STRATEGIES FOR DETECTING THE PRODUCTS OF AQUEOUS CHEMISTRY ON TITAN. C. D. Neish1,2, R. D. Lorenz3, E. P. Turtle4, J. W. Barnes4, M. G. Trainer5, R. Kirk6, B. Stiles7, C. A. Hibbitts8, 1The Planetary Science Institute, Tucson, AZ (cneish@psi.edu), 2The University of Western Ontario, London, ON, 3Johns Hopkins Applied Physics Laboratory, Laurel, MD, 4The University of Idaho, Moscow, ID, 5NASA Goddard Space Flight Center, Greenbelt, MD, 6United States Geological Survey, Astrogeology Science Center, Flagstaff, AZ, 7Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Introduction: Saturn’s moon Titan has all the ingredients needed to produce “life as we know it”. Titan’s dense atmosphere of N\textsubscript{2} and CH\textsubscript{4} supports a rich organic photochemistry, producing a suite of carbon, hydrogen, and nitrogen containing products (C\textsubscript{x}H\textsubscript{y}N\textsubscript{z}), which eventually settle onto its surface [1]. Once on the surface, the products of Titan’s photochemistry may react with liquid water in certain regions. Titan’s surface is generally too cold for liquid water, but transient liquid water environments may be found in impact melts and cryolavas. When exposed to liquid water, Titan’s organic molecules quickly incorporate oxygen [2,3] to produce a range of biomolecules such as amino acids [4]. Impact melts and cryolavas of different volumes - and hence, different freezing timescales [5] - give us a unique window into the extent to which prebiotic chemistry can proceed over different timescales.

Thus, Titan provides a natural laboratory for studying the products of prebiotic chemistry. If given enough time, it is even possible that life arose on Titan and persisted for a short interval before its habitat froze. It is thus crucial that we develop a plan to collect the results of these natural experiments. Such measurements are not possible with the currently available data from the Voyager and Cassini missions, and thus would require a new mission. In this work, we examine the ideal locales to search for evidence of or progression towards “life as we know it” on Titan. We then suggest mission scenarios to test the hypothesis that the first steps towards life have already occurred there.

Geologic settings for aqueous chemistry: Liquid water is both a crucial source of oxygen and a useful solvent for the creation of biomolecules on Titan’s surface. Thus, if we wish to identify prebiotic and/or biological molecules on Titan, we need to determine where to find evidence for past liquid water there. We are most likely to find previous liquid water environments on Titan in two distinct geological settings: (1) cryovolcanic lava flows and (2) melt in impact craters.

Cryovolcanos. On Titan, lavas are generally referred to as cryolavas, since they involve the eruption of substances that are considered volatiles on the surface of Earth (e.g. water). Two conditions must be met for cryovolcanic flows to be present on Titan’s surface: liquids must be present in the interior, and those liquids must then migrate to the surface. Both conditions appear to be met on Titan [6,7], but we can test the hypothesis that cryolavas have erupted onto Titan’s surface by looking for morphological constructs on the surface consistent with volcanism.

The Cassini RADAR instrument has imaged approximately two-thirds of the surface of Titan, producing views of the landscape with resolutions of 350 m. Although it is difficult to conclusively identify cryovolcanic constructs at these resolutions, several features remain difficult to explain through any other geologic process [8]. The most intriguing of these features is the region formerly known as Sotra Facula. If Sotra Facula is indeed a volcanic construct, the lava flows there represent an interesting location for studying the interaction of liquid water with organic molecules on Titan’s surface.

Unless this region represents a persistent hot spot, however, it is unlikely that the lava will remain liquid long enough to produce complex, biological molecules. The flow lobes at Sotra Facula are tens of meter thick [8], and so would be expected to cool over relatively short timescales. If heat is lost only by conduction, the one-dimensional thermal conduction equation predicts that it should take only one year for a ten-meter-thick flow of water or ammonia dihydrate to completely freeze. In addition, if these lava flows have a peritectic composition close to that of pure ammonia dihydrate, they would erupt at a temperature of ~176 K. This would significantly impact reaction rates. In a 13 wt. % ammonia solution at 253 K, reactions between Titan haze analogues and ammonia-water had half-lives of a few days [3]. According to the Arrhenius equation, a reaction that takes a few days to complete at 253 K would take a few hundred years to complete at 176 K. Thus, aqueous chemistry in cryolavas may not have sufficient time or energy to produce more complicated, biological molecules.

Impact craters. A better target may therefore be impact craters. When a comet or asteroid impacts a planet, energy becomes available to melt its surface. Titan’s atmosphere is capable of shielding the surface from smaller impactors [9], so any projectile that does strike the surface must necessarily be large. Such impactors would be able to melt a large amount of Titan’s crust, with melt production increasing with crater size [10]. Artemieva and Lunine [11] found that a significant fraction (10%) of Titan’s organic surface layer
within the immediate region of the crater would be only lightly shocked in an impact. Some of these organics would be deposited in the liquid water within the crater basin, where they could react to form biological molecules.

Once melted by the impact, any liquid water generated will begin to cool to the ambient temperature of ~94 K. O’Brien et al. [5] found freezing timescales of ~10⁻³⁻¹⁰⁴ yr for a 15-km-diameter crater, and ~10⁴⁻¹⁰⁵ yr for a 150-km-diameter crater. These lifetimes are considerably longer than those for lava flows, allowing more time for aqueous chemistry to proceed. Impact melt is also likely to be emplaced at temperatures higher than the liquidus. This could increase the temperature of the melt above the freezing point of water, accelerating the chemistry occurring in the melt ponds. Reactions between Titan haze analogues and liquid water are ~20 times faster at 40°C than at 0°C [2].

We therefore judge that the best targets for observing the products of aqueous chemistry on Titan are the floors of large, relatively unweathered impact craters. These will contain the largest amount of impact melt, and that melt will be easier to access with a spacecraft. There is topography data for seven craters on Titan with D > 75 km [12]. Of these, the two least degraded craters are Sinlap and Selk. The largest impact crater on Titan – Menrva – also remains a high priority for future exploration given the amount of impact melt expected in such a large crater (Figure 1).

Identifying biological molecules on Titan: To identify biological molecules on Titan, it will be necessary to obtain more detailed data than is currently available from the Cassini-Huygens mission. Reflectance spectra of common biological molecules demonstrate that an orbital spectrometer like the Visual and Infrared Mapping Spectrometer (VIMS) would have difficulty identifying their spectral features, given the limited number of atmospheric windows available on Titan (Figure 2). A more effective approach would be to send a lander equipped with a gas chromatograph and/or mass spectrometer capable of identifying a wide range of biological molecules [13,14,15]. Given the non-uniformity of impact melt exposures in the floor of a weathered impact crater [16], the ideal lander would be mobile, allowing it to identify locations where impact melt deposits have been exposed through erosion and/or mass wasting.

Conclusions: Biological molecules similar to those found on Earth could be present on Titan. To identify them, we need a new spacecraft mission, ideally a mobile lander equipped with a gas chromatograph and/or mass spectrometer. The ideal landing sites would be the floors of large, fresh impact craters. On these crater floors, mass wasting and fluvial erosion could expose fresh deposits of impact melt for sampling. Determining the extent of prebiotic chemistry within these melt deposits would help us to understand how life could originate on a world very different from Earth.