AMINO ACIDS FROM THE LATE PRECAMBRIAN THULE GROUP, GREENLAND

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Abstract. Amino acids were recovered at a concentration level of 10^{-9} M/g from the interior of chert and dolomite of the Late Precambrian Thule Group. Examination of the stability of amino acids in chert under dry-heating conditions suggests that these amino acids have been preserved with a predominance of L-enantiomers in the Precambrian chert. Enantiomer analysis of amino acids in dolomite showed a thermal effect resulting from a late Precambrian igneous intrusion. This evidence indicates that the amino acids isolated from the Thule samples were chemical fossils and not recent contaminants.

1. Introduction

Precambrian sediments contain organic compounds of biological origin. These organic compounds may have been derived directly from biological organic compounds or through diagenesis, in either case perhaps providing useful information on the origin and early evolution of life on the Earth. However, it is often difficult to establish whether these organic molecules are true Precambrian chemical fossils or contaminants introduced during the subsequent geologic history (Hoering, 1967; Calvin, 1969; Kvenvolden, 1972; McKirdy, 1974; Nagy, 1981).

Amino acids may provide a clue to the ages of organic compounds found in sediments. Since the racemization of amino acids in sediments takes place after their deposition, D/L ratios can be determined and used for establishing the geochronology of the compounds and sediments (Dungworth, 1976; Schroeder and Bada, 1976; Williams and Smith, 1977; Kvenvolden, 1975). In general it is believed that amino acids in sediments older than the Tertiary should have become racemic and, if there is an L-enantiomer predominance, the sediment is regarded to be contaminated with post-depositionally introduced biological compounds.

The presence of amino acids in Precambrian sediments was noted by Schopf *et al.* (1968). They found concentrations of 47×10^{-9} M/g in the Bitter Spring chert, 0.8×10^{9} yr-old, 18×10^{-9} M/g in the Gunflint chert, 1.9×10^{9} yr-old, and 12×10^{-9} M/g in the Fig Tree Chert $> 3.1 \times 10^{9}$ yr old. These amino acids were considered to be syngenetic, since the chert matrix and its organic constituents enhanced their stability. An alteration of some of the original amino acids was also indicated because of the finding of non-protein amino acids.

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Abelson and Hare (1969) found amino acids at a concentration of about 2×10^{-9} M/g in the Gunflint chert and concluded that these amino acids were of recent origin. They based their conclusion on the stability of amino acids in a heating experiment. There were two major reasons for this conclusion. The D-optical isomers of isoleucine, alloisoleucine were absent and serine and threonine, generally considered thermally unstable, were present.

Studies of the optical configuration of the amino acids of the Fig Tree chert were reported by Kvenvolden *et al.* (1969) and Oró *et al.* (1971). Both groups found that those amino acids were largely the L-enantiomeric forms with few D-isomers present. Kvenvolden *et al.* further suggested that these amino acids might possibly be present in Precambrian chemical fossils preserved under the extremely stable environment of the chert, greatly inhibiting a racemization reaction.

It is still uncertain whether one can find amino acids indigenous to Precambrian sediments. In studying this question, we examined cherts and dolomites of the late Precambrian Thule Group, Greenland. The present study focuses on amino acid stability in cherts by heating them under conditions different from those examined by Abelson and Hare (1969). We also studied the effect of a Precambrian igneous intrusion on amino acids present in dolomite. These studies should contribute to our understanding of the survival of amino acids in Precambrian sediments.

2. Experimental

2.1. SAMPLES

The samples used were chert and dolomite collected from the Aorfêneq member at the south of Dundas, North Star Bugt area, northwest Greenland. This area is the southern margin of the large Franklinian or Smith Sound geosyncline and is composed of the Thule Group of Late to Middle Proterozoic sediments covered by Quaternary surficial deposits (Davies *et al.*, 1963). The Thule Group is divided into the Narssârssuk, Dundas and Wolstenholme Formation. The Aorfêneq member is the middle of the Narssârssuk Formation and is distributed at the south of Dundas with a WNW-ESE trend, gently dipping southwards. A diabase dyke approximately 10 km long and 20 m wide is intruded by many igneous dykes and sills. The isotopic K–Ar age determination falls into two age groups; ages between 532 and 764 m.y. and between 1070 and 1190 m.y. The diabase dyke in this area belongs to the younger age group (Dawes, 1976).

