Climate change and the collapse of the Akkadian empire: Evidence from the deep sea

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ABSTRACT

The Akkadian empire ruled Mesopotamia from the headwaters of the Tigris-Euphrates Rivers to the Persian Gulf during the late third millennium B.C. Archeological evidence has shown that this highly developed civilization collapsed abruptly near 4170 ± 150 calendar yr B.P., perhaps related to a shift to more arid conditions. Detailed paleoclimate records to test this assertion from Mesopotamia are rare, but changes in regional aridity are preserved in adjacent ocean basins. We document Holocene changes in regional aridity using mineralogic and geochemical analyses of a marine sediment core from the Gulf of Oman, which is directly downwind of Mesopotamian dust source areas and archeological sites. Our results document a very abrupt increase in eolian dust and Mesopotamian aridity, accelerator mass spectrometer radiocarbon dated to 4025 ± 125 calendar yr B.P., which persisted for ~300 yr. Radiogenic (Nd and Sr) isotope analyses confirm that the observed increase in mineral dust was derived from Mesopotamian source areas. Geochemical correlation of volcanic ash shards between the archeological site and marine sediment record establishes a direct temporal link between Mesopotamian aridification and social collapse, implicating a sudden shift to more arid conditions as a key factor contributing to the collapse of the Akkadian empire.

Keywords: Holocene climate, Middle East, civilization collapse.

INTRODUCTION

Mesopotamia is the broad, flat alluvial plain between the Tigris and Euphrates Rivers in what is today Syria and Iraq (Fig. 1). Under the rule of Sargon of Akkad, the world's first united empire was established in this region, linking the remote agricultural hinterlands of northern Mesopotamia with the complex city-states in the south. This united empire extended from the Persian Gulf to the headwaters of the Tigris and Euphrates Rivers from ca. 4300 to 4200 B.P. Particularly important to the success of the Akkadians was the fertile, rain-fed agricultural production of the wide, northern Mesopotamian plains. Over this broad geographic area, the Akkadians imperialized agricultural production and controlled long-distance trade. After <100 yr of prosperity, the Akkadian empire collapsed abruptly near 4200 B.P. (Weiss et al., 1993). Resettlement by smaller sedentary populations occurred ~300 yr later (3900 B.P.).

Archeological investigations from the excavation site at Tell Leilan in northeast Syria (Fig. 1) have suggested that a major environmental change associated with the Akkadian collapse occurred near 4200 B.P. Tell Leilan, one of three major city-states in northeast Syria to be integrated into the Akkadian empire, was a provincial capital and primary provider of imperialized cereal production. Immediately above the collapse horizon at Tell Leilan and the nearby site Abu Hgeira, archeologists noted a thin (0.5 cm) volcanic ash layer overlain by a thick (100 cm) accumulation of well-sorted, wind-blown silts which were barren of artifacts. Weiss et al. (1993) interpreted this soil sequence to reflect the sudden onset of more arid conditions, which may have contributed to the observed collapse. This soil micromorphological evidence, however, is inherently subjective and may reflect localized phenomena unrelated to larger scale regional aridification.

The Akkadian collapse had been previously attributed to human factors, including invaders and political disintegration (Yoffee and Cowgill, 1988). Whether the Akkadians were an example of social collapse resulting from climatic degradation (Hodell et al., 1995; Sandweiss et al., 1999) or whether this collapse was related to external or internal social factors may be resolved by an independent record of Holocene paleoclimatic variations in Mesopotamia as preserved in a marine sediment core from the Gulf of Oman.

MESOPOTAMIAN CLIMATE AND DUST TRANSPORT

The climate of northern Mesopotamia is characteristically semiarid, with strong seasonality in both precipitation and temperature. Winters are cool and wet (100–300 mm/yr), whereas summers are hot, very dry, and marked by a persistent northwest wind known locally as the shamal (Fig. 1). Winter precipitation results from the eastward penetration of Atlantic and Mediterranean rain-bearing cyclones embedded within the mid-

