thetically comparable level. Curve c is the oceanic gradient normalized to a basaltic surface composition and density ($\rho_0' = 3.0$ g cm^{-3}, $A_0' = 5 \times 10^{-6}$ erg cm^{-3} sec^{-1})

$$\phi' = 1 + (Z'/13.4D_\delta') \qquad (7a)$$

where the oceanic source interval D' is interpreted as a logarithmic decrement, $D_\delta' = 50$ km. Curve c, based on D_δ' deduced from sea floor spreading, predicts the preferred density at 100 km computed by Press (*23*) for the suboceanic mantle. Curve a, however, does not discriminate between "pyrolite" and "eclogite" models, because the interval to 30 km ($3D_\delta$) contributes 95 percent of the total radioactive heat production. That is, the dotted curve in Fig. 3 could correspond to residual compositions like the solid curve in Fig. 2.

If the pyrolite model (*14*) were used to represent the continental subcrust to a depth of isostatic compensation near 400 km, apparently there would be a large mass excess beneath the oceans. The existing mass balance and the differences in surface elevations can be reconciled, however, if there is a pyrolite-type residue beneath the continents amounting to about 20 percent of this interval, or roughly 100 km. This thickness of residuum is compatible with the density distribution and heat production, and also with a granitic surface layer representing only a few percent of the original volume.

The present model of crust-mantle evolution describes a comparatively stagnant stratification in the continental crust relative to a "stirred" stratification in the oceanic subcrust. The contrast in density gradients fits the observation that a radiogenic source gradient between "basalt" and "eclogite" beneath the oceans is nearly an extension of a gradient between "granite" and "basalt" in the continents (Fig. 2). Although "eclogite" could satisfy the initial radiogenic compositions beneath continents and oceans, another common parental composition is possible.

In summary, magmatic processes triggered by tidal energy sources can provide the "working fluid" in a geodynamo operating as a coupled thermomechanical-thermochemical heat engine. Globally constant heat flux is consistent with equality of heat fluxes due to mass transfer and radioactive heat production in both continental and oceanic sections. The steady state is explained by an inverse relationship between the respective depth intervals for the two heat terms beneath continents and oceans. These intervals are related by magmatic transfers that simultaneously satisfy tidal energy, concentration of radioactive elements at continental surfaces, and sea floor spreading in the oceans. The resulting chemical gradients are consistent with heat flow and density gradients in the crust and upper mantle. The average heat flux, surface elevations, and gravity are nearly indifferent to "continental drift" relative to a depth where the chemical gradients beneath continents and oceans are similar; this depth is approximately $3D_\delta'$ (95 percent of q'_{rad}), or about 150 km by the present model.

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Exposed Guyot from the Afar Rift, Ethiopia

Abstract. *A series of originally submarine volcanoes has been found in the Afar Depression. Some of the volcanic structures are morphologically similar to oceanic guyots. One of them consists of strata of finely fragmented and pulverized basaltic glass. The fragmentation of the lava is probably the result of stream explosions taking place during the submarine eruption. The flat top of this guyot is considered to be a constructional feature; by analogy, it is suggested that not all oceanic guyots are necessarily the result of wave truncation of former volcanic islands.*

Flat-topped seamounts, known as guyots, have been reported from several localities of the Pacific Ocean in the last 30 years (*1*). Their origin is commonly ascribed to wave truncation and subsidence of former volcanic islands (*1*). As far as we know, emerged guyots have not been reported from the geological record, with the exception of a small structure from the Mono Lake area in California (*2*). Thus, it may be of interest to describe a structure in the Afar (or Danakil) Region of eastern Ethiopia that resembles oceanic guyots. Afar is a tectonic depression located between the Ethiopian Plateau and the Red Sea, from which it is separated by the Danakil Alps (Fig. 1). It is a region of great geological interest because the Eastern African Rift, the Indian Ocean (Carlsberg) Rift, and the Red Sea Rift meet there. Northern Afar is partly at altitudes lower than sea level (minimum of −120 m); it was a marine basin up to late Pleistocene time, when its connection with the Red Sea in the area

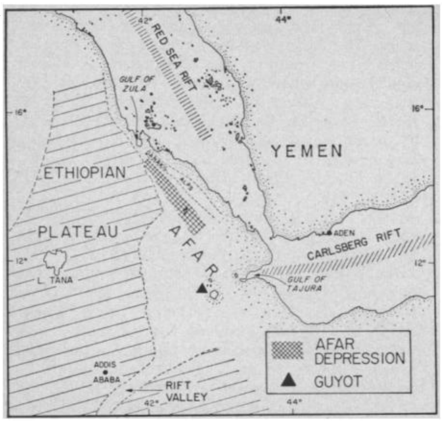

Fig. 1. Location of the Afar region and of the guyot under study.

of the Gulf of Zula was severed by volcanic structures and desiccation occurred.

