show very different properties and are held together by weak intermolecular van der Waals forces. However, it is at the intramolecular sp^3 carbon framework level, not the intermolecular level, that diamond-like properties, e.g., strength, rigidity, and stability, emerge.

The diverse geometries and varieties of attachment sites among higher diamondoids provide an extraordinary potential for the production of shape-targeted derivatives. Properties of diamond-like hydrocarbons can also be tuned by the addition of various functional groups. We have already prepared a number of functionalized tetramantanes, including bromo, hydroxyl, acetoamino, amino, oxa, and aza derivatives and have characterized them by GC-MS (*25*). Predictable and diverse derivatizable geometries are important features for molecular self-assembly and pharmacophore-based drug design (*26*, *27*). Incorporation of higher diamondoids in solid-state systems and polymers should provide high-temperature stability, a property already found for polymers synthesized from lower diamondoids (*7*). Particularly interesting may be the electronic properties of higher diamondoids because H-terminated diamond is the only semiconductor that shows a negative electron affinity, and nanocrystalline diamonds are being studied as field emitters (*2*).

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Holocene Deglaciation of Marie Byrd Land, West Antarctica

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Surface exposure ages of glacial deposits in the Ford Ranges of western Marie Byrd Land indicate continuous thinning of the West Antarctic Ice Sheet by more than 700 meters near the coast throughout the past 10,000 years. Deglaciation lagged the disappearance of ice sheets in the Northern Hemisphere by thousands of years and may still be under way. These results provide further evidence that parts of the West Antarctic Ice Sheet are on a long-term trajectory of decline. West Antarctic melting contributed water to the oceans in the late Holocene and may continue to do so in the future.

Melting of ice sheets at the end of the last glacial period raised the world's oceans by about 120 m between 19,000 and 6000 years ago (*1*). Antarctica's contribution is less well known than those of the northern ice sheets, although it is believed that Antarctic melting commenced later and continued longer than deglaciation in the Northern Hemisphere (*2*). The dynamics of the West Antarctic Ice Sheet (WAIS) (Fig. 1A), much of which is grounded below sea level and drained by fast-flowing ice streams, make it more susceptible to rapid deglaciation than is the continental East Antarctic Ice Sheet (*3–5*). The potential for instability has sustained interest in the past, present, and future behavior of the WAIS. The ice sheet is regarded as a possible source for late-glacial meltwater pulses IA and IB, episodes of rapid deglaciation around 14,000 and 11,000 years ago, which raised sea levels by 15 to 25 m in periods of less than 1000 years (*6*, *7*). Moreover, the WAIS may have shrunk to far below its present volume at least once in the mid- to late Pleistocene (*8*, *9*), and forecasts of future sea-level change depend strongly on predicting the behavior of the WAIS (*10*, *11*). Melting of the WAIS in the future would raise global sea level by ~5 m. A rapid melting event that released even a small fraction of this amount could have disastrous consequences for coastal regions.

The WAIS evolved to its present form from a much larger, ancestral ice sheet that existed during the last glacial period (*12*, *13*). Its deglaciation history provides insights into the dynamics of the ice sheet and its trajectory of change. This long-term view is also needed to assess the significance of recent changes detected by glaciological observations and remote sensing. So far, there have only been a few studies of glacial deposits onshore in West Antarctica to constrain the size of the WAIS during the late Pleistocene glacial maximum and the history of its retreat (*14–16*). Here we describe the history of deglaciation close to the ice-sheet margin in Marie Byrd Land (Fig. 1A) and show that the WAIS is still adjusting slowly to Holocene temperature and sea level. Delayed melting in this sector of the ice sheet has supplied water to the oceans since 7000 years before the present (B.P.), when the last remnants of the Northern Hemisphere ice sheets stabilized or disappeared, and will continue to influence sea level in the future.

