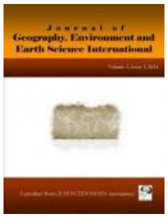

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New Concept for the Origin of Fjords and Submarine Canyons: Consequence of Whole-Earth Decompression Dynamics

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Fjords occur in different parts of the world suggesting a common origin. Although being the subject of debate for more than a century, a common origin has not yet been disclosed; the relative importance of glaciation is still controversial. Here I propose that the primary origin of fjords, like submarine canyons, occur as a consequence of decompression-driven Earth surface curvature changes, and suggest that glaciation, rather than being the primary agent of fjord formation, as widely assumed, instead is the principal agent of fjord preservation.

Keywords: Mantle convection; whole-earth decompression dynamics; fjords; submarine canyons.

1. INTRODUCTION

In 1869, Brown [1] wrote: "Intersecting the sea-coast of various portions of the world, more particularly in northern latitudes, are deep, narrow, inlets of the sea, surrounded generally by high precipitous cliffs, and varying in length from two or three miles to one hundred or more,

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variously known as, 'inlets,' 'canals', 'fjords,' and even on the western slopes of Scotland as 'lochs.' The nature of these inlets is everywhere identical, even though existing in widely distant parts of the world, so much so as to suggest a common origin." (Figs. 1 and 2) Here I propose said common origin, which could not have been deduced from 19th and 20th century geodynamics.

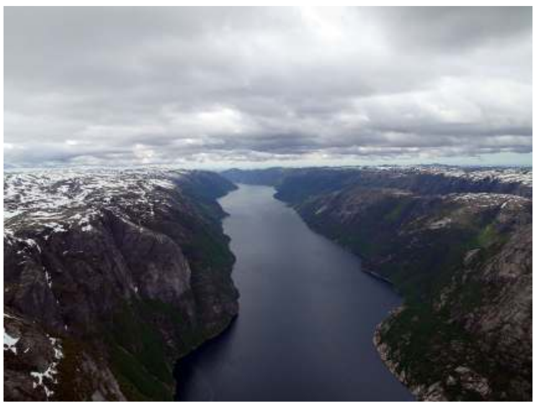


Fig. 1. Photograph of Lysefjord in Norway looking West. Photograph courtesy of Snorre

The idea that glacial-erosion has influenced the formation of fjords has been widely acknowledged since the latter part of the 19th century, although there has been and still is serious debate as to the extent of said influence [2-6]. Some authors have considered fluvial erosion [7]; others have questioned the interplay of erosion, glacial activity, and subaerial mass wasting [4]. An overriding problem is that most fjords are deeper than current sea level, some having depths in excess of 1 km. In 1913, Gregory [8] maintained that fjords are primarily of tectonic origin with glacial influence being minimal, although his tectonic reasoning was inadequate to justify such an assertion.

Fundamental, paradigm-changing understanding progresses slowly in the geosciences. In 1912 Wegener presented the most comprehensive geological evidence to date indicating that the continents had previously been joined, but had subsequently separated [9-11]. For half a century the geological community ignored that evidence, wrongly believing that the Earth was cooling and shriveling like a dried apple. Then, with new evidence of seafloor topology, Wegener's continental drift theory was revised and re-formulated as plate tectonics theory [12] which has, like the shriveling apple theory, dominated geological thinking for half a century. But plate tectonics theory cannot be correct. Why? Because, as I discovered, mantle convection, the absolutely crucial concept underlying plate tectonics, is physically impossible [13]. It may be difficult for some to imagine that mantle convection is physically impossible as frequently a high calculated Rayleigh Number is (erroneously) thought to justify mantle convection.

Lord Rayleigh [14] in 1916 applied to the Eulerian equations of motion the Boussinesq [15] approximation to derive the dimensionless number that now bears his name to quantify the onset of instability in a horizontal, thin layer of fluid heated from below. Lord Rayleigh's underlying assumptions, however, are inconsistent with the physical parameters of the Earth's mantle, viz.; Earth's mantle being "incompressible", mantle density being "constant" except as modified by thermal expansion, and pressure being "unimportant" (quotes from Lord Rayleigh [14]). Whenever possible one should read fundamental literature rather than risk propagating someone else's mistakes.

