BIPOLAR OUTFLOWS AND A NEW MODEL OF THE EARLY SOLAR SYSTEM. PART I:
OVERVIEW AND IMPLICATIONS OF THE MODEL; William R. Skinner, Department of
Geology, Oberlin College, Oberlin, OH 44074

Current models for the origin of the solar system do not adequately
account for such fundamental characteristics as chemical fractionations and
isotopic anomalies found in meteorites and planets (1-5). A modification of
the nebular hypothesis is proposed here to address these and other issues.
This new model, described in Part II, has broad implications for the early
solar system and for general theories of planetary and stellar formation.

Young stellar objects (YSO's) are known to spew material back into the
interstellar environment in the form of bipolar jets and mass outflows. Some
of this material achieves escape velocity, some does not. The major thesis of
the model developed here is that processed material derived from the accretion
disk (solar nebula) is spewed back onto the faces of the disk by fountaining
from a hot boundary layer between the protostar and the accreting disk. Gas
and solids are processed in the hot boundary layer and its associated
outflows. Some of this processed matter avoids accretion into the
protosun and is incorporated into planets, asteroids, and comets. Clues to the process
are thus preserved in these objects and in materials derived from them, e.g.,
meteorites and interplanetary dust particles (IDP's). The model is broadly
compatible with physical, chemical, and isotopic aspects of the solar system
and with observations of YSO's in star forming regions. Some implications of
the model are discussed below.

1. Meteorite precursor material was CI composition (5), contaminated by
processed material after fountaining was initiated. Dust and accreted
materials (including planetesimals) concentrated toward the midplane of the
nebula. This material was torn up and thermally processed in the boundary
layer and fountains as the nebula moved into the protosun.
2. Chondrules and other high temperature objects (CAI's, amoeboid olivine
aggregates, coarse matrix grains in CV3's, etc.) were not formed by transient
heating events in the solar nebula. They were manufactured during transient
passage through a hot boundary layer where the nebula encountered the protosun
and in hot fountains ejected from this boundary layer. Cooling times inferred
from chondrule textures (6) are compatible with this mechanism.
3. Fountaining lasted a few hundred thousand to a few million years, the span
of calculated lifetimes of bipolar outflows from solar mass YSO's (7).
4. Temperature, pressure, and redox conditions varied greatly with location
and with time in this chondrule forming region. The range of variations can
be estimated from properties of chondrules and CAI's (3,5).
5. Chondrules and chondrites were formed in very different environments.
Chondrules formed in the boundary layer and the fountains, chondrites formed
in the solar nebula in a relatively cool environment at the location of the
present asteroid belt. The association of high temperature and low
temperature fractions in unequilibrated meteorites is predicted by the model.
One aspect of the model that remains to be explored is the thermal effect on
fountained material as it encounters the surface of the nebula. Chondrule
formation is not favored in this location because the low redox conditions
expected here are not compatible with observed ferrous contents of silicates
in chondrules (3,5).
6. Chondrules and other particles were sorted by size and density by gas drag
effects during ejection in the fountains and later during gravitational
settling in the nebula. The siderophile depletion of most chondrites results
from this process (see below).
7. Metal/silicate fractionation (see Part II) resulted in a metal-rich feedstock from the fountains at small heliocentric distances. Concentration of metal in the inner nebula may explain the high core/mantle ratio of Mercury, the low ratio for Mars, and the intermediate (and similar) values for Venus and Earth. The metal/silicate ratio for Earth was probably enhanced during collisional birth of the Moon (8).

8. The model predicts that the ratios among silicate, sulfide, and metal grains would vary with distance from the protosun. Variations among meteorite groups (e.g., H, L, LL) could be due to variations in distance or to variations with time caused by fluctuations in the fountaining process.

9. The young Jupiter may have grown rapidly because of its favorable location with respect to the "nebular snowline", the "isotherm" where water vapor would condense out of gases coming from the protosolar fountains. Nonsolar compositions of the giant planets (9) may also be related to this process.

10. The offset of the oxygen isotope trend defined by the ordinary chondrites from that of the Allende mixing line (10) may reflect an evolution in the oxygen isotope composition of the solar nebula. This may have been achieved by contamination and mass fractionation as nebular gas equilibrated with anomalous material added by fountaining. Such a trend, if unidirectional, might reveal a sequence for the formation of meteorite parent bodies.

11. Olivine grains in the dust from Halley's comet (11) and in IDP's (12) may be directly related to fountaining and jetting of small grains to great heliocentric distances where they became incorporated into comets.

12. Many accretion disk theories require some mechanism to continually generate turbulence, but no consensus exists as to its nature (13). Fountaining might provide the energy input needed to maintain turbulence. The solar nebula may have been nonturbulent prior to fountaining and turbulent after fountaining began.

13. This model provides a strong correlation of observations on meteorites, planets, IDP's, and comets with current astrophysical models and recent observations of YSO's and interstellar dust. It could promote increased interaction among investigators of these related objects.

14. Bipolar outflows are commonly observed in star-forming regions and may be characteristic of early stages in stellar development (7). If fountaining is a common associate of such outflows, and if fountaining is largely responsible for driving accretion of planets by providing a coarse-grained feedstock, then planet formation would be a natural consequence of stellar evolution. Thus planets may be as common as stars.