derived from studies funded privately, but cannot be used to derive new cell lines from blastocysts. Obviously, if the procedure is legally prevented, the embryos will not be created (at least not with federal funds) and the question of their full development will remain moot.

The nuclear transfer procedure is required for both ES cell therapy and for cloning. This methodological identity has led to confusion of the two in people's minds. To avoid this problem, the terms therapeutic cloning and reproductive cloning have been introduced, but these terms must be precisely defined and the public constantly reminded of the definitions. Therapeutic cloning would involve transfer of the nucleus with the desired genetic material into an enucleated oocyte, development of the oocyte to the blastocyst stage, and derivation of ES cells from the blastocyst for therapeutic purposes. But if the blastocyst is allowed to develop into a newborn, which is then used as an organ donor, the result is also therapeutic but clearly not permissible. To avoid these difficulties, it would be much better to reserve the term cloning to describe reproductive cloning.

Current attempts at reproductive cloning in livestock and laboratory animals indicate that it is not a very safe procedure. The majority of clones fail sometime during development, and some fail after birth. If the recent "success" of cloning cows in which four out of eight calves died soon after birth (*12*) is anything to go by, it would be irresponsible and unethical to attempt the cloning of humans because this would almost certainly condemn a large fraction of the infants to death or malformation. We know very little about the events involved in reprogramming the nucleus—activation of previously silent genes, initiation of DNA synthesis, alteration in chromatin structure—and even less about the molecular pathways set in motion once the adult nucleus is placed into an enucleated oocyte.

For most, the term cloning means the creation of an exact genetic duplicate of the nuclear donor. The technique of nuclear transfer, however, can be used in assisted reproduction in such a way that cloning is avoided. Preliminary results in mice, for example, suggest that infertile couples whose infertility is caused by the lack of germ cells in one or both partners can be helped in this way. The nuclei from somatic cells of the infertile couple could be transferred to enucleated germinal-stage oocytes and, after meiosis, two haploid genomes (one from each parent) could be combined in a single oocyte. If this approach worked, the resulting child would be a random genetic combination of the parental genomes, the same as every other human.

It is our view that these and other benefits of nuclear transfer and cloning far outweigh the possible harm, but they can only be achieved through determined experimental effort. It will ultimately be up to society to decide which way to go, but one must hope that the decision will be an informed one and not based on irrational fear, ignorance, and prejudices.

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PERSPECTIVES: MARTIAN CLIMATE

A Message from Warmer Times

Matthew P. Golombek

When the Sojourner rover crawled over the martian surface last year, the images returned by the mission indicated that the site had changed little from when it was created by catastrophic floods some 1.8 to 3.5 billion years ago (Ga) (*1, 2*). This observation provides quantitative constraints on the rate of change at the landing site since that time. The Pathfinder data, taken together with those from the recent Global Surveyor missions and the 20 year old data from the two Viking landers, suggest an early warmer and wetter environment with vastly different erosion rates and a major climatic change on Mars between then and now.

Pathfinder observed a rocky surface composed of ridges and troughs, perched, imbricated, and partially rounded tabular rocks, and streamlined hills that is analogous to catastrophically deposited fans on Earth, such as the Ephrata Fan of the Channeled Scabland in Washington State (*1–4*). This similarity argues for the site being little altered since it formed (*4*) roughly 1.8 to 3.5 Ga (*5*).

Erosional features such as an exposed former soil horizon, sculpted wind tails, coarse pebble-rich surfaces (see figure), and ventifacts (rocks abraded by windborne particles) are abundant at the Pathfinder landing site, suggesting that the site has undergone net deflation or loss of material (*2, 6*). The 5- to 7-cm-thick redder band along the base of several rocks, interpreted as a deflated soil horizon, and the sculpted erosional wind tails behind rocks that are less than 3 cm high (*2, 6*) suggest extremely low deflation rates of around 0.01 to 0.04 nanometers (1 nm = 10^{-9} m) per year. Coarse pebble-rich surfaces and at least some of the dunes, such as Mermaid Dune, appear to be composed of poorly sorted material beneath an armoring veneer of dark gray granules, as could be seen in the trenches created by the rover. These have been interpreted as lag deposits (*7*) left behind after loss of finer windborne material, and thus also indicative of net erosion or deflation of the landing site. The presence of fluted and grooved rocks also argues for erosion crystalline sand-size particles carried by the wind (*8*). In contrast, wind deposits at the Pathfinder site are limited to a few dunes, including a crescent-shaped feature imaged by the rover. These features were most likely formed from sand-size grains entrained in the wind (*6*). The immaturity of the ventifacts and their different orientation from the dunes and wind trails has led to the suggestion that the dunes may have formed earlier when the supply of sand-size particles was greater (*8*).

