranded shorelines are believed to result from combination of long-term land uplift with real changes in sea level.

This conclusion follows comparison of the Firth of Thames data with observations reported for 15 other localities in New Zealand, western Europe, North America, Africa and Oceania. Contradictory theses concerning postglacial sea-level changes in these localities are reconciled if it is assumed that each locality has been affected by earth movements. Such movements are already recognized in some areas affected by isostatic rebound or by mountain-building, and are presumed in others where shorelines appear excessively high or excessively low. To facilitate comparison, two simple models that relate shoreline elevation to implied rate of uplift are used. These models are based on the supposition that the earth movements actually experienced were continuous, or can be reasonably represented as small fluctuations about a regular long-term trend.

It is not yet possible to decide whether any of the localities studied has been stable in postglacial time. Earth movements may not have affected the Cook Islands, South Pacific, however. If this is so, it would seem that the sea gained its present level several thousand years ago. Subsequent fluctuations have been in response to global climatic changes. The highest level actually attained by the sea (5.5 ft) was reached briefly in Sub-boreal time.

Journal article Published: July 1968

Tertiary sea levels in Australia and New Zealand

R.C. Glenie, J.C. Schofield, and W.T. Ward

Palaeogeography, Palaeoclimatology, Palaeoecology 5 (1): pp. 141-163

https://doi.org/10.1016/0031-0182(68)90067-9

Little is known of absolute Tertiary sea levels in Australia and New Zealand for periods prior to the Pliocene because of the widespread occurrence of earth movements, particularly in the Early and Middle Tertiary. Stratigraphic studies, however, reveal a sequence of large relative changes in land and sea level since Cretaceous times. Some of these changes are widely recorded, and there is evidence suggesting contemporary climatic changes. For these reasons it is believed that some of the changes in relative level of land and sea indicated by the sedimentary record represent, in part at least, real changes in level of the sea. In southwestern Victoria, two major Tertiary transgressional/regressional cycles can be found. The first is largely confined to the Paleocene. The second commenced in the Eocene and, with some reversals of direction, reached its culmination in the Miocene. In New Zealand, the record is inconclusive prior to the mid-Eocene, when the land was probably emergent. Subsequent transgression, recorded by sediments of Te Kuiti Group, continued to the end of the Oligocene and was interrupted in the Miocene by block-faulting.

In the Pliocene, near stability seems to have been attained near Adelaide in Australia and in northern New Zealand, and sea levels in the Early Pliocene are believed to have been below the present. The later Pliocene record is one of rising sea levels; by the end of the period (the boundary to the Pleistocene being indicated by the incoming of cool-water faunas), sea level was substantially above its present position. Subsequent large changes in ocean level indicated by stratigraphic and geomorphic studies are attributed to the growth and decay of Pleistocene ice sheets, reinforced in part by presumed tectono-eustatic movements.

Journal article Published: October 1967

Volcanic ash beds of the lower Waikato basin, North Island, New Zealand

W.T. Ward

New Zealand Journal of Geology and Geophysics 10 (4): pp. 1109-1135

https://doi.org/10.1080/00288306.1967.10423211

This report describes volcanic ash beds that occur north of Otorohanga and west of Tirau in the central part of the North Island of New Zealand. The beds lie above one another as a mantle on the land surface, and form the parent material for many modern soils. Many of the beds, before burial by younger ash, were exposed to processes of soil formation and, as a result, the deposits include many fossil soils. Although their significance to agriculture is very well appreciated, the value of the beds for correlating terrestrial Pleistocene deposits and erosion surfaces is not widely recognised.

A prominent break occurs within the ash deposits and marks a lengthy time interval. The name Kauroa Ash Formation is proposed for the beds below this break, and for the younger beds above it the name Hamilton Ash Formation is used. The beds of Hamilton Ash Formation post-date the early Pleistocene 220-250 ft terrace but pre-date the middle Pleistocene 110-130 ft terrace.

