Hox genes was a cause of the transformation. Theoretically, in *Latimeria* this could be tested. Future comparative studies on *Hox* gene expression in tetrapod, fish and shark embryos will shed light on when in the evolution of tetrapods the posterior *Hox* genes were first expressed in the pectoral appendage, and help to establish whether a shift in *Hox* expression is indeed the basis for the serial homology of fore and hind limbs.

Cliff Tabin
Ed Laufer
Department of Genetics,
Harvard Medical School,
200 Longwood Avenue,
Boston,
Massachusetts 02115, USA

Noble gases in atmospheres

SIR — Owen et al.[1] reported an interesting observation that noble gas isotope data for terrestrial samples (atmosphere, mid-ocean ridge basalt, Loihi volcanics), martian meteorites, and ice formed at 50 K lie on a line in a plot of $\log(^{84}Kr/^{132}Xe)$ against $\log(^{36}Ar/^{132}Xe)$ (see Fig. 2 of ref. 1). They suggested that the linear array represents a mixing line between two reservoirs with differing isotope abundances, one being the ice representing a comet and another an internal component in a planet. However, a line in a log–log plot does not represent mixing except for one very special case, where the line has a slope of unity. This specific condition clearly does not apply to the present case. Therefore, the mixing relation among Mars, Earth and comet noble gases

argued by Owen et al. must be dismissed.

The inadequacy of the mixing model can be further shown by comparing the noble gas isotope compositions between Earth and Mars. All the terrestrial materials (see figure) have identical noble gas isotope ratios (except for radiogenic ones)[2,3], whereas they are different from martian noble gas isotope ratios, especially in $^{38}Ar/^{36}Ar$. If the linear array for the terrestrial data is due to the mixing, the terrestrial data which are located close to Shergotty must have very similar isotope ratios to those of Shergotty, which is clearly not the case. Therefore, the above observation rules out the possibility that terrestrial noble gases are related to Mars noble gases by the mixing process proposed by Owen et al.[1].

We plotted newly obtained, high-quality data for mid-ocean ridge basalts and Loihi[2,3], and laboratory data for silicate melts and waters at various temperatures (0, 25, 50 °C) together with the Mars and ice data in a plot of $\log(^{36}Ar/^{132}Xe)$ against $\log(^{84}Kr/^{132}Xe)$ (see figure). The terrestrial data show a clearly linear array. Thus the linear array for the terrestrial samples must be attributed to cause(s) other than the mixing. It is known that equilibrium partition of noble gases between melt (either in silicate melt or in water) and gas gives rise to elemental (not isotope) fractionation to result in a linear relation in a plot of $\log(a/b)$ against $\log(c/b)$, where a, b and c stand for any of four (helium is non-conservative in the Earth) noble gases (see ref. 4). This is because noble gas solubility in the melt is, to a good approximation, proportional to $\exp(-kr_i^2)$ (where k is a numerical constant, r_i the radius of a noble gas atom

i), and hence the logarithm of elemental abundance ratio of noble gas a and b which is expressed as $\exp\{-k(r_b^2-r_a^2)\}$ necessarily shows linear relation in a logarithmic plot (for detailed discussion, see ref. 5). Fractionation during gas-loss or gas-adsorption can also give rise to a similar linear trend to that seen in the figure (ref. 5). The rough linear relation among terrestrial samples in the figure can be attributed to one or some of these fractionation processes.

Although martian and terrestrial noble gases cannot be related to each other by the simple mixing process suggested by Owen et al., the almost identical trend in the noble gas elemental abundance pattern both for Earth and Mars is remarkable, and deserves further investigation. Also, future investigation on noble gas isotope compositions on comets should resolve the significance of comets as a noble gas source for terrestrial planets.

Minoru Ozima
Naoko Wada
Department of Earth and Space Science,
Faculty of Sciences,
Osaka University,
Toyonaka City 560, Japan

OWEN AND BAR-NUN REPLY — Dr Ulrich Ott (Max Planck Inst. für Chemie, Mainz) has kindly pointed out to us that we erred in calling the straight line on our log–log plot a mixing line, representing the blending of two distinct volatile reservoirs. Ozima and Wada make the same observation above. The remarkable fit over three orders of magnitude in the value of $^{36}Ar/^{132}Xe$ and the similarity to a true mixing line over much of the distance had led us, the *Nature* referees, and various colleagues and audiences to overlook this rather obvious point.

We have therefore replotted all the data, making the simple assumption that there is a true mixing line that passes through the points for the atmospheres of Mars and Earth. In other words, we reassert our hypothesis that the heavy noble gases in the atmospheres of these two planets come primarily from the same two sources, one external and one internal to the planet. We have added data for the SNC meteorites Zagami[6] and Lew 88516 (ref. 7). This plot is shown in the figure.

It is evident from this figure that the mixing line drawn under this assumption provides a reasonable fit to the data, again implicating ice formed at temperatures near 50 K as the major external contributor of these gases to the atmospheres of Mars and Earth. Only the SNC meteorite Chassigny is not accommodated by this hypothesis. We must therefore agree with Ott[8] that the relationship (if any) between the gases in Chassigny
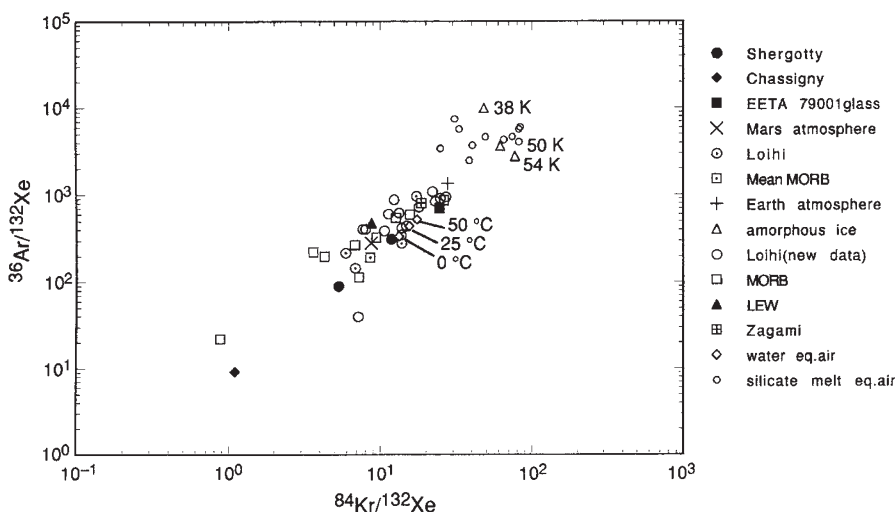
Terrestrial data (MORB (mid-ocean ridge basalt), Loihi volcanic rocks) and laboratory data (atmospheric noble gases absorbed in silicate melts such as basalt, andesite, ugandite, diopside, forsterite and in waters (0, 25, 50 °C)) are plotted in a $\log(^{36}Ar/^{132}Xe)$ against $\log(^{84}Kr/^{132}Xe)$ diagram together with Mars data. Scatter for the laboratory data (silicate melts) is probably due to the experimental uncertainty.