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World-wide 2 billion-year-old isotopically heavy carbonate carbon: the evolutionary significance and driving forces. Annual report.

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REPORT

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Title:

World-wide 2 billion-year-old isotopically heavy carbonate carbon: the evolutionary significance and driving forces. Annual report.

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Summary:

This report will show the activities carried out and the results obtained within the project entitled «World-wide 2 billion-year-old isotopically heavy carbonate carbon: the evolutionary significance and driving forces». The results shown in this report have been obtained within a year from 30.11.96 to 30.11.97. The main objectives were to reach an understanding of the ca. 2 billion-year-old positive anomaly of $\delta^{13}C_{carb}$, its significance in the evolution of the biosphere and driving forces using stable and radiogenic isotope systematics of 2.3-1.9 Ga-old sedimentary formations. The main results obtained are: (*i*) a number of fundamental changes in palaeoenvironments have been deciphered and can be shown to be linked to the Palaeoproterozoic isotope anomaly in carbonate carbon; (*ii*) genetic links between an explosive development of stromatolites and the carbon anomaly at 2.33-2.06 Ga have been documented for the Fennoscandian Shield; (*iii*) explosive development of phytoplankton followed by enhanced C_{org} burial in a stratified stagnant ocean and in a shallow-water, marine (shelf) environment, which were coupled with a high abundance of stromatolite-forming, benthic cyanobacteria in shallow-water, restricted environments, are considered the combined driving forces for the positive carbonate carbon isotope anomaly at 2.3-2.0 Ga ago; (*iv*) the global background for the isotopic shift at around 2.3-2.06 Ga, caused by enhanced C_{org} burial, can be roughly estimated at around +4‰; (*v*) the latter was locally enhanced up to +17‰ in restricted shallow-water environments inhabited by stromatolite-forming microbial communities.

Keywords: Carbon isotopes	Isotope anomaly	Dolostone
Stromatolite	Palaeoproterozoic	Shallow-water environment
		Annual report

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1. INTRODUCTION

This report will show the activity carried out and the results obtained within the project entitled «World-wide 2 billion-year-old isotopically heavy carbonate carbon: the evolutionary significance and driving forces».

The main objectives were to reach an understanding of the ca. 2 billion-year-old positive anomaly of $\delta^{13}C_{carb}$, its significance in the evolution of the biosphere and driving forces using: (*I*) stable and radiogenic isotope systematics of 2.3-1.9 Ga-old sedimentary formations, (*II*) modelling of anomalous heavy carbonate carbon formation, which occurred at around 2.3-2.06 Ga ago: global phenomenon versus local development.

Previously it has been suggested that the isotopically positive carbon anomaly might be attributed to: (*I*) an increase of the 'Ronov ratio' or 'Broecker ratio' (reduced carbon/oxidised carbon ratio), (*II*) generally different carbon pathways within the global ecosystem, possibly associated with the minimal oxygenation of the environment; or (*III*) enzymological and/or physiological differences in primary products, (*IV*) as well as other various possible models still under discussion. The possibility of diachronism in deposition of high δ^{13}Ccarb carbonates has also been considered.

The drillcore material for detailed study was obtained from the Palaeoproterozoic Pechenga Belt and the Palaeoproterozoic Onega Basin (Fig.1). The former represents an intracontinental rift environment which contains a continuous carbonate succession with isotopically heavy carbonates. The Onega Basin is an example of Palaeoproterozoic carbonate platformal sequence. The carbonate successions were sampled in detail with the purpose of isotope study and age determinations.

Five institutions took place in the research: the Geological Survey of Norway (participant 1), the Scottish Universities Research and Reactor Centre (participant 2), the Institute of Precambrian Geology and Geochronology, St. Petersburg (participant 3), the Geology Institute, Moscow (participant 4), the Geology Institute, Petrozavodsk (participant 5).

