The history of our solar system as a remnant of an exploded supernova is traced. The biochemistry of life is connected with virtual energy level of ^{12}C. The nuclear fusion of hydrogen and helium in the core of the Sun (one of the young stars) is responsible for production of heat and light for sustaining life on our planet. A new concept of origin of life is presented based on terrestrial radioactivity.

Life

through the

Nuclear Valley

George Marx[a] and H S Virk[b]

OUR YOUNG UNIVERSE

Nuclear physics became an exact science during the 3rd decade of the 20th Century. Its real technological-societal-cultural relevance was understood only in the last years of the century.

A nucleus consists of Z protons and N neutrons, altogether A = Z+ N particles, called nucleons. The positively charged protons repel each other electrically. To stabilise the nucleus it is necessary that the nucleons attract each other strongly. Experiments with collisions of nucleons show that the *nuclear force* is

- attractive, about 100 times stronger than the electric repulsion,
- charge independent, it does not distinguish between proton and neutron,
- short ranged, it vanishes beyond a distance of b~ 1fm.

The size of nuclei is of the order of magnitude of 10^{-15} = 1 fm. (The official name of 1 fm is 1 femtometer, but its nickname is 1 fermi, because Enrico Fermi used it frequently in interpreting his neutron scattering experiments.) The short range has the consequence that a nucleon feels only the nuclear attraction of its immediate neighbours, this is why the density of nuclei is

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practically constant. The volume of nuclei is practically constant. The volume of nuclei is proportional to the number *A* of the constituents, therefore, the radius of a spherical nucleus is proportional to the cube root of particle number, $R = R_0A^{1/3}$, where R_0 = 1.4 fm. The case is very similar to that of a water droplet : water molecules stick only to their neighbours; this is why the density of water is constant to a good approximation. The heat of boiling does not depend, whether we wish to boil 1 cm^3 of water from a small glass or from a huge pot. The binding of energy E is also roughly proportional to the number A of the nucleons they contain : $E \sim \varepsilon_0 A$. From our geometrical picture it follows that on the surface of a spherical nucleus a nucleon has less attracting neighbours than the one inside. Nucleons on the surface are less bound. The negative binding energy is weakened by the positive surface energy which is proportional to the $4\pi R^2$ surface area : $E_s = \varepsilon_s 4^{2/3}$. This surface tension is well known in the case of water or mercury droplets; it explains why they are spherical, in order to make their surface a minimum.

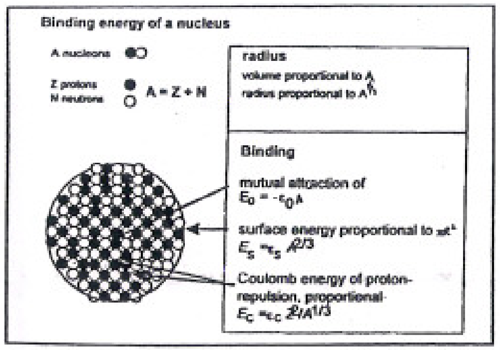

Fig 1. Binding energy

In the droplet model, to the two terms of the energy one has to add a third term, which describes the electric Coulomb energy of the nucleus, which has a charge +Ze. This energy is proportional to Z^2, and inversely proportional to R, ie, $Ec = \varepsilon_c Z^2/A^{1/3}$.

Putting three terms together (Fig 1) gives for the average binding energy per nucleon :

$$\frac{E}{A} = -\epsilon_0 + \frac{\epsilon_s}{A^{1/3}} + Ec\,\frac{Z^2}{A^{4/3}}$$

(Numerically, ϵ_0 = 2.52 pJ; ϵ_s = 2.85 pJ; E_c = 0.11 pJ; where 1 pJ = 10^{-12} Joule — or about 6 MeV in atomic physics slang).

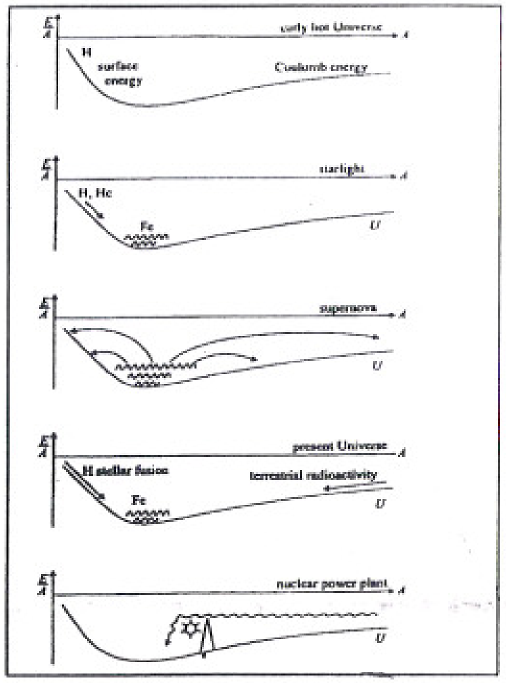

Fig 2. The Nuclear Valley

The binding energy per nucleon indicates how much the nucleons "like" to stay in a specific nucleus. Its variation with nucleon number A is shown in figure 2. This shows the nuclear valley which goes downhill with increasing A, because in smaller nuclei a larger fraction of nucleons are on the surface, where the bond is weaker. We regularly see water or mercury droplets fusing into a larger droplet in order to decrease the fraction of constituents staying on the surface. In the same way, *the fusion of light nuclei into a larger one (sliding down on the left-hand slope) results in a decrease of the total surface, thus liberating energy.*

According to the Pauli exclusion principle, only two protons and two neutrons can be in one quantum state (with opposite spins), therefore $Z \cong N$, ie, $Z \cong A/2$ is favoured by nuclei. *This has the consequence that in large nuclei, the electric repulsion of the many protons becomes important, which is why for large values of Z and A the fusion of the nucleus (sliding down on the right hand slope) liberates energy.* The deep narrow valley runs across the landscape mapped out by proton number Z and neutron number N. Depth in the Valley is binding energy per nucleon.

is

After the discovery of the expansion of the Universe, George Gamow imagined that at the beginning of time the whole world was a (neutral) neutron sea, and that later, during the expansion this fragmented into nuclei, and thus into atoms. He charged his graduate student, Ralph Alpha, to elaborate details. If the Universe were in thermal equilibrium, all the nucleons had to be at the deepest region of the Nuclear Valley, forming medium heavy nuclei.

