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Cover

Exposure of the GSSP for the base of the Guzhangian Stage (coinciding with the FAD of Lejopyge laevigata*) in the Huaqiao Formation, Luoyixi section, Guzhang County, Hunan Province, China. Strata underlying the Guzhangian GSSP belong to the Drumian Stage. Southwestern bank of Youshui River (Fengtan Reservoir) showing the Luoyixi section.*

A Message from the President of Geological Society of India

In the 21st Century, the Geological Sciences are attaining an increasingly important position globally. As the very sustenance of Planet Earth depends on how well we understand its functioning.

The International Union of Geological Sciences (IUGS) is one of the largest and most active non-governmental scientific organizations in the world. Founded in 1961, IUGS is a member of the International Council of Science. IUGS promotes and encourages the study of geological problems, especially those of world-wide significance, and supports and facilitates international and interdisciplinary cooperation in the earth sciences. At present IUGS gives special consideration to: (i) initiatives related to the identification and assessment of energy and mineral resources; (ii) global change; (iii) geological hazards; and (iv) environmental geology.

Episodes is the official quarterly journal of the International Union of Geological Sciences (IUGS). It covers developments of regional and global importance in the earth sciences and is distributed worldwide in March, June, September, and December. *Episodes* form one of the most important media to address current global problems such as climate change, depleting fresh water resources, environmental pollution, geological hazards and management of waste, geological education to prepare population to anticipate and cope up with changing environments and global climate change. *Episodes* is listed or abstracted in Chemical Abstracts, Coal Abstracts, Energy Research Abstracts, Excerpta Medica, Geological Abstracts, Geoarchives, Georef, and Ulrich's International Periodicals Directory. An annual index is published in the last issue of each volume.

From 1997, initially the former Chinese Ministry of Geology and Mineral Resources (MGMR) and then the Ministry of Land and Resources (MLR) has been providing editorial and production support. For the past twelve years the Chinese team has done an excellent job in bringing out high quality papers.

During 2008 at the 33rd International Geological Congress at Oslo, the IUGS extended an invitation to the Geological Society of India, Bangalore, to provide editorial and production support to publish *Episodes* from 2009. The Geological Society of India has accepted the invitation and entered a Memorandum of Understanding (MOU) with IUGS for four years (2009-2012) to publish *Episodes*. Following the MOU we have identified Prof. M. Jayananda, a reputed scientist with wide international contacts, as Editor.

I wish the Journal all the success.

Harsh Gupta
President
Geological Society of India

by Shao-Yong Jiang[1,2], Luba Jansa[2,3], Petr Skupien[4], Jing-Hong Yang[1,2], Zdenek Vasicek[4], Xiu-Mian Hu[1,2], and Kui-Dong Zhao[1,2]

Geochemistry of intercalated red and gray pelagic shales from the Mazak Formation of Cenomanian age in Czech Republic

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Pelagic red and gray shales are intercalated within the lower part of the Mazak Formation of Middle Cenomanian age in Czech Republic. A detailed geochemical study of major, trace and rare earth elements and carbon isotopic compositions of organic carbon has been conducted on sixteen red and gray shales. The data suggest that the shales were most likely accumulated in well-oxygenated bottom waters with very limited organic matter supply and consisted of marine organic matter mixed with minor amounts of terrestrial organic matter. The shales were deposited below CCD in one of the tectonic troughs developed along northern margin of the western Tethys. Similar geochemical covariances of major, trace and rare earth elements for the shales suggest palaeoceanographic conditions and provenance during their deposition. The most probable cause for the variation of redox bottom conditions in the mid-Cretaceous deep ocean was periodic changes in the concentration of dissolved oxygen in bottom waters, due to changes in deep water circulation and processes driven climate changes.

Introduction

Cyclicity of multicolored pelagic shales (e.g., red-brown, green gray, black) has been widely recognized in the deep-water sedimentary sequences (Lancelot et al., 1972; Jansa et al., 1979; Arthur, 1979; Dean et al., 1984; 1989; Wortmann et al., 1999). These cycles have been suggested to relate to climatic controls on influx of terrigenous organic matter and sediment, rates of upwelling, productivity, and dissolved oxygen concentration in deep waters (Dean et al., 1984). In particular, the Lower Cretaceous sediments are frequently characterized by a well-expressed cyclicity (Dean et al., 1978; Jansa et al., 1979; Wortmann et al., 1999). In the deep western Tethys basin most of the middle and late Cretaceous strata were deposited below the carbonate compensation depth (CCD), resulting in carbonate-poor and clay-rich cyclic inter-bedding of red, green, and black shale. The pelagic red clays become the dominant deep sea deposit in western Tethys during the late Cretaceous to early Eocene (Jansa et al., 1979). It is suggested that significant chemical, physical, and mineralogical variations in these pelagic shale sequence may reveal controlling factors influencing the sedimentary environment that is affected by changing chemical, tectonic, oceanographic, and climatic influences (Zhou and Kyte, 1992). However, the origin and significance of the pelagic variegated shale remain a controversy (Lancelot et al., 1972; Vogt, 1972; Dean and Arthur, 1987; Arthur, 1979). A number of studies have focused on the cyclicity of black shales in Earth history, e.g., Wortmann et al. (1999) performed a detailed major-element geochemical analysis of a 3 m long section of cyclically alternating black/green shales of latest Aptian age from the western Tethys. They interpreted the data as indicating periodic changes from a high-productivity and well-oxygenated green shale mode, to a low-productivity oxygen-deficient black shale mode. The detailed study on origin and geochemistry of the cyclically alternating red/green shale is lacking.

In recent years, the study of Cretaceous red-colored pelagic sediments, named as CORB (Cretaceous Oceanic Red Beds), has attracted great attention in the international community, and fundamental changes in the oxidation state, the circulation, and the carbon budget of the ocean during the deposition of these red beds have been suggested (Melinte and Jipa, 2005; Wang et al., 2005; Hu et al., 2005a,b; Neuhuber et al., 2007).

Here, we report a detailed major, trace and rare earth element, and carbon isotope study on a section of variegated shale of Cenomanian age, from the Mazak Formation in Czech Republic. The section is comprised of cyclically alternating red and gray shales. Geochemical study is an attempt to elucidate the cause of color banding of the shales and the palaeoceanographic processes during the deposition of these cyclic multi-colored pelagic deep-sea sediments.

Geological background

In Czech Republic, the Cretaceous strata outcrop at many places in the Carpathian Mountains chain. The most significant Cretaceous area in Czech Republic represents Silesian Unit (outer Western Carpathians) in the Moravskoslezske Beskydy Mts. The geology of the Silesian Unit (Silesian Nappe), and its lithostratigraphy was recently reviewed by Picha et al. (2006). In the Bystry potok near Trojanovice, nearby Frenstat p. R. (Figure 1), an almost continuous, favorably inclined section outcrops, containing pelitic deposits of the Lhoty Formation, comprised of highly bioturbated black shales developed in a Scisti e Fucoidi facies of Albian age. These are overlain by variegated shale strata of the Mazak Formation (Fig.2), which in turn are overlain by the lower part of the Godula Formation. The sequence stratigraphically spans Albian to Campanian. The higher part of the Godula Formation is represented by over 1 km thick sandstone turbidites. The Mazak Formation consists of intercalated red and greenish-light gray shales several centimeters up to 10–20 cm thick (Fig. 3). According to only sporadically occurring dinocysts, the Mazak Formation in the studied section belongs to the upper Middle and the Late Cenomanian.

Detailed profile of red and gray beds within the Mazak Formation of Middle–Late Cenomanian age sampled for geochemical study is shown in Fig.3. Red shales are intercalated with greenish gray shales and rare are thin beds of sandstone turbidite that become frequent higher up the section. A petrographic study of the sampled red and gray shales has shown only minor variations in the quantitative composition of mineral phases present. Main components are quartz, plagioclase, and clay minerals (Table 1). Lack of carbonates and calcareous fossils in the samples indicate their deposition below CCD.

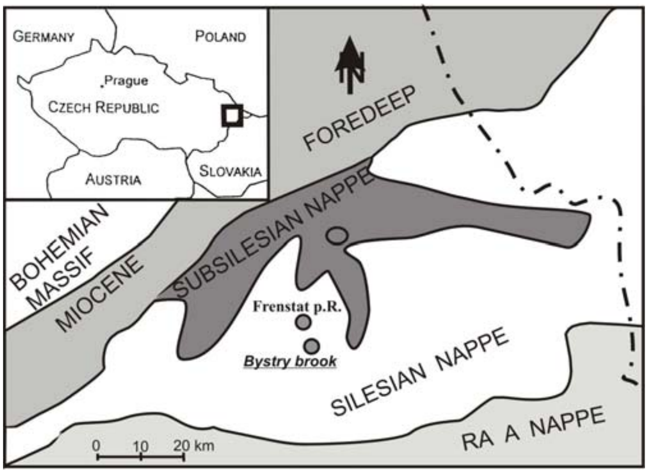

Figure 1. A geological sketch map of the studied area.

Figure 2. Red and gray shales of the Mazak Formation in Czech Republic.

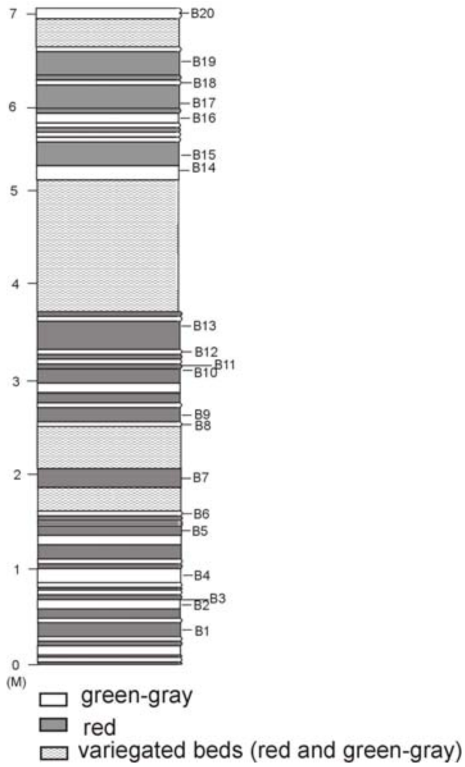

Figure 3. Stratigraphic section of the sampled Mazak Formation in Czech Republic.