Figure 1. *Geographic and geological positions of the study areas.*

2. ACCOMPLISHMENT OF THE 1996-1997 PROGRAMME (30 NOVEMBER 1996-30 NOVEMBER 1997)

The major components of the programme for the years 1996-1997 are indicated in Table 1. Almost all the activities of the programme have been accomplished apart from: (*i*) compiling data on depositional environments (50% to be done), (*ii*) cathode luminescence study (100% to be done), and (*iii*) Pb-Pb age determination (80% to be done, Table 2). The deviation in (*i*) was caused by the fact that the task has required more manpower and time than was envisaged. The cathode luminescence study (*ii*) was not carried out due to a lack of suitable material to be analysed. Considerable delay in the accomplishment of (*iii*) was caused by technical problems with the mass spectrometer at the Institute of Precambrian Geology and Geochronology in St. Petersburg, Russia.

Table 1. 12month programme for the years 1996-1997 starting 30/11/96.

Period	Activity	Participants	Remark
1	Co-ordinating meeting of all participants in St. Petersburg.	All	Accomplished
1	Compiling already available data on $\delta^{13}C_{carb}$ for the Fennoscandian Shield	1 & 5	«
1	Field work in Onega area, sampling drillcore profile across the Karelian carbonate		«
	platform Russian Karelia	5	«
1	Sample preparation for main and trace element analyses (the Karelian platform)	1 & 5	«
1	Main and trace element analyses on carbonates (the Karelian platform)	1 & 4	«
2	Compiling data on Fennoscandian Palaeoproterozoic stromatolites	4, 1 & 5	«
2	Compiling data on depositional environments of Fennoscandian Palaeoproterozoic		«
	carbonate formations	1, 4 & 5	50% to be done
2	Conventional carbonate carbon isotope analyses on samples from the Karelian platform	2	Accomplished
2	Study of Rb-Sr systematics and strontium isotopes on samples from the Karelian platform	3	«
2	Sample preparation for Pb-Pb isotope age determinartion (the Karelian platform)	1, 3 & 5	«
2	Study of U-Pb systematics and Pb-Pb isotope age determination on carbonates from		«
	the Karelian platform	3	«
3	Cathode-luminescent study of carbonates from the Karelian platform	1	100% to be done
3	Sample selection for sulphur isotope analyses on sulphide and sulphates from the		Accomplished
	Karelian platform	1 & 5	«
3	Sulphide extraction	1	«
	Sulphur isotope analyses on sulphide and sulphates from the Karelian platform	2	«
	Study of U-Pb systematics and Pb-Pb isotope age determination on carbonates from		«
	the Karelian platform	3	80% to be done
	Study of Rb-Sr systematics and strontium isotopes on samples from the Karelian platform	3	Accomplished
	Conventional carbonate carbon isotope analyses on samples from the Karelian	2	«
4	Co-ordinating meeting in St. Petersburg (all participants).	All	«
	Annual report on activity	1 & 3	«

Table 2. Sample preparation and analytical work planned for the year1996-1997 at the co-ordinating meeting in St. Petersburg, October 1996.

Analyses	Planned	Accomplished
Sample preparation	250	280 (participant 1)
XRF major and trace elements	150	168 (participant 1)
Carbon and oxygen isotopes	150	168 (participant 2)
Sulphur isotopes:		
a. sulphide	20	38 (participant 2)
b. barite	2	3 (participant 2)
Strontium isotopes		
a. carbonate	50-60 (participant 3)	29 (participant 3)
		22 (participant 2)
b. barite		3 (participant 2)
U-Pb, Pb-Pb	30	6 (participant 3)
Fe, Mn, Rb, Sr (wet chemistry)	150	168 (participant 4)

3. FUNDING

The financial contribution to the project and the expenditures made are indicated in Table 3. Apart from this, additional, though essential, financial support for analytical work was given by the Geological Survey of Norway (ca. 22,500 ECU, for field work, sample preparation and XRF major and trace elements) and by the Scottish Universities Research and Reactor Centre (ca. 20,000 ECU, for carbon, oxygen, sulphur and strontium isotope analyses) .

Table 3. Breakdown of costs of the INTAS-RFBR 95-0928 project.

