'Critical Zones' on Mars and across the Solar System. *Gail M. Ashley & Jeremy S. Delaney* Department of Earth & Planetary Sciences, Rutgers University, Piscataway, NJ 08854. *gmashley@rci.rutgers.edu*

Introduction: The concept of the Critical Zone as a means to integrate studies of the near surface terrestrial environment on planet Earth was introduced in 1998 [1], formalized by [2] and is widely applied globally. The Critical Zone (CZ) is a region of mass and energy flux [2], and is a multidimensional boundary zone(s) between the solid planet and its gaseous +/- liquid envelopes, at various locales on the surface (Fig. 1). CZ's have physical (chemical, physical, morphological) and biological aspects [3]. All solid bodies of the Solar System must have such zones though they should vary dramatically reflecting the boundary conditions on the specific planet. CZ's evolve over time.

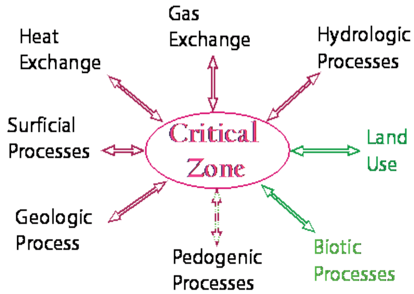


Figure 1: Summary of feed back systems physical (black) and biological (green) studied on Earth

The Earth is a 'habitable zone' planet, but we discuss the application of the Critical Zone (CZ) to other rocky planets and bodies in the Solar System [4] where the physical evidence is more accessible than the biological evidence.

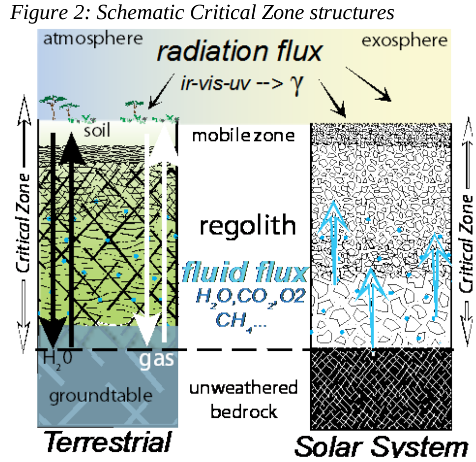
Basic factors that influence the structure and evolution of planetary CZ's are: (*1*) Hydrologic cycles; (*2*) Carbon cycles; (*3*) Gas exchange (major and trace); (*4*) Weathering (chemical & physical); (*5*) Erosion & deposition (physical processes); (*6*) Lithification (diagenesis); (*7*) Soil genesis (pedology) and include (*8*) Biology related processes (biological weathering, impact of life (microbial to macroscopic) and biochemical cycles where present. In addition, extraterrestrial CZ's include (*9*) solar and cosmic radiation fluxes, and (*10*) impact resetting events that result in punctuated evolutionary histories not studied on Earth. Both contemporaneous CZ's and paleo-Critical Zones occur. The paleo CZs, provide a holistic integration of ancient landscapes including paleo-atmosphere, paleo-hydrosphere and paleo-biosphere[5,6] Evidence of CZ can be over-printed, obliterated and even removed by surface processes, so paleo CZs may be poorly preserved or incomplete in the stratigraphic record.

Terrestrial studies of the Critical Zone have focused on the biological aspects of the concept and are mostly limited to short time scales.

Solar System Critical Zones (SSCZ): Every solid body in the Solar System has an interface with its exosphere/atmosphere that provides the locus of its Critical Zone(s). In many cases, the surface of the solid part and the exosphere are the ***only*** material available for study. Since CZ's on Earth provide the environment in which life thrives, recognizing equivalent extraterrestrial CZ's is a fundamental step to locating life on other bodies. We must work, however, from the assumption that life is not present *until we can demonstrate the contrary*. Proto-Critical Zones, (abiotic CZ's) that support organic chemistry can already be recognized (c.f. Rosetta at comet 67P-Churyumov-Gerasimenko [7,8].