The Ford Ranges of western Marie Byrd

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Land consist of chains of peaks extending east-southeast from Sulzberger Bay and disappearing ~80 km inland, where the ice sheet rises above ~1200 m (Fig. 1A). We collected glacially transported cobbles in elevation transects on seven of these peaks, located between the present grounding line (where the glaciers merge with the Sulzberger Ice Shelf) and the Clark Mountains, 80 km inland. The peaks emerge from the ice sheet at elevations between 90 m and 950 m, and stand up to ~700 m above it. They are covered by fresh glacial deposits left by the retreat of ice that overrode the peaks during the last glacial maximum (LGM). The deposits consist largely of scattered cobbles resting directly on bedrock. The scarcity of thick deposits and organized moraine ridges suggests that ice receded steadily, without prolonged stillstands that would allow debris to accumulate.

Cosmogenic ^{10}Be exposure ages (*17*) of transported cobbles from five of the mountains decrease regularly with decreasing altitude, evidently recording gradual thinning of the adjacent glaciers (Fig. 1, C, D, and F). All 17 samples from these peaks are consistent in demonstrating the trend. Elevation transects on the remaining two peaks include another 18 samples showing the same pattern. However, there are also some samples with scattered, much older ages. On Mount Rea and The Billboard (Fig. 1B), these latter samples all come from the upper slopes of the massif (above 490 m) where there is weathered gravel and bedrock without any evidence of glacial erosion. On Mount Spencer, below Mount Darling (Fig. 1E), the two anomalous samples come from an apron of weathered rock covering the lee (down-glacier) side of the mountain. In both cases, less-weathered samples from higher on the same peaks give much younger ages, consistent with the simple altitude-dependent trends on the other mountains. We interpret the weathered surfaces, and the old glacially transported cobbles resting on them, as having survived glaciation beneath thin, cold-based ice and therefore conclude that the young exposure ages record recent deglaciation and that the old "ages" are artifacts of prior cosmic-ray exposure (*18*).

Samples from near the summits of Mount Van Valkenburg, Mount Darling, Mount Blades, the Fleming Peaks, Mt. Passel, and an unnamed nunatak in the eastern Fosdick Mountains indicate that these peaks emerged from beneath the ice sheet between 9300 ± 580 and 3600 ± 300 years ago. On The Billboard/Mount Rea massif, the highest young sample has an exposure age of 10,400 ± 680 years, and erratics at lower altitude range in age from 3300 ± 180 years at 490 m to 2380 ± 210 years close to the base of the mountain. The col southeast of Mount Rea emerged 2400 ± 150 years ago, and ice has receded from its north slope since that time. The youngest exposure age below the col is 300 ± 90 years. Thus, the exposed rock in the Ford Ranges, up to 700 m above the present ice surface, was deglaciated within the past 11,000 years. We cannot constrain the maximum thickness attained by the ice sheet in this region, or date the glacial maximum, because none of the peaks we examined is high enough to have stood above the ice sheet and accumulated debris at its upper limit (*19*). Ackert *et al.* (*15*) showed that the ice sheet began to retreat from its maximum position on Mount Waesche, near the summit of the WAIS, at ~10,000 years B.P. This

