UTAH'S GEOLOGIC AND GEOMORPHIC TERRESTRIAL ANALOGS TO MARS: A TRAINING GROUND FOR FUTURE ROBOTIC AND HUMAN MISSIONS TO MARS. Marjorie A. Chan[1], Kathleen Nicoll[2], Jens Ormö[3], Chris H. Okubo[4], and Goro Komatsu[5] . [1]University of Utah, Department of Geology and Geophysics, 115 S. 1460 E. Rm. 383 FASB, Salt Lake City, UT 84112-0102 marjorie.chan@utah.edu, [2]Department of Geography, University of Utah, Salt Lake City, UT 84112 [3]Centro de Astrobiología (CSIC-INTA), Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Spain. [4]U.S. Geological Survey, Flagstaff, AZ 86001, [5]International Research School of Planetary Sciences, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy.

Introduction: Utah offers spectacular geologic features and valuable analogue environments and processes for Mars studies. Relatively intact, horizontal strata of the Colorado Plateau are analogous to Mars, where the effects of strong ground motion from earthquakes or impacts are preserved. Within Utah, easily accessible, sedimentary analogue environments lie in close proximity. The lack of vegetative cover is an advantage for remote imaging at various scales by satellite or robotic instruments. The dry, desert climate and modern wind processes of Utah are comparable to Mars and its current surface.

This paper focuses on physical and chemical environments and conditions where water existed and could support microorganisms. The development of Mars history includes: ancient and modern depositional records, burial and diagenesis, uplift and tectonic alteration, and modern sculpting or weathering of the surface exposures. Recently acquired satellite images provide unprecedented details of outcrop-scale features. Many of the key systems analogous to Martian landscapes can be field-tested in Utah using robotic instruments; conducting such studies on Earth maximizes the efficiency of extraterrestrial scientific investigations. Analog examples in Utah are prime field localities that should be utilized in planning future robotic and human missions to Mars, and for teaching the next generation of planetary explorers [1]. The existing Mars Society Desert Research Station near Hanksville, Utah, already capitalizes on this idea. Understanding Mars clearly has a solid foundation in the knowledge of our own terrestrial planet.

Justification: Both Earth and Mars had similar histories of planetary evolution with commensurate igneous/volcanic processes, tectonics, impact cratering, surficial processes (e.g., eolian, potential water, glacial/periglacial and sedimentary deposits). Terrestrial analogs include places that have physical, chemical, or biological processes, which might be presently active or may have been operative in the past. Analogs display the fundamentals of Earth processes that allow us to compare, interpret, and ground-truth data collected by orbiter and robotic missions on Mars such as THEMIS (Thermal Emission Imaging System, on the Mars Odyssey), CTX (Context Camera on the Mars Reconnaissance Orbiter), CRISM (Compact Reconnaissance Imaging Spectrometer for Mars, on the Mars Reconnaissance Orbiter), HiRISE (High Resolution Science Experiment), and the NASA MER (Mars Exploration Rovers). Few places on Earth can rival the rich, complex, and unique combination of factors offered by the state of Utah.

The reasons that Utah is such a fertile training ground for Mars explorations are as follows.

1. Vast open and easily accessible spaces.
2. Spectacular exposures and remarkable preservation.
3. Widely varied geology representing many environments.
4. Many tectonic regimes.
5. Surface geochemical environments.
6. Arid, desert regime.
7. Wind and water processes.
8. Utah's Mars-like landscape.
9. Supporting infrastructure (e.g., airport access, study and core facilities).

Environments, structural styles, and other features important to analog comparisons are presented in Table 1.

Environments: Sedimentary environments preserve the depositional products of geologic processes within a particular set of physical, chemical, and biological conditions at surface (or near surface) temperatures and pressures. The sedimentology involves the composition and genesis of the sediments or sedimentary rocks, as preserved within bedding/stratification and structures, continuing through its diagenesis during burial, uplift, exposure, and weathering.

Depositional environments include dry environments (eolian and sabkha), standing water bodies or slow moving flows (glacial, lacustrine, and spring), and fast-moving surface water (alluvial, fluvial, deltaic, and outflow).