Using specific data, this would mean *iron nuclei*, because the binding energy per nucleon is in the case of iron (A = 56) the deepest : −1.37 pJ. But in our actual Universe, the concentration of iron is very small, only 0.006%. Our Universe consists mostly of hydrogen (A = 1.75%), which is the smallest non-composite nucleus. From this evidence, around 1940, Alpher concluded that *the early universe was very hot.* At the beginning, after the Big Bang, within the first second the temperature exceeded a billion degrees, and the thermal motion was so intense that high energy collisions prevented the existence of composite nuclei. Due to the gradual expansion the Universe cooled, but it is not yet old enough for the nuclear matter to have reached its deepest energy state, to have flowed into the Iron Sea. So it seems that *our Universe is still young.*

c

SUNSHINE THROUGH BILLIONS OF YEARS

After the first few minutes free protons, inherited from the hot Big Bang, made most of the stuff in the universe. The mass of the lonely neutron is a tiny bit larger than the sum of the proton mass and electron mass, therefore, the free neutron decays spontaneously into a proton and an electron (also a neutrino) in a few minutes : $n \rightarrow p + e^-$. The temperature of the expanding universe dropped below 1000°C within 1 million years : after that the protons and electrons built up hydrogen atoms.

The electric repulsion between two protons is 10^{36} times stronger than the gravitational attraction. On the atomic scale, gravity is very weak. *Positive and negative*

charges compensate each other, but gravitational attractions of accumulating masses enhance each other. If we increase the size r of a sphere ten times, its mass M will increase thousand fold, and the magnitude of the potential energy of a particle with mass m on its surface, $E_{grav} = -GMm/r$, increases a hundred fold. In the case of big enough spheres (stars), gravitation becomes the dominating force. Eugene P Winger emphasised that the *very weak strength* of gravity results necessarily in the *very large mass* of the heavenly bodies.

Random fluctuations produced density enhancement in the primordial hydrogen clouds. If the hydrogen ball was big enough, its own gravity increased its density further. The kinetic energy of the in-falling layers heated the hydrogen gas to several million degrees. The hot sphere started shining : a star was born. Such a star is our sun. When the central temperature of the star reached several million degrees, the energetic collisions of protons began to overcome their electric repulsion, and the two protons approached each other within the range of nuclear forces. We might expect that nuclear fusion would begin, liberating energy : $H + H \rightarrow {}^2He$.

No! The ^2He nucleus does not exist. The two colliding protons leave each other unchanged. The gas remains hydrogen.

Two nucleons have only one bound state : Heavy hydrogen, *deuteron.* ^2H is made of one proton and one neutron. Its measured binding energy is $E = -0.357$ pJ.

Let us do a small calculation. If b is the range of nuclear forces, the two bound nucleons cannot be at larger distance : $\Delta X \cong b$. According to the uncertainty relation $\Delta X \Delta p \cong h$. In the nucleus the kinetic energy $E_{kin} \cong \Delta p^2/2M_p \cong h^2/2M_p b^2 \cong 1.5$pJ. This is by an order of magnitude larger than the measured binding energy, 0.357 pJ, resulting from the tight localisation due to the short range of nuclear force. The deuteron almost jumps out from the potential hole! The 2H *proton–neutron system is a very weakly bound formation!.* It is almost unstable : it has no excited state, the smallest rotation or vibration tears it apart. *There is no bound proton-proton system*, the simplest explanation is that the mild electric repulsion destabilises the ^2He. (it may be noted that nature plays also with the relative spin direction of the two particles, but we do not go here into these details.) If the fusion of two protons gave a bound system, if 2H existed, then the whole Sun could make helium and explode in one millionth of a second like a hydrogen bomb. There would not have been sunshine through billions of years, , there would not have been life on Earth. But if it is so, how does the Sun produce its nuclear fusion energy, providing a steady flow of sunshine?

In the actual Universe, in the centre of the Sun, at 15 million degree centigrade, as two protons collide for a moment they look like ^2He. If a radioactive β-decay could happen during this short moment, then $2He \rightarrow 2H + e^+$ transition

$^2He \rightarrow {}^2H + e^+$

would produce a stable deuteron. The deuteron could make further fusions : $^1H + ^2H \rightarrow ^3He$, then $^3He + ^3He \rightarrow ^4He + ^1H + ^1H$. In this or similar ways ^4He can be created. Due to its closed shell structure (Fig 3), ^4He has a very deep binding energy, 4.52 pJ, an order of magnitude deeper than ^2H. In this way a very large amount of nuclear energy can be obtained. Yes, but the β-decay (positron emission) is a *weak process*, it has a very low probability. At the centre of the Sun one single proton suffers many collisions each second, but it has to try hard through billions of years before it just happens to undergo a β-decay in the short moment of a collision. This *tight radioactive safety valve*