Sampling and analytical methods

Sixteen samples of red and gray shale from the Mazak Formation were collected from a well-exposed outcrop. During sampling, the un-weathered intervals are selected and the weathered parts of the rock have been carefully avoided in the field. In laboratory, the surface layers of rock samples were first cut away, and then these samples have been grinded into small pieces and only fresh portions of rock piece were hand picked, powdered and used for further geochemical study.

Table 1. Estimated typical mineral composition of shales in the Mazak Formation (vol%)

	Red shale	Gray shale
Amorphous part	0±5.4	4.7±6.6
Chlorite	7.24±2.04	7.81±1.8
Illite-smectite or glauconite-smectite	40.6±4.2	53.3±5.7
Plagioclase (albite)	5.78±0.87	4.71±0.87
Quartz	47.07±1.92	29.41±1.56
Hematite	1.24±0.57	0.15±0.22

In this study, we analyzed major, trace and rare earth elements, and TOC concentrations, together with carbon isotopic compositions of TOC, of the red and gray shales from the Czech locality. Major oxide analyses of the shale were performed using X-Ray Fluorescence Spectrometry (XRF). The loss on ignition (LOI) was determined by placing ~1 g of powdered sample into a weighed porcelain crucible and combusting in a furnace at ~1000°C for 4 hrs. After cooling, samples were re-weighed and LOI was calculated from the difference between pre- and post-combustion weights. Samples for XRF analysis were prepared by fusing 0.06g sample with 0.6g silica powder and 7.26g lithium borate ($Li_2B_4O_7$:$LiBO_2$ = 67:33) in a platinum crucible. The fused disks were then analyzed at the Nanjing University using a 9800XP+ X-ray fluorescence spectrometer (made by ARL Corp. of Swiss). The analytical precisions for the oxides are estimated to be <2% for Si and Al, and <5% for other elements based on duplicated analysis of several national reference rock standards. The Fe^{2+} (FeO) and Fe^{3+} (Fe_2O_3) were separately analyzed using a titration method.

The abundance of selected trace and rare earth elements was determined by using ICP-MS method. The shale samples (50 mg) were dissolved using a mixing acid of concentrated HF and HNO_3 (2:1 in volume) in tightly screwed Teflon beakers. After dissolution, the sample solutions were added 1 ml concentrated HNO_3 and dried twice to remove the HF in the samples. The sample solutions were finally dissolved in 2 ml concentrated HNO_3, and spiked with 10 ppb Rh and made up to 50 ml in 5% HNO_3 solution. These solutions were then measured using a Finnigan HR-ICP-MS at the State Key Laboratory for Mineral Deposits Research in Nanjing University. The analytical precision of trace and rare earth elements is better than 10% based on multiple analysis of a national reference rock standard.

The powdered samples were also analyzed for TOC (total organic carbon) content and $\delta^{13}C$ TOC using an EA-IRMS (isotope ratio-mass spectrometer) (Finnigan Delta Plus XP coupled with an elemental analyzer) at Nanjing University; reproducibilities were better than ±0.2 wt% and ±0.1‰ for the TOC and $\delta^{13}C$ TOC, respectively, based on replicate lab standard and sample analyses.

The isotopic compositions were reported in standard delta notation (parts per 1000 or ‰): $\delta^{13}C$ TOC = $[(R_{sample}/R_{std}-1)]x1000$, where R = $^{13}C/^{12}C$.

All the geochemical and isotopic results are listed in Table 2.

Results

Major elements

The studied shale samples are mostly composed of SiO_2 (64.7–69.9 wt%) and Al_2O_3 (13.9–17.6 wt%) with total SiO_2+Al_2O_3 >80 wt% (Table 2). Other major compositions include Fe_2O_3 (1.86–4.16 wt%), FeO (1.04–2.52 wt%), MgO (1.86–2.08 wt%), K_2O (2.80–3.49 wt%), and Na_2O (0.51–0.86 wt%). The major chemistry of the red and gray shales shows quite similar range of variations, but a significant higher Fe_2O_3 contents are observed for the red shales (Table 2).

The red and gray shale samples show an inverse correlation of silica content with Al_2O_3 and TiO_2 (Figure 4a,b), which may indicate a dilution factor by biogenic silica or quartz to the clay minerals in the shales. An inverse correlation between silica content and Fe_2O_3 is only observed for the red shales (Figure 4c), and we suggest this may reflect a dilution factor of silica to significant hematite

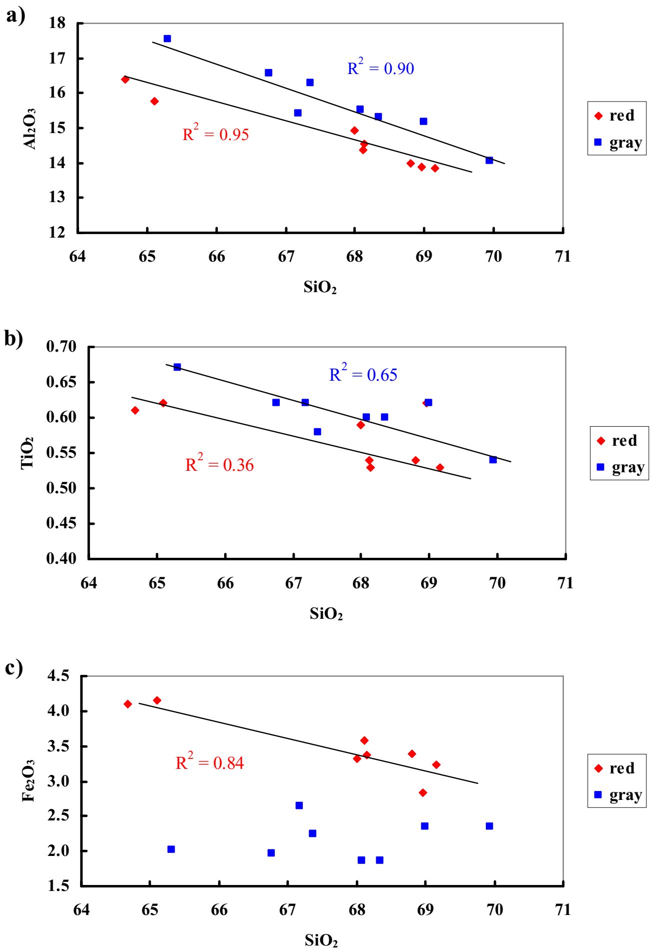

Figure 4. Plots showing correlation between (a) SiO_2 and Al_2O_3, (b) SiO_2 and TiO_2, and (c) SiO_2 and Fe_2O_3.

composition observed in the red shales, whereas hematite occurrence in the gray shales is insignificant (Table 1). A good positive linear relationship exists between Al_2O_3 and K_2O or Na_2O for the gray shales (Figure 5a,b), suggesting a major clay mineral component for the shales.

The major chemical compositions of the red and gray shales are comparable to PAAS (Post-Archean Australian Average Shale; Taylor and McLennan, 1985) and the average upper continental crust values (Rudnick and Gao, 2003), but a depletion by a factor of 4 to 8 in CaO and Na_2O contents are rather significant. The P_2O_5 contents of the red and gray shales are similar (<0.1 wt %) and are lower than PAAS and the upper continent crust (0.15–0.20 wt%).

Trace elements

In general, the trace element concentrations of the red and gray shales are comparable with each other, and they are broadly similar to those of average upper continental crust (Rudnick and Gao, 2003). But a slight depletion in Sr, Zr, Mo, Ba, Hf, and U, and enrichment in Li, Cu, Rb and Cs is observed in both, the red and gray shales (Figure 6).

When compared to the average pelagic clays, (Li and Schoonmaker, 2003), our samples show significant depletion in Mn, Cu, Mo, Ba, and Pb (strong peaks in Figure 7). A slight depletion is also observed for Co, Ni, Sr, Y, and U (Figure 7).

Table 2 Major, trace and rare earth element, and TOC concentrations and carbon isotope compositions of the shales.

