# SOLVENT LIQUIDS ON PLANETS

by

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Folyadék oldószerek a bolygókon

A szerzők megvizsgálják a legnagyobb mennyiségben előforduló folyékony állapotok feltételeit, általában és a Naprendszeren belül. Két lehetséges folyadék érdemel különleges figyelmet: a víz és az ammonia, mindkettő bőséges és jó oldószere mind a molekuláris, mind az apoláros anyagoknak. Mindkét vegyületnek jelen kellett lennie a jelenlegi földi élet születésénél, és legalább az egyiküknek folyékony állapotban.

We investigate the condition for abundant liquid states on planets, in general and in the Solar System. Two possible liquids, both abundant for molecules and both apolar good solvents get particular attention: water and ammonia. Both compounds must have been present at the parental location of present terrestrial life, at least one of them as a liquid.

*Key-words:* liquids, solvents, ammonia, water, p–T field of materials, ice meteorites, ammonia-silicates, double-liquid regions in the Solar System

# 1. INTRODUCTION

Terrestrial life is based on amino acids, and amino acids are somewhat exotic in aquatic environment. They would be simple and natural amphoteric compounds in a chemistry in ammonia solvent (having an organic acid radical on one end and an amino radical, i.e. basic radical of ammonia solvent on the other). So proto-life is more probable in ammonia solvent or in water heavily contaminated by ammonia. This focuses attention on the sufficient and necessary conditions to have liquid water or/and ammonia somewhere on a planet.

# 2. STELLAR CHEMISTRY

The five most abundant elements of the Solar System are, in decreasing order, hydrogen, helium, oxygen, carbon and nitrogen (*Novotny,* 1973). This fact gets its origin from cosmology, astrophysics and nuclear physics, so it seems to be rather general. The explanation goes in 3 steps.

1) The hot early Universe produced a gas of cca. 95 % hydrogen and 5 % helium (in number %) with no more than 0.01 % of any other nuclei (*Wagoner, Fowler and Hoyle,* 1967). All other elements were produced later in the stars in fusion processes.

2) The stellar fusion is governed by nuclear structure and binding energy. Then H produces only He. H and He cannot produce Li, since $^5Li$ is unstable; He + He cannot produce Be, since $^8Be$ is unstable; H + He + He cannot produce boron, since $^9B$ is unstable (*Novotny,* 1973). The first possible product beyond helium is the deeply bound $^{12}C$ from 3 He and then H can be consecutively incorporated into C, producing N and O. The primary product is C, but the binding is deepest in O, hence the abundances.

3) In fusion a Coulomb barrier appears. Therefore H fusion needs cca. 10 million K, the He fusion cca. 100 million K, and later steps even higher. Higher and higher masses are needed to continue the fusion. In addition, with decreasing mass the lifetime in the main branch (core H fusion) is substantially longer. Therefore the next fusion step, resulting in aluminium, magnesium &c., is exponentially rarer in stellar evolution. Iron is the deepest bound nucleus, therefore it is the final stage of any fusion, so iron is slowly accumulating in the Universe.

Therefore, although abundances change with time and central star, the general pattern is that H dominates, He is abundant but chemically inert and cannot condensate therefore ignorable henceforth. Then O, C and N is the next abundance step about

0.001 each, Mg, Al and Si the next one (maybe with Na), Fe (+Ni) is still important and other atoms are rare enough.

Consequenly, around *any* star the solid bodies (planets) can consist of: i) iron and refractory oxides near the star; ii) ices far outside; and 3) carbon and silicates at middle distances. This third point deserves some discussion. The schematic temperature map of the Solar System is shown by *Fig. 1*.
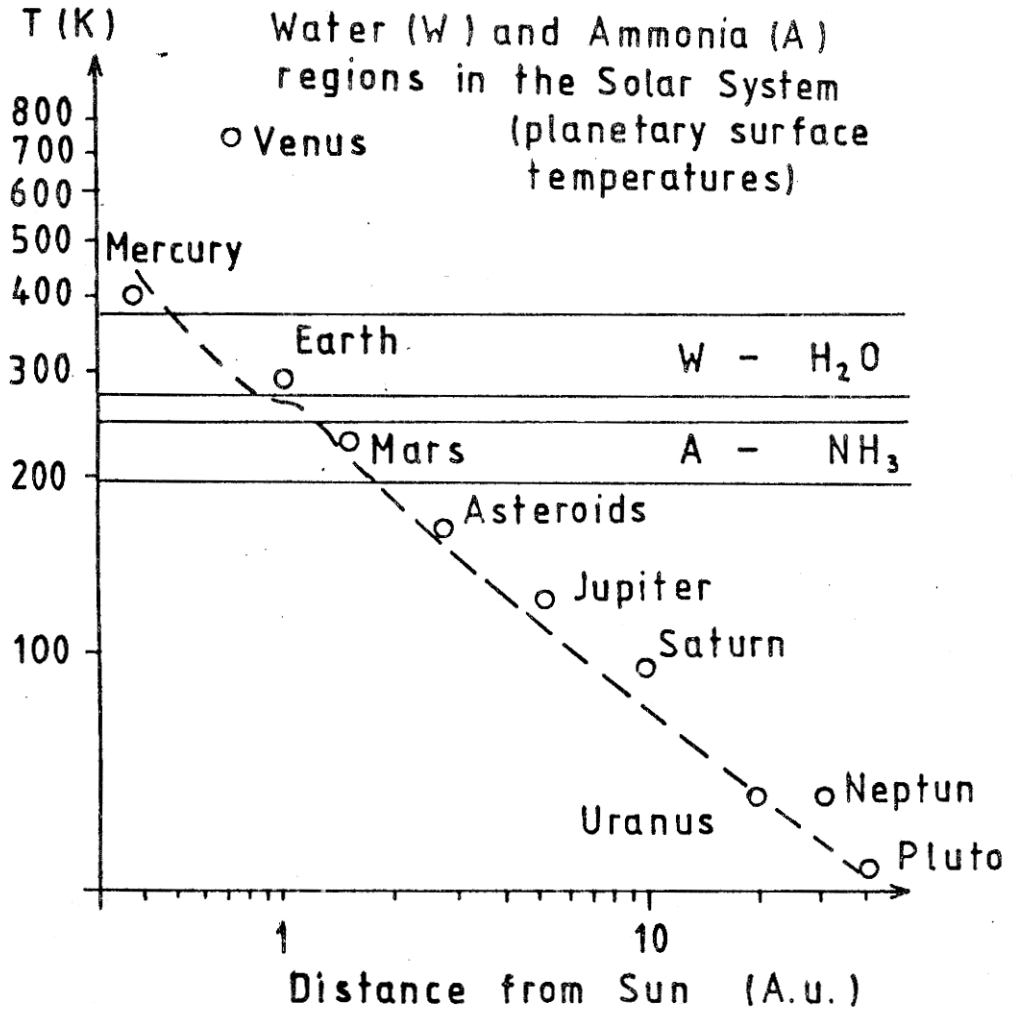