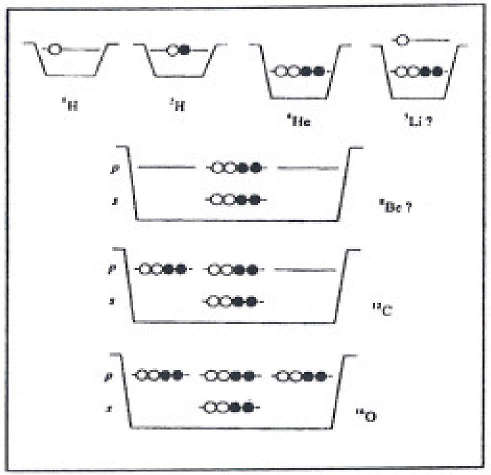

Fig 3. **Shell structure of nuclei**

prolongs the active life of the Sun from microseconds to billions of years. The Sun is not a hydrogen bomb, it is not a black cloud, but a reliable, long-lasting, light source shining in the sky.

Sir Martin Rees, the British Astronomer Royal, looks at the deuteron as the key actor in the history of our Universe. The binding energy of deuteron (which is not zero, but very tiny compared to the nuclear potential) is a very important numerical value, influencing the fate of the World. If the nuclear force were just a few percent weaker bound ^2He would exist. But in these cases we would not be present to admire the Divine Comedy.

COAL AND OXYGEN

The Universe, born with a Big Bang, is 15 billion years old. Today it contains 73.5% of H and 26.4% of He, but these are only the first two elements of the Periodic Table, at the top start of the left slope of the Nuclear Valley. (The other elements do not amount to more than one part per thousand. From hydrogen and helium, however, one cannot form complex molecules, solid bodies, living beings, pieces of art. On the lowest energy level of the nucleons, two protons and two neutrons have places (Fig 3), this is just the He nucleus in which each nucleon is attracted by the three others, keeping each other within the range of nuclear force. If ^4He wished to capture a fifth particle, according to the Pauli principle this could go only to the first excited level (figure 3), where is kinetic energy would be four times higher, too much for the nuclear potential balance. Nuclei consisting of 5 particles (^5He, ^5Li) *do not exist*. The hydrogen and helium of stars cannot fuse!

From the unification of two ^4He nuclei ^8Be would be formed (4 nucleons on the ground floor, further 4 nucleons on the first floor), but such a stable formation does not exist either, it immediately flies apart into two 4He nuclei. (The four nucleons, forced to the upper floor by the Pauli principle, prefer moving to the ground floor in another house). Thus it is a fact of nuclear physics that 99.0% of the world is made of H and He nuclei, and then STOP! The end products of the imaginable reaction $H + H \rightarrow ^2He$, $H + He \rightarrow ^5Li$, $He + He \rightarrow ^8Be$ do not occur in nature. A star, having used up its He fuel supply, will shrink to a star fossil, to a faint white dwarf.

But we do exist! Where do the C and O nuclei, the building blocks of living matter, come from? Light elements like carbon and oxygen are observed to abound in *red giants*, stars that are many times bigger than our Sun. Their temperature reaches 100 million degrees. In their cores, the collisions are much more vehement and frequent. In order to explain the formation of C, Fred Hoyle made the following assumption : the product of a $^4He + ^4He \rightarrow ^8Be$ collision exists for a very short time . During this time the ^8Be nucleus may be hit by a third ^4He nucleus before it disrupts. Lets assume — said Hoyle in 1953 — that the end product of the $^8Be + ^4He \rightarrow ^{12}C$ reaction, the C nucleus, has a high lying (virtual) energy level just at 1.22 pJ, which enhances the probability of formation of ^{12}C. Then the excited ^{12}C emits a photon and goes down to its ground state, and stable ^{12}C is born. Thus, he thought, the building block of organic chemistry might be made.

Julius Csikai (a Hungarian nuclear physicist) bombarded stable ^9Be with neutrons. He observed the emission of two free neutrons; furthermore, the creation of two ^4He nuclei. The measured directions (momentum values) of the four products showed him that the process goes on in two steps : $n + ^9Be \rightarrow ^8Be + 2n$, then $^8Be \rightarrow 2\,^4He$. Thus 8Be does indeed exist for a short time (10^{-17}s). Wiliam Fowler proved in 1957 that the 12C nucleus has indeed an excited energy level at 1.27 pJ, only 4% above the value predicted by Fred Hoyle. (This energy difference is supplied by thermal motion in hot red giants). The *key to the population of the Periodic Table is the virtual energy level of 12C, which has to beat just the required height. Thanks to it, in red giants, triple He encounters start the buildup of the Periodic Table of chemical elements.*

The next step of nuclear buildup is the capture of a new He nucleus : $^4He + C \rightarrow ^{16}O$. This goes easily because ^{16}O has closed shell structure. (The s and p states are filled up by 8 protons and 8 neutrons). The new danger is that He capture uses up all the C nuclei immediately. In a hydrogen-helium-oxygen world, rain would exist but life would not! Fortunately, 16O does not have a virtual energy level, therefore, carbon is left over. Attila Csoto and Heinz Oberhummer have shown by calculation that a few per thousand modification in the strength of nuclear forces would shift the C excited level in such a way that triple-He collisions would not make C or the favourable C/O = 1/2 ratio of the actual universe would be shifted unfavourably. *This accurate tuning of nuclear force makes it possible that our world* *contains both carbon and oxygen! This fine tuning is even more surprising than the case of deuteron. The astrophysicists wondered : what had tuned the C energy level* (thus the formation of coal and oxygen) just so that it enabled developing a C-H-O biochemistry, the birth of life!