During two recent expeditions to northern Afar (*3*) tensional tectonic features were found, namely fissures and normal faults, running along the axis of the Depression, in a direction parallel to the Red Sea axis (*4*). Basaltic volcanism, partly still active, has been extremely intense in the axial zone of the Depression; the activity has given rise mainly to fissural flows but also to central-type volcanic cones (*4*). Among the latter we observed a number of structures characterized petrologically by their being made almost exclusively of minutely fragmented or pulverized volcanic glass, and morphologically by an unusually low ratio of height to diameter of the base, from 1 : 3 to 1 : 6 (*4, 5*). Fossil coral reefs and molluscan shells were found on the summit of some of these structures which suggests that they were formed underwater.

We present here some data on one of these submarine volcanoes which may clarify our concepts on the origin of oceanic guyots. The volcano, known by the natives as "Asmara," is located at 11°15′N, 41°02′E. It is a truncated cone between 300 and 400 m high; its diameter is approximately 2.3 km at the base, about 1 km at the summit (Fig. 2). The summit is nearly flat except for a gentle inclination from the edges toward the center, the center being about 25 m lower than the edges. The flanks of the volcano have a slope of about 35°. Thus, the morphology of this structure strongly resembles that of oceanic guyots.

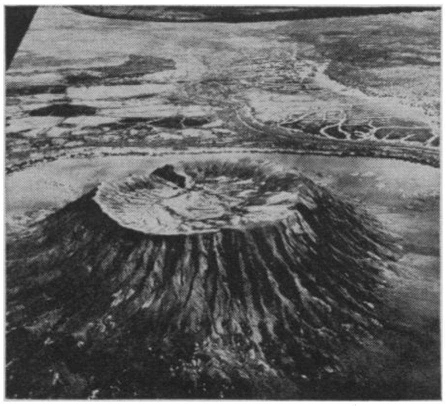

Fig. 2. Aerial view of the emerged guyot. Height, 300 to 400 m; base diameter, 2.3 km; summit diameter, 1.0 km.

Chemical and mineralogical analyses of microcrystalline rock samples from this volcano indicate that the lava which formed it is an olivine-rich, alkali basalt. The exposed surface of the volcano consists almost exclusively of ash-like, fragmented rock which displays subhorizontal stratification. Near the summit the strata are inclined a few degrees toward the axis of the truncated cone; that is, they are conformal to the dimpled top of the volcano. The fragments of lava generally range up to a few millimeters in diameter and are relatively well sorted in size within each layer; this is in contrast to subaerial ash rings, in which pyroclastics are usually poorly sorted (*5*), and it suggests that the fragments were deposited in the water. The fragments consist prevalently of rather fresh basaltic glass (Fig. 3). Diffraction powder patterns of the finer matrix within the glass grains indicate a 14-Å expandable clay mineral of the smectite group. Smectites are formed by alteration of basaltic glass in marine conditions (*6*).

Close to the foot of the volcano, within the fragmented basalt layers, we observed lenses and veins of euhedral, large (up to 1 cm) rhombs of calcite, probably formed hydrothermally during the submarine activity. Crystals of hydrothermal calcite have been found in the Pacific dispersed in deep-sea sediments close to seamounts (*7*).

Fragmentation of submarine lava can occur by two mechanisms. Fragmentation can be initiated, as in the formation of pyroclastics on land (*8*), by the rapid and ultimately explosive expansion of magmatic gas bubbles due to release of load pressure in the ascending magma. The hot fragments produced by this "primary" explosion will undergo secondary explosions because superheated steam is produced around each fragment; the heat of the lava is thus rapidly transformed into kinetic energy (*9*). As a result the explosive activity in submarine eruptions of this type is more intense than in comparable subaerial activity, as observed directly in shallow-water eruptions at Caphelinos in the Azores (*9*) and Surtsey off Iceland (*10*).

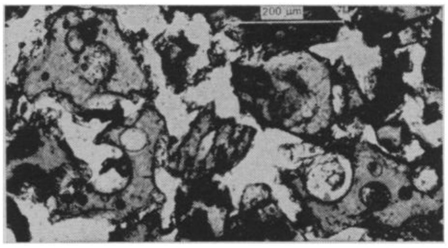

Fig. 3. Microphotograph of a thin section of glass grains from the guyot. Note that the grains are frequently broken along concave surfaces which indicate former gas vesicles.

Fragmentation can also occur by a process of thermal shattering when the hot melt is chilled instantaneously by seawater; upon vitrification of the melt stresses are built up which, depending on the viscosity of the lava, can be relieved by granulation of the material (*11*).

According to some authors (*12*) the first mechanism can operate effectively only in water shallower than approximately 1000 m for basalts because, at depths where the pressure is close to or above the critical pressure of water, expansion of gas bubbles is limited; therefore, thermal shattering alone has been suggested to explain the granulated basalts (hyaloclastites) commonly recovered from deep-sea volcanoes and adjacent areas (*13*). According to others (*5*) primary gas explosions can take place also below several thousand meters of water.