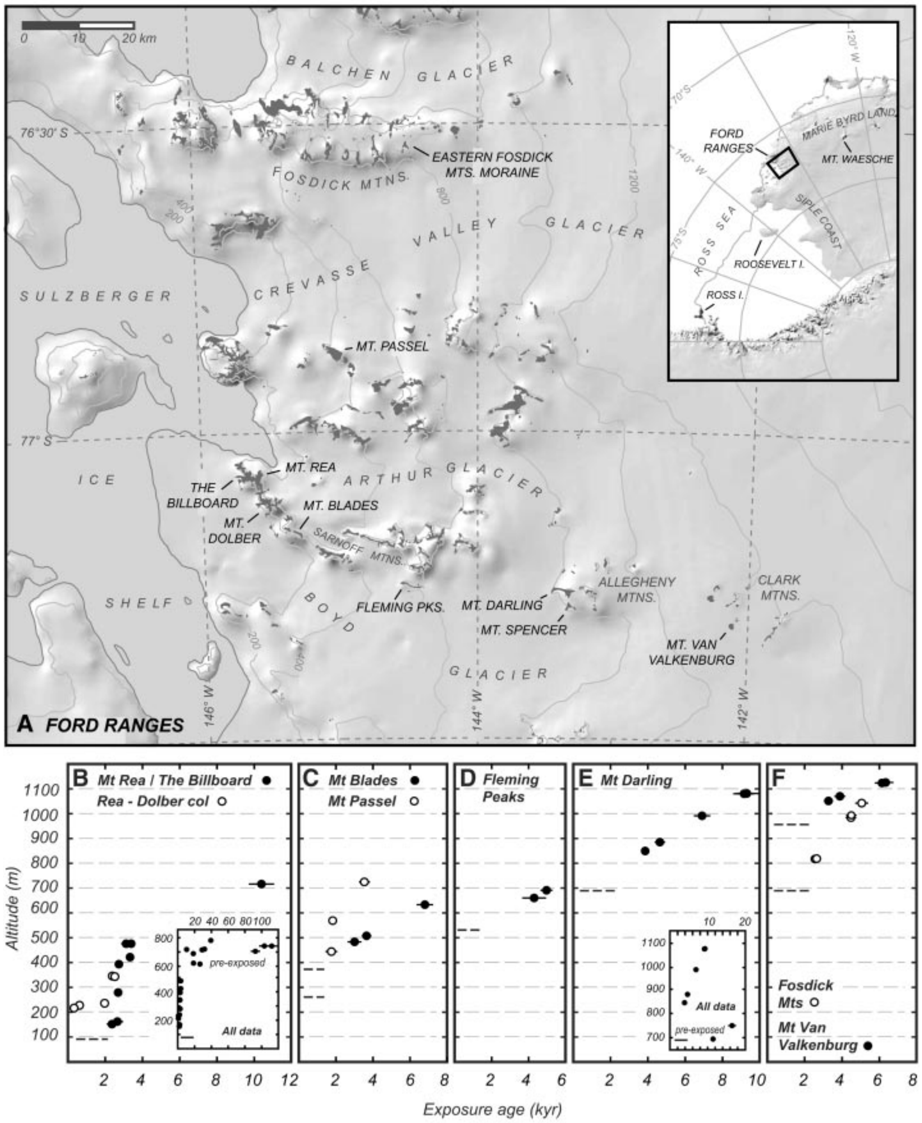

Fig. 1. (**A**) Map showing study sites in the Ford Ranges and location with respect to the surrounding West Antarctic Ice Sheet. Relief shading is based on Radarsat Antarctic Mapping Project digital elevation data (*43*). Contours, distribution of outcropping rock, and other geographic information are from the Antarctic Digital Database (*44*). (**B** to **F**) Exposure ages of glacially transported clasts, plotted versus altitude. Short dashed lines show the modern height of glaciers adjacent to each site. Complete ^{10}Be data and exposure ages are given in the supporting material on *Science* Online. (B) Mount Rea and The Billboard. Filled circles in (B) are samples from the main massif; open circles are samples from the col between Mount Rea and Mount Dolber to the southeast. (**Inset**) Apparent ages of pre-exposed clasts from the upper slopes of Mount Rea and The Billboard. (C) Mount Blades (filled circles) and Mount Passel (open circles). Upper short-dashed line shows glacier height south of Mount Passel; lower short-dashed line shows the height of the Arthur Glacier at Mount Blades. (D) Fleming Peaks. (E) Mount Darling and Mount Spencer. (**Inset**) Apparent ages of two pre-exposed clasts from the foot of Mount Spencer. (F) Mount Van Valkenburg (filled circles) and an unnamed moraine-covered peak in the eastern Fosdick Mountains (open circles). Upper short-dashed line shows height of the Boyd Glacier south of Mount Van Valkenburg; lower short-dashed line shows glacier height near the Fosdick Mountains site.

finding is consistent with our evidence that ice thickness reached a maximum prior to 10,000 years B.P. at the coast. The difference likely reflects the time required for changes in slope and thickness caused by deglaciation at the coast to propagate up flow lines to the center of the ice sheet (*20*, *21*).