But if the energy level of ^{12}C were shifted by one percent, there would be no astrophysicist wondering about the fine tuning of the ^{12}C nucleus. We are not cause but consequence. But it is hard to stop thinking further...

Collisions of He and C make oxygen, collisions of H and C make nitrogen, collisions of He and O make neon, then He and Ne make magnesium, He and Mg make silica. These elements will become able later to make pebble and dolomite, sugar and meat...

Besides the 99.9% H and He in the Universe, we find now 0.06% O, 0.023% N, 0.007% Ne, 0.006% Si; these are the most abundant elements in the Universe. They were made in the depths of the red giants at a few hundred million degree centigrade. But this temperature is not yet enough to make heavier nuclei. In the collision of two Si nuclei, the two +14e charges repel each other sixteen times more strongly than the +2e and +6e charges in the oxygen- producing He + C collision! Si + Si fusion requires temperatures an order of magnitude higher than that available in red giants. When the He fuel supply of red giants becomes exhausted, pressure cannot resist gravitation, the giants star shrinks. The work of gravity raises the temperature in the falling layers above a billion degree centigrade. Now even $^{28}Si + {}^{28}Si \rightarrow {}^{56}Ni$ fusion becomes possible. Then the ^{56}Ni nucleus transforms to ^{56}Fe nucleus by two β-decays, and iron is the most stable nucleus, lying at the deepest point of the Nuclear Valley. Iron is indeed the most common metal in the universe — 0.006%.

The absolute value of the binding energy per nucleon (E/A) is the largest in the case of iron : 1.37 pJ. 80% of this nuclear energy is liberated during H ® H fusion in sun-like stars. The leftover 10% is released in late stellar evolution, during the formation of iron. This 10% can feed the bright hot star only for a short time : the dying star exhausts the last drops of nuclear energy within decades or years. It is a rare transit phenomenon in the sky.

In the very last seconds of its active life, the pressure of billion-degree hot gas is unable to resist the increased gravity : the giant star collapses to a huge nucleus; it becomes a *neutron* star with a diameter of 1–2 km. The in-falling layers hit the surface of the neutron star, they become overheated, the nuclei begin "boiling" : they release neutrons and α-particles. These are absorbed by other nuclei. In this way, during the death struggle of the star, the whole Periodic Table becomes populated, up to uranium and even beyond (figure 2). The thermal radiation of the hot surface blows the outer layers of the neutron star. The expanding gas shell results in a sudden brightening : astronomers observe a *supernova* outburst. In the spectrum of the supernova, even the

spectral lines of transuranic elements (like californium, Z = 98) appear, testifying the hellish alchemy in the death struggle of the stars. So the active life of the ends.

Supernova explosion contaminated outer space with the 100 elements of the Periodic Table.

GEOTHERMAL HEAT

In the 19th century, Lord Kelvin considered the planet Earth to be a gradually cooling stone ball, and from the measured geothermal gradient he estimated the age of the Earth to be 75000 years. Charls Darwin, however, needed some 300 million years to explain the evolution of species. But convinced by Kelvin's thermodynamical argument, he was ready to withdraw the theory of evolution in view of the shortness of physical time scale.

The situation was changed by the discovery of radioactivity at the turn of the 19th/20th century. George de Hevesy has shown (1923) that the decay series of ^{238}U terminates in ^{206}Pb, the decay series of ^{235}U terminates in ^{207}Pb, and the decay series of ^{232}Th terminates in ^{208}Pb. By assuming that the uranium and thorium ores did not contain any lead originally, from the observed geological lead/uranium and lead/thorium ratios, Hevesy obtained 6 billion yeas for the age of the Earth, thus expanding the time scale 100000 fold. This was enough for Darwinian evolution of the biological species.

Since in the spectrum of the Sun, the spectral lines of iron are present, the Sun cannot be a primordial star, formed originally of pure hydrogen. In this region of the Galaxy, a supernova had to explode before the formation of the Solar System. The ejected supernova material mixed with the primordial interstellar hydrogen cloud. Their collision produced gas concentrations. From such a dusty hydrogen cloud the solar system was formed. At the centre the hydrogen gas was heated up to million degrees by the work of gravity. Our Sun brightened up, its power source being the fusion of H into He. The composition of the outer planets is also similar, but their mass was not enough to supply enough gravitational work to ignite nuclear fusion. From the hot regions nearer to the Sun the hydrogen and helium evaporated, from crystalline dust grains solid celestial bodies formed — Mercury, Venus, Earth, Moon, Mars.

For the heaviest nuclei ejected by the supernova, the electrical repulsion between protons makes the *fragmentation* of the nucleus advantageous (α-decays). Radioactivity supplies the internal heat of the Earth : sliding downhill on the right hand slope of the Nuclear Valley (Fig 2). On the Earth, natural radioactivity may be considered as the slow 'cooling' of 'hot' nuclei, formed in the shell of a supernova. According to the radioactive clocks of meteorites and moon rocks, the formation of the first bodies in the Solar System happened 4.5 billion years ago, rather soon after the supernova explosion. Near the sun, the Earth, having accumulated frosty dust grains, contained many elements formed in the supernova. Today , however, the Periodic Table terminates at element Z = 92: only nuclei with life times longer than a billion years have been left. Their decay produces 6 microwatts of heat per ton, and the surface of our planet radiates with an intensity

