FOCUSING THE SEARCH FOR ORGANIC BIOSIGNATURES ON MARS. D. Z. Oehler[1], M. Salvatore[2], G. Etiope[3], C. C. Allen[4]. [1]Planetary Science Institute, Tucson, AZ, USA, doehler@psi.edu; [2]Northern Arizona University, Flagstaff, AZ, USA; [3]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy. [4]NASA – Retired, Albuquerque, NM, USA.

Summary: Extensive study of subsurface organics on Earth allows prediction of areas on Mars where organic molecules could have been both concentrated and preserved. Southern Acidalia Planitia, in the northern lowlands, is one such area (Fig. 1) [1-2]. This region has never been investigated though ground-based methods, but its subsurface may be one of the best places on the planet to preserve abundant organics – both abiotic and possibly biotic (organic biomarkers).

Southern Acidalia also includes thousands of mud volcano-like features which may have expelled materials from the subsurface to the surface [1-2] (Figs. 1-2). These could provide accessible windows into the organic-rich horizons predicted to occur at depth, and they would be ideal targets for future exploration.

Why Key Locations are Critical: Identifying sites on Mars where organics are both concentrated and preserved is critical, as the planet's surface is highly destructive to organics. Yet organics are the essence of life as we know it, and organic biomarkers are among the least ambiguous of the biosignatures that might be encountered on the planet [3].

Concentration: On Earth, geologic processes that concentrate organics have been studied for decades by the petroleum industry (summarized in [1-2]), as organic-rich shales/mudstones are the source rocks for much of the oil and gas on our planet. From these studies, organic-rich sediments are known to occur in distal, quiet water facies. This arises because organic matter has low density and transports in fluvial systems with fine-grained muds and clays. Detrital organics will be most concentrated in distal locations where transport distances have been long, such that dilution by coarse grained sediments is minimal.

Preservation: Organic preservation on Mars is challenged because the planet has lacked a thick atmosphere and strong magnetosphere for much of its history, allowing damaging radiation to reach much of the planet's surface [4-10]. Although rock penetration by UV is minimal (< 1 mm [5-6]), galactic cosmic rays and oxidants like perchlorates and peroxides can degrade organics in the subsurface [7-10] to depths of meters. In addition, "gardening" by impacts, wind, and periglacial processes can mix the regolith to many meters, exposing new materials to damaging radiation and oxidation. These processes could destroy much of the organic matter at the martian surface or in the near surface, especially if exposed there for millions to billions of years.

Organics of likely martian origin have been reported from >3 Ga mudstones in Gale crater [4, 11], suggesting that organic matter may be widely distributed in the martian subsurface. While concentrations of those organics are orders of magnitude lower than commonly occurs in >3 Ga Archean samples on Earth (e.g., [12]), the Gale samples were obtained from extremely shallow drill holes (~6 cm deep), from locations in Yellowknife Bay [YKB], Pahrump Hills and Marais Pass. Data suggest that the YKB area has been exposed to cosmic radiation for ~78 million years [13], and it may be that much of the originally deposited organic matter in the tested Gale samples may have been destroyed by radiation or oxidation during the time when these strata were located just a few centimeters below the surface.

In other settings where organics were originally concentrated, then rapidly buried to depths >1 meter and never brought to the surface or uppermost meter of regolith by tectonic or erosional processes, greater accumulations of organic matter could exist at depth. *This is the scenario we predict for distal basins of southern Acidalia Planitia.*

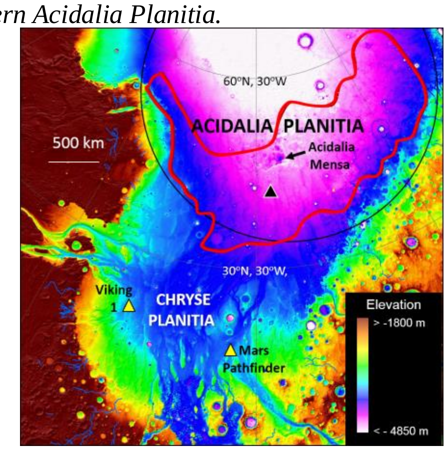

Fig. 1. Geologic context on MOLA base map. Thin blue lines, Noachian valley networks. Red outline, area with ~40,000 high albedo mounds [1-2]. Black triangle, location of Fig. 2.

Acidalia: *Concentration and Preservation:* Deep basins in southern Acidalia Planitia would have been depocenters for fluvial input through Noachian valley networks and Hesperian-aged outflow channels. (Fig. 1). That process could have transported surface and near surface organics from a large catchment in the highlands [1-2]. Abiotic organics, delivered by carbonaceous meteorites, could have been present in that catchment, perhaps deriving some protection from the combination of near-surface burial by meteoritic implant and last vestiges of the early martian dense atmosphere. If life existed on early Mars, biotic organics may have been present as well. And the long transport distances from the Noachian catchment to the deep, distal basins of southern Acidalia would maximize the concentrations of those organics.

Organic preservation in these localities would have been promoted by adsorption into clays [14] (also concentrated in distal facies sites) and rapid burial by Hesperian outflow sediments. Both processes would protect organics from destruction by surface radiation and oxidation. Additionally, burial can reduce permeability to oxidizing fluids by compaction and diagenetic cementation, and it can provide conditions for organic sulfurization which can lead to formation of refractory organic macromolecules [4].

