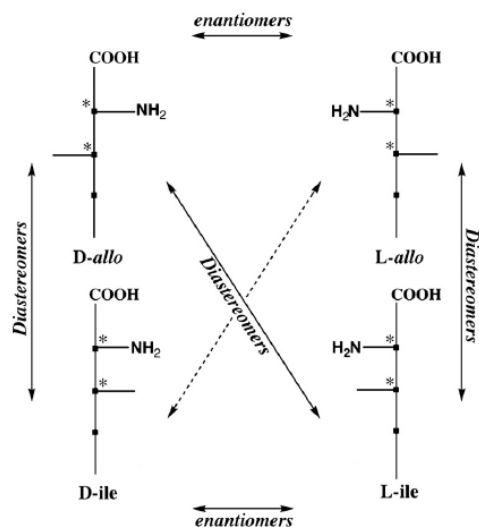


DIASTEREOMER AMINO ACIDS IN METEORITES AND THEIR SIGNIFICANCE FOR THE PREBIOTIC DISTRIBUTION OF MOLECULAR ASYMMETRY IN THE SOLAR SYSTEM. A. A. Monroë and S. Pizzarello. Dept. of Chemistry & Biochemistry, Arizona State University, Tempe AZ 85287-1604. aamonroe@asu.edu; pizzar@asu.edu.

Introduction: Isoleucine (*Ile*) is a six-carbon protein amino acid of biogeochemical interest in that analyses of *L-Ile* and its enantiomer and diastereomers in geological environments containing residual proteins or fossils may reveal sediment ages [1]. Such dating is possible because the *Ile* R group contains two asymmetric carbons and can form two isomeric compounds which show a unique behavior upon racemization or epimerization (threonine is a protein hydroxy amino acid having the same properties but has not been used for dating).

This behavior is shown schematically below for *Ile* and its non-protein enantiomer and diastereomers. It should also be remembered that a carbon is chiral (C^*) when bound to four different substituents and that, when one of these is a hydrogen and the C^* is acidic (e.g. *Ile*- C^*2 due to its closeness to an electron-withdrawing carboxyl group), may change its chiral character in water through the loss and reacquisition of that hydrogen. The *Ile*- C^*3 carbon, on the other hand, is not acidic and does not racemize so readily. In this case, inversion of the diastereomers' carbon centers is limited to C^*2 and leads not to an enantiomer but to an epimer. This process is called α -epimerization and is best known for the conversion of *L-Ile* to *D-alloisoleucine* (*Allo*) [2].



The *Ile* diastereomers are also found in CI [3], CM [4], and CR [5, 6] chondrite meteorites and display an unusual enantiomeric distribution of *L-Ile* and *D-Allo* enantiomeric excesses (ee). More recent detection of these diastereomers was verified by ^{13}C isotopic analyses [5], and their abundances were explained with the

hypothetical synthesis of the amino acids from a non-racemic precursor aldehyde containing *L-ee*.

However, some ee in Antarctic CRs were more recently found to be singularly high (Fig. 1), and it was proposed [7] that they could be biased by *L-Ile* terrestrial contamination and subsequent epimerization.

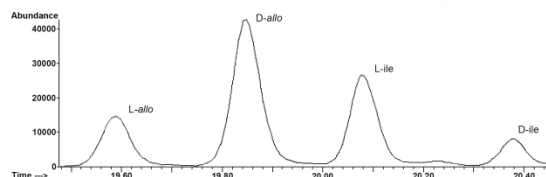


Figure 1. Distribution of the Isoleucine diastereomers in MET 00426 (MET), *D-allo* ee = 60% and *Allo/Ile* ratio = 2.2 - 2.6 [5].

Because the ee of meteorites have been considered possible sources of molecular asymmetry in prebiotic evolution, it is important to exclude the possibility of contamination: we calculated the diastereomeric distributions of the *Allo/Ile* pair *versus* time by modeling the addition of contaminant *L-Ile* and considering existing kinetic and thermodynamic studies [2].

Results: After modeling these systems at 3°C over time, two expected indicators of equilibrium were illustrated: i) *L-Ile* ee = *D-Allo* ee (as seen in Fig. 2), and ii) *Allo/Ile* = K_{ile} , the epimerization constant, previously determined to be 1.25-1.4 under certain conditions [1]. For reference, the compounds found in GRA 95229 (GRA) contained ee = 12-14% and *D-Allo/L-Ile* = 2.3; their indigeneity was validated by ^{13}C isotopic analyses [5]. Using isoleucines detected in GRA as an uncontaminated starting point, we explored the evolution of ee after addition of varying amounts of contaminant *L-Ile* (Fig. 2).