Table 1
Half-lives of the heaviest elements

Z	Symbol	Element	Half-life
100	^{253}Fm	Fermium	3 days
99	^{254}Es	Einsteinium	267 days
98	^{251}Cf	Californium	800 years
97	^{247}Bk	Berkelium	1400 years
96	^{247}Cm	Curium	16 million years
95	^{243}Am	Americium	7000 years
94	^{244}Pu	Plutonium	80 million years
93	^{237}Np	Neptunium	2 million years
92	^{238}U	Uranium	4.5 billion years
91	^{232}Pa	Protactinium	32000 years
90	^{232}Th	Thorium	14 billion years
89	^{227}Ac	Actinium	22 years
88	^{226}Ra	Radium	1600 years
87	^{223}Fr	Francium	20 minutes
86	^{222}Rn	Radon	4 days
85	^{210}At	Astatin	8 hours
84	^{212}Po	Polonium	45 seconds
83	^{209}Bi	Bismuth	Stable
82	^{208}Pb	Lead	Stable

Table 2
Radioactive elements
in the present terrestrial Crust

Element	Half-life (years)	Concen-tration	Binding energy
^{232}Th	12 billion years	20 g/ton	6.7 pJ/atom
^{238}U	4.5 billion years	4 g/ton	8.3 pJ/atom
^{40}K	1.3 billion years	30 g/ton	2.2 pJ/atom
^{235}U	0.7 billion years	0.03/ton	8.8 pJ/atom

of 10 kW/km^2 (in the infrared); the Terrestrial Power Station works with a power of 7000 GW. We inhabit a faint infrared 'star'.

When the Earth was formed 4.5 billion years ago, it contained twice as much ^{238}U, ten times more ^{40}K, hundred times more ^{235}U than it does today. The planet, formed in cold, was melted by the radioactivity which was stronger by order of magnitude than it is today. At that time the heavy elements sunk to the deep, forming the iron-nickel core. Lighter slag (metallic oxides and silicates) rose to the surface. The melted warm planet lost its primordial (apolar hydrogen, helium, methane, inert gas) atmosphere.

When the radioactivity became milder, the crust of the Earth solidified 4 billion years ago, according to the radioactive clocks. But the internal radioactivity went on working, feeding volcanism. Polar molecules (H_2O, CO_2, H_2S, NH_3), frozen originally to the dust grains, melted and bubbled to the surface. A CO_2 atmosphere and an H_2O ocean formed. The first sedimentary deposits are 3.9 billion years old. When we heat a pot of water on the stove, the upper layer of water is in contact with cool air. At the bottom, the warmed water expands, becomes lighter and rises to the surface. From the top, the cooled water of higher density sinks down. Due to the friction of water droplets, in stead of irregular mixing, a regular cellular up-down flow is formed (Bernard instability) : in certain places warm material rises upwards, in other places material — cooled at the surface— sinks down.

Inside the Earth, radioactivity has generated heat for billions of years. At certain places under the crust, hot lava rises up, producing volcanic eruptions. The solidifying continental tables swim away from each other, and cool down. As they get a higher density, they sink to the deep. Seeing the fit between the coastlines of Africa and America on the globe, Wegner recognised continental drift (early 20th Century). Palaeomagnetic measurements (initiated by the Hungarian Roland Eotvos) map the direction of geomagnetism, frozen in the crust, and this enables us to reconstruct the original positions of continents and islands. America drifts away from Europe. The Western ridge of America collides with the Pacific Table, this creates the ANDES-Cordilleras-Sierra Nevada mountain chain. Africa hits Europe, resulting in the Atlas-Pyrenees-Alps-Carpethian chain. India drifting northward with a speed of 5 cm/year, hits Asia, and the collision increases the height of the Himalayas by millimetres per year. In the mean time, the crust splits along the Atlantic, at the Red Sea, and at the bottom of the pacific, creating record depths and geothermal activity at the bottom. From the deep oceanic rifts, there is an energy outflow of several kW/km^2 intensity. Israel (along the Jordan river and the Dead Sea) tries to move off Arabia. The Eastern coast of Africa separates from the great African Table along the Rift Valley. As continents collide, mechanical

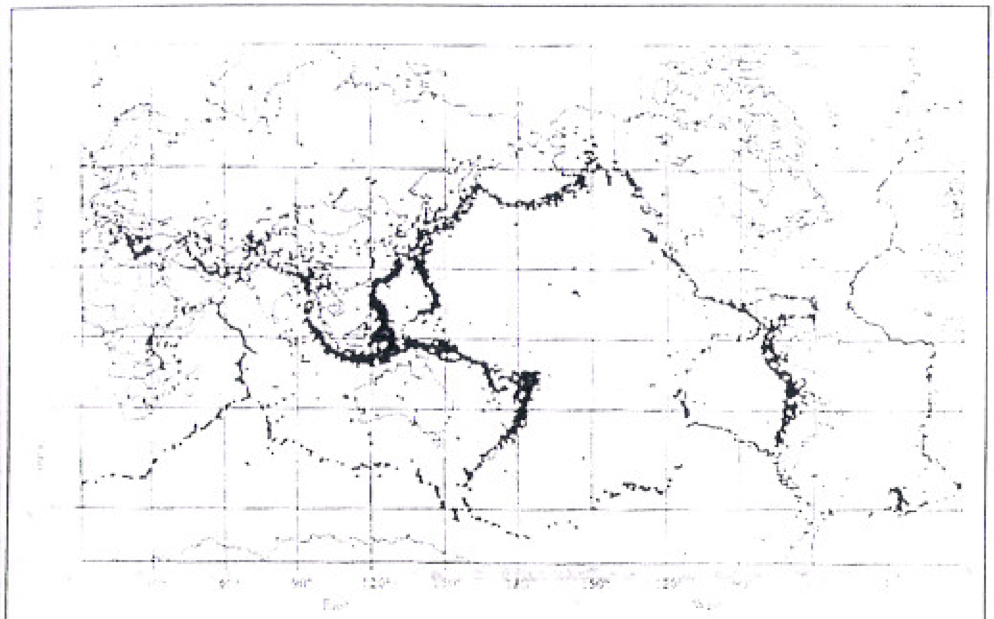

Fig 4. Earthquakes at the ridges of colliding continental tables

tensions build up, quakes occur. The recorded distribution of earthquakes maps out the border lines of continental tables (Figure 4).