Chert rocks were found mainly in the Aorfêneq member as intercalations 5 to 10 cm thick in dolomite layers. The black cherts were sometimes finely laminated with gray chert in dimensions of a millimeter. Microscopic observation has revealed several kinds of microfossils in the chert fragments with heterogenous distribution (A. H. Knoll, *pers. Comm.*). Two chert samples (T 12–1 and T 12–3) from locations more than 200 m from the diabase dyke (Figure 1) were analyzed. The thermal effect on the chert samples was considered to be negligible.

Three dark-gray dolomite samples of exactly the same geologic horizon were collected at 10 cm (T7–1), 90 cm (T7–3) and 180 cm (T7–4) from the point of contact in

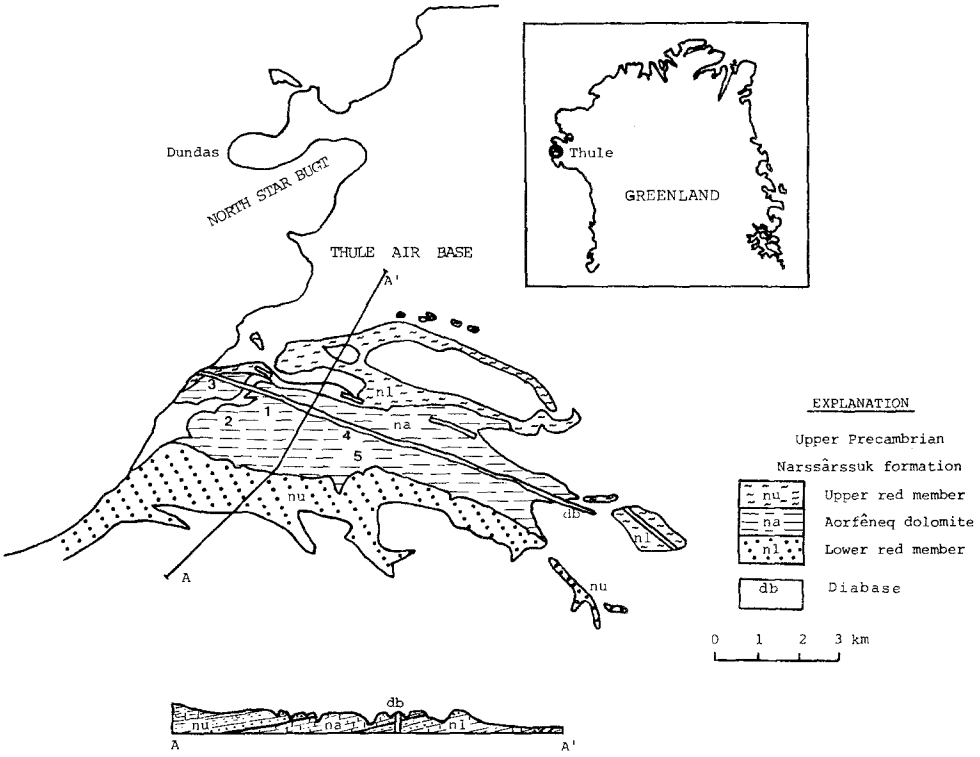

Fig. 1. The location of the sample analyzed Location 1: T12–1; 2: T12–3; 3: T7–1, T7–3, T7–4; 4: T4–5; and 5: T4–2

order to study the heat effect by the igneous intrusion. In addition, two dolomite samples were collected 30 m (T4–5) and 500 m (T4–2) from the point of contact (Figure 1). These two lightgray dolomites contained fine stromatolitic structures.

2.2. ANALYSIS

Hand-size samples of chert and dolomite were crushed into fragments of about 1 cm size. Fifteen to twenty grams of the fragments were hydrolyzed in a 250-ml Erlenmeyer flask with 30 ml of distilled 6 N HCl. Two to three ml of 49% HF were added to the hydrolysates to remove Ca ions dissolved in the solution. The solution was desalted with 15 ml of Bio-Rad AG 50W–X8 cation-exchange resin and eluted with 2 N NH_4OH. This desalting procedure was omitted in the hydrolysates having a small amount of salt. Hydrolysis of chert fragments was carried out three times until the amino acid concentration decreased to laboratory contamination level. After removing the exterior amino acids, the chert fragments were pulverized in a porcelain mortar, and then hydrolyzed with 6 N HCl. The hydrolysates were desalted by the ion exchange column. The NH_4OH elutants were dried with a rotary evaporator at 50°C, followed by lyophilizing in a small vial. The dried samples were dissolved in an appropriate amount of distelled water for amino acid analysis.