Our data show that the ice sheet was at least 700 m thicker than present at the coast, tapering to ~200 m thicker 80 km inland at Mount Van Valkenburg. Several lines of evidence suggest that the maximum ice sheet stood considerably higher than this. First, marine geophysical surveys in Sulzberger Bay indicate that grounded ice extended to the shelf break during the LGM (*22*) and would have required a steep surface profile, and thus thick inland ice, to drive flow across the rough bedrock sea floor. Second, evidence of widespread glacial erosion at low altitudes in the Ford Ranges attests to a sliding ice sheet thick enough to reach its pressure melting point at its base. Third, ice-sheet modeling (*23*) and flow-line calculations (*12*) reconstruct an LGM ice surface altitude of 1200 to 1500 m over this sector of the ice sheet (fig. S1).

The consistency of the exposure age versus elevation trends shown in Fig. 1, B to F, indicates steady deglaciation since the first of these peaks emerged from the ice sheet some time before 10,400 years ago. Inland, the ice thinned continuously at rates of 2.5 to 9 cm/year. These changes in glacier thickness reflect the balance between snowfall over the catchment upstream from each site, ablation, and outflow. The balance in this region has been negative throughout the Holocene. Antarctic ice cores show that snow accumulation rates increased by two to five times over the transition from full-glacial to Holocene climatic conditions (*24*, *25*), and this effect likely delayed deglaciation in Marie Byrd Land. However, there is no evidence of a similar delayed response in East Antarctica, where deglaciation was complete before ~8000 years B.P. (*26*).

Ice abutting the seaward peaks thinned gradually up to ~3500 years ago, then dropped abruptly in the next 1200 years. The margin of the Arthur Glacier on the northeast flank of Mount Rea dropped from an elevation of 490 m at 3300 ± 200 years B.P. to less than 160 m by 2400 ± 200 years B.P. Likewise, ice that once flowed from the Arthur to the Boyd Glacier through the col between Mount Rea and Mount Dolber thinned and separated 2400 ± 200 years ago, exposing the col at 350 m. Both glaciers then dropped to their present elevations within a few hundred years, a time span that is not resolvable within the uncertainty of the exposure ages (*27*). Similar changes occurred at Mount Passel. The rapid thinning and subsequent stabilization of ice levels at the foot of both peaks are consistent with encroachment of the grounding zone about 2400 years ago. Flotation and thinning of steeply sloping ice upstream of the grounding zone as it moved inland would have caused rapid, localized drawdown of ice on nearby peaks. On the basis of present-day surface gradients, the observed elevation changes suggest ~30 to 40 km of grounding line retreat since 3500 years B.P. (fig. S1).

Our results add to the evidence that West Antarctic deglaciation continued long after the disappearance of the Northern Hemisphere ice sheets and may still be under way. Ice in the Ross Sea remained grounded north of Ross Island until at least 9400 years B.P., and the grounding zone passed to the south of Hatherton Glacier, at 80°S on the western Ross Sea coast, at ~6800 years B.P. Grounding-line retreat in the eastern Ross Sea isolated Roosevelt Island (79°S) between 4000 and 3000 years B.P. (*28*). Satellite images show that the grounding line has retreated at rates up to ~120 m/year since the 1960s along parts of the Siple Coast (*29*), although whether this is the continuation of the long-term deglaciation trend or is due to unsteady motion of the Siple Coast ice streams is uncertain (*30*, *31*). Although the ice sheet in Marie Byrd Land is largely grounded above sea level, it shows the same pattern of steady, Holocene deglaciation as the marine ice sheet in the Ross Sea. Ice in both regions has thinned and retreated since 7000 years ago, when the last remnants of the LGM ice sheets disappeared in the Northern Hemisphere, and there is strong evidence that the limit of grounded ice in both regions [and in Pine Island Bay (*32*, *33*)] is still receding.

Nakada and Lambeck (*34*) argued that Antarctic deglaciation must have continued into the late Holocene, in order to explain sea level changes on tectonically stable coasts far from the influence of glacio-isostatic rebound (*35*). Although there is evidence of localized advance and retreat of Antarctic glaciers in this period (*36*, *26*), Nakada and Lambeck argued for a substantial net loss of ice. More recent data compilations and sea-level modeling (*37–40*) call for meltwater addition equivalent to 3 to 5 m of sea level (from Antarctica and other sources), mostly in the period 7000 to 3000 years B.P. Our data show that part of this meltwater came from West Antarctica. If the deglaciation history of the Ford Ranges is representative of the Marie Byrd Land coast, the total loss of ice from this sector would have contributed ~0.4 m of equivalent sea level (esl) since 10,000 years B.P., about half to three-quarters of which would have entered the oceans since 7000 years B.P. (*41*). Moreover, the pattern of recent change is consistent with the idea that thinning of the WAIS over the past few thousand years is continuing, and is contributing to present sea level rise.

