by Phe 29 in KOL and McPC603, but is external. Although the experimental structure may have to be modified, as the three residues have main chain conformations usually disallowed because of steric hindrance, the predicted structure is incompatible with the electron density. In retrospect, it appears that the reduced volume of two important side chains (29 and 34) may have changed the packing to produce a different fold.

Table 4. Fit of V_L-V_H framework. Comparisons of predicted and observed structures. In Tables 4 to 7, the model SA is based on structure analysis, and model CE on conformational energy calculations starting from a structure derived initially from McPC603. Δ is the root-mean-square deviation in angstroms after superposition.

Residues	Δ (N, Cα, C, and O atoms) SA	CE
V_L: 4–6, 19–25, 33–48, 52–54, 61–76, 84–90, 97–107; V_H 3–12, 17–25, 33–52, 56–60, 68–82, 88–95, 102–113	1.0	1.0

Table 5. Shifts of framework residues adjacent to hypervariable regions. Shift is the difference (angstroms) in position of residue after superposition of the framework.

Residues		Shift SA		CE	
V_L: 25	33	0.6	0.3	2.5	0.8
48	52	0.6	0.8	0.2	0.6
90	97	0.8	0.4	0.9	0.8
V_H: 25	33	0.9	1.8	0.6	1.2
52	56	1.5	1.8	1.7	0.7
95	102	1.2	1.0	1.3	0.6

Table 6. Fits of hypervariable loops.

Residues	Δ (N, Cα, C, and Cβ atoms) SA	CE
L1 26–32	0.85	3.76
L2 49–51	0.63	0.47
L3 91–96	0.97	1.10
H1 26–32	2.07	1.68
H2 53–55	0.50	0.89
H3 99–104	0.86	0.87

Table 7. Fit of maximal well-fitting portion, including framework and all lysozyme contact residues (model SA).

Residues	Δ (N, Cα, and C atoms)
V_L: 2–6, 19–65, 69–92, 96–104; V_H: 3–7, 14–27, 30–59, 67–75, 78–81, 84–113	1.0

None of the residues at which the model differs from the observed structure is involved in antigen contacts. The main chain conformation of the binding site itself is predicted accurately (Fig. 2).

Both the models based on conformational energy calculations correctly predicted the framework and the folds of L2, H2, and H3. Loop L1 is very different from the experimental structure because it was built from the extended part of McPC603 L1 rather than from the part common to other V_κ chains. L3 and H1 are similar to those in the model based on structure analysis.

The comparisons show that the prediction of the main chain conformation of D1.3 was largely successful (Tables 4 to 7 and Figs. 1 and 2). They support the premise that the binding site conformation is determined principally by specific interactions of a few residues, and that these residues can be identified and used to formulate rules valid for structure prediction. A structure of D1.3 at higher resolution will permit a more detailed evaluation of the predictions, as well as the refinement and extension of the rules.

The predictions treated an isolated V_L–V_H dimer. The observed D1.3 structure is contained in a Fab-antigen complex. The close similarity of the observed and predicted D1.3 binding site and framework implies that the association with antigen does not significantly alter the main chain conformation of the antibody.

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Cambrian River Terraces and Ridgetops in Central Australia: Oldest Persisting Landforms?

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Fluvial sediments in paleovalleys cut in the Ashburton surface of the Davenport province of central Australia form terrace remnants that appear to retain their original depositional tops and have probably existed as subaerial landforms since their inception. Marine fossils in sediments conformable with the fluvial sediments near the southeast margin of the province give a Cambrian age for the terraces; the Ashburton surface forming the ridgetops between the paleovalleys is Cambrian or older.