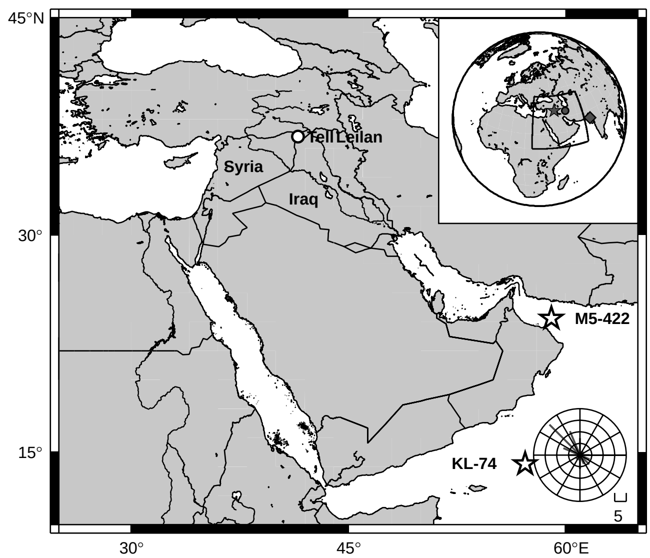

Figure 1. Location of Gulf of Oman core M5-422 (24° 23.40′N, 59°2.50′E; 2732 m deep). Average summer (June–August) wind rose is shown in lower right. Tell Leilan archeological site and Arabian Sea core location KL-74 are also shown. Area of detail is shown in upper right with the Mesopotamian floodplain (star), Zagros Mountain (circle) and Indus River (diamond) geochemical end members.

Data Repository item 200041 contains additional material related to this article.

latitude westerly flow. The marked seasonality of Mesopotamian rainfall and wind makes this region a rich source of mineral dust to the atmosphere, with many regions reporting over 200 days per year of dust-impaired visibility (Pye, 1987). Analysis of satellite imagery and marine sediments (Al-Bakri et al., 1984; Al-Ghadban, 1990; Sirocko and Sarnthein, 1989) indicates that these mineral dusts are transported southwest by the shamal to the Persian Gulf and Gulf of Oman with an estimated mass flux of 100×10^6 tons per year (Pye, 1987). Mesopotamian dusts have characteristically high concentrations of detrital dolomite, calcite, and quartz (Al-Bakri et al., 1984; Sirocko and Sarnthein, 1989). During the more arid conditions that prevailed during the last glacial maximum and Younger Dryas, as much as 50% of the total measured calcite content in the Gulf of Oman sediments was composed of fine, silt-sized detrital carbonate eolian grains (Sirocko, 1989; Sirocko et al., 1993). Dolomite concentration variations in northwest Indian Ocean sediments have been used previously to reconstruct late Pleistocene variations in Mesopotamian aridity (Sirocko, 1989; Sirocko et al., 1993).

METHODS AND AGE CONTROL

Core M5-422 (Fig. 1; 24°23.40′N, 59°2.50′E; 2732 m deep) from the Gulf of Oman was continuously subsampled at 2 cm intervals to reconstruct a marine sediment record of Holocene variations in regional aridity. The position of this core within the Mesopotamian dust trajectory and its distal location away from shelf and slope redeposition sources make it ideal for determining past changes in Mesopotamian climate. An oxygen isotopic stratigraphy from analyses of *Globigerinoides ruber* (Fig. 2) indicates average Holocene sedimentation rates of 15 cm/k.y., as the deglacial transition occurs at a depth of 150 cm, and our temporal resolution averages about 100 yr (Fig. 2). Samples were analyzed for magnetic susceptibility, calcium carbonate content, quantitative X-ray diffraction mineralogy, oxygen isotopic analyses, and Sr and Nd isotopic composition of the extracted detrital fraction using a sequential extraction technique described in Sirocko et al. (1993).

Age control was established using eight accelerator mass spectrometer (AMS) radiocarbon dates on monospecific (*G. sacculifer*) foraminifera. Conventional radiocarbon dates on mixed planktonic foraminifera (>150 μm fraction) of four samples were also obtained (Table 1).[1] Conversion to calendar ages (Table 1, see footnote 1) was accomplished using the Calib 3.03c calibration program (Stuiver and Reimer, 1993) after applying a reservoir correction of –560 yr derived for pre-bomb northwest Indian Ocean surface waters. All ages are in calendar years before present (B.P.) unless otherwise indicated. Sedimentation rates average 23 cm/k.y. over the mid-late Holocene portion of the record (past ~5000–6000 yr).