A different procedure was applied to dolomite samples. Hydrolysis with NaOH at 110°C for 24 hrs was carried out to remove the surface contamination. After establishing that no amino acids were recovered from the surface, the dolomite fragments were pulverized. The pulverized samples were demineralized with 6 N HCl at room temperature. The insoluble residues were separated from the solution by a 4–5.5 glass-filter. After the solution was dried by a rotary evaporator, both insoluble and soluble fractions were hydrolyzed with 6 N HCl at 108°C for 24 hrs, followed by the same desalting procedure as the chert sample.

The glassware was cleaned by washing with distilled water and heated in a furnace at 460°C overnight. All procedures of sample preparation were carried out in a clean room to prevent any laboratory contamination.

Amino acid analysis was carried out using a Durrum Amino Acid Analyzer Model–500. Enantiomers of amino acids were analyzed by a Perkin–Elmer 900 gas chromatograph equipped with an N-detector. For this work, N-trifluoroacetyl-isopropyl ester derivatives of amino acids were prepared and examined by a glass capillary column (23 m x 0.3 mm O.D.), coated with Chirasil-Val.

To examine the stability of amino acids to racemization and degradation, the chert fragments were heated in a furnace at various temperatures between 150 and 278°C in an open 10 ml glass vial. Sealed vials were used for the heating experiment at 158°C with or without H_2O as a comparison with the data obtained by Abelson and Hare (1969). Amino acids, recovered from both the exterior and the interior after heating, were examined as was stated above.

3. Results and Discussion

3.1. Laboratory and Field Contamination of Amino Acids in Chert

Hydrolysis by 6 N HCl was the best procedure for the removal of amino acids from the surface of chert fragments. The amino acid concentration levels were 10^{-7} M/g of chert in the first hydrolysates. These concentrations were less than 10^{-9} M/g in the second and to 10^{-10} M/g in the third (Figure 2). This result showed that three sequential hydrolyses were enough to remove the amino acids completely from the surface of chert fragments. As the desalting procedure by a cation-exchange column was not needed for the third hydrolysate, laboratory contamination was found to be smaller in the third than in the first and second hydrolysates.

Immersion in a chromic-sulfuric acid solution was sometimes not enough to remove the amino acids from the surface of chert fragments. Amino acids persisted at a concentration level of 10^{-9} M/g in some chert fragments of T12–1 even after immersion in a chromic-sulfuric acid solution for two days. Therefore, it is necessary to establish that no amino acids would be recovered from the fragments by sequential 6 N HCl hydrolysis at least three times.

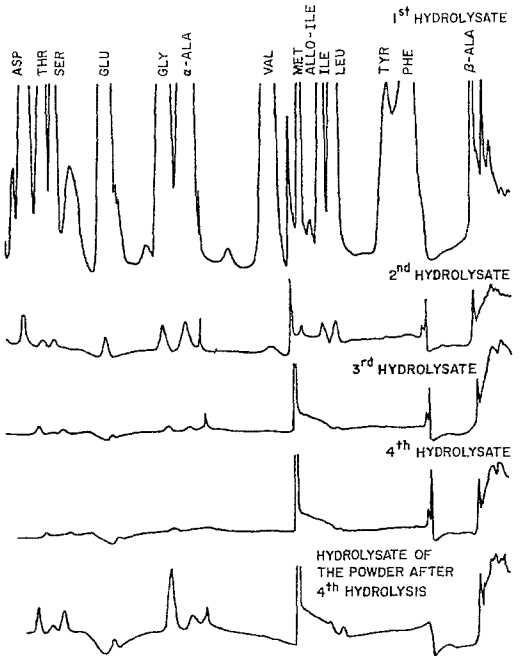

Fig. 2. Ion exchange chromatograms of amino acids progressively removed from the exterior of the Aorfêneq chert (T12 1) and from the interior.