Fig. 1          Temperature regions in the present Solar System

Sun's planetary system represents some 0.15 % of the total mass, but the majority of this is Jupiter and Saturnus, mainly H and He. A stone planet retaining substantial atmosphere seems to have to have, say, third of terrestrial mass, so $10^{-6}$ part of solar mass. So the only elements, solid in middle temperatures, which can build up substantial planets, are C, Mg, Al, Si, S, Ca, Fe (and Ni). Others cannot dominate the mass.

These solids can take up gaseous elements into compounds, as the abundant H, N and O. Now let us see the possibilities.

C is very abundant, but its simple compounds with H, N or O are gaseous in the temperature range considered. So during condensation, or afterwards in radioactive heating, much C is lost from the solid body. (The same is true for S.) Therefore one guesses that in most stellar system the bodies os substantial stony planets are dominated from the compounds of Si, Al and Mg, called generally as *silicates;* maybe together with those of Ca (a characteristic *earth metal*). Si's oxigen compounds are *not* gaseous at middle temperatures. The atmospheres may contain the abundant gases H, He, N and O, together with their gaseous compounds with each other, with C and S. There are more than 1000 H atoms for each C one in stars and interstellar gases (*Novotny*, 1973). Therefore the most abundant form of carbon compounds may be methane, $CH_4$, or derivatives.

Now let us see, which can be the dominant liquid on the surface or in the atmosphere, if liquid can exist on the planet at all. The most abundant liquid will be the general solvent of the planetary chemistry. According to the above arguments, 3 molecules are possible in large quantities: water $OH_2$, ammonia $NH_3$ and methane $CH_4$. Other possible combinations as e.g. dicyan $C_2N_2$, oxygen $O_2$ etc. are expected in smaller amount according to cosmic abundances. Now, methane is not liquid at middle temperatures, and it is not too good a solvent either, being apolar. But ammonia and water are roughly similar to each other; the differences are quantitative not qualitative. (See Chap. 3) Therefore the most probable alternative of terrestrial chemistry under planetary circumstances is a chemistry with liquid $NH_3$ as solvent. We guess that this would be rarer than the aquaeous chemistry, and in Sects. 5 and 6 we shall give arguments and rough estimates for this; however liquid ammonia oceans do not seem very exceptional in the Galaxy.

The ammonia-based chemistry (A-chemistry henceforth as compared to the familiar terrestrial W-chemistry) is not a very exotic topic and some experiments have been performed. Anyway, it needs $-40$ C° at normal atmospheric pressure or 8 atm at room temperature, not impossible in laboratories. Ammonia-based biochemistry is a more difficult matter. However, the starting blocks of ammonia-based organic chemistry are familiar molecules of terrestrial chemistry too.

Non-aquaeous solutions can produce reactions unfamiliar to water-based common sense (*Audrieth and Kleinberg*, 1953). A general definition of acids, bases and salts can be made with respect to the solvent, following e.g. *Lewis*. Then the solvent dissociates to a pair of positive and negative ions; acid is the molecule which dissociates to the positive ion of the solvent, and a foreign negative ion; basis is the molecule dissociating to the negative ion of the solvent and a foreign positive ion; salt is a molecule which does not give any ion of the solvent in dissociation. A neutralisation reaction is in which a basis reacts with an acid, giving a salt and more solvent. So the relations (ignoring such details as hydratation &c.) go as

*Table 1*

Fundamental comparative chemistry

| Solvent | Water | Ammonia |
|---------|-------|---------|
| Dissoc. | $H - OH$ | $H - NH_2$ |
| Acid | $P - H$ | $P - H$ |
| Basis | $Q - OH$ | $Q - NH_2$ |
| Salt | $P - Q$ | $P - Q$ |
| Neut. r. | $P - H + Q - OH =$ | $P - H + Q - NH_2 =$ |
| | $= P - Q + H_2O$ | $= P - Q + NH_3$ |

Therefore every aqueous acid is acid in ammonia, and $H_2O$ is in addition an acid there: but no aqueous basis is basis in ammonia.