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19. Reconstructing the surface slope and elevation of the Boyd Glacier from transects on Mount Darling, Mount Blades, and Mount Rea (fig. S1) shows that a cluster of ~1100-m peaks in the eastern Sarnoff Mountains may have stood above the LGM ice surface. We examined these peaks but found no glacial deposits on them. Either flow lines terminating on their flanks did not connect with debris sources upstream or the peaks were capped during the LGM by a small local ice dome flowing outward.
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of thinning depend on whether the erratics emerged from beneath through-flowing glacier ice at a time when the glaciers abutted the peaks directly or after the present pattern of skirting ice fields developed. In the first case, glacier axes must have stood higher than the erratics at the time of deglaciation. In the latter case, the elevations of the glacier axes may not have changed much since deglaciation. Although this makes it difficult to resolve very recent changes, it is a minor consideration for samples located hundreds of meters above the modern glaciers.
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Orangutan Cultures and the Evolution of Material Culture

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Geographic variation in some aspects of chimpanzee behavior has been interpreted as evidence for culture. Here we document similar geographic variation in orangutan behaviors. Moreover, as expected under a cultural interpretation, we find a correlation between geographic distance and cultural difference, a correlation between the abundance of opportunities for social learning and the size of the local cultural repertoire, and no effect of habitat on the content of culture. Hence, great-ape cultures exist, and may have done so for at least 14 million years.

Among the numerous definitions of culture, the idea that it is a system of socially transmitted behavior is particularly useful for comparative purposes (*1*). Because the creation of culture under experimental conditions illuminates neither the extent of culture among wild animals nor its content, documenting culture's existence in nature remains essential. Unfortunately, this task is not easy; even if a study lasts long enough to show that a newly observed variant is an innovation, it remains difficult to demonstrate convincingly that the variant's acquisition by others is guided by social transmission. However, recent work on chimpanzees has shown geographic patterns in many behavioral variants that are consistent with the operation of cultural processes. A variant is considered cultural if it is customary (shown by most or all relevant individuals) or habitual (shown by at least several relevant individuals) in at least one site but is absent in at least one other ecologically similar site (*2*, *3*). Intraspecific genetic variation is almost certainly not responsible for these patterns (*4*).

Critics have stressed that the geographic approach may generate a type I error, spuriously leading us to conclude that cultures exist, when in fact unrecognized ecological differences between sites have produced within-population convergence and between-population divergence through individual learning (*5–7*). Hence, further tests are essential to increase our confidence in a cultural interpretation (*8*, *9*).

Orangutans (*Pongo pygmaeus*) showing variation in two forms of tool use consistent with culture (*10*, *11*) provide an opportunity for further testing. Here, we systematically apply the geographic approach to six different wild orangutan populations in Borneo and Sumatra (*12*) and test additional predictions derived from a cultural interpretation.

Table 1 lists three categories of geographic variants (*13*): (i) very likely cultural variants, which are behaviors present in at least one site at customary or habitual levels and absent elsewhere without clear ecological differences; (ii) likely cultural variants [as in (i) above] for which ecological explanations for absence, though unlikely, cannot be excluded; and (iii) rare variants that are unlikely to be maintained by social transmission. We shall refer to the first two as "putative cultural variants."

The list of putative cultural variants at the six sites (Fig. 1) contains 24 elements; an additional 12 local variants did not spread to customary or habitual level at any site. Data from additional sites would expand the list (*14*), as it does for chimpanzees (*3*). Of the putative cultural variants, 10 involve specialized feeding techniques, including tool use, and 6 are alternative forms of social signals, such as kiss-squeaks. As in chimpanzees (*2*, *3*), some variants may come close to reflecting shared meaning based on arbitrary symbols. In particular, the "raspberry" vocalizations, emitted in the

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