Laboratory contamination was examined by using a procedure blank of 20 g of quartz sand, preheated overnight at 460°C after washing with distilled water by sonification. The 1 N HCl extract from quartz sand was hydrolyzed with 6 N HCl at 108°C for 24 hrs (1 N HCl extract). Direct hydrolysis of cleaned quartz sand was carried out with 6 N HCl at 108°C for 24 hrs and removing the salts using a cation-exchange column (6 N HCl hydrolysate). The procedural blank showed that glycine was the highest contaminant at a concentration of 0.03×10^{-9} M/g and aspartic acid, serine, glutamic acid, and alanine were present at 0.01×10^{-9} M/g or less in the 6 N HCl hydrolysate.

Abelson and Hare (1969) recovered glycine (1030×10^{-9} M/g), alanine (270×10^{-9} M/g and serine (630×10^{-9}) from the surface of a 400 g cobble of the Gunflint chert. The chert fragments studied here contained a smaller total amount, 64×10^{-9} M/g in fragments A and 108×10^{-9} M/g in fragments B of the T 12–3 sample (Table I). The D/L ratios of the exterior are much higher than those produced during the 6 N HCl hydrolysis procedure of precleaned chert fragments. The D/L ratios of the surface suggest that at least part of the exterior amino acids of the chert fragments was derived from the amino acid contamination of younger geologic age.

TABLE I

Amino acid compositions of the exterior of the Aorfêrneq chert (T12–1) before and after heating (mole %)

Heating Temperature (°C)			190	205	235	255	278
Heating time (hrs)	0	0	72	22	24	24.5	24.5
Aspartic acid	10.9	11.3	11.6	13.0	14.8	21.9	21.5
Threonine	7.8	4.3	4.4	5.7	2.2	1.1	0.3
Serine	6.5	3.4	3.5	4.2	1.7	1.0	0.3
Glutamic acid	16.2	16.7	17.1	18.7	17.9	15.8	17.2
Glycine	11.7	9.5	13.7	13.4	13.9	17.1	21.5
α-Alanine	16.5	18.3	18.8	16.4	21.9	18.7	17.0
Valine	6.7	7.5	9.3	4.9	6.4	6.0	4.2
Methionine (Norvaline)	2.7	3.0	1.9	4.2	3.7	2.1	1.9
allo-Isoleucine	0.04	0.05	0.08	0.10	0.16	0.22	0.30
Isoleucine	4.0	3.7	4.5	4.2	2.9	2.4	1.3
Leucine	6.9	7.4	8.3	8.6	6.5	4.4	2.7
Tyrosine	1.9	1.3	1.8	1.8	0.9	–	0.1
Phenylalanine	4.6	3.5	5.0	4.2	3.0	2.5	1.4
β-Alanine	2.9	6.0	+	4.8	4.1	6.3	10.5
Histidine	0.5	0.5	0.04	0.4	–	–	–
Lysine	–	3.5	+	–	–	0.7	–
Arginine	0.2	–	–	0.3	–	–	–

3.2. AMINO ACIDS FROM THE INTERIOR OF CHERT FRAGMENTS

A considerable amount of amino acids was recovered from the hydrolysates of the interior samples of T12–1 and T12–3 (Table II). Twelve amino acids were recovered with a predominance of glycine and alanine. Amino acids of the interior were equal to nearly 1/100 concentration of the exterior and show a similar composition except for higher percentages of glycine in the interior. Hydroxy amino acids, threonine and serine were detected in the hydrolysates of all samples analysed. The D/L-ratios of alanine, aspartic acid, glutamic acid and lysine except phenylalanine were slightly higher in the interior than in the exterior (Table III).

Abelson and Hare (1969) showed a marked degradation of serine and threonine and the conversion of half of the L-isoleucine to D-alloisoleucine by heating at 165°C for 3 days. They concluded that the amino acids recovered were possibly of recent contamination, even if the amino acids were clearly obtained from the interior. However, their heating experiment was carried out with the powdered sample in the presence of water. Water appears to be an important factor affecting the stability of amino acids (Hare, 1974; Akiyama, 1978).