In the 1940s, 1950s, and early 1960s, the protoplanetary origin of Earth was discussed [16-19], but discussion effectively ceased with the publication of a planetesimal model of planetary formation [20]. This was the idea that dust condensed from a gas of solar composition at a low-pressure, about 10^{-4} atmospheres. Then progressively accumulated into rocks, boulders, planetesimals, and finally into planets [21,22]. These models developed contemporaneously with plate tectonics. But that planetesimal model cannot in the main be correct. Why? Because, as I discovered, thermodynamic considerations lead to oxidized iron, instead of iron metal, existing at low pressures and corresponding low temperatures in solar matter, a contradiction to observations of massive-core terrestrial planets [23,24].

In the following I describe a new basis, published in the scientific literature, for understanding Earth's formation from which follows a new understanding of geodynamics that supersedes plate tectonics theory. Here I set forth a fundamentally new idea for the primary origin of fjords and submarine canyons that follows logically from the new understanding of geodynamics that I call Whole-Earth Decompression Dynamics (WEDD).

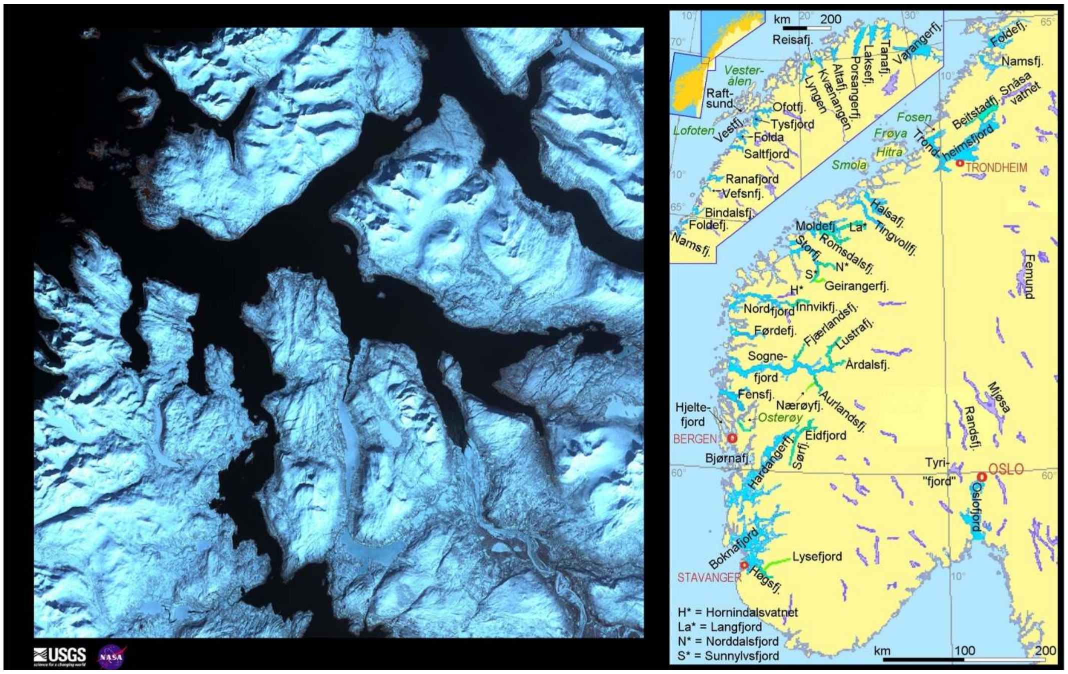


Fig. 2. USGS/NASA satellite view of the northern portion of Norway showing fjords and map of Norway showing fjords

2. DISCUSSION

In 1850 Boisse [25] suggested that the composition of meteorites is relevant to the bulk composition of planet Earth. Almost half a century later, Wiechert realized that the mean density of Earth, as measured by Cavendish [26], is too great for the planet to consist entirely of rock, and suggested that the Earth has at its center a core of iron metal, like the metal of iron meteorites [27]. Less than a decade later the seismologist Oldham discovered Earth's core [28].

Neither Boisse's suggestion [25] nor Wiechert's idea [27], even in light of Oldham's discovery of the Earth's core [28], could be considered anything more than circumstantial evidence of a connection between the elements of Earth and those of meteorites. Theodore W. Richards received the 1914 Nobel Prize in Chemistry for making precise measurements of atomic weights. Richards observed that copper from Germany and copper from America have the same atomic weight. He also observed that iron from the Earth has the same atomic weight as iron from a meteorite [29]. A year before Richards' Nobel Prize, Joseph John Thompson discovered that the atomic weight of an element is really an expression of the weighted average of the weights of its individual components, later called isotopes [30]. Isotopic composition is like a fingerprint, forged at the element's birth and, particularly for heavy elements, is virtually unalterable. Francis William Aston followed, inventing the mass spectrograph and with it eventually identified about 70% of the 244 naturally occurring stable isotopes now known to exist [31]. Soon scientists throughout the world began to measure isotopic compositions, the fingerprints of the elements from the Earth and from meteorites, and found each element to be identical, except in a few very special circumstances. In other words, the Earth and the meteorites (and, found later, the Moon) in the main formed from well-mixed matter of common origin. The similarity of isotopic fingerprints of Earth and meteorites, however, says nothing of how much of each element was present in the original mix, but that too was subsequently learned.