	B1	B3	B5	B7	B11	B13	B15	B19	avg.	B2	B4	B6	B8	B12	B14	B16	B20	avg.
SiO_2 (wt%)	68.1	68.8	69.2	64.7	68.0	68.1	65.1	69.0	67.6	68.4	67.4	68.1	65.3	66.8	69.9	69.0	67.2	67.7
Al_2O_3	14.5	14.0	13.9	16.4	14.9	14.4	15.8	13.9	14.7	15.3	16.3	15.5	17.6	16.6	14.1	15.2	15.4	15.7
TiO_2	0.53	0.54	0.53	0.61	0.59	0.54	0.62	0.62	0.6	0.60	0.58	0.60	0.67	0.62	0.54	0.62	0.62	0.6
Fe_2O_3	3.37	3.40	3.23	4.09	3.33	3.57	4.16	2.84	3.5	1.86	2.24	1.87	2.02	1.97	2.35	2.34	2.64	2.2
FeO	2.52	2.37	2.34	2.12	2.01	2.30	2.19	1.94	2.2	2.12	1.62	1.86	1.80	1.76	1.44	1.40	1.04	1.6
CaO	0.42	0.40	0.39	0.43	0.44	0.40	0.44	0.52	0.4	0.47	0.44	0.46	0.50	0.44	0.63	0.54	1.18	0.6
MgO	2.08	2.00	1.98	2.08	1.96	2.02	2.08	1.92	2.0	2.00	1.97	1.90	1.98	1.96	1.86	1.88	1.94	1.9
MnO	0.03	0.12	0.12	0.11	0.08	0.03	0.04	0.05	0.1	0.14	0.05	0.15	0.05	0.04	0.30	0.16	0.38	0.2
K_2O	2.98	2.98	2.92	3.47	3.32	3.02	3.28	3.02	3.1	3.01	3.21	3.18	3.44	3.24	2.80	3.08	3.25	3.2
Na_2O	0.52	0.58	0.56	0.61	0.64	0.54	0.54	0.55	0.6	0.80	0.81	0.75	0.86	0.80	0.63	0.67	0.63	0.7
P_2O_5	0.10	0.08	0.09	0.10	0.10	0.09	0.09	0.09	0.1	0.09	0.07	0.09	0.10	0.09	0.07	0.10	0.10	0.1
LOI	4.34	4.18	3.16	4.82	4.25	4.20	4.71	4.30	4.2	4.43	4.60	4.43	4.81	4.65	4.42	4.38	5.26	4.6
Total	**99.57**	**99.45**	**98.35**	**99.50**	**99.66**	**99.22**	**99.04**	**98.70**	**99.2**	**99.17**	**99.25**	**98.88**	**99.11**	**98.91**	**99.05**	**99.35**	**99.64**	**99.2**
Li (ppm)	39	45	42	48	38	42	49	35	42	45	49	45	49	48	40	42	42	45
Be	1.7	2.0	1.9	2.1	1.8	1.7	2.0	1.9	1.9	2.1	2.2	2.3	2.6	2.3	1.9	2.1	2.3	2.2
Sc	7.6	12	12	14	11	11	13	11	11	13	13	14	15	15	12	13	13	14
V	93	92	88	117	94	92	95	87	95	130	164	115	174	136	111	95	110	129
Cr	72	65	63	74	62	59	72	61	66	68	71	74	80	75	63	72	72	72
Co	23	24	24	22	20	22	21	20	22	21	21	21	22	21	20	18	20	21
Ni	51	54	52	54	49	50	56	47	52	49	58	49	55	53	50	46	52	51
Cu	52	37	51	110	46	43	48	26	52	66	88	65	187	117	27	78	50	85
Zn	72	88	75	75	66	73	73	199	90	108	71	68	71	104	71	67	76	80
Ga	15	16	16	18	15	16	18	16	16	17	20	18	19	18	17	18	19	18
Rb	81	135	130	151	112	114	139	120	123	129	134	144	151	147	123	136	147	139
Sr	48	71	70	88	61	70	77	69	69	82	102	86	95	88	72	78	82	86
Y	12	16	17	19	15	18	16	15	16	19	23	19	21	21	17	18	15	19
Zr	76	78	78	81	77	109	86	133	90	95	145	87	92	113	93	86	86	100
Nb	10	11	11	13	11	14	13	11	12	12	26	13	13	13	13	12	12	14
Mo	0.7	0.6	0.7	0.9	0.7	0.7	0.9	0.5	0.7	0.3	0.2	0.4	0.5	0.3	0.3	0.3	0.4	0.3
Sn	2.8	2.9	2.9	3.6	2.9	2.8	3.4	2.9	3.0	3.2	3.8	3.2	3.4	3.5	3.0	3.1	3.0	3.3
Cs	6.1	9.4	9.4	10.6	7.8	8.4	10.1	8.7	8.8	9.0	9.1	9.9	11	10	9.0	9.6	11	9.8
Ba	240	353	343	392	327	371	343	391	345	387	365	398	399	392	347	356	393	380
Hf	1.5	1.5	1.6	1.7	1.6	1.5	1.7	2.6	1.7	2.1	3.7	1.8	1.9	2.1	1.6	1.7	2.0	2.1
Ta	0.7	0.8	0.7	0.8	0.8	0.6	0.8	0.9	0.8	1.0	1.3	0.9	0.9	1.1	0.8	0.9	1.1	1.0
W	2.9	8.4	2.6	2.8	20	3.1	7.9	2.1	6.3	2.2	1.9	2.2	2.4	2.2	3.8	2.1	2.0	2.3
Pb	24	22	25	27	19	21	25	17	22	17	16	15	340	33	14	18	37	24
Bi	0.4	0.3	0.3	0.6	0.3	0.4	0.4	0.3	0.4	0.4	0.5	0.5	1.2	1.0	0.2	0.4	0.4	0.6
Th	5.5	8.5	8.6	10.3	8.5	8.3	9.7	8.0	8.4	9.8	10.3	10.1	11	11	8.6	9.6	9.2	9.9
U	1.1	1.2	1.2	1.4	1.3	1.2	1.4	1.3	1.3	1.6	1.5	1.6	3.5	2.0	1.4	1.9	1.6	1.9
La	13.8	27.3	26.5	26.8	24.1	25.2	27.5	24.7	24.5	27.2	36.9	28.1	33.3	28.2	26.3	27.6	28.1	29.4
Ce	58.7	67.5	64.9	80.0	58.4	64.1	68.1	51.5	64.1	71.0	104	77.5	94.4	80.5	57.2	68.9	56.7	76.2
Pr	3.13	5.53	5.48	6.49	5.12	5.26	5.98	5.23	5.3	6.25	8.69	6.68	7.97	6.86	5.64	6.60	5.97	6.8
Nd	11.7	20.2	19.5	24.2	18.8	19.3	21.5	19.3	19.3	23.8	32.0	24.7	30.1	25.6	20.5	24.0	21.2	25.2
Sm	2.53	3.62	3.52	4.56	3.63	3.85	3.82	3.62	3.6	4.49	5.45	4.45	5.56	4.82	3.82	4.31	3.34	4.5
Eu	0.56	0.74	0.76	0.98	0.78	0.77	0.80	0.73	0.8	0.90	0.96	0.93	1.09	0.97	0.76	0.86	0.68	0.9
Gd	2.59	3.26	3.33	4.25	3.33	3.80	3.41	3.06	3.4	4.10	4.59	3.98	4.73	4.53	3.47	3.81	2.87	4.0
Tb	0.34	0.41	0.41	0.53	0.42	0.51	0.42	0.40	0.4	0.52	0.62	0.50	0.59	0.55	0.46	0.48	0.36	0.5
Dy	2.22	2.71	2.74	3.36	2.70	3.33	2.76	2.45	2.8	3.23	4.08	3.20	3.77	3.52	3.03	3.07	2.45	3.3
Ho	0.46	0.57	0.58	0.70	0.55	0.68	0.57	0.51	0.6	0.68	0.83	0.67	0.75	0.74	0.62	0.64	0.53	0.7
Er	1.34	1.68	1.74	2.02	1.64	1.93	1.68	1.46	1.7	1.95	2.44	1.96	2.23	2.16	1.85	1.82	1.63	2.0
Tm	0.19	0.25	0.27	0.29	0.24	0.27	0.24	0.21	0.2	0.28	0.34	0.29	0.32	0.32	0.27	0.26	0.25	0.3
Yb	1.22	1.66	1.71	1.89	1.59	1.70	1.58	1.36	1.6	1.94	2.09	1.90	2.00	2.09	1.76	1.72	1.66	1.9
Lu	0.19	0.25	0.26	0.29	0.24	0.25	0.23	0.21	0.2	0.28	0.31	0.28	0.31	0.30	0.26	0.26	0.25	0.3
Ce/Ce*	2.06	1.27	1.24	1.40	1.21	1.28	1.23	1.04	1.3	1.25	1.33	1.30	1.34	1.34	1.08	1.18	1.01	1.2
Eu/Eu*	0.51	0.59	0.61	0.69	0.61	0.58	0.62	0.59	0.6	0.64	0.63	0.67	0.71	0.66	0.59	0.63	0.57	0.6
La_N/Yb_N	0.83	1.22	1.15	1.04	1.12	1.09	1.28	1.34	1.1	1.04	1.30	1.09	1.23	1.00	1.10	1.18	1.25	1.1
Gd_N/Yb_N	1.28	1.19	1.18	1.36	1.27	1.35	1.31	1.36	1.3	1.28	1.33	1.27	1.43	1.31	1.20	1.34	1.05	1.3
TOC (%)	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03
$\delta^{13}C$ (‰)	-26.8	-26.4	-27.4	-26.8	-26.7	-26.7	-27.1	-26.2	-26.8	-27.2	-26.2	-27.0	-26.8	-26.5	-26.4	-26.5	-26.5	-26.6

Note: $Ce/Ce^* = 2Ce_N/(La_N+Pr_N)$; $Eu/Eu^* = Eu_N/(Sm_N+Gd_N)^{0.5}$

In particular, the redox-sensitive elements such as V and U are generally lower but Mo concentrations are slightly higher in the red shales (Table 2). There are no significant differences in the Ni contents of the shales (Table 2). The Mn contents in red and gray shales are highly variable from 241 to 967 ppm and 299 to 2966 ppm, respectively, with the latter having slightly higher Mn contents (Table 2). We used the Al-normalized trace element plots, and found no significant correlations between element pairs of V/Al, Mo/Al, U/Al, and Th/Al in both the red and gray shales (Figure 8).

Rare earth elements

We normalized the rare earth elements concentration in our studied shales to the REE concentrations of Post Archaean Australian Average Shale (PAAS) compiled by Taylor and McLennan (1985).