NTAS MEMBER STATE PARTICIPANTS

PARTICIPANT	STATUS	COST CATEGORIES						TOTAL (ECU)
		Labour costs	Overheads	Travel & subsistence	Equipment	Consumables	Other costs	
1. Melezhik, V.A.	Granted	-	1000	5000	-	-	-	6000
	Spent	-	543.25	2173.02	-	-	-	2716.27
	Available	-	456.75	2826.98	-	-	-	3283.73
2. Fallick, A.E.	Granted	-	1500	2500	-	2000	-	6000
	Spent	-	0	2667.86	-	0	-	2667.86
	Available	-	1500	-167.86	-	2000	-	3332.14

NIS PARTICIPANTS

PARTICIPANT	STATUS	COST CATEGORIES						TOTAL (ECU)
		Labour costs	Overheads	Travel & subsistence	Equipment	Consumables	Other costs	
3. Gorokhov, I.M.	Granted	11700	1000	2500	1500	5500	-	22200
	Spent	6588	94	0	770	3263	10715	
	Available	5112	906	2500	730	2237	11485	
4. Semikhatov, M.A.	Granted	5600	890	1200	1200	1840	-	10730
	Spent	3180	59	0	1856	585	-	5680
	Available	2420	831	1200	-656	1255	-	5050
5. Kheiskanen, K.I.	Granted	4300	500	2500	1500	270	-	9070
	Spent	2080	0	0	1500	0	-	3580
	Available	2220	500	2500	0	270	-	5490

4. SCIENTIFIC MEETINGS

The results obtained were presented at two international meetings which are listed below:

- Seventh Annual V.M. Goldschmidt Conference, June 2-6, 1997, Tucson, Arizona;
- European Union of Geosciences, EUG 9, Strasbourg - France, 23-27 March 1997.

5. PUBLICATIONS

One article has been published in *Precambrian Research*, and two abstracts were published in abstract volumes of international conferences. One article and one extended abstract are in press. One manuscript has been submitted to *Precambrian Research* and one to Transactions of the Russian Academy of Science. All the publications are listed below:

1. Gorokhov, I.M., Kusnetsov, A.B, Melezhik, V.A., Konstantinova, G.V. & Mel'nikov, N.N. Strontium isotopes from the Tulomozerskay Formation dolostones (Jatulian stratotype). *Transactions of the Russian Academy of Science*. (submitted).
2. Gorokhov, I.M., Kusnetsov, A.B, Melezhik, V.A., Konstantinova, G.V. & Mel'nikov, N.N. $^{87}Sr/^{Sr}86$ ratios in marine and nonmarine Jatulian palaeobasins, south-eastern Karelia. *Abstract volume, Symposium on Precambrian sedimentary formations and their metallogeny*, April 1998, St. Petersburg, Russia. (submitted).
3. Melezhik, V.A., & Fallick, A.E. 1997. Paradox regained? Reply. *In*: A widespread positive $\delta^{13}C$ anomaly at around 2.33-2.06 Ga on the Fennoscandian Shield — Comments and Reply. *Terra Nova, 6* (in press).
4. Melezhik, V.A., Fallick, A.E., Makarikhin, V.V. & Lyubtsov, V.F. 1997. Links between Palaeoproterozoic palaeogeography and rise and decline of stromatolites: Fennoscandian Shield. *Precambrian Research, 82*: 311-348.
5. Melezhik, V.A., Fallick, A.E., Medvedev, P.V. & Makarikhin, V.V. 1997. 2.0 billion year old isotopically heavy carbonate carbon: comparison of distal and proximal carbonate sequences from the Onega palaeobasin, Karelia, Russia. *Abstract Volume, Seventh Annual V.M. Goldschmidt Conference, June 2-6, 1997, Tucson, Arizona,* 140.

