channel genesis as a function of channel type and morphology, slope, elevation, age, latitude, type of material dissected, and proximity to specific geologic features. In turn, the influence on channel origin by possible global or local anomalous climates may be assessed.

Although some work has been done to assess the timing of erosion and crater obliteration along the highland/lowland boundary [e.g., 28,29], we still know little about the volume of material eroded. We intend to measure depths of dissection by using photoclinometry, which will enable us to estimate these volumes of eroded material (and, consequently, volumes deposited in the northern plains).

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POLAR SEDIMENT ACCUMULATION: ROLE OF SURFACE WINDS AT THE TWO POLES. P. C. Thomas and P. J. Gierasch, CRSR, Cornell University, Ithaca NY, USA.

The accumulation of the large deposits of volatile and nonvolatile sediments at both martian poles has occurred through periods of likely climate change. Most data on wind directions near the martian poles and seasonal activity relate to a very short period of time, at one point in climate cycles. It is still uncertain what the net budgets to the poles are and how this budget (if known) would fit into longer climate/sediment cycles. Pending further data we examined the full suite of Viking high-resolution, high-latitude images for wind markers of all sizes and types. These probably represent timescales of formation from days to several tens of thousands of years. The goal is to estimate the effectiveness, and possible drivers, of wind systems that bring materials near the surface to the regions of polar sediments, and also remove materials from the polar areas.

The simple polar vortex model of French and Gierasch [1] accounts for only a part of the observed features; most particularly it lacks the poleward flow seen near 75–80 latitude in both polar regions, but especially the north. Observations of crescentic dunes, framing dunes, and some wind streaks show confinement of the north polar erg by off-pole winds near the margins of the layered deposits and prograde, on-pole winds slightly farther south. The on-pole winds have formed features as transitory as wind streaks and as long lived as large framing dune complexes. Exceptions to the pattern of confining, on-pole wind directions occur in some longitudes and might be due to topographic control. The present topographic data are inadequate to model these effects. In the south, intracrater dune fields are imaged well enough to show field orientations, and thus very-long-term winds, but the bedforms are largely transverse with 180° ambiguities in wind directions. Streaks show some on-pole flow, but in a retrograde sense.

It is desirable to discriminate between feedback effects, such as the dunes' low albedos, that might confine the winds to a narrow belt, and causes that are independent of the dune presence, which would allow poleward transport of the sand and some dust at the surface, for inclusion in the polar deposits. Surface transport of the saltating materials to the polar regions would remove the dilemma of saltating materials being present in deposits thought to be made up of suspension load and condensed volatiles.

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N94- 33234 3

S44-91 ABS. ON

THE MARTIAN SOURCES OF THE SNC METEORITES (TWO, NOT ONE), AND WHAT CAN AND CAN'T BE LEARNED FROM THE SNC METEORITES. A. H. Treiman, Code C-23, Lockheed Engineering and Sciences Co., 2400 NASA Road 1, Houston TX 77258, USA, now at Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113, USA.

The SNC meteorites almost certainly from the martian crust, have been inferred to come from a single impact crater site, but no known crater fits all criteria. Formation at two separate sites (S from one, NC from the other) is more consistent with the sum of petrologic, geochronologic, and cosmochronologic data, and eases crater selection criteria. If the source craters for the SNC meteorites can be located, Mars science will advance considerably. However, many significant questions cannot be answered by the SNC meteorites, and await a returned sample.

Introduction: The SNC meteorites are rocks of basaltic parentage, inferred to be samples of the martian crust, and have been important in providing "ground truth" to other observations of Mars throughout the MSATT and predecessor programs. Although the SNCs have provided essential information on mantle and magmatic processes, the hydrosphere, and the composition of the atmosphere, their utility is limited because their source site(s) on Mars are not known. The most comprehensive effort at determining a source impact crater for the SNC meteorites [1] was not entirely successful, as no martian crater met all the criteria for an SNC source. However, it seems likely that the SNC meteorites came from two separate sources on the martian surface, and a number of craters fit this relaxed criterion.

If efforts toward determining the martian sources of the SNCs are successful, we will reap a bountiful harvest of knowledge about Mars. However, the SNC meteorites cannot tell about the whole planet of Mars, and many significant questions will remain, answerable only by analysis of returned samples.

Source(s) for SNC Meteorites: Most studies have inferred that the SNC meteorites originated near a single source crater on Mars [1–4, but see 5,6]. The source crater has been inferred to be on or near Tharsis, home to the youngest basalt flows on Mars [1–4], because the SNCs all formed from basaltic lavas and are all quite young in planetary terms (Table 1). Nine potential source craters in Tharsis were located by [1], but none satisfied all known (or presumed) constraints.

Two Source Craters: S ≠ NC. Rather than invoking a single source crater, it is more plausible that the SNC meteorites originated from two separate sites. Support for this hypothesis follows from the profound differences between the shergottites (S) and the nakhlites and Chassigny (NC), the extent of which has not been appreciated.