The simplest neutralisation reaction in water goes as

$$NaOH + HCl = NaCl + H_2O$$
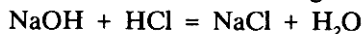
Mutatis mutandis, we can keep the structure and get the „mirror" ammonia-based neutralisation reaction as e.g.

$$NaNH_2 + HOH = NaOH + NH_3$$
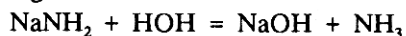
or, by words, in ammonia sodium amide and ice is expected to produce sodium hydroxyde and ammonia; indeed, this reaction goes even under terrestrial circumstances, without being solved in ammonia, if water vapour of cca. 200 C° is ejected on sodium amide crystals.

In environments where $NH_3$ is liquid, $H_2O$ is expected to be still abundant, and either a liquid or a solid (cf. Chap. 7). So water or water ice is an important matter there; similarly as ammonia was on the pre- and protobiotic Earth.

# 3. THE COMPARISON OF WATER AND AMMONIA AS SOLVENTS

Let us compare the properties of water and ammonia *as solvents*. Methane qualitatively differs from both, being apolar. Therefore methane is a poor solvent of some salts. On the other hand, water and ammonia differ only qualitatively. For more details see *Bailar et al.* (1973).

*Table 2*
Main physical properties of the two solvents

| Property | Water | Ammonia |
|---|---|---|
| Freezing p. K | 273 | 195 |
| Boiling p., K | 373 | 240 |
| Crit. temperature, K | 647 | 405 |
| Crit. pressure, atm | 218 | 112 |
| Density (liq.), g/cm$^3$ | 1 | 0.65 |
| Dipole moment | 1.85 | 1.47 |
| Dielectric constant | 81 | 22 |
| Spec. heat (l) | 1 | 1.1 |
| Melting heat, cal/g | 80 | 84 |
| Evapor. heat, cal/g | 541 | 327 |

For solubilities of salts, we mention that NaCl definitely dissolves worse than in water (as most chlorides too); the numbers are 2.1 g vs 36 in 100 g solvent. However

for bromides the solubility is more comparable. Ammonia practically cannot solve chlorides of earths; but can solve some metals in relevant quantities, while water cannot.

Therefore in general ammonia is not worse a solvent than water on Earth. The high specific and melting heats are advantageous to stabilize the environment and to make the meteorologic phase transitions gradual. Ammonia is nearly as polar as water, so in general solves salts almost as well as water, although differences may be large for individual salts; and ammonia in general is the better solvent of organic compounds. The dielectric constants are comparable and high, although the difference is substantial. Ammonia is much inferior in self-dissociation; however by solving electrolites (e.g. any salt or water ice) the ionic concentration will be enhanced.

For ammonia-water mixtures we note that they mix without limits. The phase diagram is very complicated; the lowest freezing eutectic is $2H_2O*NH_3$, with cca. 176 K melting point at 1 atm. With methylalcohol ammonia can also mix without limit.

We will not deal here with the details of biochemistry, with the properties of amino acids and their formation; for that see *Bérczi and Lukács* (1994a). Here we note only that amino acids are solvable both in water and in ammonia.


# 4. ON THE ABUNDANCES OF LIQUIDS
# IN THE SOLAR SYSTEM


Apart from theory we know something about *present* abundances, and on Earth something about prehistory too.

Present astronomy does not show any liquid on Mercury, Venus, Mars and on the asteroids. On Mars subsurface water or $H_2O - CO_2$ mixtures or chlatrates are not totally ruled out. On some Galilean moons of Jupiter liquid water is probable below the frozen ice crust, and on Io volcanoes throw up liquid sulphur. Its liquid space is impossible on the low pressure surface but not below. For the moons of Saturn, Uranus and Neptune data are scarce. Atmospheric pressure is substantial on Titan and Triton, and sometimes criovulcanism is assumed. See e.g. *Kargel* (1992). As for Earth, liquid water is very abundant; other liquids are not too frequent but liquid hydrocarbons are not rare. For the freezing and boiling points af paraffines and some of their derivatives are shown by *Fig. 2*.