To examine the influence of water on racemization and degradation of amino acids, three grams of dried chert fragments (T12–1) were heated at 158°C with 300 μl of H_2O for 2 days and without H_2O for 3 days. The amino acids recovered from those heated

TABLE II

Amino acids recovered from the interior of the Aorfêrneq chert (nM/g)

	T12–1		T12–3	
	A	B	C	D
Asp	0.07	0.09	0.05	–
Thr	0.04	0.04	0.05	0.07
Ser	0.07	0.07	0.07	0.06
Glu	0.08	0.10	0.08	–
Gly	0.22	0.21	0.16	0.15
α-Ala	0.24	0.10	0.14	0.17
Val	0.05	0.06	0.04	0.07
Ile	0.02	0.05	0.05	0.05
Leu	0.07	0.10	0.09	0.09
Tyr	–	0.01	+	0.01
Phe	0.02	0.02	0.03	0.04
β-Ala	0.07	–	–	0.03
Total	0.95	0.85	0.76	0.74

TABLE III

Enantiomer ratios of the exterior and interior amino acids of the Aorfêrneq chert (T12–1)

	Esterior Fragments		Interior Fragments		
	A	B	A	B	Procedural Blank
D/L-Ala	0.13	0.13	0.20	0.15	0.06
D/L-Leu	–	0.01	0.01	0.01	–
D/L-Asp	0.10	0.13	0.14	0.13	0.07
D/L-Phe	0.14	0.09	0.07	0.07	0.06
D/L-Glu	0.28	0.28	0.37	0.36	0.06
D/L-Lys	0.02	0.05	0.11	0.26	0.02
D/L-Ile	0.01	0.01	–	–	–

chert fragments by hydrolysis are shown on the amino acid chromatograms (Figure 3) and on the gas chromatograms (Figure 4). Marked differences were observed between the two conditions. No significant changes of amino acids were observed in the absence of water before and after heating, while the degradation of serine and threonine and the racemization reaction of alanine, leucine, aspartic acid and glutamic acid were remarkable when heated in the presence of water as reported by Abelson and Hare (1969). Since amino acids in the chert were stable to degradation and racemization in the absence of water, systematic experiments of amino acid stability under dry conditions were performed with those chert fragments.

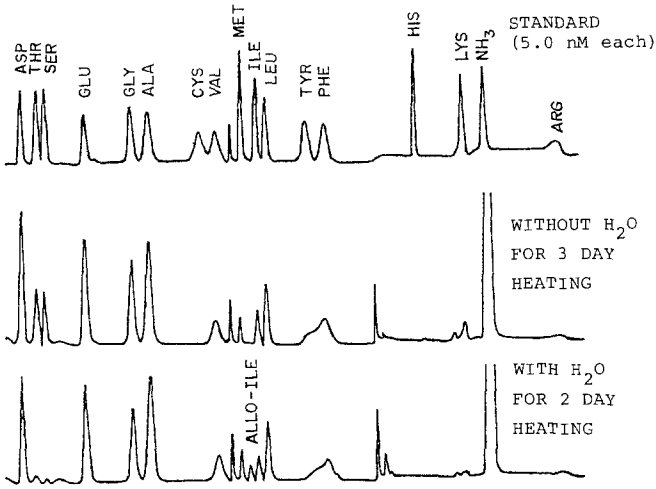

Fig. 3. Ion exchange chromatograms of the exterior amino acids from the Aorfêneq chert (T12–1) after heating at 158°C with or without H_2O

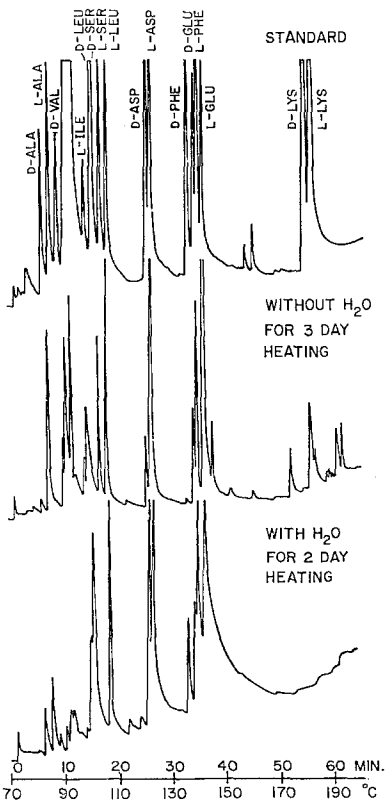

Fig. 4. Gas chromatograms of N-trifluoroacetyl-isopropyl esters of D- and L-amino acids from the exterior of the Aorfêneq chert (T12–1) after heating at 158°C with or without H_2O