6. Melezhik, V.A., Semikhatov, M.A. & Fallick, A.E. 1997. The positive carbon anomaly and stromatolite explosion at around 2.3-2.0 Ga ago: are they linked? *Abstract Volume, Global Carbon Cycle, EUG 9, European Union of Geosciences, Strasbourg - France, 23-27 March 1997*, 252
7. Melezhik V.A., Fallick A.E. & Semikhatov M.A. 1997. Could stromatolite-forming cyanobacteria have influenced the global carbon cycle at 2300-2060 Ma? (extended abstract), *Norges geologiske undersøkelse Bulletin* (in press).
8. Melezhik, V.A., Fallick, A.E., Medvedev, P. & Makarikhin V.V. Isotopically heavy carbonates of the Jatulian stratotype in Karelia, Russia: palaeoenvironmentally independent enrichment in ^{13}C. *Precambrian Research.* (submitted).
9. Melnikov, N.N. & Ovchinnikova, G.V. The three-dimensional approach for the interpretation of U-Pb systems in metasedimentary carbonates subjected to superficial alteration. *Abstract volume, Symposium on Precambrian sedimentary formations and their metallogeny*, April 1998, St. Petersburg, Russia. (submitted).
10. Semikhatov, M.A., Raaben, M.E., Sergeev, V.N. and Veis, A.F. Biotic events and the 2.3-2.0 Ga-old positive anomaly of carbonate carbon. *Stratigraphy. Geological correlation.* (submitted).

6. SCIENTIFIC RESULTS

6.1 Isotope anomaly and interrelated phenomena

We have observed a number of events, that within analytical error of the radiometric age determinations, coincide with the Palaeoproterozoic isotope anomaly (Fig. 2). These are: (1) continental rift expansion; (2) development of carbonate platforms; (3) the first stromatolite reef development; (4) a dramatic rise in the oxygen content of the atmosphere; (5) widespread formation of dolostones; (6) widespread development of evaporites; (7) sedimentary and diagenetic phosphate accumulation; (8) development of world-wide 'red beds'; (9) definite Fennoscandian excursion to high $\delta^{34}S$ of both sulphate and sulphide; (10) the first development of diagenetic concretions with highly oxidised iron and manganese, and carbonate concretions as a result of C_{org} oxidation; and, finally, (11) high diversity and abundance of stromatolite taxa.

6.2 Genetic link between explosive development of stromatolites and the carbon anomaly at 2.33-2.06 Ga.

Through a review of the literature and new data we have documented two major events in the Palaeoproterozoic history of stromatolites as indicated by palaeontological and palaeoenvironmental studies. With a time resolution of between 40 to 200 Ma we have recognised maximum in diversity and abundance of stromatolites on the Fennoscandian Shield between 2330-2060 Ma ago (Jatulian diversification, Fig. 3). We suggest that this taxonomic diversity was driven by a major phase of cratonisation, formation of the Karelian carbonate platform and numerous rift-related shallow-water carbonate basins supersaturated with Ca^{+2}, Mg^{+2} and CO_2. The Jatulian biomass fertility was synchronised with a positive $\delta^{13}C_{carb}$ shift of Jatulian age carbonates. We have also documented stromatolite decline, which occurred on the Fennoscandian Shield somewhere between 2060 and 1900 Ma ago. This decline both in abundance and in taxonomic diversity is interpreted as having been caused by the first phase of 'oceanisation'. The 'oceanisation' led to considerable reduction in ecological niches that could be utilised by photosynthetic cyanobacteria. The post Jatulian decline of stromatolites coincides with an abrupt, downward $\delta^{13}C_{org}$ shift from -19‰ to -38‰ and is roughly coeval with the appearance of the first eukaryotic algae documented elsewhere. The systematics of the Fennoscandian diversity of Palaeoproterozoic stromatolites is identical to that reported from India and China and reveals a dissimilarity with abundance and diversity patterns in Australia and Northern America.

6.3 Possible mechanism for the explanation of the 2.33-2.06 Ga isotope anomaly.

Base on the data obtained, we have concluded that an explosive development of phytoplankton followed by enhanced C_{org} burial in a stratified stagnant ocean and in a shallow-water, marine (shelf) environment (Fig. 4a), which were coupled with a high abundance of benthic cyanobacteria (stromatolite-forming microbial communities) in shallow-water, restricted, basins are the combined driving forces for the positive carbonate carbon isotope anomaly at 2.3-2.0 Ga ago. Based on the Francevillan (Gabon), Lofoten-Vesterålen (Norway) and Central Lapland (Finland) areas the global background for the isotopic shift at around 2.3-2.06 Ga, caused by enhanced C_{org} burial in deep-water basins, can be roughly estimated at around +4‰ (Fig. 4b). This was locally enhanced up to +17‰ (Fig. 4b) in restricted shallow-water environments inhabited by stromatolite-forming microbial communities, perhaps due to the development of a high biomass, enhanced uptake of ^{12}C, and the production and consequent loss of CO_2 and /or CH_4.