GARDEN OF EDEN

In his classic experiment, Stanly Miller placed a mixture of H_2O, CH_4, NH_3 and H_2S in a reagent bottle which contained a reducing atmosphere. Then electric discharges were produced. The free energy introduced fabricated unsaturated molecules like $H_2C{=}O$, $HC{\equiv}N$, which polymerised into carbohydrates, amino acids, polypeptides (proteins), nucleic acids in the bottle-sized Garden of Eden. Oparin thought that similar reactions might occur in the primordial terrestrial atmosphere. According to his idea, in sunlit lukewarm ponds, energy-rich molecules were formed, their free energy being used to buildup self-reproducing structures: in the Garden of Eden — the young planet — life could have emerged.

According to our best geohistorical knowledge, however, at the time of the formation of oceans, planet Earth had an oxidised atmosphere. CO_2 and CO are more hostile than friendly to life. Thus, this simple explanation of the terrestrial origin of life had to be given up.

Conventional biology considered 60^{o}C to be the upper limit of life. Therefore, it was a great surprise that in the 80^{o}C hot springs of the Yellowstone Park, living micro-organisms were found.

Near the Galapagos Island, at the bottom of the Pacific, runs a geotectonic rift which spreads at a speed of 3 cm/year. In 1977, the American deep sea submarine *Alvin* was sent to explore this rift geochemically and geophysically. The *Alvin* made 24 descents, down to 2.5 km depth. The voyagers of the submarine experienced s steep temperature rise, an outflow of hot water rich in carbohydrogens and hydrogen sulphides from the geotectonic rift. The most surprising observation was, however, that life was found in the hot (100^{o}C) water. These micro-organisms lived by chemosynthesis, and snake-like animals were eating the microorganisms, in a way completely independent of the photosynthesis-based surface life. The outflowing hot water was rich in life — 1g living matter per litre, corresponding to a thousand billion bacteria! Thus they recognised that the steep temperature gradient feeds organic life in a reducing environment, reminiscent of Stanly Miller's experiment. (Even montmorillonite is present; this material is a good catalyser of molecular polymerisation). Jack Corliss was one of the participants in this deep-ocean expedition. Later, he elaborated the hypothesis that *terrestrial life was born in the deep oceanic rifts, and the required free energy was not supplied by sunshine but by terrestrial radioactivity* (1979). Jack Corliss is now professor of environmental science at the Central European University, founded by George Soros in Budapest. Is it possible that the Garden of Eden is still on Earth, here even now? One of the deep-oceanic hot springs is indicated by the name *Eden* on the map.

In 1994, Americans made a deep borehole at the Savannah River, which brought up living bacteria from a depth of half a kilometre. Some stones contained 10 million bacteria per gramme. Since then, living bacteria have been found even 3 km deep, like *Bacillus infernos*. Under high pressure the soil water is liquid over 100^{o}C, and *hyper-thermofil micro-organisms* live there under these conditions. Some of them survive even above 120^{o}C under laboratory conditions. These microbes inhale hydrogen and eat sulphur (the reaction $H_2+S \rightarrow H_2S$ is their source of free energy). The question arises : whether micro-organisms living in the several km deep hell of oceans and continents are degenerated relatives of organisms enjoying sunshine on the planetary surface? Or are they an independent colony.

The *Genome Programme* of the 1990s read the genetic information in the DNA of different species. This enables us to recognise systems of relations between species. On the genetic tree (figure 5) humans and animals are at the top (being the latest arrivals). At the root we find protozoa, single cell organisms without a cellular nucleus. All terrestrial creatures work on the basis of DNA, they are all relatives of one another, as shown in figure 5. Thicker lines indicate hyperthermophilic organisms. One of the most ancient — and still alive — species is the *methanothermus*, which enjoys 100^{o}C, and consumes methane (CH_4) and carbon dioxide (CO_2), in order to make organic molecules. The genetic tree indicates without doubt that *our ancestors were hyperthermophilic microbes*. Life started several km deep underground, possibly to hide itself from the sterilising ultraviolet rays of the Sun. The appearance of O2 and then the ozone shield made their excursion to the surface of the Earth possible, but only later. It seems that the Hell of Hades was the Garden of Eden. A hundred years ago, after the discovery of radioactivity, it was a general belief that radioactive baths and mineral waters are good for human health. Only the lung cancers of the uranium miners and leukaemia cases of the Hiroshima victims proved the dangers of intensive radioactive irradiation — "*Any radioactivity is dangerous*" — became the slogan.