It is generally difficult to distinguish the rocks produced by one or the other of the two mechanisms above by field observations or observations of hand specimens. However, such a distinction is possible with thin-section optical microscopy. This is based on the fact that the glass granules produced by gas explosions are commonly broken along spherical or ellipsoidal surfaces representing former gas bubbles; this is never observed in glass granules formed by thermal shattering (*2, 14*). This criterion was applied to samples from the Asmara guyot, and it was established that primary and steam explosions were mainly responsible for the fragmentation of the basalt (Fig. 3).

The slight centerward depression of the summit of the Asmara guyot and the lack of evidence of wave action (such as rounded pebbles) suggest that the nearly flat top did not result from wave truncation. We propose that this flat top is a primary, constructional feature; during each eruptive episode the minute glass fragments (produced either by steam explosions or by thermal shattering) formed suspensions in the water, were dispersed to various extents according to the size of the grains, water currents, and so forth, and subsequently were deposited in well-sorted, nearly horizontal layers. The aforementioned low ratio of height to diameter of base in submarine structures, relative to subaerial ash cones, can also be explained by the fact that the pyroclastics settle more slowly and are dispersed over wider areas when they are ejected and set in suspension in water rather than air.

The evidence in favor of wave truncation for the origin of many oceanic guyots is overwhelming (*1*). Our observations on this Ethiopian guyot, however, support previous suggestions (*2*, *15*) that not all flat-topped seamounts have formed by wave truncation and subsidence of volcanic islands; in some cases they may be primary structures constructed by a particular mechanism of submarine volcanic activity.

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Covalent Polymers of Water

Abstract. *A new covalent structural scheme for water polymers is proposed. The observed properties of "polywater" are related to the structures of the suggested homologous series of molecules. Mechanisms of formation are suggested.*

Several groups of investigators have reported (*1–6*) that when water vapor condenses in fine quartz or Pyrex capillaries it sometimes forms a viscous liquid of abnormally high density and refractive index. At low temperatures the liquid separates into two phases (*3*). It has a lower vapor pressure, a lower freezing point, and a higher boiling point than normal water. While no differences from ordinary water could be detected in the viscous liquid (*4*) by mass spectrometric and nuclear magnetic resonance techniques, other techniques revealed infrared and Raman spectra very different from those of water and ice and showed that these spectra are not associated with impurities which were sought and identified at negligible concentrations (*5*, *6*).

To chemists and physicists familiar with the molecular properties of water and its solutions, and with theories of their structure and properties, these reports have been very surprising. They bring to mind earlier studies of some properties of colloidal systems for which it has been suggested that there may be exceptionally long-range ordering forces extending many water molecule diameters from surfaces into the solvent. These proposals have been examined and are inconsistent with other properties (*7*). Furthermore, the unusual features of the "anomalous water" are retained when the liquid is removed from the capillaries for spectral studies (*6*).

It was first suggested (*2*) that the observations could be explained in terms of the existence of an allotropic form of liquid water. Measurements of thermal expansion in fine capillaries, as a function of temperature, demonstrated that the liquid possessed properties quite different from those of ordinary water (*3*). Supercooling to near −50°C was accompanied by the development of turbidity and a separation into two liquid phases. Deryagin *et al.* (*3*) cited acetaldehyde trimerization

$$3\,(C_2H_4O) \rightarrow (C_2H_4O)_3$$

as a similar example of a liquid with two phases, described earlier as a "pseudo-one-component" system, and referred to the "two-component behavior of water" as "evidently an indication of the existence either of isomers of water or of dimers, the transitions of which are frozen." They observed that evaporation from a column produces a condensate of decreased "anomalousness."

The well-established Gibbs phase rule states that

$$f = c - p + 2$$

where f is the number of degrees of freedom, c is the number of components, and p is the number of phases in equilibrium. This rule asserts that an allotropic liquid form of water in equilibrium with ordinary water is not possible in a one-component system. However, if a covalent polymer is formed with the aid of a catalyst, which is then removed, the polymer would not be in dynamic equilibrium with the monomer and thus should be considered as a separate component. With $c = 2$, we may have two liquid phases in which each component in a given liquid phase is in equilibrium with the same component in the other liquid phase, although the components in the same liquid phase are not in equilibrium with each other. If there were more components, for example, oligomers of lower molecular weight, this increase would allow for the existence of more liquid phases for the system. Thus, the two liquid phases reported are entirely consistent with the Gibbs phase rule if we assume the formation of a covalently bonded polymer which can be counted as a separate component because of "freezing" or stopping of the conversion process.

Although only submicrogram quantities of "anomalous water" were available, Raman and infrared studies with sensitive instrumentation showed spectra far different from those of water and ice (*6*) and supported the indications of an earlier study (*5*). Proposals were made that the anomalous properties are due to the formation of a new substance, "polywater" (*5*), consisting of tetrahedral (*8*) or square (*5*) tetramers, or of long chains of water molecules or hexagonal planar nets with symmetrical O–H–O bonds (*5*). These structural proposals have unattractive features. Why should the O–H–O bonds of water become symmetrical when they are normally much more stable in unsymmetrical states? Moreover, comparisons with