Journal article Published: May 1967

The Adelaide area: A reply (to criticism by C.R. Twidale et al., Journal of Geology 75 (2): 237-242, 1967)

W.T. Ward

University of Chicago Press, Journal of Geology, 75 (3): pp. 352-357

https://doi.org/10.1086/627263

Conference paper Published: 1967

Soils of the Adelaide area, South Australia, in relation to time

W.T. Ward

In 'Quaternary Soils' (eds. R.B. Morrison and H.E. Wright), Volume 9 of the Proceedings of the 7th Congress of the International Association for Quaternary Research, Desert Research Institute, University of Nevada: pp. 293-306

The soils of the Adelaide area fall in regular developmental sequences when arranged according to parent material and age of land surface, and they can be used for correlation and age classification of erosional and depositional slopes. Six sets of soils are recognized upon ten land surfaces. Each set is the record of a specific interval of geological time.

The rate of weathering is slow, and climatic changes in the Pleistocene apparently did not materially affect the general process of soil formation.

Ages postulated for two fossil soils suggest that more than 25,000 years elapsed in the interval between the Late Monastirian and Epimonastirian high sea levels. This is consistent with Zeuner's chronology, but not with the time scale proposed by Emiliani for the last interglacial.

CSIRO Technical Memoir Published: 1966

Soil survey of Glenthorne Experimental Station, O'Halloran Hill, South Australia

W.T. Ward

CSIRO Division of Soils, Technical Memoir 42/66

CSIRO ONLY (No public access)

Book Published: 1966

Geology, geomorphology and soil of the southwestern part of county Adelaide, South Australia

W.T. Ward

CSIRO Division of Soils, Soil Publication No. 23 (115 pages + 4 maps)

https://doi.org/10.25919/5db33828b9852

From the Preface of the 1986 reprint:

This publication uses geological and geomorphic observations to explain soil variation in the area south of Adelaide. This approach is uncommon, for most soil reports do not use information of this nature to develop a greater understanding of soil origins and distribution. They are limited instead, by convention, to the plain description and classification of arbitrarily-defined soil profiles.

Geological reports, similarly, are confined to the origins of the rocks. The subsequent weathering to soil is ignored.

It is usual, too, for geomorphologists to describe landscapes without referring to the weathering horizons that lie below the land surface. The three scientific disciplines are thus developed separately, as if their objects of study were quite independent natural phenomena. They have large common areas of interest with respect to soil evolution, however, and one should view them as different facets of a single scientific enquiry. To integrate the three disciplines is a continuing task for the modern earth scientist.

Geology and geomorphology benefit from this integration as much as soil science. To the geologist soils give evidence of interrupted erosion or deposition, and the character of the soil can indicate the nature of the past environment. To the geomorphologist similarity of soil mantles can be evidence of contemporary landscape development. Correlation of landforms in different drainage basins is facilitated by soil examination and firm conclusions can be drawn on denudation chronology, where the evidence otherwise may be ambivalent.

For the pedologist, to describe soils is not enough. It is necessary to support the description with an explanation of the relationships with landscapes and parent rocks. Until then, one may be sure that some significant soil features will pass unnoticed, or their significance be not appreciated.

The work reported here was developed as a basic reference for later investigators, and to encourage debate on soil formation. In the 24 years since the field work was completed, however, very little new information has become available. The publications noted below touch upon some points of particular interest.

Advances in knowledge of coastal geology make some revision of the text desirable, but no changes have been made for this printing [1986]. The large inferred changes of sea level relative to the land (pages 52 to 57) would not be attributed today to sea-level change alone. Moreover, one would relate the stranded shorelines to deep-sea sedimentation, rather than to the pioneering Mediterranean shoreline stages.

W.T. Ward

Journal article Published: July 1965

Eustatic and climatic history of the Adelaide area, South Australia

W.T. Ward

University of Chicago Press, Journal of Geology, 73 (4): pp. 592-602

https://doi.org/10.1086/627095

Late Tertiary and Quaternary events in the Adelaide area are recorded by an alluvial sequence, locally with intercalated marine and eolian beds. The sediments occur in fault-angle depressions but are essentially post-deformational. Deposition began with a major eustatic rise of sea level which reached 600 ft. before the close of the Pliocene, and was controlled during the Pleistocene by a series of glacio-eustatic oscillations of sea level, the earliest positive movement attaining a level of 370 ft. The data permit revision of a published eustatic curve. Four major regressions of the sea are identified and correlated with the four major glaciations of the northern hemisphere.

