THEORY OF GEOCHEMICAL/GEOLOGICAL HOMOLOGY APPLIED TO HYDROCARBON AND ORGANIC SUBSTANCES ON ICY SATELLITES AND OTHER SOLID PLANETARY OBJECTS. Jeffrey S. Kargel (kargel@hwr.arizona.edu), Dep't. of Hydrology & Water Resources, University of Arizona.

Abstract: Under the appropriate conditions of temperature, pressure, differential stress, and so on, and placed in the right configurations, planetary materials undergo folding and faulting, diapirism, glacial-style flow, melting, sublimation and condensation, physical breakdown of lithologic structure into mineral grains, eolian transport, and other physical changes that constitute geologic activity. Homologous series of hydrocarbon and organic materials provide well-populated series of physical properties and numerous substances from which natural planetary, satellite, and minor bodies select as geologically active materials. Almost any processes that do geologic work on silicates and ices also should do geologic work on hydrocarbon and organic materials where those substances are sufficiently abundant.

Introduction: There are particular types of physical transformations of materials that are quite general to almost all geologic substances and which exhibit comparable phenomenology even when the substances being compared are very different. Under the appropriate conditions, geologic materials melt, sublimate, evaporate or condense, precipitate from solution or saturated atmospheres, dehydrate or hydrate, dissociate or react, they soften and flow in a ductile manner or become brittle and fracture, break into constituent mineral grains and are prone to eolian and fluvial transport, and so on.

This theoretical framework of geological and chemical homology has not been considered at any length for carbonaceous and organic materials. Such extension may imply that these substances also can form volcanoes, sand dunes, river valleys, marine coastal features, glaciers, thermokarst, and many of the landforms once known only on Earth. The Cassini and Huygens missions to Titan have highlighted numerous familiar features produced, it seems, by exotic substances.

Geologic/geochemical homology: This schema, general to all geologically active bodies but applied here to organic/hydrocarbon materials, derives from several theorems and axioms:

1. The solid planets and minor bodies are assemblages of many naturally occurring substances.
2. Electronic classes of materials (e.g., polar molecules, and apolar molecules, acids and bases, silicates, oxides, free metals, large ion lithophile elements, chalcophile elements, etc.) have particular affinities (by dissolution or bonding) for other substances in their class or affinities to react with or repel members of other classes.
3. Each planetary object contains numerous individual substances and reactive or interactive/soluble mixtures.
4. Each substance and each reactive or soluble combination has unique physical properties.
5. Together, the substances comprising each object span a wide range of physical properties.
6. Each planetary object retains materials that exist as condensed phases or gravitationally bound gases and lose (or never accrete) others that are too volatile for the prevailing conditions or too reactive to exist in pure and unreacted form.
7. For any set of planetary surface and interior conditions, there are substances that will be close to or cross over key melting transitions, vapor saturation curves, Gibbs' free energy transitions, or other transformations, or are prone to crystalline deformation or other marked changes of state or physical configuation.
7. Some materials will be so closely situated to key phase transitions or physical instabilities under the range of oscillating surface conditions on a planet that they will unidirectionally or repeatedly undergo these chemical transitions or physical changes on time scales shorter than the age of the planetary object.
8. The materials which undergo the aforementioned changes on time scales shorter than the changes of other materials are those which are dynamic in geological, geochemical, geomorphological, or climatic senses.
9. Each planetary object, being composed of many substances, selects materials that are dynamic in this geologic context.
10. Regardless of surface environments and available energy, some selection of materials are able to undergo notable physical changes and thus produce geologic activity, and they do so on timescales shorter than the changes effected by other substances and processes. These fast-responding materials are responsible for creating the observable surface landforms and landscapes; more slowly responding substances have their visible surface effects erased by the fast-acting materials. The geologic record is the sum of effects of all overprinting processes.
11. These physical changes are of just a few generic types: melting/solidification, evaporation or sublimation, dissociation, solid-state creep, dissolution, and so on.

12. Landforms shaped by similar physical changes share some similar qualities.
13. We can expect to see repetitions of familiar processes and familiar landforms on worlds throughout the Solar System and beyond.