The rim heights of small craters at the site are similar to those expected for fresh martian craters. This places similar (<1 nm/year), albeit less precise, constraints on erosion rates at the Pathfinder (*9*) and the Viking 1 landing sites (*10*) and suggests that a cold and dry environment, similar to today's, has prevailed since 3.1 to 3.7 Ga.

A variety of observations by Pathfinder indicate that the earlier martian climate was warmer and wetter than today's desiccating environment. Rounded pebbles and cobbles (*7*), evidence for abundant sand-size particles (*6*), and possible conglomerates (*7*) at the Pathfinder landing site sug-

The author is at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA. E-mail: mgolombek@jpl.nasa.gov

Cold and dry for eons. Mosaic of the Mars Pathfinder landing site and the Sojourner rover acquired in the late afternoon of its second day on the surface of Mars. The low sun emphasizes the bright wind tails behind rocks such as Barnacle Bill and others immediately to the left of the rover. The sculpted appearance of these wind tails suggests that they are dominantly erosional forms. The pebbly surface on which the rover sits and the dark areas to the right of the rover are interpreted as a lag deposit in which finer grained particles have been removed by the wind.

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gest an early fluvial environment with relatively abundant liquid water. Airborne dust particles collected by the Pathfinder magnetic targets further support this hypothesis (*11*). The particles are composite silicates containing a highly magnetic mineral interpreted to be maghemite. This mineral may have freeze-dried as a stain or cement from liquid water that had previously leached iron from crustal materials in an active hydrologic cycle. Sand is most likely present at the Pathfinder landing site and trapped sand dunes appear to be abundant elsewhere on Mars in orbiter images (*12*). On Earth, sand typically forms via water-dominated weathering, erosional and depositional processes that mechanically break down rocks into smaller fragments (*13*), which may be another indicator of a warmer and wetter past on Mars.

The suggestion that the early martian environment was warmer and wetter is not new [see, for example (*14*)]. Valley networks (one of which shows a central fluvial channel formed by running water in high resolution, about 10 m/pixel, Mars Global Surveyor images) and associated dry lake beds (*14*); possible shore lines, beaches, and terraces inferring a northern ocean (*15*); and rimless, degraded craters in ancient heavily cratered terrain (*16, 17*) have all been described in Viking orbiter images and used to argue for a warmer and wetter past in which liquid water was present. Erosion rates calculated from the erosion of impact craters in ancient heavily cratered terrains estimated to be older than 3.5 Ga (*5*) are 3 to 6 orders of magnitude higher (0.1 to 10 μm/year) than those calculated for more recent times and are comparable to those in slow erosion environments on Earth (*16, 18*).

Our knowledge of the martian surface layer developed from global imaging (average 250 m/pixel) and thermal inertia measurements from the two Viking orbiters, and from imaging of the Viking and Pathfinder landing sites from the surface and orbit agrees with the very slow erosion rates described above. These observations suggest that since 3.1 to 3.7 Ga, a surface layer of order meters to up to several tens of meters thick has been redistributed around Mars (*19*). This layer likely consists of sand- and dust-sized particles that are collected and transported by the wind (*20*). Dust can be deposited and removed at much higher rates over short time periods than the rates discussed above, which represent averages over long time periods. For example, deposition of dust on Pathfinder's solar panels during the 3 months of the mission has been estimated at roughly 20 μm/year (*7, 21*). But this value cannot represent long-term averages, as such high rates would result in the accumulation of meters of dust within a comparatively short span of a million years. However, there seem to be other areas that are net sinks for this material. For example, Amazonis Planitia's thermal inertia, radar, and imaging properties suggest that this is an area with dust accumulations several meters in thickness (*19*). The large region of sand dunes surrounding the polar cap may be another sink (*20*). In contrast, areas such as the Pathfinder landing site appear to have been swept clean or even deflated.

All these data seem to point to a significant climatic change at some time in the past, but exactly when this occurred is not tightly constrained because of uncertainties between the density of craters and absolute age of martian surfaces (*5*). All three landings on Mars have been on surfaces that document extremely slow erosion rates, with crater densities that suggest the present-day dry desiccating environment since 3.1 to 3.7 Ga. In contrast, valley networks appear to be dominantly >3.5 to 3.8 Ga in age (*14*). The impact degradation of many valley networks further suggests that they may have formed at the tail end of heavy bombardment around 3.9 Ga (*22*). Clues to climate change on Mars will come from the Mars Global Surveyor, Mars Climate Orbiter, and Mars Polar Lander missions; future lander and rover missions that explore ancient terrain in situ will also help to uncover the nature of the early environment on Mars.

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