Late Quaternary climatic changes which accompanied the changes in sea level are indicated by the distribution and character of the contemporary sediments. Periods of storminess interrupted the generally arid conditions of the last interglacial, and mild humid conditions prevailed at the time of the last glaciation. Increased wind velocities at the time of the Flandrian transgression are postulated.

Journal article Published: February 1965

Changes of sea level in southern Australia

W.T. Ward and R.W. Jessup

Nature, London, 205 (4973): pp. 791-792

https://doi.org/10.1038/205791a0

Recent geomorphic investigations in relation to the history of sedimentation and to soil development in the Adelaide, Yorke Peninsula, and Gippsland areas of southern Australia have shown that the varied landforms of these areas are related to a sequence of stranded shorelines which extend from modern sea-level up to a height of several hundred feet. These shorelines are marked by former coastal features, including submarine platforms backed by abandoned sea cliffs, often with beach deposits at their base, coastal foredunes and bars, and notches of marine erosion. Their elevations above mean sea-level and other data relating to them are listed in Table 1.

DSIR Soil Bureau Bulletin Published: 1964

Soils and agriculture of Ellesmere County, Canterbury

W.T. Ward, C.S. Harris and H.P. Schapper

New Zealand DSIR Soil Bureau Bulletin No. 21 (81 pages + 2 maps)

https://doi.org/10.7931/dl1-sbb-021

The field work on which this report is based was commenced in 1943 by Mr C. S. Harris, who was responsible for the definition of the soils and the preparation of the map. Mr Harris was assisted in the field from time to time by Messrs F. J. F. Fisher, M. G. Garlick, and E. J. B. Cutler, and in 1945 a provisional map of the soils was completed.

Owing to other surveys, the preparation of the report was put aside until 1956 when the tasks of checking the field work, gathering data on the soils, and compilation of the bulletin were undertaken by Mr W. T. Ward, Mr Harris having left the Soil Bureau in 1954.

The study of the agriculture of the county by Dr H. P. Schapper was carried out in 1948–1950. Mr Ward is now with Division of Soils, CSIRO, Australia, and Dr Schapper is Reader in Agricultural Economics, University of Western Australia, Perth.

Journal article Published: October 1962

Soil type and land valuation in Ellesmere County, Canterbury

W.T. Ward

New Zealand Geographer 18 (2): pp. 170-183 + 2 maps

DSIR ONLY (No public access)

The value of land is determined by the benefit that might be expected to accrue from its possession. It is decided by a great many factors and intrinsic soil properties, such as soil fertility, may be of small account.

In general terms, value is related to the income derived from the land, which is partly a measure of land quality and, perhaps more significantly, a measure of the owner's ability and resources. Value is also related to the market price of the land-the measure of the would- be-owner's appreciation of the benefits to be gained by possession.

For fair and equitable land taxation and local-body rating and for death and gift duties, the state requires periodic land valuation. Lending agencies must know the value of the land on which they are asked to lend money, and the government valuation limits the amount of trust monies available on mortgage. These and other professional valuations are available to the public, and may be used as a guide by prospective purchasers.

In a broad way, valuation is determined by capitalisation of the annual net income, or by analysis of recent sales of comparable land. Neither technique is straightforward, the former being greatly influenced by different management abilities and the latter by constraints on the market and by family transactions. The valuer applies both methods in his calculations, giving different weight to various factors according to circumstances. The resulting valuation represents the sum the property would realise if it were offered for sale on reasonable terms by a bona fide seller. It is termed the capital value, and is the value of the entire parcel of land, including buildings, fences and other amenities.