Some of these differences are given in Table 1, from which it is clear that S and NC have been distinct at every stage of their development, from mantle through eruption through alteration through impact ejection. The most parsimonious conclusion from these data is that NC and S had essentially nothing to do with each other. They most likely formed at different sites on Mars, and were ejected from Mars as small meteoroids at the ages indicated by their cosmic ray exposures. (The cosmic ray exposure age of the shergottite EETA79001 is 0.5 m.y. [5], which probably dates a disruptive collision in space [15]). Problems related to the two-crater hypothesis [4] are discussed below.

Problems with Single-Crater Origins: The current paradigm for SNC origins, that they were ejected from Mars in a single impact event [1–5], seems unconvincing in detail. The size of the ejection crater is unconstrained by geology or petrology. A large crater might overlap two distinct terranes (for S and NC); a small crater might have impacted a thin veneer of younger basalt (S) over older (NC).

Ejection at ~180 m.y. [1–4] could be consistent with the SNC cosmic ray exposure ages only in the following scenario: (1) At least two boulders (>5 m diameter [5]) were ejected, one each for S and NC; (2) Two of these boulders were disrupted in space to form meter-sized and smaller fragments at 11 m.y. and 2.8 m.y., the precise (within error) cosmic ray exposure ages of all NC and all S respectively to form meter-sized and smaller fragments; (3) Following disruption in space, fragments that had been exposed to cosmic rays for ~180 m.y. were segregated from those that were totally shielded; and (4) Following both disruptions, all of the fragments that had been exposed to cosmic rays for ~180 m.y. were prevented from entering Earth-crossing orbits. Events (1) and (2) are plausible, but (3) and (4) strain credulity.

Ejection at a younger age, 11 m.y. to satisfy the cosmic ray exposure ages of NC (discussed in [4,5]), would require equally difficult scenarios. If the SNCs had been ejected as a single boulder, its core must have been all S and its rind all NC to satisfy cosmic ray exposure ages. This watermelon model of an SNC meteoroid seems fanciful. On the other hand, the NC could have been ejected as small meteoroids and S ejected as a meteoroid so large its core was shielded from cosmic rays. In this case, events like (3) and (4) from the paragraph above must have occurred, and credulity is again strained.

TABLE 1. Selected properties of SNC meteorites.

	S	NC
Source Nd/Sm, Rb/Sr, etc.	Enriched (>CI) [7]	Depleted (<CI) [8,9]
Magma incompatible elements	Depleted (>CI) [10]	Enriched (<CI) [8,9]
Crystallization age	~180 m.y. [11]	~1250 m.y. [8,9]
Preterrestrial aqueous alteration (where present; all include salts)	Aluminosilicate [14]	Smectite-iron oxide [12,13]
Shock pressure (maskelynite vs. plagioclase)	»29 GPa	<29 GPa
Cosmic ray exposure age	2.8 ± 0.3, 0.5 m.y. [5]	11 ± 1 m.y. [5]

Implications of Two-Crater Model: If the SNC meteorites originated in two separate craters on the martian surface (as implied by petrology, geochronology, and cosmochronology), some other inferences about Mars must be revised.

First, some of the objections to the nine potential source craters of [1] are removed. It is no longer required that a single crater have access to all SNC lithologies, so craters in monolithologic, simple units are permitted. Among the choices of [1], S could have come from their craters 1, 3, 7, or 9 and NC could have came from craters 2 or 4–9.

Second, one of two current understandings of Mars must be incorrect: Either the mechanics of ejecting rock from Mars, or absolute ages inferred from crater-counts. If the ages are nearly correct, ejection of rock Mars to solar orbit must be possible with craters of 35 km (Table 1 of [1]), smaller than the 50 km suggested by current understanding of crater formation and rock ejection [4]. So either the mechanics are inaccurate to a factor of 1.5 or the ages inferred for the young martian surfaces are too old.

Third, the absence of meteorites from the older martian terranes must now be explained. In single-crater models, the lack of meteoroids from the older terranes, >95% of the Mars surface [1], can be ascribed to chance. But the odds of the only two meteorite-forming impacts on Mars hitting the young terrane are 0.0025. It is most likely that the older terranes have experienced impacts that could have yielded meteoroids. Perhaps the physical properties of the older terranes prevent ejection of meteorites, or perhaps meteorites from the older terranes do fall on Earth and are not recognized (e.g., granite, sandstone, or limestone?).

What If We Locate the SNC Source Craters?: If the source craters for the SNC meteorites can be located, following the method of [1], our understanding of Mars will be advanced significantly. First, it will be possible to assign absolute dates to martian crater-count chronologies, at least at the young end. This will remove some considerable uncertainties from models of the history of Mars (e.g., cooling, volatiles, etc.). Second, knowing the geologic settings of the SNCs will permit understanding of their aqueous alteration histories in terms of real martian geology, and greatly advance knowledge of the reservoirs of water on Mars. Third, we will be able to calibrate remote sensing data (both in hand and in the future) against known lithologies. These advances are only a few among many possibilities.