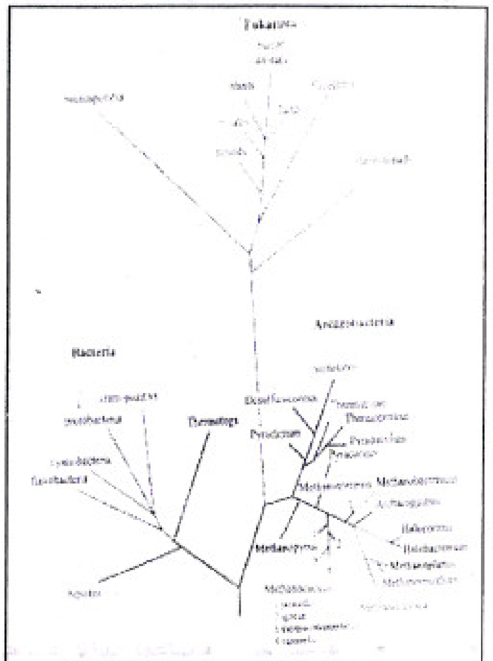

Fig 5. Genetic tree of the biosphere

It is a plausible scientific task to investigate empirically the health impact of radioactive irradiation at doses as low as possible. Since the 1970s, such investigations have been done in Sweden, Germany, China, Japan, USA and Hungary. The preliminary outcome of these empirical (epidemiological and laboratory) investigations was that *there is a minimum of the cancer risk curve at a certain dose region which is higher than the natural radioactive dose.* This looks surprising! But one must not forget that *life started evolving on Earth when the level of radioactivity was higher than it is now-a-days, and the animal immune defence system adjusted itself to those conditions.* Laboratory experiments at cellular level indicate the moderate ionising radiation activates the production of repair enzymes. If a cell is hit by a β-electron, it dies or lives with a certain probability. If it is hit by two electrons simultaneously, the chance of death is more than twice as much. But if the second hit comes only later (but within 6 hours), the second hit does not increase the risk because the first hit activated the production of repair enzymes. *Moderate ionising* radiation may have a defence role against cancer in the way that vaccination may defend against some diseases. This is why the French Academy of Sciences did not accept the recommendation of radiologists suggesting 1mSv/year as the dose limit for nuclear industry.

We see that the 1990s brought a sharp turn in our view concerning the origins of life. It is probable that on planet Earth geothermal heat (from sliding down the right-hand slope of the Nuclear Valley) supplied the required free energy. It may be that photosynthesis (utilising sunshine due to sliding down the left-hand slope of the Nuclear Valley) is a later development. It is not difficult to understand the philosophical consequences. Till now we thought that life is restricted to the immediate neighbourhood of the Sun (or another star). But geothermal activity has been observed even in faraway region of the Solar System. Very recent palaeomagnetic research has shown that 4 billion years ago, plate tectonics also worked on the planet Mars. It may be that in the shady valleys of Mars, even now-a-days, water springs are at work, driven by underground radioactivity. On the Jovian moon 'Io', volcanic eruptions were sighted; on the other Jovian moon, 'Europa', possibly an ice covered liquid sea exists, as shown by the broken ice sheets. (The geothermal activity of the Jovian moons is probably powered by the tidal effect of Jupiter. Is it possible that even gravity may be a source of free energy for the emergence of life?)

Space probes are underway to search for life on more faraway places in the Solar System.

THE EMERGENCE OF HUMANS

Biological evolution has a history several billion years long. It is essentially the interplay (marriage dance) of atoms, resulting in biochemical reactions. Sunshine — feeding the dancers — was prolonged from milliseconds to billions of years by a tight radioactive vent called the β-decay. It is worth thinking a bit about the coincidence of the *biochemical time scale* and the *radioactive b time scale*, about the interplay of nuclear astrophysics and evolutionary biology.

At the turn of the millennium, disciplinary boundaries gradually fade away. We see Nature (from nuclei to stars) and civilisation (from humans to high technology) as one single picture. The picture is majestic and beautiful.

We recognise that deep forces are at work in Nature : *gravitation* making celestial bodies, the *nuclear force* feeding celestial bodies with free energy, *electricity* directing life and evolution, and *weak β-radioactivity* regulating time for the whole interplay. We feel that the most beautiful fruits of this interplay are we — the humans — who understand and wonder at the whole Divine Comedy.

Originally, 75% of the Solar material was hydrogen. During the 4.5 billion-year long operation, a considerable fraction has been used up. Now about 50% may be left in the central region. This is why the Sun moves to higher and higher temperatures in order to be able to cover the radiation loss. This is why the Sun becomes 5% brighter in each billion years. At the formation of the Solar system, the sunshine reaching the Earth was only 70% of present amount. But terrestrial evolution required a rather steady temperature for its 4 billion-year long evolution on the planetary surface, in order to make the permanent presence of a lukewarm liquid ocean possible. What could be its air-conditioning system, working so efficiently through 4 billion years?

At the formation of the Earth, the atmosphere consisted mostly of CO_2, like that of our sister Venus and brother Mars. The CO_2 lets the visible sunlight through. But it absorbs the infrared thermal radiation of the soil because its frequency just agrees with an eigenfrequency of the chemical bonds in the polar O=C=O molecule. This is why a CO_2 atmosphere (like a farmer's glass greenhouse) warms the soil below it. This CO_2 concentration gradually decreased to the present 1/3rd, just compensating the increasing brilliance of the Sun.

Plate tectonic circulation brings silicates (like $CaSiO_3$) to the surface (this is a constituent of volcanic basalt). The atmospheric CO_2 is dissolved by rainwater, becoming carbonic acid (H_2CO_3). The carbonic acid attacks silicates, washing the products of weathering into the sea. Sea animals extract $CaCO_3$ for their shells and bones. After their death, limestone sinks to the bottom of the sea.

$$CO_2+H_2O \rightarrow H_2CO_3,$$
$$2H_2CO_3+CaSiO_3 \rightarrow CaH_2(CO_3)_2+H_2SiO_3,$$

$$CaH_2(CO_3)_2 \rightarrow CaCO_3+H_2O+CO_2,$$
$$H_2SiO_3 \rightarrow SiO_2+H_2O.$$

Under its increasing weight, the limestone sank deeper as part of the plate tectonic circulation. In the deep, geothermal heat dissociated the limestone (as people do in making lime). Through fractures of the crust the CO_2 released diffuses out. Stone rises in the form of silicate-lava to the surface.

$$CaCO_3 \rightarrow CaO+CO_2, \quad CaO+SiO_2 \rightarrow CaSiO_3.$$

The plate tectonic circle closes itself. In Short :

Weathering on Surface :
$CaSiO_3$ (basalt)+$CO_2 \rightarrow CaCO_3$ (limestone)+ SiO_2 (sand).