3.3. STABILITY EXAMINATION OF AMINO ACIDS FOR RACEMIZATION

Amino acids were recovered from the hydrolysates of both the exterior and interior of chert fragments heated at various temperatures between 150°C and 278°C in an open 10 ml glass vial. The exterior amino acids were those recovered from chert fragments by 6 N HCl hydrolysis under refluxing for 24 hrs, and the interior amino acids were those recovered by hydrolysis from the pulverized chert after completely removing the exterior amino acids.

TABLE IV

Racemization reaction rate constants of isoleucine and alanine recovered from the hydrolysates of the Aorfêrneq chert (T12–1) heated at various temperatures

	Temperature (°C)	Heating time (hr)	D/L	k (hr^{-1})	log k
Ile	158	72	0.011	1.39×10^{-5}	−4.86
	190	72	0.018	1.11×10^{-4}	−3.96
	205	22	0.02	4.15×10^{-4}	−3.38
	235	24	0.06	2.07×10^{-3}	−2.68
	255	24.5	0.10	3.63×10^{-3}	−2.44
	278	24.5	0.22	8.41×10^{-3}	−2.08
α-Ala	190	72	0.17	5.68×10^{-4}	−3.25
	205	22	0.16	1.39×10^{-3}	−2.86
	235	24	0.30	7.45×10^{-3}	−2.13
	255	24.5	0.36	1.00×10^{-2}	−2.00
	278	24.5	0.52	1.82×10	−1.74

Enantiomers of amino acids were analyzed by the gas chromatograph except for alloisoleucine and isoleucine which were analyzed by the amino acid analyzer. Racemization rate constants for alanine and isoleucine (Table IV) were calculated from D/L-values of the hydrolysates of chert fragments (exterior amino acids), using the following formula (Bada and Schroeder, 1975):

$$\ln \frac{1 + \mathrm{D/L}}{1 - \mathrm{D/L}} - \text{constant} = 2kt; \quad \text{for alanine}$$

$$\ln \frac{1 + \mathrm{D/L}}{1 - K'(\mathrm{D/L})} - \text{constant} = (1 + K')kt; \quad \text{for isoleucine,}$$

where k is the first-order rate constant for interconversion of the L- to D-enantiomer, t is time expressed in hrs and D/L is the amino acid enantiomeric ratio. The value K' is a reciprocal of equilibrium D-alloisoleucine/L-isoleucine ratio (= 1.38).

Figure 5 shows the Arrhenius plot of D-alloisoleucine – L-isoleucine epimerization kinetics obtained from the heating experiment, compared with the other data of epimerization. The plot suggests that under dry conditions the epimerization reaction constant was very slow for the exterior amino acids. Amino acids recovered from the interior heated chert fragments at and below 205°C showed no detectable racemization.