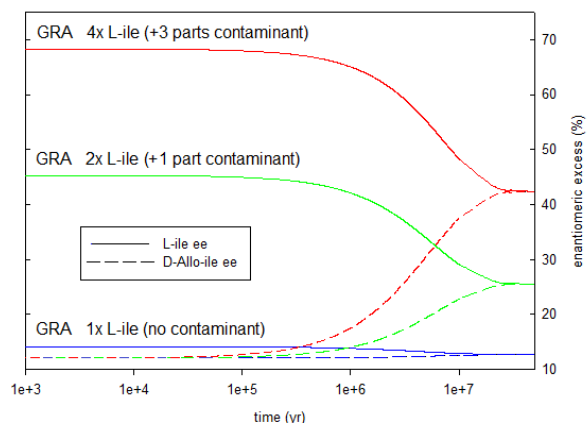


Figure 2. Equilibration of enantiomeric excesses during theoretical α -epimerization. Solid lines denote *L-Ile* ee, dashed lines *D-Allo-Ile* ee.

As more contaminant L-Ile is added, equilibrium ee is raised at the cost of lowering the *Allo/Ile* ratio. In this particular study using GRA, it is evident that the ee of D-*Allo* cannot exceed the greater ee of L-Ile.

Discussion: These models account only for α -epimerization and used epimerization and rate constants calculated for fossil bones [8]. This choice of constant is meant only to be illustrative of the behavior of a system using published values. For the next portion, no rate or epimerization constants are needed because they cancel during derivation.

It is important to address the real possibility of contamination of a meteorite with L-Ile and to define the effects this contamination can (and cannot) produce *via* α -epimerization. Beginning with the premise that only a system destined for increasing D-*Allo* ee is of interest here, we define the inequality:

$$\frac{d}{dt}(\text{D-}Allo\text{ ee}) > 0 \quad (1)$$

Following some rearranging and assuming reversible first-order kinetics and conservation of all species during conversion, we eventually obtain another inequality:

$$\text{L-Ile ee} > \text{D-}Allo\text{ ee} \quad (2)$$

This derived form of (1) demonstrates that D-*Allo* ee can only be raised if L-Ile ee exceeds it. If a sample has been contaminated by L-Ile but not sufficiently contaminated to satisfy (2), the contaminant cannot increase D-*Allo* ee. MET 00426, with D-*Allo* ee = 60 and L-Ile ee = 50 [6], would be subject to such a scenario because it lacks sufficient L-Ile (contaminant or not) to contribute to D-*Allo* ee. In fact, if (2) is false and curatorial conditions allow α -epimerization, contaminant L-Ile will be added to by α -epimerization of indigenous D-*Allo*. On the other hand, if (2) is true, α -epimerization proceeds until L-Ile ee = D-*Allo* ee, (2) becomes false, and equilibrium is reached.

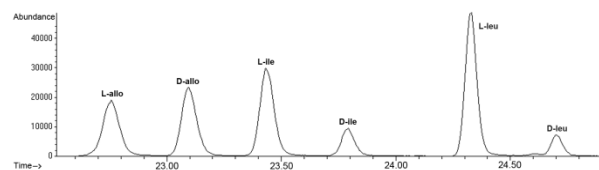


Figure 3. The distribution of Isoleucine diastereomers and Leucine enantiomers in a Murchison meteorite extract (*unpublished results*).

The likely low T of the Antarctic was not considered for the above calculations, but the kinetics and thermodynamics of the *Allo/Ile* epimerization process cannot be disregarded. *Ile* is among the slowest protein amino acids to racemize [9]: this property justifies studying its conversion in fossil materials, and its complete rac-

emization is not a scenario to be expected for meteorites during their Earth residence [7]. Furthermore, *Ile* is a smaller component of bacterial contaminants [10], and its presence in the meteorite should not be expected in the absence of large ee from other and usually more abundant protein amino acids. Fig. 3 contains an example of likely input of *Ile* contaminant in a sample of the Murchison meteorite. Here contamination is more obvious due to the large peak of L-Ile, *e.g.*, compare with Fig. 1, and note the far larger ee of L-leucine (leu), a more common contaminant, in Fig. 3.

It is evident by calculation (and Fig. 3) that any significant input of L-Ile to a set of *Ile* diastereomers will noticeably lower and alter the *Allo/Ile* ratios and can only raise D-*Allo* ee under certain and definable circumstances.

References: [1] *Biogeochemistry of Amino Acids*, Hare P.E. et al. Eds.; Wiley & Sons, 1978. [2] Bada J. et al. (1986). [3] Pizzarello S. *unpublished results* [4] Pizzarello S. and Huang Y. (2005) *Geochim. Cosmochim. Acta*. [5] Pizzarello S. et al. (2008) *PNAS* 105, 3700-04. [6] Pizzarello S. et al. (2012) *PNAS* 109, 11949-54. [7] Elsila et al. (2012) 10.1073/pnas.1213261109. [8] Bada J. (1972) *Earth and Planet. Sci. Letters* 15, 223-231. [9] Whemiller J. and Hare P.E. (1971) *Science* 173, 907-11. [10] Lehninger A.L. *Principles of Biochemistry*, D.L. Nelson and M.M. Cox Eds; VH Freeman and Company, New York, NY, (2008) pp 73. [11] Oró J. and Tornabene T. (1965) *Science* 150:1046-48.