Modifying environments represent settings and processes that act upon or affect the pre-existing primary depositional features. Analogues include: diagenetic environments, soils and weathering, patterned grounds, structural styles, volcanoes, and impact craters.

GEOLOGIC SYSTEMS	NOTABLE FEATURES
DEPOSITIONAL ENVIRONMENTS	
Eolian	Dune morphology, cross bedding, ripples, deflation, ventifacts, yardangs
Sabkha & Saline Bodies	Evaporites, crystal molds, soft-sediment deformation, desiccation structures
Glacial	Sculpted bedrock, landforms, poorly sorted tills
Lacustrine	Shorelines, beach ridges, laminated basinal sediments
Springs	Chemical mineral precipitates, travertine/tufa, vents
Alluvial	Radial fan apron, mass movement
Fluvial	Braided & meandering/sinuous channels, point bars
Deltaic	River-fed depo center at lake or ocean shoreline
Outflow Channels	Megachannels, immense bars
MODIFYING ENVIRONMENTS	
Diagenetic Concretions	Iron oxide concretions, cementation, bleaching, secondary porosity
Weathering, Soils,	Pedogenic structures, Soil horizons, collapse, talus, mass transport
Sapping, Knobs, Pinnacles	Dissected terrain, positive geomorphic knobs
Crusts, Desert Varnish	Mineralogic surface coatings
Patterned Ground	Patterns (cm to 10s m or more) along bedding planes
Polygonal Weathering	Surficial crack patterns
STRUCTURAL STYLES	
Faults, joints, fractures	Offsets, truncated beds
Deformation Bands	mm-scale ridges, to m-scale zones, of crushed, indurated, or disrupted rock
Folds	Deformation, shearing, dipping beds
Salt Tectonics	Salt flowage, dissolution
VOLCANIC	
Volcanoes	Igneous minerologies, volcano morphology
Ash, Cones	Ash falls, cones, flows
IMPACT CRATERS	Crater morphology, circular ring, radial structures, ejecta, breccias, melts, shock metamorphism
MICRO-BIOTA	Constructive buildups, skeletal remains, organic films
"MARS LANDSCAPE"	Desert conditions

Table 1. Summary table of analog features for study.

Structural Styles Crustal deformation, that is, changes in the shape and volume of rocks due to external stresses, alters the morphologies and mechanical characteristics of rock. Deformation can be manifested at a variety of scales, from hundreds of km down to the micron scale. Deformation can be pervasive on any planetary surface and is not limited to specific environmental settings. The styles of deformation that are most likely to occur within the shallow Martian crust (<10 km depth) include structural discontinuities, such as joints, faults, and deformation bands, as well as folds and diapirs.

Volcanism and impact cratering create their own distinctive structures that have been well discussed elsewhere in the literature.

Summary: Utah's geologic and geomorphic analogs are valuable for understanding Mars. Planetary scientists can quickly gain knowledge of many terrestrial environments and expressions with both ancient and modern examples, all in close proximity and accessible in the field. Utah is an excellent training ground for many scientists, including the oil industry where subsurface geophysical instrumentation is somewhat akin to the planetary remote explorations, and tangible outcrop examples provide ground-truth for applied interpretations. Each of the examples presented here is a stepping-stone to a broader field of study with endless possibilities.

Various robotic instruments can be given trial runs in Utah's terrains to increase the likelihood for fruitful outcomes in actual missions to Mars. The best robotic instruments should simulate trained geologists who are familiar with a tremendous range of environmental parameters. Utah's landscapes provide an breadth of conditions for instrument testing. Interdisciplinary collaborations among astronomers, geologists, geochemists, geophysicists, engineers, planetary scientists, computer modelers, meteorologists, and others can collectively bring rich new ideas and tests in the search for water and potential life on Mars, and to attain the very best manned or robotic missions to the red planet.

References: [1] Chan, M.A., et al., (2009 in review) submitted to Gerry, B., and Bleacher, J., eds., Analogs for Planetary Exploration: *Geological Society of America Special Paper.*

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