Overall, the shale samples in our studied section show similar or slightly lower total rare earth element contents than those of PAAS, and an almost flat PAAS-normalized REE pattern (Figure 9). The red and gray shales display similar flat PAAS-normalized REE patterns with slightly heavy rare earth element (HREE) depletions

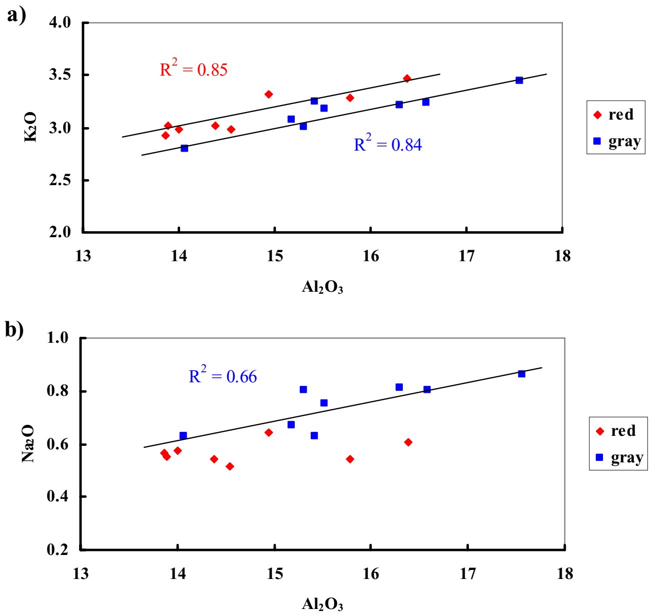

Figure 5. Plots showing correlation between (a) Al_2O_3 and K_2O and (b) Al_2O_3 and Na_2O.

(La_N/Yb_N = 0.83–1.34 and 1.0–1.30, and Gd_N/Yb_N ratios = 1.18–1.36 and 1.05–1.43, respectively). Most of the red and gray shales also show significant positive Ce anomalies with Ce/Ce* values vary from 1.04 to 2.06 in the red shales, and 1.01–1.34 in the gray shales (Table 2). A negative Eu anomaly is observed for all the shale samples with Eu/Eu* values of 0.51–0.69 and 0.57–0.71 for the red and gray shales, respectively (Table 2).

Organic carbon contents and carbon isotopic compositions

The red and gray shales show no difference in their total organic carbon (TOC) concentrations and $\delta^{13}C$ TOC values, which are

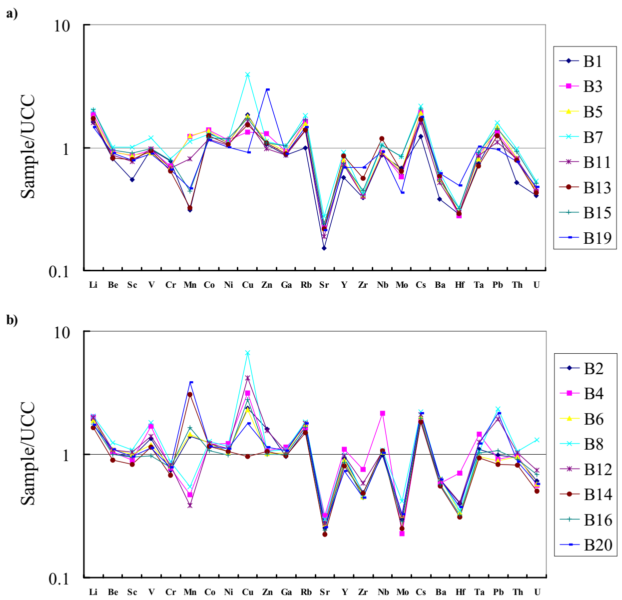

Figure 6. Trace element concentrations normalized to the average upper continental crust values (Rudnick and Gao, 2003). (a) red shales, (b) gray shales.

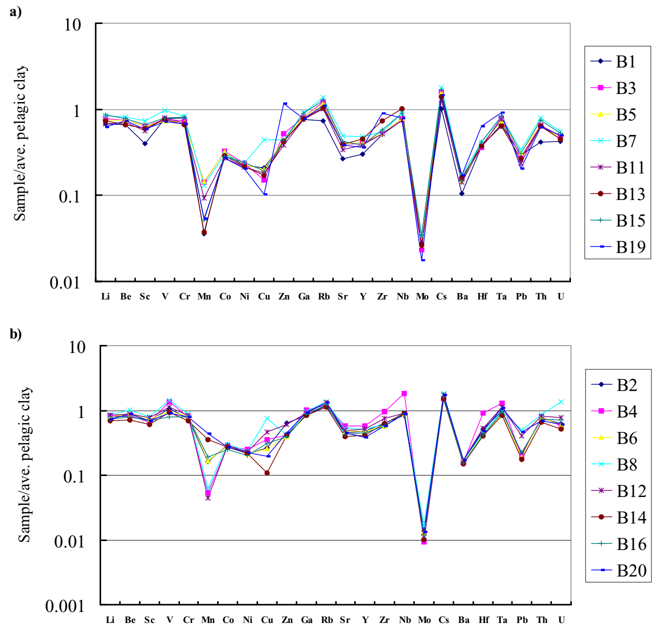

Figure 7. Trace element concentrations normalized to the average pelagic clays (Li and Schoonmaker, 2003). (a) red shales, (b) gray shales.

characterized by extremely low TOC contents of <0.04 wt% with very limited $\delta^{13}C$ TOC variation from –26.2 to –27.4‰. In comparison, the Upper Cretaceous interbeded red and green claystones from the DSDP Leg 93 site 603 show higher TOC contents of 0.07 to 0.18 wt%, and 0.08 to 1.14 wt%, respectively, and the green claystones also show heavier $\delta^{13}C$ TOC values of –24.3 to –26.1‰ (Dean and Arthur, 1987). The TOC concentrations at the top of underlying black shales of the Lhoty Formation vary from 0.3% up to 3.5%.

Discussion

Origins of color banding and their implication

The cycles of multicolored pelagic sediments in deep sea setting is a widespread phenomenon in Earth history. However, the cause for color banding and its implication for palaeoceanographic environment is still a matter of debate. Many researchers suggest that the color is caused by some compound of iron, in particular the relative abundance of the iron ion valence in the silicate structure, the specific bonding of these ions, and hematite is regarded as a pigmenting agent of red shale (Robb, 1949; Velde, 2003; Yamaguchi and Ohmoto, 2006). The source of iron has been suggested to be derived either from submarine hydrothermal venting, or from diagenetic mobilization of iron in pore water. For example, in order to explain the mineralogy and chemistry of the multicolored claystones from DSDP Leg 11 in the western North Atlantic, Lancelot et al. (1972) proposed that volcanic or hydrothermal exhalations superimposed on slow rates of pelagic clay deposition could account for the color banding, mineralogical variations and enrichments of several trace transition elements, such as Mn, Zn, Cu, Pb, Cr, Ni. Vogt (1972) also proposed that the metal content in the Upper Cretaceous claystones was related to increased plume activity in the Atlantic at the time of their deposition. In contrast, the inter-bedding of variegated shale in the Upper Cretaceous of the western Atlantic has been suggested by Arthur (1979) to reflect diagenetic mobilization of redox-sensitive metals

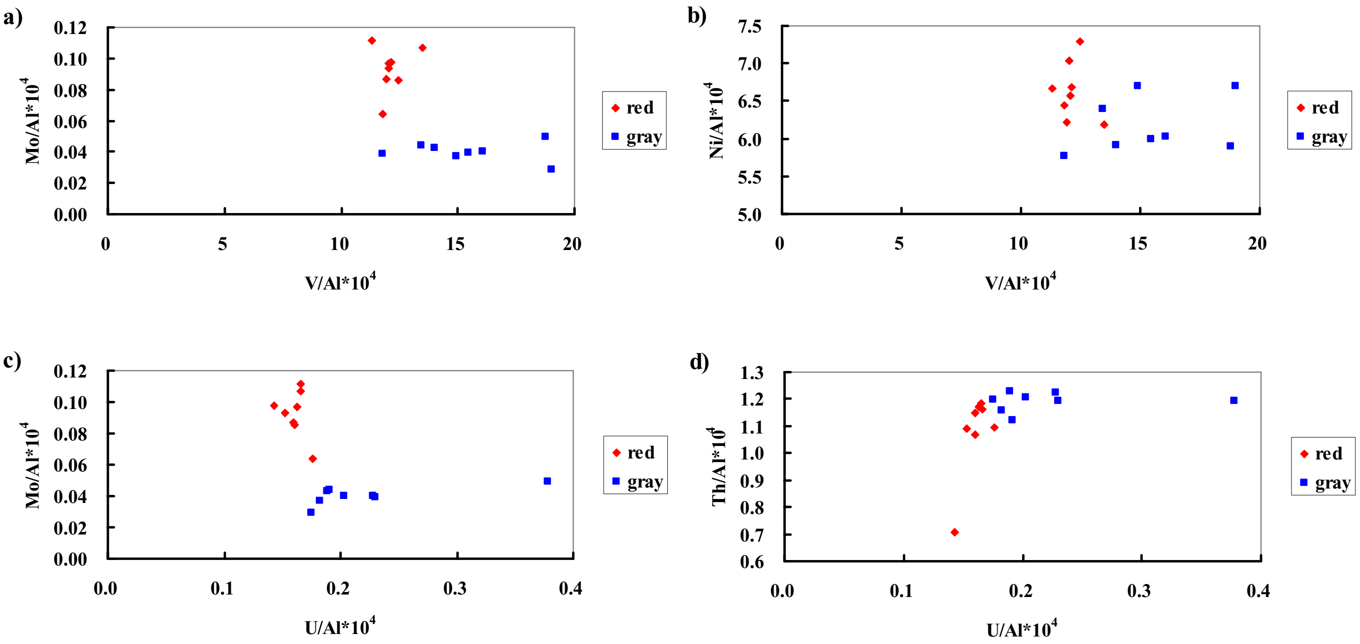

Figure 8. Interelement relationship for the Al-normalized redox-sensitive trace elements in the shales. (a) V/Al-Mo/Al, (b) V/Al-Ni/Al, (c) U/Al-Mo/Al, (d) U/Al-Th/Al.

within anoxic pore waters of the Lower Cretaceous black shales and upward diffusion/advection into the oxidized claystones. Dean and Arthur (1987) suggested a similar mechanism involving upward advection and diffusion of metals from the underlying Middle Cretaceous black carbonaceous claystones for the multicolored claystones of the overlying Upper Cretaceous to lower Tertiary sedimentary sequence at site 603 of DSDP Leg 93.