Inland Australia is well known for the flatness of its landscape and the antiquity of its erosion surfaces (*1*, *2*). The highest surface in the Tennant Creek region of central Australia, the Ashburton surface, has long been thought to be Cretaceous or older (*2*). We report evidence from the Davenport province of the Tennant Creek region (Fig. 1) that suggests that, during the Cambrian, fluvial sediments were deposited in valleys between ridges whose tops are remnants of the Ashburton surface. Subsequent dissection of the sediments formed terraces and mesas, but where preserved, the relation of the terraces to the adjoining ridges indicates that the terraces and mesatops have existed as subaerial landforms since the Cambrian sedimentation. The Ashburton surface itself is therefore Cambrian or older.

The Davenport province (*3*) is a broad

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topographic dome, most of which consists of the mid-Proterozoic Hatches Creek Group, composed of terrigenous clastics and volcanic rocks that were folded, metamorphosed, and intruded by granite about 1640 million years ago. They were later eroded to a planation surface of very low relief, the Asburton surface.

The present Davenport landscape (Fig. 2) is dominated by steep-sided ridges and valleys with up to 100 m of relief. The ridges have planar tops that slope gently toward the margins of the province, average about 500 m in altitude with a maximum of 584 m, and are composed of resistant sandstone units of the Proterozoic sequence. Their planar tops are remnants of the Ashburton surface (Fig. 2).

Paleovalleys cut into the Ashburton surface are carved in friable sandstone, shale, carbonate rocks, and volcanics of the Proterozoic sequence, and contain the Cambrian sediments. The paleovalley gradients are slightly less than the ridgetop gradients, and eventually bring the valley floors to the same level as the ridgetops near the margins of the Davenport province. Narrow valleys (less than about 300 m wide) have an open v-shaped cross section between the steep ridge sides, with exposed bedrock or scree fans from the ridges meeting in the middle, and in places contain small terraces of conglomerate and sandstone lying unconformably on bedrock. Wider valleys have floors of bedrock or alluvium flanked by scree fans; some in the south and southwest of the province contain terraces and mesas up to 50 m high of flat-lying conglomerate and sandstone (Fig. 2, localities a and b; Fig. 3).

The terrace and mesa-forming conglomerate consists of angular to rounded clasts of sandstone, up to 1 m across, derived from the Hatches Creek Group, in a matrix of coarse-grained porous clayey lithified sandstone. The clasts are commonly arranged in imbricate structure. Sandstone beds are coarse-grained, porous, well-lithified, and show scours filled with medium to low-angle unidirectional cross-laminae that are concave upward in both longitudinal and transverse section. The conglomerate and sandstone are in places bleached, iron-stained, or silicified to patchy silcrete, but nowhere has a silcrete or laterite capping been found on top of them. Because of their sedimentary structures, the conglomerate and sandstone are considered to be remnants of an extensive fluvial deposit of which only a small amount survives. At many localities the flat top of the fluvial deposit meets the sandstone ridge a few meters (typically 2 to 5 m) below the ridgetop, with an angular junction between fluvial flat top and ridgeside (Figs. 2 and 3). In places, the