Understanding the nature of the solar spectrum, developed during the early part of the nineteenth century, made it possible to detect the presence of elements in the photosphere of the Sun. By 1893, forty one elements were claimed to have been identified in the Sun by the absorption lines in the solar spectrum [32].

In the 1920s, astronomers began to tackle the extremely difficult problem of determining the relative amounts of the elements identified through their absorption lines in the atmosphere of the Sun [33]. Almost immediately, the relative abundances of elements in the Sun and in chondritic meteorites were realized to be quite similar [34]. Yet decades would elapse before a ten-fold discrepancy in the abundance of iron would be resolved [35].

Ultimately, though, chondrites, such as the Orgueil carbonaceous chondrite meteorite and the Abee enstatite chondrite meteorite were found to have quite similar corresponding elemental abundance ratios in the Sun, at least for the less-volatile elements [36-40]. Moreover, the abundances of the elements were shown to be related, although in a complex way, to nuclear properties [41]. No longer a circumstantial connection, now it can be said with reasonable certainty that the primordial matter from which Earth, and, presumably, all the bodies of the Solar System formed, had a well-defined chemical composition, and that composition to a great extent is yet manifest in the photosphere of the Sun and, for less volatile elements, in certain chondrites, such as Orgueil and Abee.

Two centuries of investigations of meteorites by chemists, physicists, mineralogists and petrologists have led to a vast amount of data on hundreds of chondrite meteorites that to a great extent differ from one another in major ways. My own approach differs from others in that I attempt to reduce the many-component problem to one of just a few fundamental components that can be understood.

The simplification method that I find most useful is based upon the abundances. Only five major elements account for about 95% of the mass of a chondrite, and by implication, the mass of the Earth: silicon (Si), magnesium (Mg), iron (Fe), oxygen (O), and sulfur (S). Those five major elements constitute a buffer assemblage that controls the oxidation state; minor and trace elements are slaves to that buffer assemblage.

Chondrites are important, not because of the presence in most of chondrules, but because their elements were not appreciably separated from one another or from the readily condensable portion of the well-mixed primordial assemblage from which they were derived. Consequently, through an understanding of the thermochemical behavior of those five major elements, one may discover the nature of the processes that led to diverse chondrite mineralogy and to the formation of planets, especially Earth. By adding to that the behavior of the four minor elements which with major elements comprise about 98% of the mass of a chondrite, a richer and more complete picture emerges. The trace elements, of course, follow as they must, being slaves to that buffer assemblage.

There are essentially three groups of chondrites. These groups differ considerably in oxidation state as illustrated by their chemical states of iron.

- Carbonaceous Chondrites – highly oxidized: Little or no iron metal
- Ordinary Chondrites – medium oxidized: oxidized iron in silicates, iron sulfide, and iron metal
- Enstatite Chondrites – highly reduced: nearly devoid of oxidized iron, iron sulfide with calcium and magnesium sulfides, iron metal with dissolved silicon