RESULTS

High abundances of detrital (eolian) dolomite and calcite at the base of core M5-422 concur with the well-documented and widespread aridity that was prevalent in Mesopotamia during the last glacial maximum and Younger Dryas cold period; dust fluxes to Arabian Sea sediments were two to five times greater than present values during the last glacial maximum (Clemens and Prell, 1990; Sirocko, 1989; Sirocko et al., 1993). By 11 500 B.P. the region became abruptly more humid due to the well-documented intensification of the Indian monsoon. Increased humidity in the region is documented in core M5-422 by abrupt decreases in eolian dolomite and calcite concentrations commencing near 145 cm (ca. 12 000 B.P.; Fig. 2) and is also documented by parallel changes in eolian deposition and monsoon-related upwelling in the Arabian Sea (core 74 KL; Fig. 1) (Sirocko et al., 1996).

A dramatic mid-Holocene increase in eolian dolomite and calcite deposition occurred between 70 and 56 cm in the core, corresponding to an ~400 yr period spanning 4025–3625 B.P. based on four calibrated AMS radiocarbon ages (Fig. 2; Table 1, see footnote 1). Dolomite concentration, which reflects eolian mineral supply from Mesopotamian sources, increased from 1.5% to peak values approaching 9% by weight at 68 cm, a level dated to 4025 ± 150 B.P. We calculate that the mass flux of eolian dolomite (a component of solely eolian origin) increased from background values of 0.39–0.43 g/cm^2/k.y. to a weighted average value of 0.97 g/cm^2/k.y. during this abrupt mid-Holocene aridification event. Calcium carbonate in this core, which reflects contributions from both eolian carbonate grains as well as biogenic microfossil tests, increased from 19% to nearly 39% by weight. Under petrographic microscope, these sediments had marked increases in subrounded, well-sorted (25–30 μm) lithic dolomite, limestone, and quartz grains relative to adjacent sediments. A smaller amplitude increase in eolian dolomite and calcite concentrations was also detected at a depth of 86–90 cm (Fig. 2) within core M5-422, corresponding to about 5200 B.P., although this level was not radiocarbon dated directly.

PROVENANCE OF THE 4025 B.P. INCREASE IN EOLIAN DEPOSITION

We employed radiogenic isotope analyses (Nd and Sr) to determine the provenance of the 4025 ± 150 B.P. increase in eolian deposition. The εNd and $^{87}Sr/^{86}Sr$ isotopic signatures of marine sediments have been used previously to identify the provenance of lithic particles in marine sediments globally (Goldstein and O'nions, 1981; Grousset et al., 1988), and in the northwest Indian Ocean in particular (Dia et al., 1992). There are three principal sources of terrigenous sediments to the northwest Indian Ocean (Fig. 1), each with its own characteristic εNd and $^{87}Sr/^{86}Sr$ isotopic composition (Sirocko and Ittekot, 1992): the Zagros Mountains (Iran), the Indus River (southwestern Asia), and the Mesopotamian flood plains (Fig. 3). Estimates of the εNd and $^{87}Sr/^{86}Sr$ compositional ranges for these three end members are summarized in Figure 3. We use εNd and $^{87}Sr/^{86}Sr$ analysis to reconstruct past variations in the relative contributions of Zagros and Mesopotamian detrital sources with respect to the terrigenous sediment fraction in the M5-422 core top.

[1]GSA Data Repository item 200041, Tables 1–3, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/drpint.