The atmosphere of present Earth is product of billion years of biologic activity. E.g. free oxygen is impossible without continuous oxygen source. The palaeoatmosphere is a matter of speculation. *Miller* (1953) was able to produce amino acids in an artificial reducing atmosphere with $H_2O$, $CO_2$, $NH_3$ and $H_2$. While $H_2$ and $H_2O$ do not need explanation, and $CO_2$ is present at Venus and Mars, $NH_3$ seems to belong to the outer
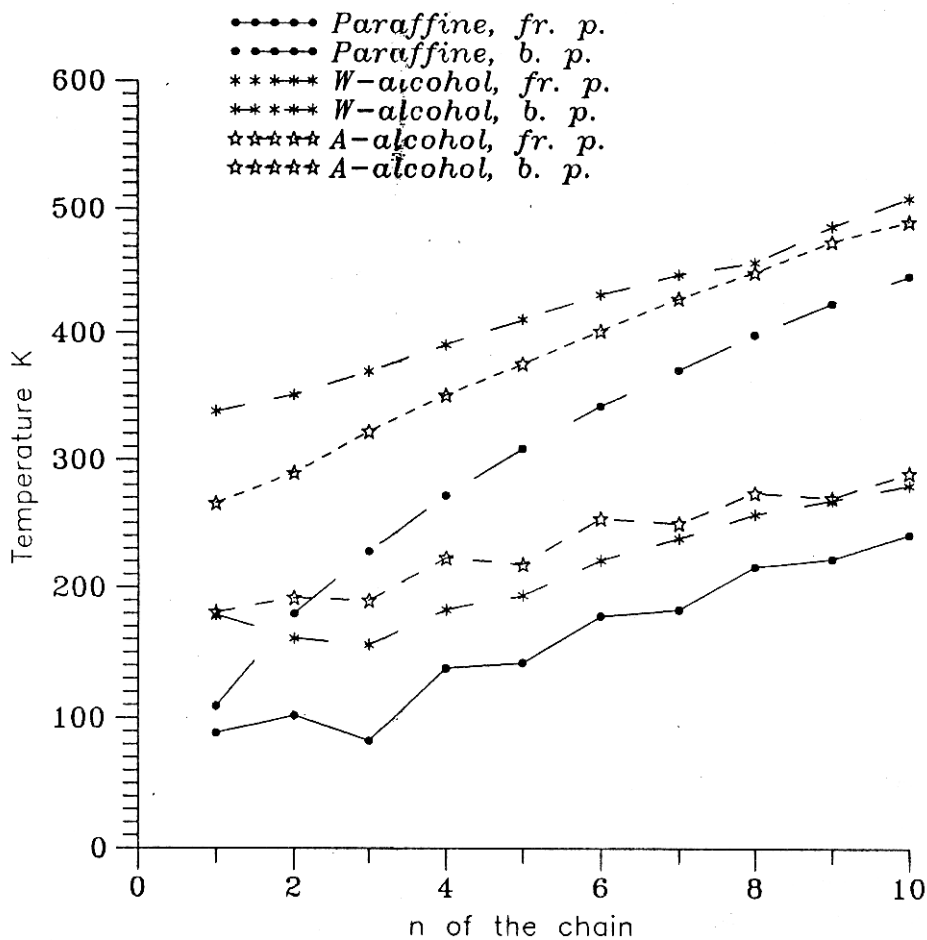
*Fig. 2*   Freezing and boiling points of paraffine chains and alcohols
of different chemistries

Solar System, and so its original presence is often questioned. Two important definite observations indeed do not confirm the simple schemes.

*Szalay* (1975) found $H_2$, $H_2O$, $N_2$, $CO_2$ and $CH_4$ in precambrian sediments, but not $NH_3$. No geologic traces of the often assumed „primordial bouillon" of sugars, amino acids, nuclear acid building stones &c have been found. The earliest layers seem poor in nitrogen; e.g. the amino acid concentration of such sediments seem to be not higher than $10^{-9}$ (*Schöpf, Kwenvolden and Barghoorn,* 1968). This low concentration

comes from the Fig Tree layer where the oldest fossil microorganisms were identified (3.7 – 3.0 Gy old). So ammonia on proto-Earth (liquid or gas) is indicated by life byt not confirmed by geology. Water must have been liquid at least at some parts of the terrestrial surface from the time of oldest preserved microorganisms. Other liquids seem to have been always of minor abundance.

A possibility is extraterrestrial origin of terrestrial life from an ammonia-rich planet: a microorganism survived space travel on meteorite, found an ammonia-free atmosphere and their descendants converted the reducing atmosphere into oxidative. This is possible if there was life somewhere else in the Solar System. Up to now there has not been found any evidence for such extraterrestrial life, but it may have existed on proto-Mars with substantial atmosphere. It is interesting to see what were the possibilities for ammonia to have appeared in the terrestrial and Martian palaeoatmospheres. For any case, some 2 Gy ago Mars was geologically active, gases and vapours continuously emerged and the atmosphere must have been dense enough to keep *something* (water or ammonia) in liquid state because huge riverbeds have been preserved up to now.

Now comes the theory. According to the *Barshay-Lewis model* (1975) ammonia could have condensated somewhere outwards from Saturn. Gas evaporation from the bulk of Earth may have seriously contributed to the palaeoatmosphere, but the present Earth litosphere seems very poor in ammonia.

Ammoniates and aminated silicates may help, if they contributed to primordial Earth, and then lost the ammonia when the bulk of the planet was being heated up. Unfortunately the present knowledge about silicates with structural ammonia is next to nothing so they are not included into condensation calculations for the early Solar System. Therefore no serious theoretical predictions exist for the ammonia content in the inner Solar System. Anyway, hydrated, ammoniated and aminated silicates must have been more abundant in the Martian condensation than in the terrestrial process. In addition, a collision with an ammonia-rich planetesimal during the formation of Earth or Mars is not impossible. A planetesimal of R ~ 1000 km from beyond Uranus could have filled up the terrestrial palaeoatmosphere to 1 atm partial pressure. Of course, then remains the problem that no geologic remnant of this ammonia is found on Earth. From Mars data are very scarce.