Through a study of color variability and Mn contents in the multicolored sediments from the Lomonosov Ridge in the central Arctic Ocean, Jakobsson et al. (2000) found that the high MnO

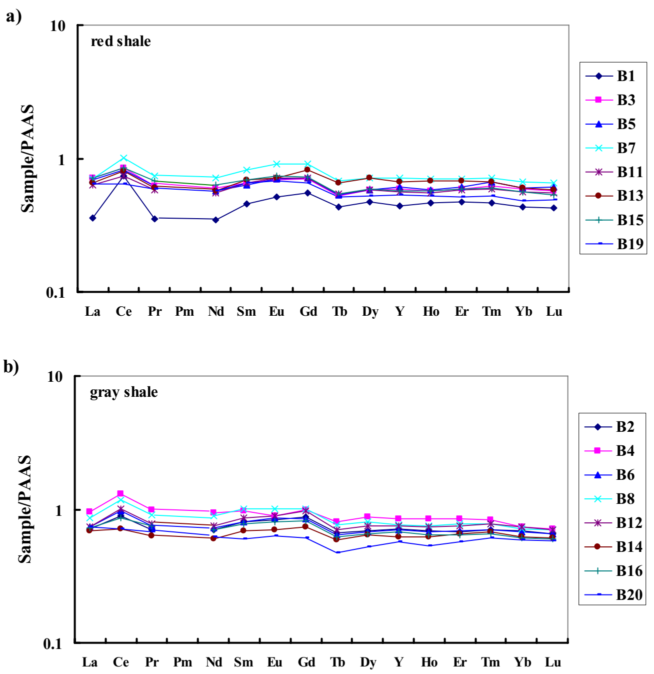

Figure 9. The PAAS-normalized REE patterns for the shales. (a) red shales, (b) gray shales.

contents are corresponding to the dark to medium brown color banding in the sediment.

These authors also suggested two different processes for the cyclic pattern of color banding and manganese concentration. One is climatic forcing of the transport of source material with large quantities of manganese from northern Siberia during interglacial. The other is relative degree of ventilation of Arctic Ocean waters driven by glacial-interglacial contrasts, which would enhance the precipitation of manganese during interglacials, because of higher bottom water oxygen concentrations. Chemical analysis of the red and gray shales from the Mazak Formation revealed a difference in both the iron and manganese contents. The red shales show higher Fe_2O_3 content (2.84–4.16 wt%) than those of the gray shales (1.86–2.64 wt%). Mineralogically, higher hematite contents are also identified in the red shales (Table 1). However, the Mn concentration shows opposite trend with higher Mn in the gray shales (299–2,362 ppm) than in the red shales (241–967 ppm). Hence, we suggest that the main cause for the color banding in the pelagic sediments of the Mazak Formation is the difference in their ferric iron and hematite concentrations.

Through a study of Precambrian red beds, Yamaguchi and Ohmoto (2006) suggested that red shales are products of oxidizing environments with an adequate supply of Fe^{3+} that is ultimately converted to hematite, the pigmenting agent of red shales, which probably formed *in situ* by oxygenated pore waters during weathering of the source rocks and/or diagenesis of shales. However, if hematite-rich sediments accumulated in sulfate-poor, but anoxic environments, Fe^{3+}-oxides would leach out and gray/green shales would form.

Sedimentary environments for the multicolored shales

Using geochemical proxies, it is possible to trace the redox environments of marine sediments in Earth history (Moffett, 1990,

Table 3. Four groups of redox conditions for low calcic shales (after Quinby-Hunt and Wilde, 1996)

Group		I	II	III	IV
		oxic		anoxic	
Fe	(3.75 wt%)	H	H	L	L
Mn	(800 ppm)	H	L	L	L
V	(320 ppm)	L	L	L	H

Note: H - higher; L - lower

1994; Quinby-Hunt and Wilde, 1994, 1996; Yang et al., 2004; Yamaguchi and Ohmoto, 2006). For example, Th/U ratio has been used to infer paleoredox conditions in depositional environments because uranium and thorium behave differently in aqueous environments of different redox conditions. Under oxic conditions, U^{4+} oxidizes to highly soluble U^{6+}, whereas Th^{4+} is not particularly soluble in aqueous solutions and occurs only as Th^{4+} in nature, which led to the geochemical decoupling of U and Th in oxidizing environments. In this study, the red shales show a Th/U ratio of 4.96 to 7.18, while a slight lower Th/U ratio is observed for the gray shales (3.16–6.84). In comparison, the average Th/U ratio of PAAS and the upper continental crust is 3.8 and 3.7, respectively (Taylor and McLennan, 1985). It is suggested that the preferential loss of U over Th probably occurred during diagenesis of the shale. The occurrence of red shales indicated a more oxidized environment that have slightly enhanced U when compared to the gray shales.

Based on Fe, Mn, and V concentrations, Quinby-Hunt and Wilde (1996) proposed four discrete categories of depositional and early diagenetic redox conditions for low calcic shales of [Ca]<0.4% (Table 3). Group I shales are characterized by oxic conditions and high Eh with high Mn (>800 ppm, average 1,300 ppm) and Fe (>37,500 ppm, average 56000 ppm) but low V (<320 ppm, average 130 ppm) concentrations. Fe and Mn are present as insoluble Mn and Fe oxides in this group. Group II shales are deposited under anoxic, nitrate reducing to sulfate reducing conditions at intermediate pH. Mn concentrations are low (<750 ppm, average 310 ppm) owing to its reduction to soluble Mn^{2+}, while Fe may remain bound in oxides or sulfides with concentrations comparable to Group I. Concentration of V in this group is also low (<320 ppm, average 140 ppm).

Group III shales are characterized by anoxic but non-sulfate reducing Eh conditions and intermediate to low pH, which have relatively low Fe (<37,500 ppm, average 23,000 ppm), Mn (<750 ppm, average 170 ppm), and V (<320 ppm, average 170 ppm) concentrations. Group IV shales are characterized by relatively low Fe (<37,500 ppm, average 19,000 ppm) and Mn (<750 ppm, average 76 ppm) but high V (>320 ppm, average 1500 ppm) concentrations, indicating deposition under conditions of high organic matter preservation, suggesting low pH and Eh conditions and possibly conditions favoring methanogenesis (Quinby-Hunt and Wilde, 1994, 1996). On average, the Fe, Mn, V concentrations in the red and gray shales in our studied section suggest they belong to Group I of oxic conditions.

The Ce anomaly in ancient marine sediments is one of the promising tools to trace oceanic redox conditions. A negative Ce anomaly is commonly observed in modern seawater because Ce^{3+} in seawater can be oxidized to insoluble Ce^{4+} and then removed (e.g., Piper, 1974; Elderfild, 1988; Piepgras and Jacobsen, 1992). Moffett (1990, 1994) suggested that this Ce oxidation took place relatively rapidly in the shallow water environment through bacterial mediation.

Under oxidized conditions, compared to the other REE, Ce is hard to dissolve into water due to insoluble Ce^{4+}. The resulting solution attains a negative Ce anomaly and the residue has a positive Ce anomaly. The hydrogenetic Fe-Mn nodules and crusts usually show a positive Ce anomaly due to oxidative scavenging of Ce by Fe-Mn oxyhydroxides (Pattan and Banakar, 1993; Bau et al., 1996). It is suggested that the REE in Fe-Mn nodules and crusts are derived from oxic seawater that typically shows a pronounced negative Ce anomaly (Elderfield, 1988). In the studied red and gray shales, we suggest that the positive Ce anomaly may indicate an oxic condition during sediment deposition and/or diagenesis. In a plot of Eu/Eu* and Ce/Ce* for shales (Figure 10), the gray shales form a linear trend; some of the red shales also plot near this trend, but several samples fall out from this trend with higher Ce/Ce* values, which provide further evidence for a more oxidized condition for the red shales.

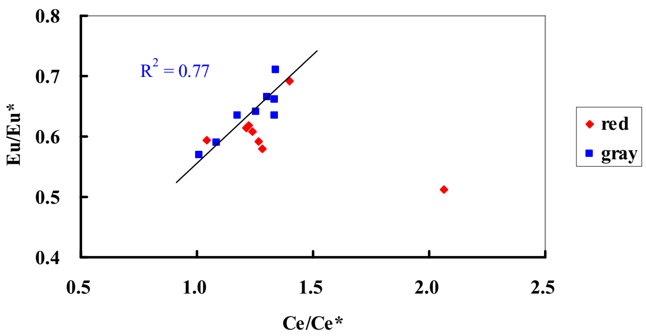

Figure 10. Correlation between Eu/Eu* and Ce/ce* in the shales.

In pelagic sediment, barite is the only sulfate mineral present in abundance, and Ba enrichment has been observed from various settings, such as the Central Indian Basin, the Peru margin upwelling, and the Pacific equatorial divergence. This enrichment generally reflects high biological productivity (Von Breymann et al., 1990, 1992). Although absolute Ba concentration in our studied pelagic shales cannot be used to quantitatively estimate palaeoproductivity, the very low Ba contents (240–399 ppm) in the samples likely imply a low bioproductivity at surface water. Due to the low productivity, the trace elements in the shales are therefore also low, which is in contrast to the high concentrations of trace elements in sediments located in high bioproductivity areas (Brumsack, 1986). The low P contents in our studied shales (below average upper crust value of 742 ppm, Taylor and McLennan, 1985) further points to low nutrient availability during the periods of shale accumulation.

