Dynamic of the liquid masses on Titan. G. G. Ori, A. Baliva, L. Marinangeli, and M. Bressan Dipartimento di Scienze, Universita' d'Annunzio, Viale Pindaro 42, 65127 Pescara Italy, ggori@sci.unich.it.

Apart from Earth, Titan is the only body in the Solar System supposed to have masses of free liquid at the surface [1]. Its hydrological cycle is largely unknown and several models has been constructed.

However, if liquid is available at its surface, the hydrodynamic behaviour of these masses can be modelled. Some modelling has been performed in order to understand the influence of the tidal forces on the putative ocean, but the detailed dynamic of the liquid under stress and on movement has been neglected. The liquid on the surface of Titan can be present in several modes: a large ocean covering part of the body [2], lakes [3], and flowing fluvial-like liquid due to direct atmospheric rain. In order to model the hydrodynamic characteristics of this liquid we used the Lunine composition for the bodies of standing liquid, whereas for the fluvial-like liquid we used a composition ranging from that of the Lunine putative ocean to pure methane [4]. We calculated the physical properties of the liquids using the Peng-Robinson state equation at 94 K of temperature and 0.15 MPa of pressure. The liquid of the ocean or lakes show a density of 615.22 kg/m^3 and a viscosity of 547.81 μPa s, whereas the pure methane liquid show a density of 447.81 kg/m^3 and a viscosity of 187.16 μPa s. Generally speaking, the Titanian liquidsphere show values of densities and viscosities lower than on the Earth. These data, along with a lower gravity (1.35 m/s), provide a quite different scenario with respect to the Earth hydrosphere. A model for the dynamics of the Titanian surface liquid should take into account different mechanisms [5]: i) types and mode of liquid motion, ii) erosional power of the flows and waves, iii) mechanisms of transport and sedimentation. While the first and the third mechanisms involve variables that can be reasonably estimated, the second one is strictly linked to the nature of the sedimentary interfaces and their interaction with the shear stress caused by the moving liquid. These relations are largely experimentally investigated and, due to the large number of assumptions on the type of surfaces, a large number of experiments is needed. We concentrated so far on the theoretical treatment of the movement of the liquid and, partially, of the transport and sedimentation. The liquid on Titan can move as waves and as unidirectional flows; the former can be subdivided in i) progressive waves, generated by tidal forces, and ii) wind waves (or simply waves) generated by wind shear stress on the liquid - atmosphere interface.

Waves. The wave geometry is controlled by the total wave energy (E_{wt}) according to the gravity and the density of the liquid because

$$E_{wt} = \frac{1}{2} \rho g a^2 L$$

where ρ stands for the liquid density, g for the acceleration due to gravity, *a* for the wave amplitude and L for the wavelength. This means that for tidal forces or wind speeds comparable to the Terrestrial ones, we get larger waves. This suggest that we can think of the progressive waves as shallow water waves because the wave amplitude will be large and the wave motion will interact with the sedimentary interface even in relatively deep liquid. In fact, the maximum horizontal velocity (U) of progressive waves is

$$U = a\sqrt{\frac{g}{h}}$$

where h is the liquid depth. Thus, for example, at comparable horizontal velocities with an ocean 400 m deep, the maximum compatible wave amplitude on Titan will be 12 m, whereas on the Earth will be less than 4 m. The putative ocean should be considered shallow even if the larger depth estimation are taken into account. Moreover, the theoretical erosional power of the progressive waves seems to be larger than on the Earth. The behaviour of the wind waves depends chiefly by the wind speed and the fluid viscosity (η). In fact the motion of a wave under shear stress (τ) as produced by winds is

$$\tau = \eta \frac{dU}{dy}$$

where y stands for the height of the liquid. Thus, comparing the Titanian condition to the Terrestrial ones, even for weak wind speed (and consequently weak shear stress) the deformation of the liquid mass, and hence the wave geometry, will be large. These facts suggest that wave amplitude and length on Titan are larger than on Earth. According to the Bernoulli equation a greater pressure occurs in the wave troughs than on the crests, leading to an increase of the wave amplitude. This wave growth is chiefly limited by the gravity, that, being lower on Titan, will allow the waves to grow to larger geometries.

Another limiting factor of the wave geometries is the dimension of the bodies of standing water. In fact, the dimension of the fetch strongly controls the energy that can be released to the fluid mass: larger is the fetch, greater is the energy and the wave period. As a consequence, the larger basin will show larger waves and the beaches will be extensive and complex.

Unidirectional flows. The composition of possible flowing liquid on the surface of Titan is not clear at all, because it will be the direct results of atmospheric precipitation from clouds likely composed of methane. We used a range of values from a composition similar to the putative ocean to pure methane. The flow of liquid results from the balancing of forces, the driving forces (DF) and resisting forces (RF)

$$DF = (whl)(\rho_w - \rho_a) g \sin\beta$$

$$RF = (wL)\pi_s + L(2h + w)\pi_b$$

in which w is the channel width, h the flow depth, L a representative flow length, ρ_w and ρ_a respectively the density of the liquid and of the air, b the angle of slope of the bed, τ_s and τ_b respectively the boundary shear stress over the water surface and the wetted bed. On Titan the driving forces acting over a flowing mass of liquid will be from 11.9 to 16.4 than the Earth and the resisting forces will range from 1.8 to 5.3 than the Earth. This means that the it is easier for a mass of water to flow on Titan than on Earth, and with an equal erosional capacity [6] (that is unfortunately a major question mark) the Titanian streams will tend to erode channels and form, more efficiently, fluvial networks. This is supported by the fact that the shear stress is directly dependent on the depth of the flow, the density of the liquid, the gravity and the slope. Thus, even if this last relation is approximate and the flow is supposed to be uniform and steady, it provide us a clue in understanding the possibility of the existence of a real fluvial network formed by raining liquid. The Reynolds number

$$\mathrm{Re} = \frac{\rho h U}{\eta}$$

suggest that turbulent conditions are easily achieved on Titan, mostly if the liquid composition approach that of the methane.

Bed forms. The capability of the Titanian moving fluids to produce bedforms depends on several factors. The first one is the Froude number that relate the depth of the current with the velocity. The Titanian conditions are note quite different from the Terrestrial ones and the production of bedforms will be similar, as far as the Froude number is concerned. However, a major role is played by the density of the fluids and solids and the viscosity of the fluids. This aspect can be investigated by the Galileo number (Ga). Considering the transported sediments a mixture of siliciclastics and water ice, likely, the formation of bedforms will be more difficult than on the earth.

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