# 5. ON CONDENSATION MODELS OF SOLAR SYSTEM


For the details of planetary composition one must see in which sequence the abundant elements form their compounds. Condensation models of the Solar Nebula

have deduced the type and sequence of mineral belts which has been formed around the early Sun. (*Barshay and Lewis,* 1975; *Grossman and Larimer,* 1974; *Grossman,* 1972). In these models the temperature was the main factor which differentiated the belts according to the principal mineral constituents.

From a gas with solar elementary abundance water, ammonia, and methane ices were the most important (by mass, volume, modal weight) condensates in the outer Solar System. *Lewis* (1974) worked out in details the sequence of condensation for outer solar system mineral constituents, mainly ices. We refer here this work and show the steps of the equilibrium condensation sequence, as follows:

*Table 3*

The Lewis – Barshay sequence of condensation

| Temperature | Chemical process, mineral transformation or condensation |
|---|---|
| ca. 500 K | Formation of **TREMOLITE** (from Ca, Al, Mg, Silicates with $H_2O$) |
| ca. 400 K | Formation of **SERPENTINE** (from Mg(Fe), Silicates with $H_2O$) |
| ca. 170 K | Condensation of **WATER – ICE** (which exhaust all $H_2O$ gas) |
| ca. 110 K | Formation of **$NH_3.H_2O$ AMMONIA – CLATHRATE** (exhausts all $NH_3$) |
| ca. 60 K | Formation of **$CH_4.8H_2O$ METHANE – CLATHRATE** (exhausts all solid $H_2O$) |
| ca. 25 K | Condensation of $CH_4$ and Ar gases to **METHANE –** and **ARGON – ICE** |
| ca. 8 K | Condensation of Ne gas to **NEON – ICE** |
| ca. 7 K | Condensation of $H_2$ gas to **HYDROGENE – ICE** |

The last two condensations are strongly hypothetical, and observe that crystals with structural water are included but those with structural ammonia are not; such crystals are known, e.g. $CaCl_2$ can take up 8 molecule ammonia into its lattice.

This table shows that the most abundant volatile phase, the $H_2O$ first appears as a component added to the higher temperature condensates to transform (metamorphose) them: such forming hydrous silicates of tremolite and serpentine.

There is a wide gap in temperature between these hydrous silicates condensation and ice-condensation. In this region carbonaceous compounds condensate according to the *Ryoichy – Anders model* (1981), but these results were yet unknown in 1974, when Lewis calculated his sequence referred here.

Ammonia probably enters too into stones and form ammoniated silicates. However for it there is another possibility. The ammonium ion can substitute potassium

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and rubidium in silicate *lattice points*. Potassium is rare and rubidium is negligible; the ammonium ion can form from $NH_3$ and H at moderate temperatures where $NH_3$ is abundant. In the Solar System this region is definitely outside the terrestrial orbit; some ammonium compound is reported from Ceres (*King et al.*, 1993). The best known terrestrial ammonium silicate is buddingtonite (*Erd et al.*, 1964). Such silicates may have formed in condensation and may have entered the proto-planets. At higher temperature the ammonium ion disintegrates, ammonia leaves the silicate, and H is left behind. (The substantial size difference disrupts the lattice.)

Water, ammonia and their mixtures condensate somewhere between 200 K and 100 K. In this region first the water-ice, then a compound ice of $NH_3.H_2O$ ammonia clathrate precipitates. Considering the Cameron adiabat from the *Lewis-Barshay model* (1975) which intersects the phase boundary of water-ice at ca. 170 K between Jupiter and Saturn we may estimate the planetary provinces of the W−A mixtures.

Then one can see that water of the inner planets does *not* come from water-ice condensation. The proto-temperature there was just low enough for silicate condensation, much above ice freezing point. So the stony planets formed their water from hydrated silicates; and ammonia can be formed analogously from ammonia or ammonium-bearing silicates. Under appropriate climatic conditions, large bodies of aquaeous (W) or ammonia (A) solvent can form on the surface.

There are two types of planetary provinces, where W−A hybride chemistry could have developed. One type of province is on the satellites of these two giant planets. Mainly subsurface inner zones may be considered as suitable places for liquid conditions to any of the two solvents. The other type of province is on the Jovian Planets themselves. Their atmospheres contain such zones, where the necessary p−T conditions are suitable for W−A organic chemistry.

In the early protosolar nebula the temperatures differed from the present. Reasons can be manifold, and one of them is the different protosolar luminosity. In our system we can deduce the condensation temperatures from the compositions of the planets (*Barshay and Lewis,* 1975). The proto-temperatures seem to have been roughly the doubles of the present equilibrium blackbody temperatures. Then Earth was just at the inner boundary of the hydrated silicate belt, with a small amount of primordial bulk water. Mars was well inside of the hydrated silicate belt, the bodies of the asteroid belt must have originated with mixtures of $H_2O$ ice and hydrated stones (a fact suggesting internal fragility), and $H_2O$ ice is a main component in the Galilean moons of Jupiter. Outwards from Jupiter ammonia gradually takes over. Unfortunately the papers contributing to *Table 3* did not include stony components with structural ammonia, which may exist, but of course cannot be expected in natural terrestrial environment, where ammonia does not have a chance to replace the dominant water. In addition, silicates do exist in which some alkalies are substituted by ammonium ion, e.g.

buddingtonite (*Erd et al.,* 1964). So behind the orbit of Mars *Table 3* cannot be complete in the present state of knowledge. Obviously rough guesses should be done until the ammoniate analogons of hydrated silicates will be known better.