Recent studies support a view of extensive, fine-grained and water-saturated sedimentation in Acidalia. [15-16]. Moreover, as [16] proposed that a volatile-saturated, mud-rich unit was deposited in the plains surrounding the ~ 4 Ga Acidalia Mensa plateau, it is possible, that this high standing structure impeded NNE flow of late Noachian and Hesperian rivers, resulting in relatively thick sedimentary deposits to its south.

Habitability: The deep distal basins of Acidalia would have been among sites of last water as the planet dried. And Hesperian burial may have promoted subsurface, organic thermogenesis, a process which can produce habitability-enhancing methane [17-19]. Potential microbes living in these sites of long-lived habitability, could have added *in-situ* biotic organics to the *detrital* organics delivered by rivers.

*Potential Mud Volcanism***:** The distal region in Acidalia includes 1000s of bright mounds (Fig. 1, red outline, and Fig. 2), which have been compared to terrestrial mud volcanoes (MV) (e.g., [1-2, 20]). This is consistent with the history of the region, as mud volcanism on Earth occurs where fine-grained, organic-rich sediments are rapidly buried.

MV are diapiric slurries that rise through the subsurface as a result of overpressure. In this process, MV extrude mixtures of fluid, sediment, and rock to the surface from depths of meters to kilometers [1-2]. Mud volcanoes are also a major source of methane, emitting CH_4 generated by microbes, abiotic processes, and thermogenesis of buried organics [17-19]. Compared to impacts, mud volcanism is a low temperature/low pressure process, and samples erupted by MV commonly include well preserved organic biomarkers.

In Acidalia, organics within the mounds could be protected from surface processes by adsorption into associated clays. In addition, indurated/lithified blocks associated (and presumably erupted) with the mounds may offer further protection. Some of these blocks are meters across, and their size and apparent induration could enhance preservation of innermost organics in samples exposed on the martian surface for extended periods of time. *Thus, the bright mounds in Acidalia may provide surface-accessible, minimally altered samples of potentially organic-rich strata from depth.*

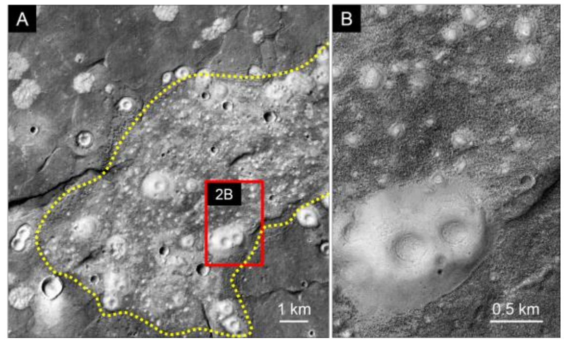

Fig. 2. Bright mounds in Acidalia (Context Camera mosaic (NASA/Google Earth); CenterPoint, 41.1°N, 333.76E. **A)** Yellow line surrounds apparent flow. **B)** Enlargement.

Conclusions: Distal-facies sites in S. Acidalia are ideal locations in which to search for organic biomarkers. This is where Noachian organics (both *detrital* and potentially *in-situ*) would have been concentrated and subsequently preserved by Hesperian outflow burial. The rapidity of that burial might also have resulted in subsurface overpressure, triggering mud volcanism, a process erupting samples from depth, enhancing habitability, and providing accessible targets which could host minimally altered biomarkers.

What distinguishes Acidalia is the combination of a large Noachian catchment, long transport distances from catchment to depocenters, and rapid burial by Hesperian outflows. Together these characteristics make depocenters in southern Acidalia outstanding candidates for future, biosignature exploration – a case made even stronger by the possibility that mud volcanism has provided easy access to expected organic-rich strata from depth. *Few other places on the planet offer comparable history.*

References: [1] D.Z. Oehler, C.C., Allen, 2012. *SEPM Sp. Vol. 102*, Sed. Geol. of Mars, 183-194. [2] D.Z. Oehler, C.C. Allen, 2010. Icarus 208 (2), 636-657. [3] Summons et al., 2010. AbSciCon, Abs. #5256. [4] Eigenbrode et al., 2018. Science 360 (6393), 1096-1101. [5] R.C. Garry et al., 2006. MAPS 41(3), 391-405. [6] J.E. Moores, A.C. Schuerger, 2012. JGR Plan., doi:10.1029/ 2012JE004060. [7] L. Dartnell et al., 2007. GRL 34, doi: 10.1029/ 2006GL027494. [8] A.A. Pavlov et al., 2012. GRL 39, L13202. [9] J. Lasne et al., 2016. Astrobiol. 16 (12), 977-996. [10] J. Vivas et al., 2020. Astrobiol. Doi: 10.1089/ast.2020.2257. [11] C. Freissinet et al., 2015. JGR Plan. 120 (3), 495-514. [12] L.J. Duck et al., Prec. Res. 2007. 154, 205-220. [13] K.A. Farley et al., 2014. Science 343, (6169), 1247166. [14] J. Tan et al., 2021. Astrobiol. 21 doi: 10.1089/ast.2019.2211. [15] M. Salvatore, P.R. Christensen, 2014. JGR Plan. 119, 2437-2456. [16] M.A. Ivanov, H. Hiesinger, 2020. Icarus 349, 113874. [17] D.Z. Oehler, G. Etiope, 2017. Astrobiol. 17 (12), 1233-1264. [18] D.Z. Oehler, G. Etiope, 2021. *In* Mars Geological Enigmas, (eds. Soare et al.), Elsevier. [19] G. Etiope, D.Z. Oehler, 2019. PSS 168, 52-61. [20] I. Di. Pietro et al., 2021. Icarus 354, doi.org/:10.1016/j.icarus. 2020.114096.