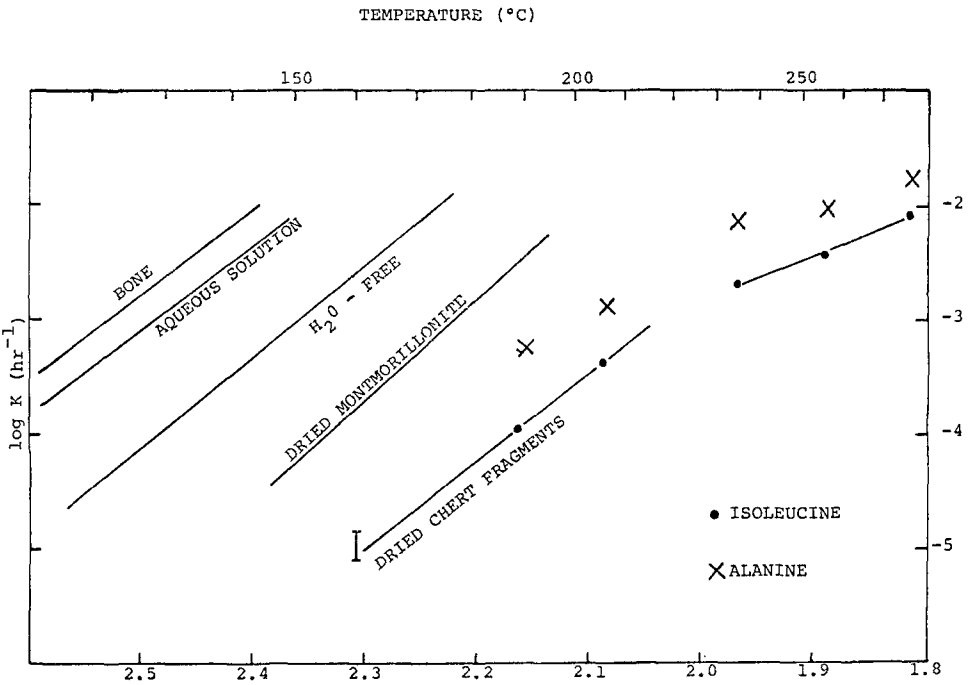

Fig. 5. Arrhenius plot of L-isoleucine epimerization and L-alanine racemization kinetics of the exterior amino acids from the Aorfêneq chert (T12–1) in comparion with those in various conditions (Lee *et al.*, 1976; Akiyama, 1978)

From the extrapolation to lower temperatures in Figure 5 the reaction rate constants of L-isoleucine to D-alloisoleucine at 15°C and 5°C were obtained, which were 10^{-14} and 10^{-15} hr^{-1}, respectively. Substitution of these values into the kinetic equation gave D/L ratios of 0.07 and 0.01 for the amino acids of the late Precambrian (0.6×10^9 yr = 5.256×10^{12} hrs). Since the reaction rate in the interior is considered to be less than these values, D-alloisoleucine/L-isoleucine ratios should be less than the values calculated above. These were below the detection level, and indeed, this is what we observed.

Alanine is less stable to racemization than isoleucine (Bada and Schroeder, 1975; Dungworth *et al.*, 1975). A D/L ratio was measured as 0.20 in the interior of chert. If this ratio is substituted in the D/L ratio in the reaction kinetic equation of alanine, 3×10^{-14} hr^{-1} is obtained as a reaction rate constant when t was the late Precambrian ($t = 5.256 \times 10^{12}$ hr.) This rate constant is very close to the ratio obtained from an extrapolation to 5°C in Figure 5, indicating that the reaction rate constant in the interior is less than that of the exterior.

It is very likely that the chert has provided an extremely stable environment for racemization reaction and that the low D-amino acid concentrations observed are reasonable for the chert samples. The predominance of L-amino acids in these Precambrian cherts should not simply be attributed to recent contamination. Hydrogen bonding of amino acids with SiO_2 and/or binding with humic acid or kerogen under the dry conditions of

a chert matrix appears to enhance the stability to racemization. It has been noted that the amino acid stability to racemization is strongly dependent on the environment in which the amino acids have been preserved. Humic acid is one example of such an environment. Alloisoleucine-to-isoleucine ratios in the humic acid fractions of Pleistocene and Miocene *Mercenaria* shells were significantly less than those obtained from the total shell material (Hare and Hoering, 1977). Humic acid fractions extracted from Cretaceous belemnite shell showed the presence of unstable hydroxy amino acids and the absence of alloisoleucine (Westbroek *et al.*, 1979).

3.4. Effect of Contact Metemorphism on Dolomite

Dolomite samples, collected at 10 cm (T7–1), 90 cm (T7–3) and 180 cm (T7–4) from the point of contact, were analyzed to study the heat effect by an igneous intrusion in late Precambrian times. After refluxing with 2 N NaOH, the pulverized samples were extracted with H_2O. A three-time extraction of the powder reduced the amino acid concentration to less than 10^{-11} M/g. After the digestion of the powder with 6 N HCl, amino acids at a concentration level of 10^{-10} M/g were recovered from the 6N HCl hydrolysates of the residue (Table V). The amino acids of the residue were certainly derived from the interior of dolomite. If there was a thermal effect on dolomite by the dyke intrusion, an increasing trend in D/L amino acid ratios should be observed with increase of distance from the dyke. Results do not indicate such a trend for the three dolomite samples as suggested by the abundances (Table V) and by the D/L ratios (Table VI). However, the D/L ratio of amino acids is higher than those from the racemization by the hydrolysis procedure. These results suggest that the amino acids were not recent contaminants but were associated with the dolomite at least from the time of the igneous intrusion in the very late Precambrian time.