# 6. ON THE ASTRONOMIC POSSIBILITY OF AMMONIA SOLVENT AND A-CHEMISTRY

Now we can look around for extraterrestrial environments with at least some physicochemical possibility for liquid water or/and ammonia. We follow the complex map of *Figs. 3–5.* It is a p–T phase diagram.

The curvilinear triangles indicate regions where liquid $OH_2$ (dashed) and $NH_3$ (solid) are possible. The corresponding localities are obviously planetary surfaces, depths or atmospheres. The almost horizontal T–p curves are the condensation lines of some important molecules (*Barshay and Lewis,* 1975). By intersecting them with the Cameron adiabats (on the extreme left) one gets the actual condensation conditions in the Solar System; for other planetary systems only the actual adiabat differs, for which see *Bérczi and Lukács* (1994b). The present average values for Venus, Earth, Mars and Titan are indicated by fans, whose apices are the planetary surfaces, and otherwise they are depths or atmospheric localities; model atmospheric layers of Jupiter and Saturn are shown by the steep curves.

Present Venus is too hot for both solvents, although the upper atmosphere may be conform with liquid $H_2O$. There no large contiguous body of the solvent can exist; one may at most contemplate about an earlier W-life of the original not too hot surface to emigrate to the upper atmosphere.

Present Earth is conform with liquid $H_2O$, and according to geology this was so at least in the last 3.7 billion years. Present Earth is not conform with liquid $NH_3$, except for some underwater situations, where however liquid ammonia would be in hopeless minority; on proto-Earth atmospheric pressure may have been quite high and then ammonia might have been in liquid phase.