The similar, but extremely low TOC contents (<0.05 wt%) and small variations in $\delta^{13}C$ values of the red and gray shale samples in the studied section (Figure 11) indicate that the sediments were most likely accumulated in an oxygenated water body that probably contained very little organic matter. The carbon isotope compositions of organic carbon (OC) in marine sediments often have been interpreted in terms of the source of the organic matter. Previous studies have shown that Cretaceous marine OC had $\delta^{13}C$ values of about –27 to –29‰, whereas Cretaceous terrestrial OC had $\delta^{13}C$ values of about –23 to –25‰ (Dean and Arthur, 1987). The carbon isotope study of OC in black claystones from DSDP Hole 603 in the western Atlantic shows a $\delta^{13}C$ range from –24.4 to –26.7‰, whereas the $\delta^{13}C$ values of OC in DSDP Hole 367 in the eastern North Atlantic

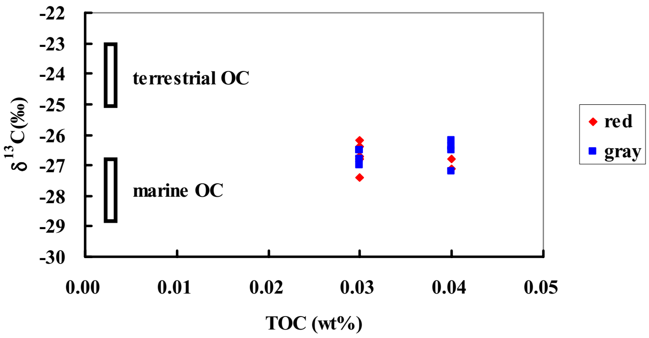

Figure 11. TOC contents and $\delta^{13}C$ values of the shales.

are ~2 to 3‰ lighter. Dean and Arthur (1987) suggested that at Site 603, the organic matter is largely terrestrial, probably derived from the coastal wetlands of North America that produced extensive Cretaceous coal deposits (Parrish et al., 1982). In contrast, at Site 367, the organic matter is largely marine, derived from accumulations of phytoplankton debris in highly productive shelf and slope environments under strong upwelling conditions that existed along the coast of Northwest Africa in the Cretaceous (Barron, 1985). It is suggested that the organic matter in the marine sediments at Sites 603 and 367 represents two different end-member sources for organic matter in Cretaceous proto-Atlantic Ocean (Dean and Arthur, 1987). Our data ($\delta^{13}C$ = –26.2 to –27.4‰) suggest that the OC in the red and gray shales from the Mazak Formation may have been derived from a mixing of terrestrial and marine organic matters in a fairly constant proportion, suggested by the small variation in $\delta^{13}C$ (Figure 11). The isotope data also indicate that the organic matter was mainly marine, mixed with some terrestrial organic matter and deposited in well-oxygenated bottom waters.

The intercalated red and gray shales in the Mazak Formation of Cenomanian age from the Czech Republic were deposited below CCD in one of the tectonic troughs developed along northern margin of the western Tethys. Our analyses show similar geochemical covariance of major, trace and rare earth elements for both gray and red shales, suggesting similar palaeoceangraphic conditions and provenance. Association and variation of major elements (Si, Ti, Al, Fe, Mn, Ca, K, Na, and P), trace elements (Zr, Hf, Sc, Th, Mo, V, Ni, U), and rare earth elements support the interpretation that both the red and gray shales were deposited in an oxygenated, pelagic deep-sea environment, possibly similar to the environments presently accumulating pelagic red clays in the deep basins of the Pacific and Atlantic oceans (Jansa et al., 1979).

We consider it important that our geochemical study of these multicolored shales indicate that the most probable cause for the variation of redox bottom conditions in the mid-Cretaceous deep ocean were periodic changes in the concentration of dissolved oxygen in bottom waters. We can only speculate what such changes could be. They can emanate from changes in the source of the bottom water, or as result of major changes in bottom ocean water circulation, due to changes in basins orography, as the mid-Cretaceous was a period of intensified, global, plate tectonic changes.

The variegated shales of the Mazak Formation are sandwiched between Albian black shales of Scisti e Fucoidi facies below and similar dark gray shales of Turonian age above. The variegated beds do not occur in other parts of the Lower and mid-Cretaceous, thus they do represent, on a broader time scale, a unique paleoceanographic event. They represent an amalgamation of two different processes. One, which resulted in general increase in oxygenation of bottom waters, and the second one, which drives the cyclic red/green bed alteration. The cause of the first process, as mentioned above, could have been a temporary inflow of more oxygenated bottom waters. However, the alternative hypothesis which should not be discarded is that the sediments oxidation is result of a major decrease in sedimentation rates (Buckley and Cranston, 1988 and references herein). However, as the sediments were deposited below CCD, they lack any calcareous microfossils to allow high bio-stratigraphic resolution of the age for the strata, to compute sedimentation rates.

The red/green bed cyclicity is of similar scale to that observed on Mesozoic and Cenozoic sediments in the western Tethys, interpreted as resulting from climate changes triggered by the precession of the earth rotation axis (circa 21ka period, Dean et al., 1978; Herbert et al., 1986).

Conclusions

Our geochemical study indicates that the shales from the Mazak Formation in Czech Republic show the following major characteristics:

1) The major element chemistry of the red and gray shales shows similar range of variations, with contents of SiO_2 of 64.7–69.9 wt%, Al_2O_3 of 13.9–17.6 wt%, MgO of 1.86–2.08 wt%, K_2O of 2.80–3.49 wt%, and Na_2O of 0.51–0.86 wt%. The red shale shows a significantly higher Fe_2O_3 contents (2.84–4.16 wt%) than those of the gray shales (1.86–2.64 wt%) and contains some amounts of hematite.
2) The trace element concentrations of the red and gray shales are comparable with each other, and they are broadly similar to those of average upper continental crust, although a depletion in Sr, Zr, Mo, Ba, Hf, and U, and enrichment in Li, Cu, Rb and Cs are observed in both the red and gray shales. The shales contain low concentrations of the redox-sensitive elements such as Mo, V, Ni, and U.
3) The red and gray shales display similar flat PAAS-normalized REE patterns with slightly heavy rare earth element (HREE) depletions (La_N/Yb_N = 0.83–1.34 and 1.0–1.30, and Gd_N/Yb_N ratios = 1.18–1.36 and 1.05–1.43, respectively), significant positive Ce anomalies (Ce/Ce* = 1.04 to 2.06 in the red shale, and 1.01–1.34 in the gray shale), and negative Eu anomalies (Eu/Eu* = 0.51–0.69 and 0.57–0.71).
4) The red and gray shales show extremely low TOC contents of <0.04 wt% and a limited range of $\delta^{13}C$ TOC values from –26.2 to –27.4‰. In conclusion, the variegated shales of the Mazak Formation (mid to late Cenomanian) deposited below CCD, in a well-oxygenated bottom waters. Organic matter supply was limited and dominated by organic matter of marine origin, which was mixed with some terrestrial organic matter. Both of these shales were deposited in a similar palaeoceanographic setting and are of similar provenance.

Lack of changes in bioproductivity-sensitive elements suggest, that the occurrence of deep sea oxic deposits is most probably result of periodic increase in dissolved oxygen in bottom waters. We suggest that the inflow of colder bottom waters was triggered by local tectonics, resulting from intrabasinal morphological changes effecting ocean floor.

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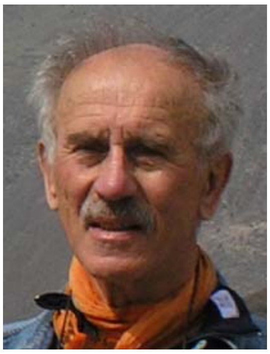

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Biodiversity and palaeoclimatic implications of fossil wood from the non-marine Jurassic of China

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Fossil woods are widely recorded in the non-marine Jurassic deposits of China from nine provinces and 18 localities. About 33 species referred to 17 genera have been documented, which are mainly ascribed to coniferales, cycadales and bennettitales. Stratigraphically, the fossil woods vary between a variety of horizons in the Lower, Middle and Upper Jurassic; the occurrences predominate in the Aalenian-Bajocian, Bathonian-Callovian and Oxfordian-Tithonian intervals. Jurassic woods are mainly distributed in the Northern Floristic Province in China, whereas they are rare in the Southern Floristic Province. Diversity and anatomical characteristics, especially the growth ring feature analysis implies climatic conditions with distinct seasonal variation in the Northern Floristic Province during the Early, Middle and Late Jurassic periods.

Introduction

Fossil wood materials are crucial because they represent an important archive of data for palaeoenvironmental reconstructions. They occur in either marine or non-marine strata preserved in all major depositional facies and palaeoecosystems. Systematic studies of fossil wood improve our knowledge of the composition of past vegetation. The growth ring patterns of fossil wood may provide key information regarding regional palaeoclimate as well as a tree palaeoecology and phenology in deep time (Falcon-Lang, 2005). Fossil wood is very abundant in China ranging from Late Palaeozoic to Cenozoic. Over 180 species of fossil wood referred to 106 genera have been recorded in China from several hundreds of localities (Zhang et al., 2006). Here we report fossil wood from the non-marine Jurassic deposits of China with special reference to their biodiversity and palaeoclimatic implications.

The research history of fossil wood in China can be dated back to the 1920s when C.Y. Chang (1929) described fossil wood from the Jurassic in Hebei, northern China. Later, Shimakura (1935-36) reported some Jurassic wood material from Jilin in northeast China. In 1951, H.C. Sze investigated fossil wood from northeastern China, including one taxon from Upper Jurassic volcanic rocks. Over 10 years later, H.C. Sze et al. (1963) published a monograph entitled "Mesozoic Fossil Plants of China", in which a special chapter, "Fossil Gymnospermous Wood" summarized the Jurassic and Cretaceous wood materials.