TABLE V

Amino acids recovered from the interior of the Aorfêrneq dolomite (nM/g)

	T7–1	T7–3	T7–4	T4–5	T4–2
Aspartic acid	0.05	0.04	0.03	0.16	0.12
Threonine	0.03	0.02	0.02	0.01	0.03
Serine	0.03	0.03	0.02	0.03	0.06
Glutamic acid	0.05	0.04	0.04	0.12	0.10
Glycine	0.09	0.08	0.08	0.14	0.15
Alanine	0.04	0.04	0.03	0.10	0.11
Valine	0.03	0.02	0.02	0.14	0.07
Allo-isoleucine	–	–	–	0.01	0.01
Isoleucine	0.02	0.01	0.01	0.07	0.05
Leucine	0.03	0.03	0.04	0.22	0.10
Tyrosine	0.01	0.01	–	–	0.02
Phenylalanine	0.01	0.01	0.02	0.07	0.03
Histidine	0.01	0.01	0.01	0.01	0.01
Total	0.40	0.34	0.32	1.08	0.86

TABLE VI

Enantiomer ratios of the interior amino acids of the Aorfêrneq dolomite

	T7–1	T7–3	T7–4	T4–5	T4–2
D-/L-Alanine	–	0.10	0.19	0.92	0.31
D-/L-Leucine	–	0.01	0.02	0.77	0.23
D-/L-Aspartic acid	0.22	0.14	0.23	0.68	0.46
D-/L-Phenylalanine	0.11	0.22	0.36	–	0.45
D-/L-Glutamic acid	0.16	0.43	0.32	0.48	0.28
D-/L-Lysine	–	0.14	0.07	0.73	–
D-Allo-/L-Isoleucine	–	–	–	0.24	0.21

Amino acids at a concentration level of 10^{-9} M/g were recovered in the hydrolysates of the residue from the two dolomite samples at 30 m (T4–5) and 500 m (T4–2) from the contact point (Table V). The same extraction procedure as for the T7 series suggests that the amino acids were derived from the interior of the dolomite. These abundances are two or three times greater than those of the samples closer to the contact point. An examination of enantiomers revealed that D/L amino acid ratios were high in the T4–5 and then decrease again in the T4–2 (Table VI). The evidence suggests a possible heat effect from the dyke intrusion. The amino acids recovered from the interior of the T4–5 dolomite could be Precambrian chemical fossils. Additional work on the samples collected systematically between 2 and 30 m from the contact point is needed to confirm the effect of the contact metamorphism.

To remove surface contamination, the dolomite samples were treated with 2 N NaOH. It is possible that this treatment might have enhanced the racemization of the amino acids, resulting in high D/L values for amino acids from the T4–5 dolomite. To examine such a possibility 6 N HCl instead of 2 N NaOH was used to remove the outer 10% of the sample. The results were the same and indicate that the amino acids in the interior of the dolomite fragments were not affected by the alkaline treatment.

4. Conclusion

Careful analysis of the late Precambrian chert and dolomite collected from the Thule Group, Greenland reveals that amino acids at a concentration level of 10^{-9} M/g were recovered from the interior of the rocks. Amino acids of the chert contained largely L-enantiomers with a small amount of D-enantiomers. Diagenetic simulation experiments under dry conditions suggest that the racemization reaction was greatly inhibited in the chert, and a predominance of L-enantiomers may have been preserved in the Precambrian chert. The late Precambrian igneous intrusion seemed to enhance the racemization reaction of amino acids in the stromatolitic dolomite. This offers positive evidence that the amino acids were incorporated into the dolomite before the dyke intrusion. The present study gives some hope that amino acids in even older Precambrian rocks may be studied as a help to understanding the origin and early evolution of life on the Earth.

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