Present Mars in average is not suitable for any of the solvents. A very moderate simultaneous increase of temperature *and* pressure would put it within the liquid $H_2O$ region, and such situations may or may not exist in subsurface chambers of the giant extinct (?) volcanoes. On the other hand the present temperature with a substantial paleoatmosphere (from 1 atm upwards) might create a possibility for A-chemistry. Observations show ancient riverbeds of running liquid, but do not tell if it was water or ammonia. If liquid ammonia existed in the Martian past, it contained substantial amount of solved $H_2O$, from the ice.
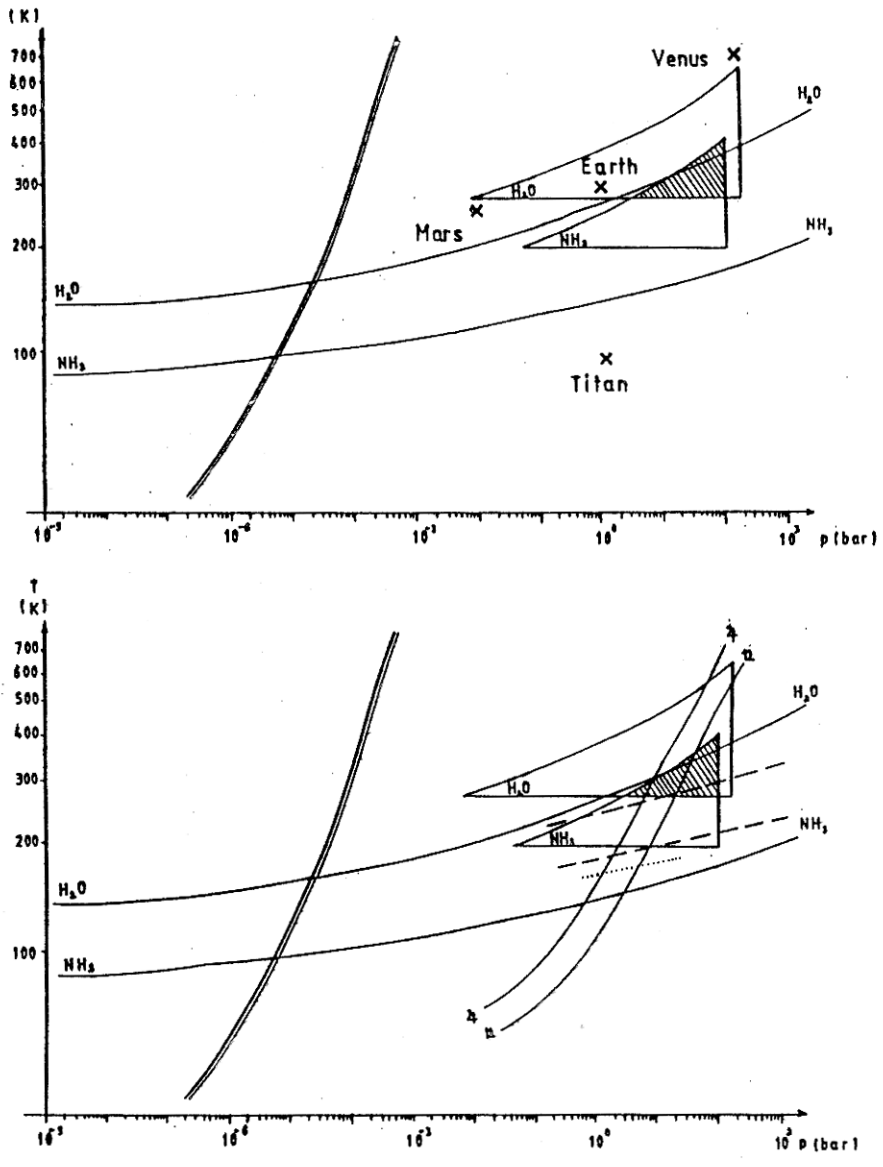
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*Fig. 3*       The combined T–p diagram of the Solar System
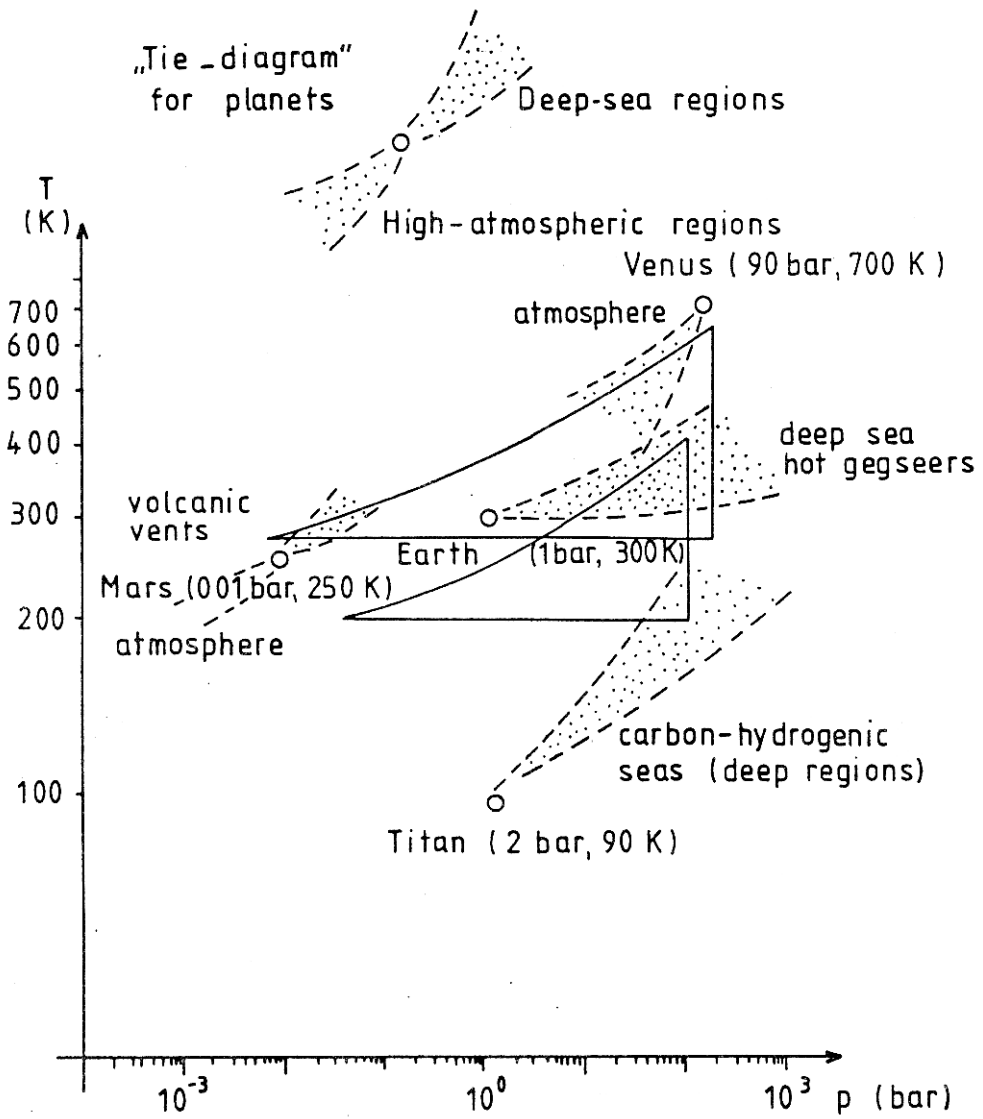              and the two main solvents (details in the text)