Since the 1980s, an increasing number of works regarding the Jurassic wood floras have been published in China. Du (1982) described two wood fossils from the Late Jurassic in Jiayin, Heilongjiang Province, including *Xenoxylon latiporosum* (Cramer) Gothan and *Protopiceoxylon amurense* Du. When studying Late Mesozoic plants from eastern Heilongjiang, Zheng and Zhang (1982) reported two taxa of Jurassic wood, including *Protocupressinoxylon mishanense* and *Xenoxylon peidense*. Duan (1986) documented the wood species *Xenoxylon latiporosum* from Jurassic deposits in Yanqing, near Beijing. Zhang and Cao (1986) recorded *Cupressinoxylon hanshanense* from the Late Jurassic in Anhui, which represents an important find for Jurassic wood in southern China. Subsequently, Zhou and Zhang (1989) reported a fossil wood taxon *Protocupresinoxylon* sp. from the Yima Formation in Henan Province.

In recent decades, the study of Jurassic wood has become more active with an increasing number of publications. New specimens of Jurassic wood have been reported from northeastern China (Philippe et al., 1999; Ding et al., 2000; Duan, 2000; Zhang et al., 2000a; Zheng et al, 2001, 2005; Zheng, 2004). Additionally, He and Zhang (1993) described fossil wood from Jurassic coals in Henan and Ningxia. Duan and Peng (1998) recorded a fossil wood *Araucarioxylon zigongensis* from the Middle Jurassic in Zigong, Sichuan Province. The first record of *Scotoxylon* in China was reported from the Middle Jurassic of Yanqing (Zhang et al., 2000b). Wang et al. (2000) studied fossil woods from the Late Jurassic fossil forest in Qitai, Xinjiang, northwestern China. A fossil cycad-like stem, *Lioxylon liaoningense* was identified from the Middle Jurassic in western Liaoning, which shows a close systematic relationship to cycads (Wang et al., 2005; Zhang et al., 2006). Moreover, a rich and diverse silicified wood assemblage has recently been discovered from Shehong in Sichuan Province. These fossil woods are preserved in the Upper Jurassic Penglaizhen Formation and show good preservation of xylem structures (Wang et al., 2005, 2006). More results are expected in the coming years along with further research on Jurassic fossil woods in China.

The Non-marine Jurassic system and fossil wood horizons

The Jurassic system is well developed and widely distributed in China. Marine Jurassic strata are distributed mainly in the Qinghai-Tibetan Plateau (especially well exposed in the central part of the northern Himalayas, i.e., Tingri-Nyalam area), bear abundant fossils such as ammonites that are widespread in the Tethyan Realm (Chen, 2003; Shi et al., 2006; Yin et al., 2007). In contrast, non-marine Jurassic strata are developed extensively in the large areas of China.

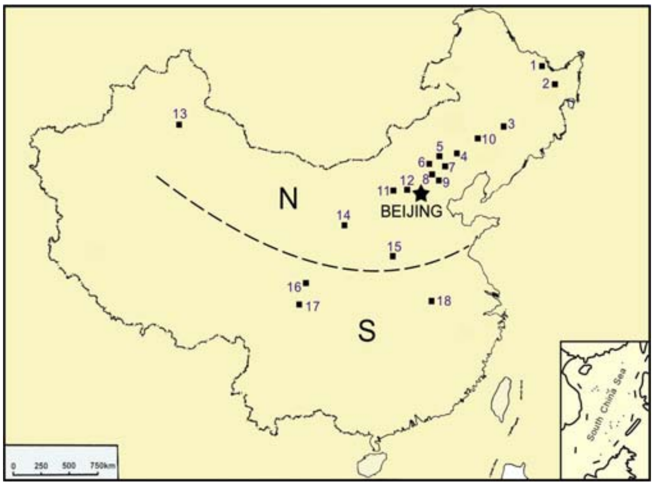

Figure 1. Geographical distribution and major localities of Jurassic woods in China. 1 Jiayin of Heilongjiang; 2. Mishan of Heilongjiang; 3. Yingcheng of Jilin; 4. Fuxin of Liaoning; 5. Beipiao of Liaoning; 6. Chaoyang of Liaoning; 7. Yixian of Liaoning; 8. Liaoyuan of Liaoning; 9. Kazuo of Liaoning; 10. Tieling of Liaoning; 11. Zhuolu of Hebei; 12. Yanqing of Beijing; 13. Qitai of Xinjiang; 14. Lingwu of Ningxia; 15. Yima of Henan; 16. Shehong of Sichuan; 17. Zigong of Sichuan; 18. Hanshan of Anhui. N-Northern Floristic Province; S- Southern Floristic Province.

In the western part of China there are large inland basins, such as the Ordors, Sichuan, Qaidam, Junggar and Tarim basins. In this region the Jurassic is generally characterized by fluvial to lacustrine sediments, intercalated with a few carbonates of non-marine origin. In the eastern part, the Jurassic is characterized by the development of thick volcanic rock successions (Chen, 2003; Shi et al., 2006). Fossil woods are recorded mainly from the non-marine Jurassic deposits in China. Available data indicate that northern China is a major source of fossil wood with diverse and well-preserved specimens (Fig. 1).

Stratigraphically, fossil wood specimens are reported from a variety of horizons ranging from Lower, Middle and Late Jurassic intervals with different types of depositional sequences (Figs. 2, 3). The Early Jurassic timespan is only recorded in the Beipiao Formation in western Liaoning, corresponding to the Pliensbachian to Toarcian. During the Middle Jurassic, more horizons occur over a wider region, ranging from the Aalenian to the Bajocian and Bathonian to Callovian, such as the Haifanggou and Tiaojishan Formations in western Liaoning, the Nankangzhuan Formation of Tieling in Liaoning, the Yima Formation in Henan, the Lower Shaximiao and Xintiangou Formations in Zigong, Sichuan. Late Jurassic woods show increased diversity of taxa and distribution by regions and horizons, ranging from Oxfordian to Tithonian. The major horizons include: the Chaoyangtun Formation in Baoqing, the Ningyuancun Formation in Jiayin, the Dongshengcun Formation of Mishan in Heilongjiang Province; the Huoshiling Formation of Yingcheng in Jilin; the Tuchengzi Formation in Liaoning; the Houcheng Formation of Yanqing near Beijing; the Shishugou Formation in Qitai, Xinjiang; and the Penglaizhen Formation of Shehong in Sichuan.

Age (Formation / Area)		Northern China: Junggar Basin (Northwest type)		Northern China: North Hebei & Western Liaoning (Northeast type)	Southern China: Sichuan Basin (Southwest type)	Southern China: Jiangsu and Anhui (Southeast type)	
Early Cretaceous		Tugulu Gr.		Yixian Fm.	Cangxi Fm.	Xihengshan Fm.	
Late Jurassic	Tithonian			Dabeigou Fm. Zhangjiakou Fm.	Penglaizhen Fm. ▲		Hanshan Fm. ▲
	Kimmeridgian	Kalaza Fm.		Tuchengzi Fm. ▲	Suining Fm.		
	Oxfordian	Shishugou Group ▲	Qigu Fm.				
Middle Jurassic	Callovian		Toutunhe Fm.	Tiaojishan Fm. =Lanqi Fm. ▲	Upper Shaximiao Fm.	Beixiang-shan Fm.	Luoling Fm.
	Bathonian				Lower Shaximiao Fm. ▲		
	Bajocian	Xishanyao Fm.		Haifanggou Fm. ▲	Xintiangou Fm. ▲		
	Aalenian						
Early Jurassic	Toarcian	Sangonghe Fm.		Beipiao Fm. ▲	Ziliujing Fm.	Nanxiang-shan Fm.	Moshan Fm.
	Pliensbachian						
	Sinemurian	Badaowan Fm.		Xinglonggou Fm.	Zhengzhuchong Fm.		
	Hettangian						
Upper Triassic		Haojiagou Fm.		Laohugou Fm.	Xujiahe Fm.	Fanjiatan Fm.	Lalijian Fm.

Figure 2. Representative non-marine Jurassic sequences from different regions of China and the major fossil wood horizons. The stratigraphical subdivision and general correlation between stages and formations are based on schemes proposed by Chen (2003) and Shi et al. (2006), with modification. Black triangles indicate the major fossil wood horizons.

Biodiversity of Jurassic fossil wood

The Jurassic woods documented from China are mainly found at 18 localities in nine provinces, most of them in northern China. The main localities are: Beipiao, Fuxin, Chaoyang, Yixian, Lingyuan, Kazuo, Tieling of Liaoning, Jiayin, Baoqing, Mishan of Heilongjiang, Yincheng of Jilin, Zhuolu of Hebei, Yanqing of Beijing, Yima of Henan, Lingwu of Ningxia, Qitai of Xinjiang, Zigong and Shehong of Sichuan, and Hanshan of Anhui (Fig. 1).