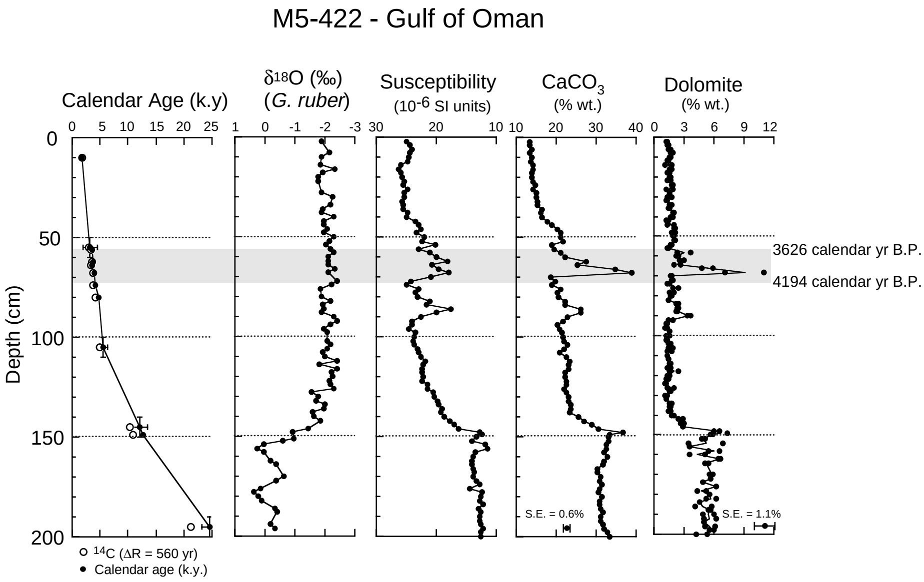

Figure 2. Core M5-422 (24°23.40′N, 59°2.50′E; 2732 m deep) increase in eolian dolomite and $CaCO_3$ between 4194 and 3626 calendar yr B.P. Conventional bulk (>150 μm fraction) radiocarbon analyses are shown with error bars, respective analytical precisions are shown.

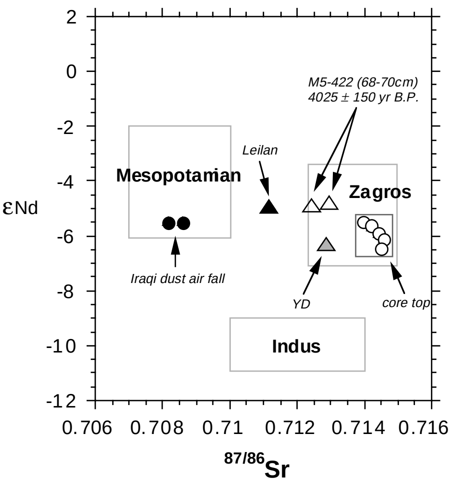

Figure 3. Radiogenic isotope (εNd and $^{87}Sr/^{86}Sr$) data measured for core M5-422, Tell Leilan–Abu Hgeira (northeast Syria), and samples of atmospheric mineral dust fallout collected in Baghdad, Iraq. Zagros, Indus, and Mesopotamian terrigenous εNd and $^{87}Sr/^{86}Sr$ end-member compositions are estimated (after Sirocko et al. [1993]).

Analyses of the extracted terrigenous fraction of core-top samples (open circles) from core M5-422 demonstrate that the dominant source of terrigenous sediment to this site is derived from the Zagros drainage (Fig. 3; Table 2, see footnote 1). A modern sample of atmospheric mineral dust fallout collected in Baghdad, Iraq, (closed circles) in the summer of 1995 was analyzed and its isotopic composition is within the Mesopotamian end member. Measured samples taken from the collapse horizon at the Tell Leilan–Abu Hgeira archeological site in northeast Syria (closed triangle) are consistent with an increased Mesopotamian end-member composition as compared to the core top. The εNd and $^{87}Sr/^{86}Sr$ isotopic composition of the 149 cm level (shaded triangle) in M5-422, representing the Younger Dryas (Table 1, see footnote 1), is shifted ~25% toward the Mesopotamian dust end member as compared to the core top (Fig. 3; Table 2, see footnote 1). This result confirms previous studies documenting greatly increased Mesopotamian aridity and dust supply during the hyper arid last glacial maximum and Younger Dryas cold periods (Sirocko and Sarnthein, 1989; Sirocko et al., 1993). The εNd and $^{87}Sr/^{86}Sr$ values obtained for the 68 and 66 cm samples (two open triangles) imply a return to arid conditions during the mid-Holocene and confirm an increased supply of eolian detritus from Mesopotamian sources at 4025 ± 150 B.P. (Fig. 3; Table 2, see footnote 1). The $^{87}Sr/^{86}Sr$ values for this level (0.7124–0.7128) are clearly lower than the core-top sediment value (0.7145) and are shifted ~30% along a Nd-Sr mixing line toward the less radiogenic Mesopotamian dust end-member value (0.7082–0.7086). We interpret the radiogenic isotope and mineralogic results to reflect an abrupt and rather short-lived (~400 yr) aridification of Mesopotamian dust source areas (primarily the Tigris and Euphrates flood plains) commencing near 4025 ± 150 B.P.