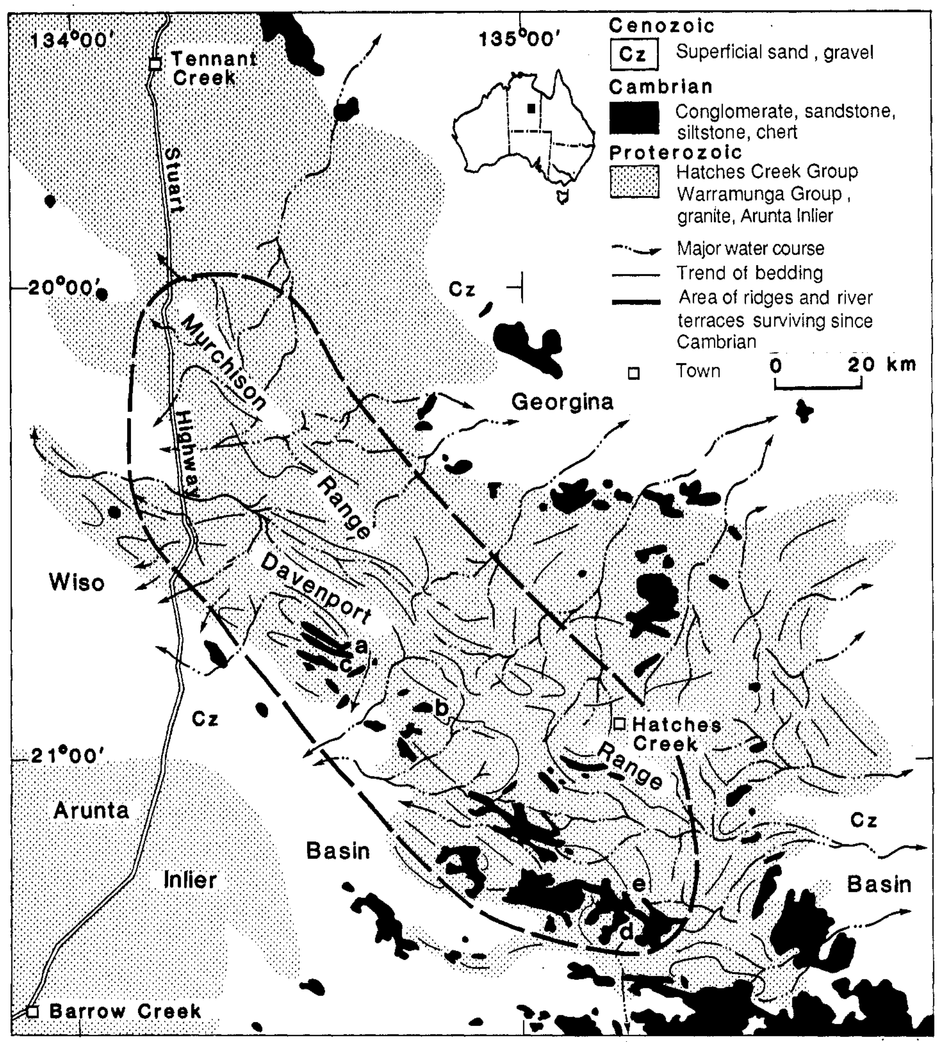

Fig. 1. Locality map of Davenport province showing distribution of Cambrian strata (black), major drainage, and area of ridges and river terraces surviving since the Cambrian (inside dashed outline). Small letters (a–e) refer to localities depicted in Fig. 2.

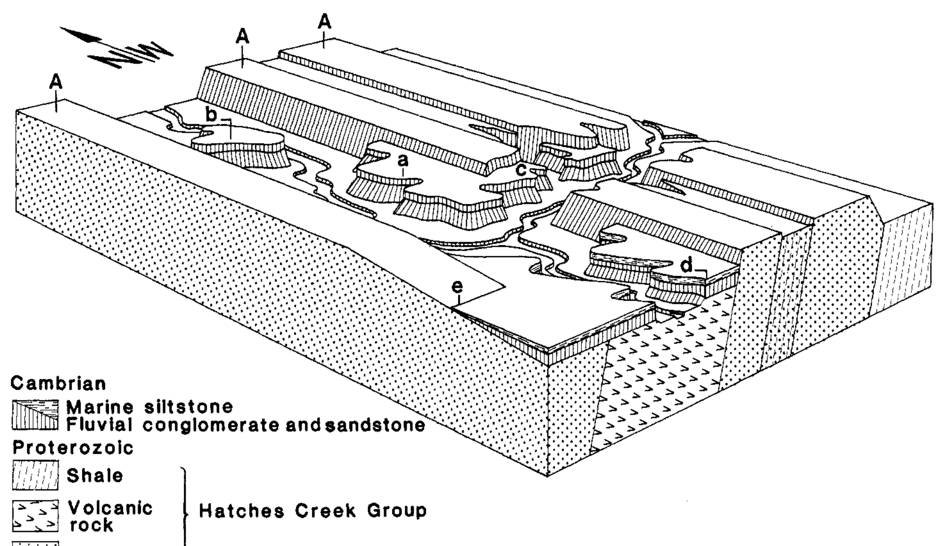

Fig. 2. Pictorial representation showing remnants of Ashburton surface (A) on ridges of steeply dipping Proterozoic Hatches Creek Group, terraces (localities a, c, and d), and mesas (locality b) of flat-lying Cambrian strata in valleys cut below Ashburton surface; Cambrian strata lap onto Ashburton surface at locality e.