But the SNCs cannot answer all the important questions about Mars. No matter how much is learned from the SNCs, they cannot replace a carefully considered successful Mars sample return mission. The SNCs are limited because they represent only one type of sample formed during a small part of Mars' history on a small part of Mars. For instance, continued study of the SNCs cannot determine: the mineralogy and origin of the martian dust; the abundances of many reactive gas species in the martian atmosphere; the natures and compositions of the martian highlands; the compositions of paterae volcanics; the natures and compositions of layered deposits; and whether living organisms ever existed on Mars. To solve these questions will require continued spacecraft investigations of Mars, including orbiters, landers, and especially sample returns.

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S4591 ABS

TEMPORAL CHANGES IN THE GEOGRAPHIC DISTRIBUTION, ELEVATION, AND POTENTIAL ORIGIN OF THE MARTIAN OUTFLOW CHANNELS. S. Tribe[1] and S. M. Clifford[2], [1]University of British Columbia, Canada, [2]Lunar and Planetary Institute, Houston TX 77058, USA.

Introduction: Observational evidence of outflow channel activity on Mars suggests that water was abundant in the planet's early crust. However, with the decline in the planet's internal heat flow, a freezing front developed within the regolith that propagated downward with time and acted as a thermodynamic sink for crustal H_2O. One result of this thermal evolution is that, if the initial inventory of water on Mars was small, the cryosphere may have grown to the point where all the available water was taken up as ground ice. Alternatively, if the inventory of H_2O exceeds the current pore volume of the cryosphere, then Mars has always possessed extensive bodies of subpermafrost groundwater. We have investigated the relative age, geographic distribution, elevation, and geologic setting of the outflow channels in an effort to (1) identify possible modes of origin and evolutionary trends in their formation, (2) gain evidence regarding the duration and spatial distribution of groundwater in the crust, and (3) better constrain estimates of the planetary inventory of H_2O.

The channels studied in this analysis were compiled from a variety of sources and include virtually all major channels identified in the literature whose bedforms exhibit significant evidence of fluvial erosion. Following a review of previously published work, these channels were investigated by a detailed examination of selected Viking photomosaics and high-resolution images. Where possible, channel ages were determined by reconciling previously published crater counts with those associated with the revised stratigraphic referents of Tanaka [1]. Where inconsistencies or conflicts in these ages were noted, the discrepancies were usually resolved by examining superpositional relationships with other units whose relative ages are better constrained. In the discussion that follows, all cited elevations refer to that of the channel source region or, in those instances where no identifiable source region is visible, the highest elevation at which the channel is first visible. All elevations are based on the U.S.G.S. Digital Terrain Model [2].

Observations and Discussion: Although there is considerable uncertainty regarding when the first outflow channels actually formed, three of the oldest—Ma'adim Vallis (–27°,183°), Al-Qahira Vallis (–19°,199°), and Mawrth Vallis (19°,13°)—are probably Late Noachian to Early Hesperian in age [1,3,4]. A fourth and much larger channel, located near Argyre (–65°,55° to –57°,46°), is also thought to date from this period [5]. A characteristic common to all four channels is their lack of a localized and readily identifiable source region, an observation that may reflect a subsequent period of intense localized erosion or possible burial by lavas and sediments. Whatever the explanation, the highest elevations at which three of the channels appear lie between 2 and 3 km, while the highest elevation of the fourth—Mawrth Valllis—occurs near 0 km. No statistically significant geographic clustering of these four channels is observed. Although Ma'adim Vallis and Al-Qahira Vallis are located within ~800 km of each other, the area of channel activity defined by this association is geographically distinct from the areas defined by the locations of the other two channels. This spatial separation, combined with the absence of any unique geologic characteristic common to the local environment of all four channels, suggests that the earliest martian outflow channels had a polygenetic origin.

As noted by previous investigators, outflow channel activity reached a conspicuous peak during the Late Hesperian. The majority of this activity was concentrated in and around the Chryse area; however, other regions of potential activity included Deuteronilus Mensae (42°,338°), Mangala Vallis (–19°,149°), as well as a number of smaller channels to the south of the Chryse system—including Nirgal Vallis (–28°,45°) and Uzboi Vallis (–29°,36°).

The abrupt emergence of the Chryse channels from regions of chaotic terrain is usually attributed to the widespread disruption and subsidence of the crust due to the catastrophic discharge of groundwater [e.g., 6]. Areas of chaos range from ~1000 km^2 for the source of Shalbatana Vallis (0°,46°), to over 25,000 km^2 for the chaos at the eastern end of Valles Marineris in Capri Chasma (–15°,52°). These areas are comparable to those affected by prolonged, high-volume groundwater extraction on Earth (e.g., extensive pumping in the San Joachim valley of California has resulted in up to 9 m of subsidence over an area of 13,500 km^2 [7]).

The spatial and temporal association of the Chryse outflow channels with the development of Valles Marineris and Tharsis has frequently been cited as evidence of a possible genetic relationship [6,8]. In this context, several mechanisms for initiating outflow channel activity appear viable. For example, prior to the development of Valles Marineris and Tharsis, Mars may well have possessed an extensive aquifer system consisting of subpermafrost groundwater confined beneath a thick (>1-km) layer of frozen