Differences between CZ's on Earth and other rocky bodies in the Solar System:

Figure 2: Schematic Critical Zone structures



(*1*) Water is an essential component of all Critical Zones. The presence or absence of water influences not only the potential for extant life but also the physical evolution of the surface zone of a body. The role of H_2O phases must be considered in detail. (*2*) Carbon cycles for other bodies remain poorly understood. Both biogenic and abiogenic carbon cyclicity are fundamental and, indeed, are the 'Holy Grail' of biogenic CZ studies. (*3*) On Earth, interaction with the dense atmosphere, in addition to the hydro/cryosphere, is fundamental to Critical Zone evolution, but atmospheres/exospheres on other bodies have analogous gas exchange processes. (*4*) Weathering and (*5*) Erosion are the most readily accessible aspects of planetological Critical Zones. Because the effects of these processes are observable from telescopes, satellites, and landers they have received most attention. (*6*) Lithification is critical to the preservation of the Critical Zone evidence that can be studied either remotely or in more detail by sampling. (*7*) Soil formation processes transform local regolith to the most widespread surface material on Solar System bodies. (*8*) The absence of unequivocal evidence of extraterrestrial life permits us to neglect biological aspects at present.

Accessing Extraterrestrial Critical Zones: Comets, asteroids, rocky planet(oid)s all have boundary regions that qualify as proto-Critical Zones. The gas giants may also have such a boundary zone below their atmospheres but these are inaccessible. Rocky and icy satellites of all classes of bodies have Critical Zones. Studies of extraterrestrial CZ's are currently limited to remote sensing techniques and some meteorite samples. Sample returns from the regolith of the Moon and a few asteroidal bodies may be useful. The only portion of every astronomical body that has been studied is effectively the outermost solid layer of their Critical Zones and the adjacent exosphere. While relevant data is rapidly accumulating, only three bodies have been documented in sufficient detail to allow inferences to be made about the extent and character of their Critical Zones. Those bodies are the Moon, planet Mars and comet 67P/ Churyumov-Gerasimenko. Asteroids 4 Vesta and 1 Ceres may also be amenable to study using currently available results [9-12]. Meteorites provide limited information when proximity to their parent body surfaces is derived from cosmic ray studies [13-15]. The continuing exploration of Mars has focused on both water and habitability, making that body the prime target for Critical Zone studies.

Critical Zones on Mars: Identification of CZ's on Mars, is already feasible at Gale Crater [16] and using GPR techniques [17,18] but sampling aimed at elucidating the internal structure of a CZ will require coring and sampling at a minimum. Investigating life on Mars, requires that we identify and document the environments most conducive to life (CZ's) across the entire planet. We expect the processes and thus the structure of the CZ to vary with latitude, longitude and elevation, aspect, bedrock, and energy flux.

Terrestrial precedent is based on Critical Zones, where water and its biological consequences dominate (Figure 2). If Mars was ever habitable [19-21], Martian CZ's are more likely to reveal the transition from proto-CZ (abiotic) to biotic CZ than on Earth where biology dominates and has done since the first evidence of life appeared about 3-4 Ga ago.

Discussion of potential CZ's on Mars in the form of 'inverted' Critical Zones [22] has begun, but remains to be explored in greater detail. Mars has abundant water [23]. The triple point of water is stable in the relatively shallow subsurface of Mars and may represent the locus of mass and energy fluxes in Martian regolith and soil. The physical, chemical (and biological) consequences of coexisting H_2O phases in the near surface will differ across the surface of Mars.

Critical Zones on Mars are the optimum sites for identifying any extant life. Paleo-CZ's will provide the record of any biological activity during the Noachian and Hesperian.

Atmospheric pressure on Mars ranges from 610Pa in Hellas basin, to 72Pa on Olympus Mons. The triple point of water (611Pa) is easily achieved at depth in many regions of Mars and hence chemical reactions that are catalyzed by liquid water must occur in lowland regions (such as Hellas, Valles Marineris and Vastitus). The almost ubiquitous presence of briny solutions on Mars [23,24] is direct evidence of Critical Zone processes on Mars.

Impact resetting of surface layers has occurred throughout geological time and provides a stratigraphic constraints on Critical Zone studies.

CZs are the most important archive of near surface planetary processes where deposition and erosion provide a mobile surface. On balance CZs are steady-state dynamic environment and their 3-D structure evolves (continuously) with time and should be the primary targets of surface exploration.

Summary: The concept of the Critical Zone, as a record of mass and energy fluxes at surface of rocky bodies, is useful and is widely applied on Earth. It can be effectively applied to the study of rocky surfaces throughout the Solar System.

References

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