Newsletter article Published: 1962

Genesis of the brown granular loams of the Waikato

W.T. Ward

New Zealand Society of Soil Science, New Zealand Soil News, 1962, 5: pp. 216-220

https://doi.org/10.7931/DL30-1962_VOL10_5_ORC

The brown granular loams of the Waikato district are developed on a thick series of volcanic ash beds first described in 1931 by Grange and Taylor who gave the name “Hamilton Shower” to the topmost of the deposits, the parent material of the soils lying on the hills at Hamilton city. Hamilton Shower consists typically of dense reddish brown halloysite clay with clearly developed clay skins lining the fissures and coating the aggregates. It is completely weathered and no remnant of the original ash or relict of stratification is apparent. The beds beneath Hamilton Shower are generally referred to as the “older Hamilton showers” and contain several fossil soils. In all there are eight Hamilton ash beds and individually they may be traced with ease from Otorohanga to Tuakau and from Morrinsville to Raglan. The beds are thickest in the south, the total depth at Otorohanga being seventeen feet, and thin out to the north. At Hamilton the modern soil is developed wholly on the Hamilton Shower but near Tuakau and Pukekohe it is developed partly on the Hamilton Shower and partly on the underlying beds. In the north, this contribution to the parent material of the modern soil by the older ash beds is probably responsible for some of the variations in soil chemistry noted by workers at Rukuhia Soil Research Station.

The decrease in depth of the ash with distance from the source of eruption provides evidence of the location of the volcanic centre. The present author's study of the depth of the ash beds does not support Grange and Taylor's (1932) opinion, apparently based on studies of the mineral content of the ash, that the source was Mt Egmont, but shows that the beds increase in thickness towards the Rotorua - Taupe volcanic field. It is likely, therefore, that the source lay in this region. South east of Te Awamutu the Hamilton beds disappear below younger Taupo ash beds.

Journal article Published: September 1961

Soils of Stephens Island

W.T. Ward

New Zealand Journal of Science 4 (3): pp. 493-505 + 1 map

http://doi.org/10.7931/DL1-SBP-0198

Morphological and chemical properties of seven soils occurring on Stephens Island (370 acres) are described. Two soils, which together occupy 90 acres, are extensively burrowed by nesting sea birds whose effect is discussed with reference to the process of soil formation. The two soils are extremely acid and possess a very high content of citric-soluble phosphorus and a very small content of exchangeable cations. It is inferred that manuring by sea birds makes the soils acid and enriches them in nitrogen and phosphorus. These effects are accompanied at first by enrichment of bases but intense leaching occurs as the pH falls.

Journal article Published: November 1956

Soils and forestry of the northern part of Te Wera State Forest, Taranaki: A study in the application of soil survey to forest planning

W.T. Ward and G.H. Hocking

New Zealand Journal of Science and Technology 38 (3): pp. 157-186 + 3 maps

http://doi.org/10.7931/DL1-SBP-0107

From basic data collected in the course of a detailed soil survey, a forester assessed the forest potential of each soil. With due regard to other site factors and principles of forest management, he assigned to each forest compartment a species ecologically adapted to it and having as high a utility and yield as possible.

This study in the method of using soil data in the problem of species siting has shown that a soil map and report are of real value in assisting the forester to plan his forest with greater speed and confidence.

Conference paper Published: 1956

The soils of Canterbury

W.T. Ward

In New Zealand Society of Soil Science, Proceedings of the 2nd Conference, 2-9 November 1956, Lincoln, 2: pp. 18-19

https://doi.org/10.7931/dl30-prov2

Some 200 soils have been mapped in Canterbury, which has an area of 15,000 square miles. To group this large assemblage simply for ready comprehension, one must seek unifying threads that bring together related soils.

Because of the dominant effect of topography, the soils may be first separated into three classes: Soils of the steep lands, soils of the downs and hills, and soils of the flat lands.

Journal article Published: November 1951

The tors of central Otago

W.T. Ward

New Zealand Journal of Science and Technology 33 (3): pp. 191-200

http://doi.org/10.7931/DL1-SBP-0035

Much of Otago is formed by a schist and greywacke massif on which a peneplain was developed during the Cretaceous. This was subsequently buried under a non-marine cover. Following mid-Tertiary crustal unrest, another peneplain, later warped and dislocated by the Kaikoura orogeny, was cut across the whole.

Wherever it is seen, the Cretaceous peneplain is underlain by soft residual rock, the product of an ancient period of deep weathering. The surface separating the residual schist from the basement schist is extremely irregular, as the depth of weathering was controlled by jointing and differences in resistance to weathering within the rock. Owing to differential erosion in the current cycle, salients on this basement schist surface now appear in the present landscape as tors.

Minor irregularities and cavities on the surfaces of many tors are regarded as irregularities, developed by local deep weathering, of the basement schist surface. These, like the tors, have appeared as the residual schist has been stripped away.