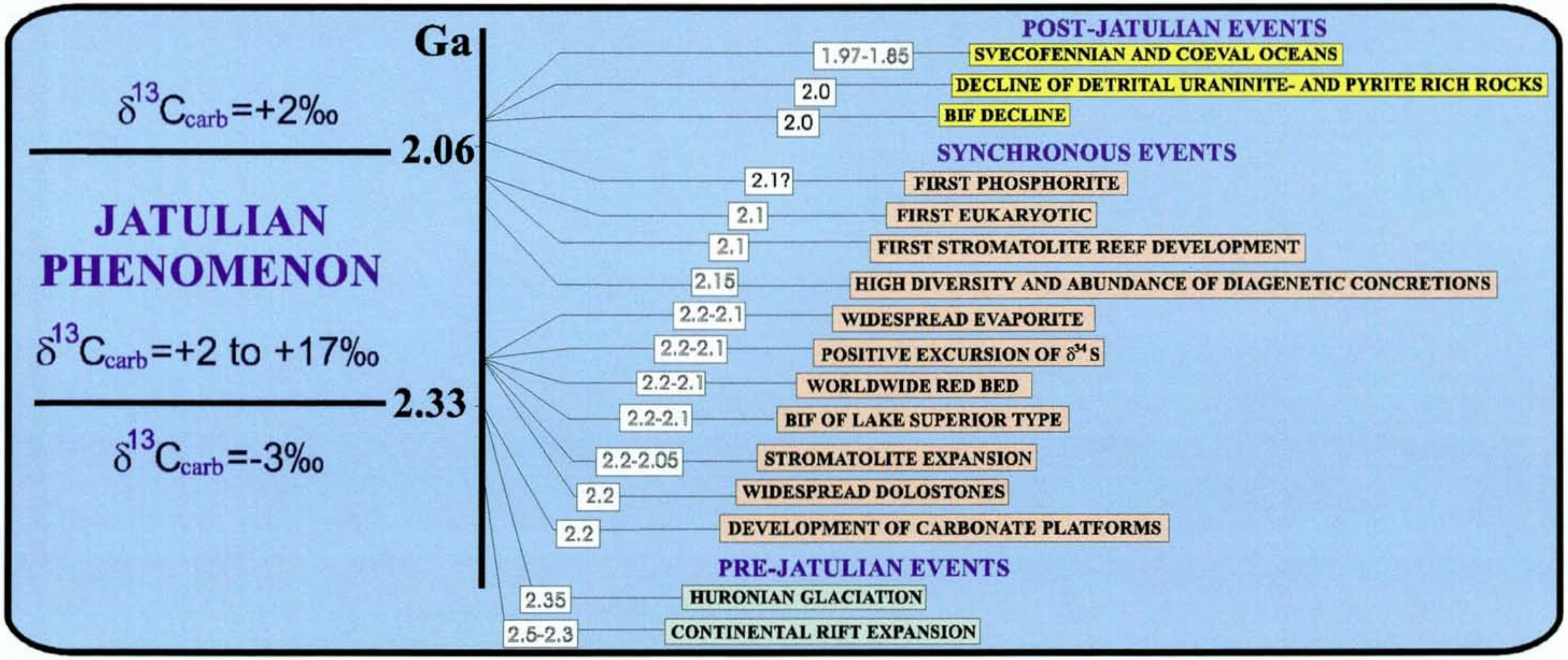

Figure 2. Major phenomena related to the Jatulian isotopic event.