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*Fig. 4*   Planetary surface p−T conditions extended up to the atmosphere,
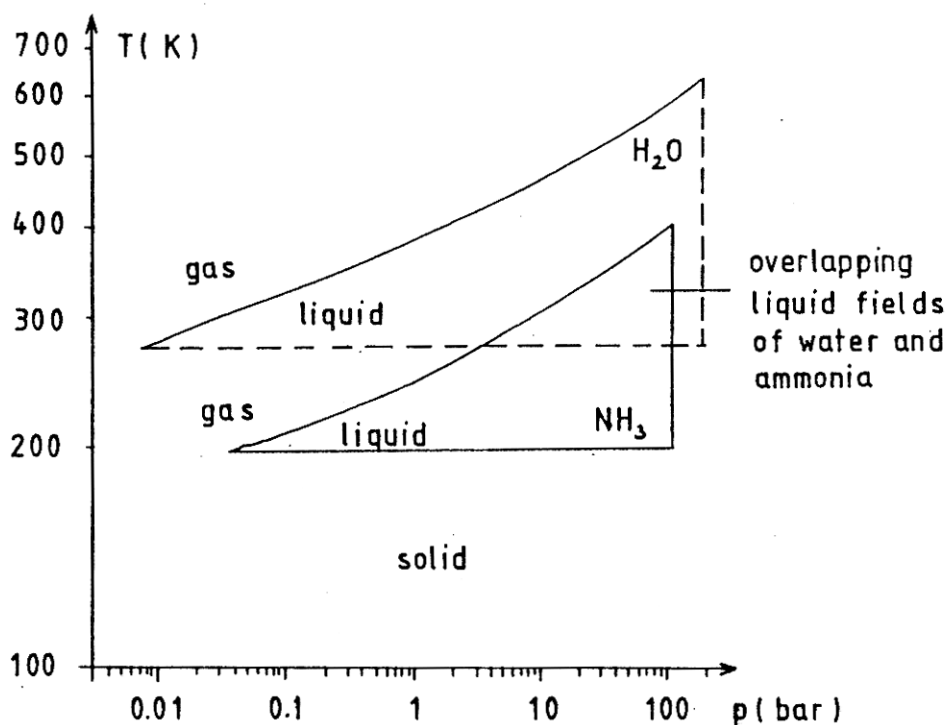and down below surface or sea level

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*Fig. 5*        Melting and boiling conditions for water and ammonia

Titan seems too cold for any of the solvents, although ammonia may be a major constituent of it.

Somewhere in the atmospheres of the two gas giants ammonia may be a liquid; it is not clear if life could have started in an atmosphere.

Because of the very low pressures no asteroid surface can have had any of the two solvents in liquid phase in the last 4 billion years.

In the overlap region (hatched) both possible solvents are in liquid phase. In this case the more abundant one will determine the fundaments of local chemistry. Our guess is that according to cosmic abundances water will generally dominate.

Around stars the belt for liquid ammonia partly overlaps with that for water, and lies on its outer side. For stars not too different from Sun the planets condensated there will inevitably contain structural water in the litosphere, so on a planet with ammonia oceans water still will be available in ice phase and therefore hydroxyle ions will appear in the solvent. For much different stars the thermal history of the protostar

should be investigated to decide if hydrated silicates condensated in the belt of cca. 250 K equilibrium blackbody temperature in the later fusion era of the star. In addition, as told above, we do not know too much in the present state of art about the condensation of silicates with structural ammonia, a major source of surface ammonia (*Bérczi and Lukács*, 1994b).

# 7. DISCUSSION

The goal of this paper was to clarify the necessary planetary and stellar conditions for liquid water or ammonia, good solvents in planetary chemistries. This condition selects 2 belts around any star, partly overlapping; plus a high enough atmospheric pressure to avoid sublimation, i.e. a substantial planetary radius. For water solvent the belt starts just outside of Venus's orbit and marginally reaches Mars. The ammonia belt overlaps at the outer edge of the water belt and extends to greater distances roughly by 40 %. However substantial atmospheric pressures are needed too, present on Earth but not on today's Mars.

It seems that even in aquaeous environment the emergence of life would need or would be speeded up by substantial amount of ammonia. Ammonia seems to be not abundant in the internal part of the aquaeous belt because of the high temperature of the nebula.

Applying all these to the Solar System, Venus is almost in the water belt, but in her present status the high greenhouse effect evaporated water. Venus must always have been poor in ammonia.

For Earth there is a problem. Earth is and seems always have been in the water belt. However in 1 AU not too much ammonia must have been in the solar nebula, while terrestrial life suggests substantial ammonia stores on the early Earth. To be sure, ammonium silicates have been suggested for ammonia source (*Eugster and Munoz*, 1966), and they could have taken part in the formation process of proto-Earth (albeit in this temperature zone even ammonium silicates seems to have been rare), or Earth may have got an impact of an ammoniated planetesimal from the outer system. The problem is that the earliest known deposits are N-poor, even in the neighbourhood of the first known fossil procariotes. This controversy needs an explanation, not available now.

Neither water nor ammonia is liquid on present Mars. Some 2 Gys ago Mars had some liquid because riverbeds are seen. Then Mars may have had either liquid ammonia with abundant water ice, partly solved, or liquid water, with abundand gaseous ammonia, partly solved; Mars may have got substantial amounts of both hydrated and

ammoniated and ammonium silicates. We only note that *King et al.* (1993) found ammonium saponite on Ceres by spectroscopy. Therefore there is a chance that ancient Mars generated life, either W or A.

Outwards from Mars liquid water is impossible; for liquid ammonia we got that it is improbable in the outer system.

Finally we note that there is a narrow temperature range where neither water nor ammonia is liquid but an ammonia-water mixture is. At 1 atm pressure this range is between 176 and 195 K, which is cca. at 2.2 AU. There is no substantial body here in the Solar System, but by pure chance a planet may appear at analogous position in another system. In such a solvent chemistry will be rather complicated and we cannot guess if the sharply tuned processes of any biochemistry are compatible with such an ambivalent system, although our biomolecules seem to be WA hybrides.

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