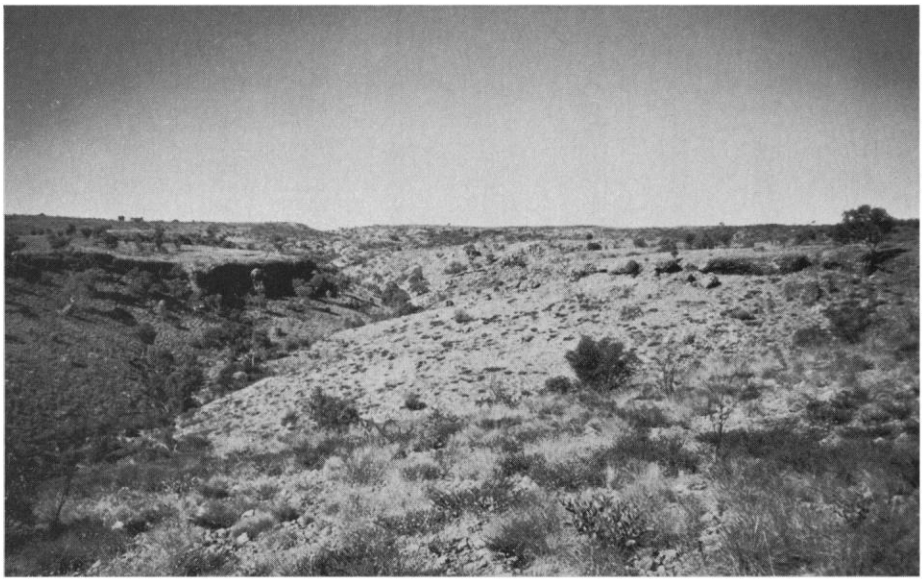

Fig. 3. Photograph looking east at mesas and terraces of Cambrian strata (dark ledge in middle ground) resting unconformably on shale of the Hatches Creek Group (foreground) and adjoining a ridge of resistant sandstone of the Hatches Creek Group (background). Location is in the southwest of Davenport province (20°46′02″S, 134°36′46″E).

fluvial deposit extends into side valleys incised through the ridges (Fig. 2, locality c), and even here maintains its flat top and angular junction with the ridge. Hence, the flat top appears to represent an original aggradational fluvial surface of a river terrace.

To the southeast, the fluvial conglomerate and sandstone pass laterally into, and are overlain by, fine-grained marine sediments of the Georgina Basin, and, except where cut by narrow Cenozoic gullies, the terraces that they form can be traced continuously from areas of fluvial deposits only (Fig. 2, locality a), through areas where fluvial conglomerate and sandstone are overlain by marine sediments (Fig. 2, locality d), to areas where only marine sediments—the fossiliferous Middle Cambrian Sandover beds (*4*)—are present. There can be little doubt that the fluvial sediments are older than, or in part lateral equivalents of, the marine strata. Trilobites, brachiopods, and hyolithids collected from marine fine-grained sandstone and siltstone conformably overlying fluvial conglomerate adjacent to sandstone ridges (*5*) are Middle Cambrian (*6*). Hence, the valleys containing the terraces and mesas were eroded into the Ashburton surface in the Middle Cambrian or earlier.

The major present-day drainage in the region is approximately radial (Fig. 1). Tributary valleys, however, are typically eroded into soft units of the bedrock and are therefore parallel to bedding trends (Fig. 1). This erosion had already occurred by the time the Cambrian sediments were laid down because the valleys contain and hence predate the Cambrian sediments. The radial pattern of the drainage suggests that the Davenport province was a topographic dome when fluvial erosion began. The cause of doming is not known.