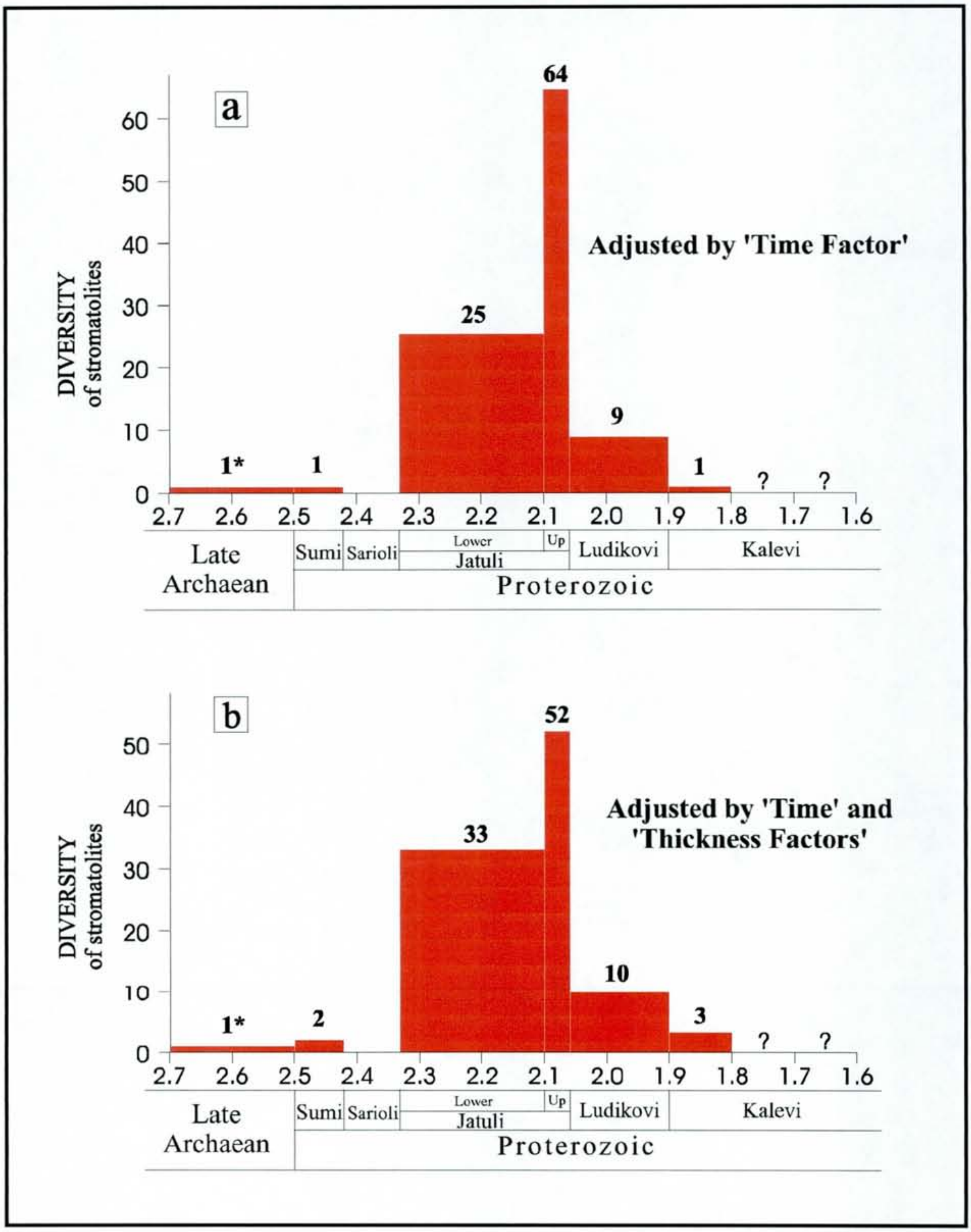

Figure 3. *Diversity of taxa of Palaeoproterozoic stromatolites corrected by (a) 'Time Factor' and (b) 'Thickness Factor'. *Diversity is not adjusted due to lack of reliable information.*