TEPHROSTRATIGRAPHIC CORRELATION TO TELL LEILAN (NORTHEAST SYRIA)

There remains the significant task of documenting a direct temporal link between this aridification event near 4025 ± 150 B.P. and the purported aridification event ascribed to the collapse of the Akkadian empire dated as 4175 ± 150 B.P. (Weiss et al., 1993). The calibrated radiocarbon ages for the aridification and social collapse events are synchronous in their joint 1 σ dating errors (Fig. 4) but other factors such as changes in the marine reservoir age correction, for example, can shift apparent marine radiocarbon ages by several hundred years (Bard et al., 1994).

Geochemical correlation of volcanic ash fallout layers presents an analytically robust way to document synchroneity. A thin (0.5 cm) volcanic ash horizon from an as-yet unknown source volcano was identified in the Tell Leilan and nearby Abu Hgeira site strata (level 43 90-2) that immediately postdated the Akkadian collapse horizon but predated the ~300 yr occupational hiatus (40–100 cm of eolian sediments barren of artifacts). Abundant rhyolitic ash shards were observed and the major element geochemistry of these shards was determined by electron microprobe analysis (Weiss et al., 1993) (Table 3, see footnote 1). We examined the 68 and 70 cm levels in core M5-422 for volcanic shards under the petrographic microscope and found very rare volcanic ash shards which were clear, evidently rhyolitic, largely arcuate in shape, and with evident bubble-wall junctions. No shards were found in the sediments directly above and below this level (Fig. 4).

These samples were acidified to remove carbonate material, sieved at 38 µm, and the >38 µm fractions were then analyzed by electron microprobe analysis. Samples were analyzed on a Cameca SX-50 electron microprobe equipped with four wavelength-dispersive spectrometers. The accelerating voltage was 15 kV, the beam current 25 nA, and the beam diameter was between 5 and 25 µm. Elemental concentrations were calculated from relative peak intensities using the ϕ(ρz) algorithm (Pouchou and Pichoir, 1991). The resulting major element oxide compositions from a total of seven probe analyses on two shards are presented in Table 3 (see footnote 1). The oxide compositions of the Tell Leilan–Abu Hgeira sites and core M5-422 (Gulf of Oman) volcanic ash shards are extremely similar (Table 3, see footnote 1). The Si, Ti, Fe, Mn, Mg, and Ca oxide