The simplest scenario for the evolution of the Davenport landscape is the following. (i) The Proterozoic rocks were folded with steep limbs before 1640 million years ago. (ii) The folded rocks were planed down during the middle and late Proterozoic, forming the Ashburton surface. (iii) Slight doming initiated approximately radial drainage. Differential erosion carved valleys in the less resistant rocks and left intervening flat-topped ridges on the more resistant sandstones. During the Cambrian, detritus from the sides of the sandstone ridges was deposited in the valleys by rivers that flowed into the sea surrounding the Davenport province. At the margin of the land area, shallow marine sediments were deposited conformably on the fluvial sediments. Some fossiliferous sediments are in valleys between sandstone ridges (Fig. 2, locality d), suggesting a ria coastline (*7*). Marine sediments lapped onto sandstone ridges in the southeast (Fig. 2, locality e). (iv) Subsequent dissection of the Cambrian alluvium left remnant terraces and mesas.

An alternative scenario is that the entire Davenport province was covered by Cambrian sediments that were largely removed by later erosion. If this were the case, the present drainage pattern would be superimposed from the cover and therefore younger than the Cambrian sediments. Hence, it should have little or no relation to the underlying bedrock geology. This is clearly not the case; the drainage is markedly controlled by alternating hard and soft bedrock (Fig. 1) and predates deposition of the Cambrian sediments. Also, remnants of the Cambrian cover could be expected on top of the Ashburton surface but, except in a few places near the margins of the Davenport province, the only cover on the beveled ridgetops is a thin patchy reddish-brown soil. The possibility that some other process such as etchplanation lowered the surface of a hypothetical Cambrian cover to a level just a few meters below the Ashburton surface and confined within numerous paleovalleys over an area of thousands of square kilometers is remote. Furthermore, we know of no way that erosion could produce the widespread angularity of the terrace-ridge junction, an angularity that is maintained into transverse side valleys (Fig. 2). We prefer the simpler interpretation that the angular junction was produced by deposition.

The Cambrian sediments in the paleovalleys show that the Ashburton surface is Cambrian or older, and that the present-day flat-topped ridges were already in existence when the Cambrian sediments were deposited. The evidence also strongly suggests that the Cambrian mesas and terraces in the central part of the Davenport province, an area of about 10,000 km^2, have never been covered by younger sediment. The Cambrian ridges and terraces of the Davenport province appear to have existed as subaerial landforms for some 500 million years and may be the oldest persisting, or stagnant (*8*), landforms in the world.

The longevity of the Davenport river terraces is consistent with the marked tectonic stability of much of northern Australia during the last 1500 million years, particularly the last 500 million years (*9*, *10*); the Georgina and Wiso basins east and west of the Davenport province contain Cambrian and Ordovician strata which, except in localized areas, are flat-lying (*4*, *9*, *11*). Although lithified, weathered, and dissected, the Cambrian terraces in the Davenport province, like the adjoining flat-lying Cambro-Ordovician strata, have remained virtually undisturbed since their formation. Weathering has had relatively little effect, despite the long time available, because the porous, siliceous conglomerate and sandstone are incapable of substantial alteration. Dissection has removed about 90% of the original terraces.

The Davenport terraces and ridgetops in central Australia increase the possible age of persistent landforms from Cretaceous (*2*) to Cambrian. This implies prolonged tectonic stability and also low rates of weathering and erosion, resulting from remoteness from coasts, low elevation, and stable parent material.

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Equatorial Pacific Seismic Reflectors as Indicators of Global Oceanographic Events

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The origin of a series of regionally correlatable seismic horizons in the Neogene sediments of the central equatorial Pacific is examined through seismic modeling and the detailed analyses of stratigraphic and physical property relationships in Deep Sea Drilling Project cores. These regionally traceable reflectors are synchronous; the younger reflectors are the direct result of carbonate dissolution events, the older ones of stratigraphically selective diagenetic processes. The changes in ocean chemistry associated with these events appear to be linked to global reorganizations of surface- and bottom-water circulation patterns, the most dramatic of which are associated with reorganizations of North Atlantic bottom waters. These deepwater seismic horizons appear to correlate with the major events on the "relative sea-level" curve of Vail *et al.* for the Neogene.