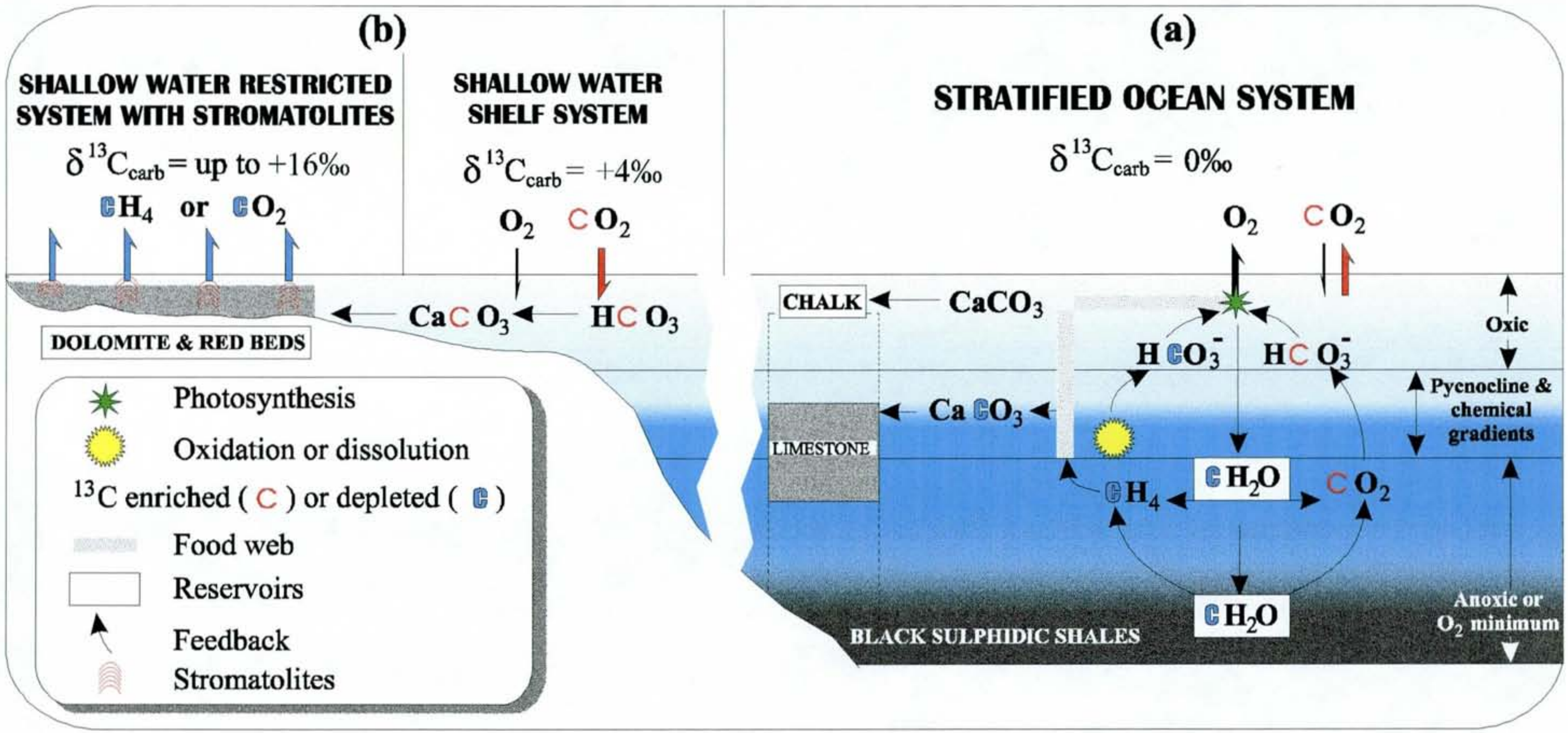

Figure 4. *Simplified diagram showing carbon transfers and reservoirs in (a) a stagnant ocean and (b) in developing marginal seas. A horizontal food-web pattern represents dominant phytoplankton components, and a vertical pattern dominant bacterial components. Carbon isotope fractionation is shown schematically by blue and red carbon symbols.*

7. FUTURE ACTIVITIES

Assuming that the Jatulian high $\delta^{13}C$ phenomenon was a global event caused by perturbation in a vast carbon reservoir, which resulted in subsequent change of balance in the carbon cycle and a complementary release of oxygen, this process should have phenomenal reverberations on the sedimentation and diagenesis as well as on the interrelated sulphur and strontium cycles. Therefore it is crucial to carry out future investigations of $\delta^{34}S$ $^{87}Sr/^{86}Sr$ excursions throughout the whole carbonate succession of the study area from which we have obtained and discussed the $\delta^{13}C_{carb}$ development. Direct Pb-Pb age determinations are necessary to constrain precise depositional time of isotopically heavy carbonates and that will be the next important task.