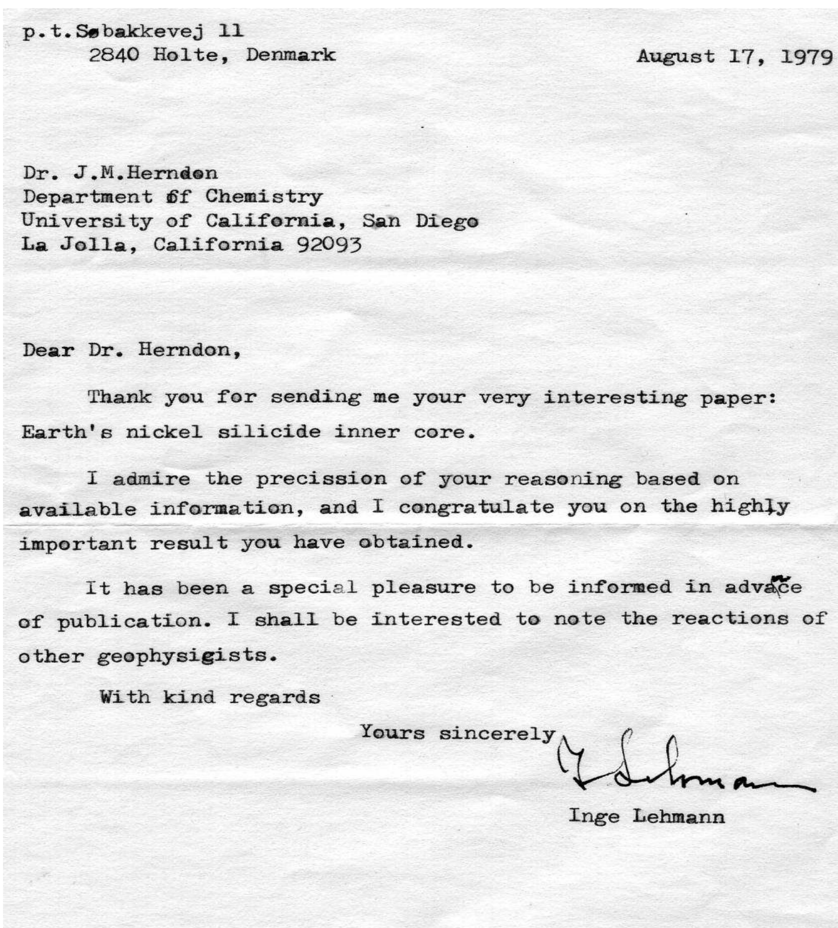
About 80% of the meteorites that are observed falling to Earth are *ordinary chondrites*, so-called because they are very common [42]. These are composed of iron metal, iron sulfide and silicates. If an ordinary chondrite is heated to an elevated temperature, the iron metal and iron sulfide meld forming a liquid alloy at temperatures at which the silicates are still solid. Much of textbook geophysics is underlain by the idea that Earth as a whole resembles an ordinary chondrite [43,44]. This is an old idea going back to the 1940s, maybe earlier [43,44]. At the time the rare carbonaceous chondrites were discounted as not having enough iron metal to account for Earth's core. The rare highly-reduced enstatite chondrites were completely ignored because they contain minerals such as oldhamite, CaS, that do not occur naturally on Earth's surface. At least superficially, the ordinary chondrites seemed to account for the Earth having an iron alloy core surrounded by a silicate mantle.

In 1936 Inge Lehmann discovered Earth's inner core [45]; four years later its chemical composition being partially crystallized iron metal was deduced based upon the assumption that Earth resembles an ordinary chondrite [46] according to the following rationale: In ordinary chondrites, nickel is always found alloyed with iron metal. The relative amounts of all elements heavier than nickel, if added together, would not form a mass nearly as large as the inner core.

Therefore, if Earth resembles an ordinary chondrite, the inner core must be explained as partially crystallized nickel-iron metal. No evidence was ever set forth to account for the observed specific mass of the inner core. This textbook interpretation of the composition of Earth's inner core is still dominant today, but evidence indicates that it is not correct.

In the 1970s while investigating enstatite meteorites, I realized a different explanation for the composition of Earth's inner core. In some of these highly-reduced meteorites the mineral perryite, nickel silicide, occurs. I realized that if silicon occurs in the Earth's core, then in principle the silicon could combine with nickel and precipitate a mass of nickel silicide virtually identical to the inner core mass. I derived that idea logically and Nobel Laureate Harold C. Urey communicated my manuscript to the *Proceedings of the Royal Society of London* where in 1979 after peer-review it was published [47]. The abstract *in toto* states: "From observations of nature the suggestion is made that the inner core of the Earth consists not of nickel-iron metal but of nickel silicide." I received a complimentary letter from Inge Lehmann, discoverer of the inner core (Fig. 3). The response of the geophysics community was neither to refute nor to cite, but to ignore, which is not good science.

I reasoned: If the inner core is indeed nickel silicide, then the core must be similar in composition to the alloy portion of an enstatite chondrite and it must be surrounded by a nearly FeO-free silicate shell, like the enstatite chondrite silicates. Table 1 shows that the major mass ratios of the Abee enstatite chondrite are essentially identical to corresponding mass ratios of the inner 82% of the Earth.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August 17, 1979

Dr. J.M.Herndon
Department of Chemistry
University of California, San Diego
La Jolla, California 92093

Dear Dr. Herndon,

Thank you for sending me your very interesting paper: Earth's nickel silicide inner core.