A FUNDAMENTAL GOAL OF SEISMIC exploration is the complete extraction of geologic information from the seismic record. Recent improvements in seismic sources and advances in data acquisition, processing, and analytical techniques have brought us much closer to this goal, especially in the continental margin areas that have been the subject of detailed petroleum industry exploration. Of particular significance has been the pioneering work of Vail *et al.* (*1*) in developing an approach toward seismic interpretation that permits identification of the depositional environment through "seismic facies analysis" and the establishment of stratigraphic position based on the analysis of relative onlap and offlap curves and their correlation with globally derived sea-level curves. Although the approach of Vail *et al.* has proven invaluable to industrial and academic researchers, several aspects remain controversial, including the validity of the correlation with global sea-level fluctuations (*2, 3*) and the applicability of this technique to deep-sea studies (*4*). These two issues are not necessarily separate. If the seismic events that Vail *et al.* have correlated in marginal sedimentary basins around the world are indeed representative of global events, then there should also be some indication of these events in the deep sea. In this report we examine the origin of a series of regionally correlatable seismic horizons in the Neogene pelagic sediments of the central equatorial Pacific, a region of key importance to paleoceanographic studies and one far removed from the dynamic processes of the continental margins responsible for the Neogene seismic events correlated by Vail *et al.*

The fertile waters of the central equatorial Pacific have produced a thick section of biogenic sediment that is an extremely sensitive indicator of the interplay among tectonism, circulation, productivity, and diagenesis. Deep-sea drilling in the region has produced an intriguing record of paleoceanographic change for the past 40 million years (*5*), but detailed studies have been frustrated by incomplete coring and core disturbance. These difficulties were overcome during Deep Sea Drilling Project (DSDP) Leg 85, which used the hydraulic piston corer in the upper, unconsolidated part of the section and rotary coring in the deeper parts, thereby collecting nearly complete and relatively undisturbed sedimentary records of the past 40 million years. These cores provide a wealth of data for detailed studies of biostratigraphy, isotopes, carbonates, and physical properties in the central equatorial Pacific (*6*). In preparation for Leg 85 drilling, seismic surveys at each drill site and in the general region used the relatively new, high-resolution, watergun seismic source (*7*). The collection of detailed physical property and stratigraphic data, in conjunction with high-quality, digital high-resolution seismic profiles, presents an opportunity to use quantitative modeling techniques (synthetic seismograms) to understand the origin of seismic reflectors in the region and to examine the potential of equatorial Pacific seismic stratigraphy as a paleoceanographic tool.

If we use DSDP core data to examine the geologic origin of seismic horizons, we must know where in the cores to look for a particular reflector. An initial difficulty is that the core information (for example, physical properties or biostratigraphy) is measured as a function of depth below the sea floor (a spatial-domain record) but the seismic profile is recorded as a function of travel time (a time-domain record). Fundamental to the correlation of seismic data with drill hole results is the accurate conversion from travel time to depth (or vice versa). This requirement demands an exact knowledge of the in situ velocity versus depth function—information that is rarely available.

In the absence of well-log data, the detailed velocity structure for the Leg 85 sites was obtained from closely spaced (1 m) shipboard measurements of sonic velocity on core samples corrected to in situ values [a correction that has a mean value of 7.1% and that can be as great as 18% in the 500-m-thick section (*8*)] in order to produce an in situ velocity profile. By combining corrected velocity values and corrected saturated bulk density values (also from shipboard measurements), we generated an in situ acoustic impedance profile that, in conjunction with a measured watergun outgoing pulse, becomes the basis for constructing synthetic seismograms. The details of measurement techniques, in situ corrections, the seismic

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