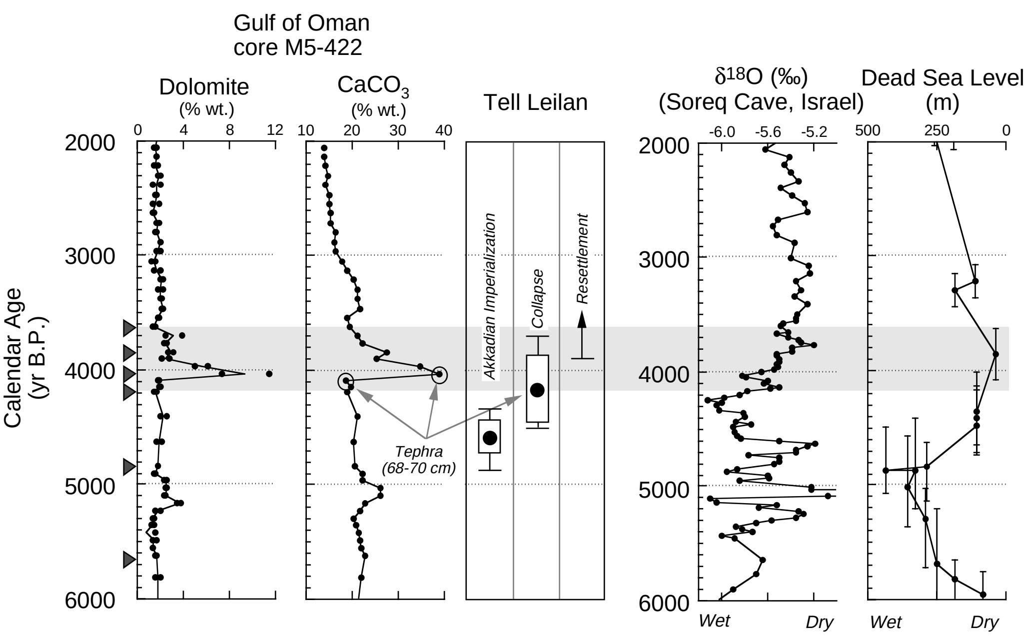

Figure 4. Eolian mineral concentration data for 6000–2000 calendar yr B.P. interval in core M5-422. Calibrated radiocarbon ages of imperialization, collapse, and resettlement phases of Akkadian empire as determined from archeological investigations at Tell Leilan are provided (dates from Weiss et al. [1993]). Mean calibrated ages of these phases, their 2 σ and full age ranges, are represented by filled symbols, boxes, and range bars, respectively.

compositions are identical within their joint 1 σ errors, and the Al oxide compositions agree within their joint 2 σ errors (Table 3, see footnote 1). The Na and K oxide compositions are not used for correlation purposes owing to the analytical interference between Na and K volatility with variable water content (Cerling et al., 1985). The relative scarcity of ash shards found in the core M5-422 samples for probe analysis did not permit us to increase the number of shard analyses and thereby reduce error, but the two oxide chemistries are sufficiently close to support a geochemical correlation linking the aridification and social collapse events in time (Fig. 4).

DISCUSSION

The mineralogic and geochemical data from Gulf of Oman core M5-422 document an abrupt onset of arid conditions in Mesopotamia which occurred near 4025 ± 150 B.P. This aridification event was evidently short-lived, lasting only a few centuries and may have been the result of large-scale changes in ocean-atmosphere-vegetation boundary conditions (Claussen et al., 1999). This 4025 B.P. event was of uncommonly large amplitude compared to the rest of the Holocene, and it nearly matched the mineralogic and geochemical amplitudes associated with the Younger Dryas aridification (Figs. 2 and 4). All available evidence indicates that this event records a dramatic mid-Holocene change in regional climate and is not a depositional artifact due to sediment disturbance or redeposition. The AMS radiocarbon dates increase monotonically across the event (Fig. 2) and there were no visible indications of disturbance at this level in the sediment core. The Nd and Sr isotopic data indicate a proportional increase in terrigenous sediment of Mesopotamian (i.e., eolian) origin (Fig. 3), the volcanic ash chemistry is correlative with tephra extracted from the Tell Leilan–Abu Hgeira sites (northeast Syria) (Table 3, see footnote 1), and the calibrated dates of the aridification and social collapse events are indistinguishable within their joint errors (Fig. 4).

Other paleoclimate records from the Middle East have documented shifts to much more arid conditions commencing near 4000–4200 B.P. (Fig. 4). In Lake Van of eastern Turkey, situated at the headwaters of the Tigris and Euphrates Rivers, oxygen isotopic and other geochemical analyses of lake sediments were used to estimate that lake-level fell between 30 and 60 m beginning near 4190 B.P. (Lemcke and Sturm, 1997). Stable isotopic records of U/Th-dated cave deposits in Israel document a 20–30% decrease in precipitation between 4200 and 4000 B.P. (Bar-Matthews et al., 1997), and the Dead Sea level fell abruptly by ~100 m at this time (Frumkin, 1991). Drier conditions are also recorded in the High Plateau of Yemen (Wilkinson, 1997), lake levels were anomalously low in subtropical North and East Africa (Gasse and Van Campo, 1994; Halfman and Johnson, 1988) as well as Morocco (Cheddadi et al., 1998). Archeological evidence and regional paleoclimate data collectively implicate abrupt climate change as having been a key factor that contributed to the demise of this sophisticated culture which had imperialized Mesopotamia. Social signatures of the collapse varied geographically; settlements in the rainfed agricultural plains of northern Mesopotamia were dramatically reduced, while populations in the south swelled with the arrival of northern refugees. These dislocations were sufficient to destabilize the region and to fundamentally alter the social, political, and economic fabric of this once-unified culture. Furthermore, these responses occurred despite the fact that the Akkadians had implemented sophisticated grain-storage and water-regulation technologies to buffer themselves against historical (interannual) variations in rainfall (Weiss et al., 1993).

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