I admire the precission of your reasoning based on available information, and I congratulate you on the highly important result you have obtained.

It has been a special pleasure to be informed in advance of publication. I shall be interested to note the reactions of other geophysigists.

With kind regards

Yours sincerely

Inge Lehmann

Fig. 3. Letter to J. Marvin Herndon from Inge Lehmann, discoverer of Earth's inner core

Table 1. Comparison of major mass ratios of the Abee enstatite chondrite with corresponding mass ratios of the inner core, core, and lower mantle. Data from [48,49]

Fundamental earth ratio	Earth ratio value	Abee ratio value
lower mantle mass to total core mass	1.49	1.43
inner core mass to total core mass	0.052	theoretical 0.052 if Ni_3Si 0.057 if Ni_2Si
inner core mass to lower mantle + total core mass	0.021	0.021

Whereas the alloy portion (sulfide plus metal) of ordinary chondrites contains only siderophile elements, the alloy portion of the Abee enstatite chondrite contains some calcium and magnesium as sulfides [49]. In the Earth's highly-reduced core, calcium and magnesium are expected to precipitate at high-temperatures and float to the top of the core (Table 2).

Table 2. Comparison of major mass rations of the Abee enstatite chondrite with corresponding mass ratios of the inner core, core, and lower mantle. Data from [48-50]

Fundamental earth ratio	Earth ratio value	Abee ratio value
D″ mass to total core mass	0.09^{+++}	0.11^{+}
ULVZ** of D″ CaS mass to total core mass	0.012^{++++}	0.012^{+}

$^{+}$ = avg. of Abee, Indarch, and Adhi-Kot enstatite chondrites
D″ is the "seismically rough" region between the fluid core and lower mantle
$^{++}$ ULVZ is the "Ultra Low Velocity Zone" of D″
$^{+++}$ calculated assuming average thickness of 200 km
$^{++++}$ calculated assuming average thickness of 28 km

The seismic roughness at the core-mantle boundary results from high-temperature precipitates from the Earth's highly-reduced core [51-53]. This is further evidence that the inner 82% of Earth resembles an enstatite chondrite.

Uranium and thorium occur almost exclusively in the alloy portion of the highly-reduced Abee enstatite chondrite [54] and, by inference from the relationships shown in Tables 1 and 2, in the highly-reduced Earth's core. I suggested that uranium precipitated from the fluid core, presumably as a sulfide, and settled to Earth's center where it functions as a nuclear fission reactor powering and generating the geomagnetic field [51,52,55-58]. Strong evidence for the existence of the georeactor, as it is called, is that the $^{3}He/^{4}He$ ratios of fission products observed in Oak Ridge National Laboratory nuclear fission georeactor simulations occur in the same range of compositions observed in submarine basalt and "hotspot" basalt [55].

From thermodynamic considerations, Eucken demonstrated that Earth formation by condensing and raining-out at high temperatures and high pressures from a gas of solar composition would lead to core formation as a liquid before mantle condensation had occurred [17]. I showed that similar condensation conditions would lead to a highly-reduced condensate with a similar oxidation state to that of the Abee enstatite chondrite [17,23,59]. Having shown, as just described, that the inner 82% of Earth has that same highly-reduced state of oxidation connects to Earth's formation by condensing and raining-out at high pressures and high temperatures. I have suggested that Earth's complete condensation occurred before thermonuclear ignition of the Sun. This would lead to Earth having originated as a Jupiter-like gas giant [23,24,60-62].

Earth originally formed as a Jupiter-like gas giant with the rocky portion compressed to about 66% of present diameter by about 300 Earth-masses of primordial gases and ices. The thermonuclear ignition of the Sun, with its violent T-Tauri solar winds, stripped Earth's gases and ices leaving the compressed rocky portion retaining much of the stored energy of protoplanetary compression. That is the primary energy for subsequent decompression, augmented by nuclear fission and radioactive decay energy. The manner of Earth's decompression is the fundamental basis for surface geology and geodynamics, and is the basis for a new, fundamentally different, indivisible geoscience paradigm, called Whole-Earth Decompression Dynamics theory [13,23, 24,57,60,63,64], which is a consequence of Earth's protoplanetary formation. Virtually all geological and geodynamic activity is accounted for in a logical, causally-related manner. Here I describe how the primary initiation of fjords and submarine canyons follows as a natural consequence of Earth's formation in that manner.