Of course, like human and animal faces composed of several generic features, there are myriad combinations of more subtle differences that make for unique planetary surfaces. However, from the general schema above flows the concept that certain types of geologic activity and associated landforms are widespread, even if completely different materials are involved and details differ. This concept is by now fairly well established in the planetary science community for silicate worlds and increasingly is recognized as applying also to worlds made of volatile molecular ices, thus giving a physical-chemical basis to planetary data interpretation based on analog reasoning.

This theory may have perhaps its finest expression waiting to be discovered among organic and hydrocarbon materials from Earth outward to the Kuiper Belt.

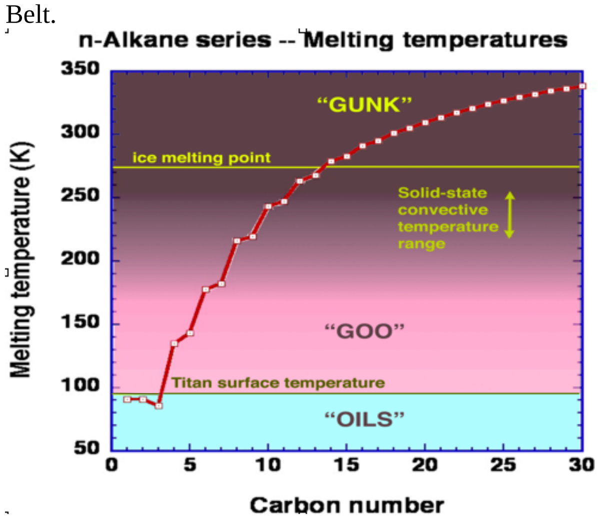

Figure 1. Melting points of the alkane series. The prevailing surface temperature of Titan also is indicated, showing that methane, ethane, and propane exist as liquids (or as a multicomponent solution also including nitrogen and argon), but butane and heavier alkanes would be solids. On Triton (surface temperature = 38 K) even methane would be solid, though within its icy crust geothermal heating would cause it to become a soft, deformable solid, perhaps giving rise to tectonic deformation. On Ceres, on the other hand, where mean global surface temperature is about 147 K, even butane and pentane would be liquids near the surface. Near Earth's surface (T = 270-310 K), hydrocarbons lighter than C14 are liquids or gases, C14 through C18 may oscillate between liquid and solid states, and those heavier than C18 are solids. For reference, ordinary candle paraffin includes a dominant fraction of C18-C28 alkanes, along with some hydrocarbons of other homologous series.

Not only is there a wide range of properties represented by these materials, but that range is heavily populated by physically incrementally distinct substances. This is illustrated in Figure 1 by the small variations in the series of melting temperatures, and in Figure 2 with the densities, of the alkanes. In the carbonaceous matter of many chondritic meteorites alkanes occur mainly in the C20's; and in Titan's atmosphere they are C1 and C2. Terrestrial petroleum includes a wide range of alkanes from C1 through about C30. Alkanes also are abundant in comets and other objects of the outer Solar System.

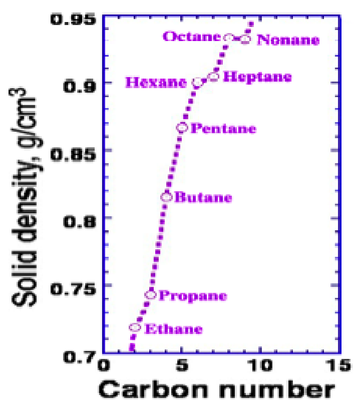

Figure 2. Densities of C2-C9 alkanes. Heptane and lighter alkanes are less dense than ice Ih; octane and nonane have about the same density as ice; heavier alkanes are more dense.

There are many cosmically abundant hydrocarbon and organic materials from which carbonaceous planets can select for just the right behavior in each given geologic role, such as in polar condensation, glaciation, fluvial activity, geyser eruptions, solid-state crustal diapirism, crustal folding and faulting, or cryovolcanism. Extending the logic of point 9 to point 13, above, there ought to be a series of superb landform analogs even among objects differing markedly in surface temperature and other environmental characteristics. Each set of active substances will adjust their geological roles as latitude and obliquity vary; as heliocentric distance varies; as solar flux increases over time; as radiogenic heat declines; or as satellites move into or out of resonances favorable to tidal dissipative heat generation. Shifting geologic roles also occur due to the global loss of volatiles to space, and to photolytic, metamorphic, hydrothermal, or metabolic conversions of volatiles to other molecular forms.