Decay in the deep :
$CaCO_3$(limestone)+SiO_2(sand)$\rightarrow CaSiO_3+CO_2$

Remember, atmospheric CO_2 absorbs infrared radiation of the soil, thus more CO_2 means a higher atmospheric temperature. *Under a warmer climate, chemical reactions accelerate on the surface, weathering becomes faster*, thus more CO_2 is extracted from the air, resulting in a *cooling climate. A cooling atmospheric temperature*, however, *slows down the chemical reactions on the surface*, more CO_2 is left in the atmosphere, which enhances the greenhouse effect and *warms the atmosphere.* Inside the Earth, the chemical reactions are kept at a steady rate by the radioactive heat. Therefore, *the plate tectonic circulation works like air-conditioning on planet Earth.* When the Sun brightens, this gradually decreases the atmospheric CO_2 concentration, thus stabilising the temperature on Earth. The driving force of this efficient air conditioning, working well through billions of years, is terrestrial radioactivity.

Venus is near the Sun, the oceans boiled away, there is no weathering at work, there is no carbonic acid : at 400°C, there is no life.

Mars is ten times than the Earth, its internal radioactive heat quickly escapes through the surface. On Mars, (as on the Moon), there is no plate tectonics at work any longer. The thinning CO_2 atmosphere made Mars a frozen desert.

Thinking all these, we learn to respect our mother Earth, which was born in such a good place with such a good size. We don't look upon the forces of nature (like radioactivity) as our enemies. We have only to worry that in the last decades, burnt fossil fuels (coal and oil) raised the atmospheric CO_2 concentration steeply, 1% per year. If we go on in this way, the atmospheric CO_2 will double in the 21st century, resulting in several degrees centigrade warming, raising the sea levels, climate instability, floods and hurricanes — as we are experiencing a bit already in recent years. (Melting Antarctic ice would result in a rise of oceanic level by 60 metres!) The problem is that the geological air-conditioning works slowly, on a time-scale of ten, or a hundred years, but *the Homo sapiens* are doubling the atmospheric CO_2 on a much shorter time-scale. The World Climate Conference in Kyoto (1988) agreed upon restricting coal- and oil-consumption (supported mostly by island states and the European Union, because of the long coast line and continuously rising sea level) but the USA and other countries don't keep the agreement. What can one do?

THE 'U' STORY

There is one isotope left in the Earth, which can be split by one slow neutron, releasing energy and 2–3 neutrons in nuclear fission : this is ^{235}U, having a shorter half life than ^{238}U making only 0.7% of the present natural terrestrial uranium. 99.3% is the long lived ^{238}U, which absorbs medium-energy neutrons without fission. This is why one has to enrich ^{235}U up to 2–3%, and this is why fast fission neutrons must be slowed down outside the uranium blocks, eg, by water, in order to let the slow neutrons obtained make new fission events.

The half life of ^{235}U is 0.7 billion years. Its concentration was above 2%, two billion years ago. At that time, no enrichment was necessary! Geological research has shown that 2 billion years ago natural uranium reactors were working in some rich uranium deposits in Central Africa. Soil water slowed down the neutrons. If the chain reaction began running too fast, the water boiled off, the reactor stopped, cooled down, water returned and the reactor worked again, controlled by nature! How easy it would have been to construct nuclear power plants 2 billion years ago!

Let's play with this idea. Imagine a world in which *Homo sapiens* emerged 2 billion years earlier. For them nuclear power was as natural as for our ancestors the wind, the rain and the river were. Primitive people could use nuclear ovens by flooding natural uranium ore by natural water. (In that world the "environmentalists" might have demonstrated against "artificial" inventions like the matchbox. One must not light fire, one must not light a cigarette, because they were harmful to one's health — not to speak of other dangers of chemical oxidative reactions :gun powder, dynamite, etc.)

But at the opposite extreme, if after the origin of life human emergence had needed 2 billion years more time, practically all the ^{235}U would have decayed. In such a world one would not have nuclear reactors and nuclear weapons......

What a strange coincidence again — the half life of uranium isotopes and the Darwinian evolution time to get to *Homo sapiens* are of the same order of magnitude! We emerged at a time when utilisation of nuclear power is still just possible: with high technology we can realise it and with great responsibility we can use it — in order to prevent climatic catastrophe from burning fossil fuels.

The opposition against nuclear power says that biomass, hydropower and coal burning are "natural" energy sources, but nuclear energy is "artificial", unnatural, and, therefore, dangerous. The explanation of this judgement is the nuclear illiteracy of the grownups (media reporters, politicians, etc). Young people can receive nuclear literacy in the school — it is certainly not more difficult than the resistance in a circuit of an alternating current. They understand what James Lovelock, initiator of the Gaia model of the biosphere said —

> *The natural energy of the Universe is nuclear energy, this feels starlight in the sky. But if it is so, if God's Universe runs by nuclear power even today, then why do people demonstrate against the possibility of obtaining electricity from nuclear power?*