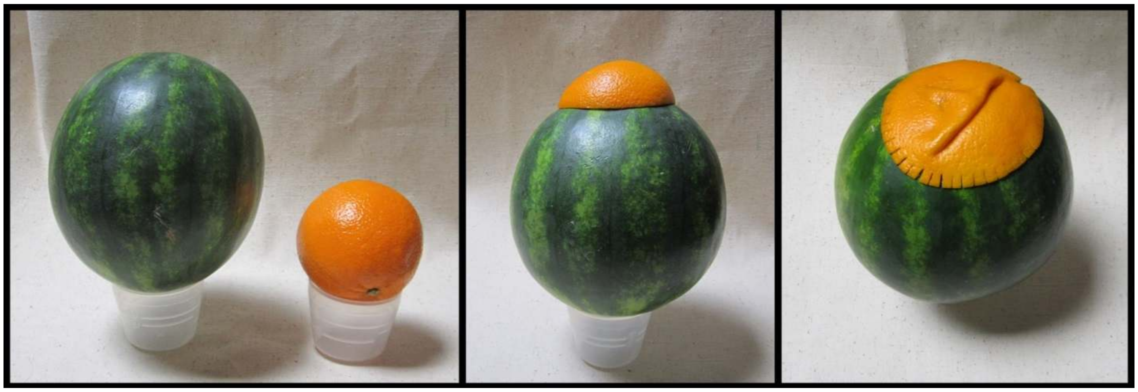

Fig. 4. Demonstration illustrating the crustal curvature dynamics that are a consequence of whole-Earth decompression. From left to right: 1) Orange represents ancient Earth at beginning of Archean, melon represents Earth at a later time after some decompression; 2) A circular section (continent) of ancient crust (orange) showing the curvature mismatch on a more decompressed Earth (melon) and showing the 'excess area' contained within the continent perimeter; and, 3) The manner by which the ancient crust 'flattens' itself to adjust to new curvature by buckling, solving the age-old problem of the origin of mountains characterized by folding, and by having tension fractures along the perimeter that, I posit, represent the primary, common origin of fjords and the primary origin of submarine canyons, which are subsequently eroded

Following the quantitative removal of Earth's gas/ice mantle, the rocky portion of Earth was about 66% of present diameter. Slowly over time pressures within the Earth increased, presumably due to georeactor-produced heat. At some point the first crack appeared in the Earth's entirely sial crust. Eventually that crack grew longer and other cracks formed as the Earth began to decompress. Decompression necessitates changes to the surface.

As planetary diameter increases, surface area must likewise increase. My Whole-Earth Decompression Dynamics (WEDD) theory describes that process as the consequence of crack formation. Two types of cracks form: Those with underlying heat sources, and those without heat sources. Basalt extruded from the former type crack flows by gravitational creep across the surface until it falls into and infills a crack of the latter type. This is the way ocean basins form.

As planetary diameter increases, surface curvature must change; the surface must conform to the larger planetary diameter. Consider for example a circular section of 'earlier' crust placed on the surface of a 'later' size Earth. There is a mismatch of curvature. The section from the earlier, smaller-diameter Earth appears to have 'extra' area confined within its perimeter as illustrated by the demonstration that is Fig. 4. The primary mechanism Earth's surface makes to adjust its curvature is by buckling, breaking and falling over: I suggested that mechanism is the solution to the age old problem of how mountains characterized by folding formed [65].

Matter on the surface of a sphere tends to make adjustments to minimize surface energy. Curvature mismatch, as illustrated in Fig. 4, will cause fold-mountain formation as well as tension fractures along the continent perimeter. These peripheral tension fractures, I posit, are the primary, common origin of fjords and the primary initiation of submarine canyons.

3. CONCLUSIONS

Tension fractures inevitably form at the edges of continents that are undergoing whole-Earth decompression-caused crustal-curvature adjustments. In the far northern and far southern latitudes, these tension fractures are the primary initiation of fjords. Glaciation, rather than being the agent of fjord formation, as widely assumed, instead is the principal agent of fjord preservation. In the middle latitudes tension fractures suffer severe fluvial erosion, yet nevertheless are recognizable as submarine canyons.

In a broad sense, the challenge for geologists is to determine the time-sequence of whole-Earth decompression-driven continent fragmentation, starting with closed, contiguous shell at Archean beginning, and to determine the conditions on Earth throughout these events. Observations of fjords, as indicators for decompression-driven crustal-curvature adjustments, may be useful for deducing geological history and for understanding present geology, especially discoveries made in Antarctica.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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