To date about 33 species belonging to 17 genera of fossil wood have been recorded from the Jurassic in China (Fig. 3, Table 1). They are mainly preserved as silicified type, which is predominant group of fossil preservation. Some fossil woods are preserved as siderite and a few as coalified woods. Anatomically, most specimens of the taxa have only secondary xylem preserved, and about four genera have been reported with pith structures, including *Lioxylon*,

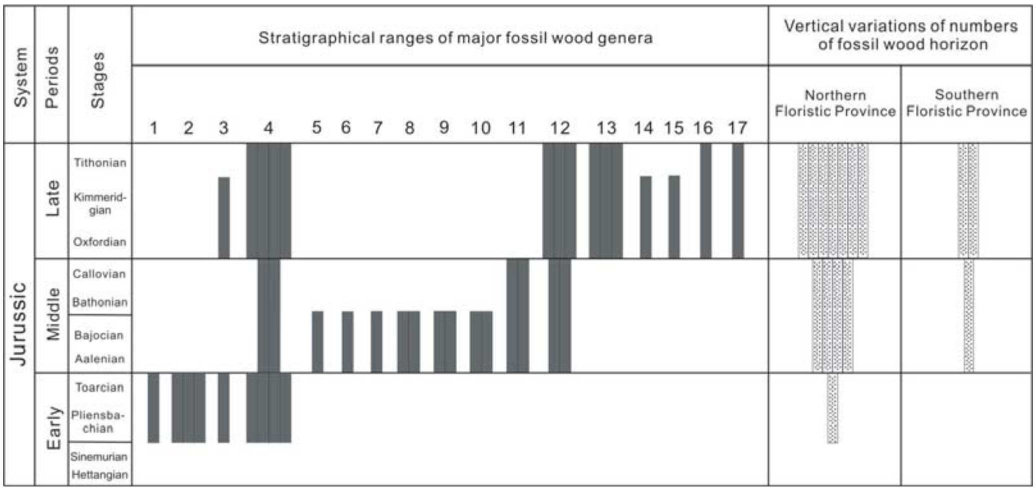

Figure 3. Stratigraphical ranges of major fossil wood genera and the numbers of fossil wood horizons from the non-marine Jurassic of China. The numbers of dark bars (left part) indicate the number of species for each fossil wood genus; and bar with dots (right part) represents a fossil wood horizon. 1. Sciadopityoxylon; 2. Protosciadopityoxylon; 3. Protophyllocladoxylon; 4. Xenoxylon; 5. Protocupressinoxylon; 6. Haplomyeloxylon; 7. Lioxylon; 8. Protocedroxylon; 9. Perisemoxylon; 10. Sahnioxylon; 11. Araucarioxylon; 12. Protopiceoxylon; 13. Cupressinoxylon; 14. Protocarpoxylon; 15. Prototaxodioxylon; 16. Scotoxylon; 17. Phyllocladoxylon.

Scotoxylon, *Haplomyloxylon* and *Sahnioxylon*. Based on anatomical features and comparisons with living wood anatomy, the Jurassic fossil woods from China may be taxonomically ascribed to the following four plant groups (Table 1).

1) Cycadales: only one fossil genus has been ascribed to this clade, i.e., *Lioxylon*. This genus is a structurally preserved stem composed of large pith seen in transverse section with a xylem cylinder, and many petioles and cortexes. Detailed anatomical evidence indicates a close systematic affinity of *Lioxylon* to fossil and living cycads (Wang et al., 2005; Zhang et al., 2006).

2) Bennettitales: two species can possibly be referred to this group, i.e. *Perisemoxylon bispirale* and *Perisemoxylon* sp. *P. bispirale* was reported from the Middle Jurassic in Henan and Ningxia (He and Zhang, 1993). The inner and outer walls of the tracheids display spiral thickenings. The trunk surface cuticles are strongly waved with short ray cells. *Perisemoxylon* sp. was collected from the Middle Jurassic in Ningxia (He and Zhang, 1993). The tracheids of this species are very small and the morphology of the pits varies considerably; the stomata in the trunk epidermis are syndetochelic. Although these features are indicative of bennettialean affinity, nevertheless, because of the type of preservation of specimens, further work is needed to confirm the systematic position of this species.

3) Coniferales: this is the dominant fossil wood group in the Jurassic of China ranging in age from Early to Late Jurassic. The fossils are distributed in Liaoning, Heilongjiang, Jilin, Beijing, Hebei, Xinjiang, Henan, Anhui, and Sichuan provinces, including 29 species ascribed to 14 genera. The major taxa include: *Araucarioxylon* (2 species), *Cupressinoxylon* (3 species), *Protocupressinoxylon* (1 species), *Haplomyeloxylon* (1 species), *Protopiceoxylon* (5 species), *Protocedroxylon* (1 species), *Phyllocladoxylon* (1 species), *Protophyllocladoxylon* (2 species), *Protopodocarpoxylon* (1 species), *Prototaxodioxylon* (1 species), *Sciadopityoxylon* (1 species), *Protosciadopityoxylon* (3 species), *Xenoxylon* (6 species) and *Scotoxylon* (1 species) (Figs. 3, 4).

4) Other plant groups: only one genus in this category, *Sahnioxylon* was recently reported from China. This is a Mesozoic wood morphogenus, its affinity has long been debated as bennettitales or angiosperm. Recent investigation indicates that *Sahnioxylon* is neither bennettitalean nor true angiosperm wood (Zheng et al., 2005). It mostly represents an evolutionary transition link between the Paleozoic wood *Guizhouoxylon* and the Late Triassic genus *Paradoxoxylon,* and is an ancestral plant type of angiosperms without vessels.

It is noted that there are some discrepancies for taxonomical status of some genera. For example, *Araucarioxylon* Kraus has been used repeatedly, although it is illegitimate and superfluous, most of the wood species referred to this genus should actually be transferred to *Agathoxylon* (Vogellehner, 1964; Philippe, 1993; Bamford and Phillipe, 2001). *Pinoxylon* is suggested to be the correct name for *Protopiceoxylon* Gothan (Medlyn and Tidwell, 1979; Bamford and Phillipe, 2001). For *Scotoxylon*, it should be made clearer that some of these names are for isolated secondary xylem pieces (tracheidoxyls) and some others for specimens with pith plus secondary xylem. According to recent considerations, from secondary xylem point of view, *Scotoxylon* is a synonym of *Protopiceoxylon*. *Sciadopityoxylon* is probably a taxonomical synonym of *Xenoxylon* Gothan (Bamford and Phillipe, 2001). The use of these genera name in China has a long history and it is therefore necessary to make a revision for all the above mentioned type species described in China, not only for the Jurassic taxa, but also for the taxa of other episodes. This is, however, out of focus of the present account.

Discussion on palaeoclimatic implications

The Jurassic phytogeography of the Euro-Asian Continent was proposed to be subdivided into a Continental Floristic Province and a Maritime Floristic Province. In China, these two provinces are generally called the Northern Floristic Province and the Southern Floristic Province (Zhou, 1984, 1995). They are bordered by the mountain ranges of the Kunlun Mt. – Qinling Mt. and Dabie Mt.

Table 1. Diversity of taxa and distribution of Jurassic fossil wood in China.

Plant group	Genera	Number of species	Name of species	Locality & Horizon	References
Cycadales	*Lioxylon*	1	*Lioxylon liaoningense* Zhang, Wang, Zheng, Saiki et Li	Beipiao of Liaoning, J_2	Zhang et al., 2006
Bennettitales	*Perisemoxylon*	2	*Perimesoxylon bispirale* He et Zhang	Yima of Henan, J_2	He and Zhang, 1993
			Perisemoxylon sp.		
Coniferales	*Araucarioxylon*	2	*Araucarioxylon zigongensis* Duan	Zigong of Sichuan, J_2	Duan and Peng,1998
			Araucarioxylon batuense Duan	Chaoyang and Yixian, J_2 Liaoning, J_2	Duan, 2000
	Cupressinoxylon	3	*Cupressinoxylon hanshanense* Zhang and Cao	Hanshan of Anhui, J_3	Zhang and Cao, 1986
			Cupressinoxylon baomiqiaoense Zheng et Zhang	Baoqing of Heilongjiang, J_3	Zheng and Zhang, 1982
			Cupressinoxylon fujeni Mathews et Ho	Zhuolu of Heibei, J_3	Sze et al., 1963
	Protocupressinoxylon	1	*Protocupressinoxylon* sp.	Yima of Henan, J_2	Zhou and Zhang, 1989
	Haplomyeloxylon	1	*Haplomyeloxylon tiaojishanense* Zhang et Wang	Beipiao of Liaoning, J_2	Wang et al., 2006
	Protopiceoxylon	5	*Protopiceoxylon amurense* Du	Jiayin of Heilongjiang, J_3	Du, 1982
			Protopiceoxylon extinctum Gothan	Zhuolu of Hebei, J_3	Sze et al., 1963
			Protopiceoxylon xinjiangense Wang, Zhang et Saiki	Qitai of Xinjiang, J_3	Wang, Zhang and Saiki , 2000
			Protopiceoxylon chaoyangense Duan	Chaoyang and Yixian, J_2	Duan, 2000
			Protopiceoxylon yabei (Shimakura) Sze	Huoshiling of Jilin, J_2	Sze et al., 1963
	Protocedroxylon	1	*Protocedroxylon lingwuense* He et Zhang	Lingwu of Ningxia, J_2	He and Zhang,1993
	Phyllocladoxylon	1	*Phyllocladoxylon* cf. *eboracense* (Holden) Kräusel	Yingcheng of Jilin, J_3	Shimakura, 1935-36
	Protophyllocladoxylon	2	*Protophyllocladoxylon chaoyangense* Zhang et Zheng	Chaoyang of Liaoning, J_1	Zhang, Zheng and Ding, 2000a
			Protophyllocladoxylon franconicum Vogellehner	Beipiao of Liaoning, J_3	Zhang, Zheng and Ding, 2001
	Protopodocarpoxylon	1	*Protopodocarpoxylon batuyingziense* Zheng et Zhang	Beipiao of Liaoning, J_3	Zheng, 2004
	Prototaxodioxylon	1	*Prototaxodioxylon romanense* Philippe	Beipiao of Liaoning, J_3	Zheng, 2004
	Sciadopityoxylon	1	*Sciadopityoxylon heizyoense* (Shimakura) Zhang et Zheng	Lingyuan of Liaoning, J_1	Zhang, Zheng and Ding, 2000a
	Protosciadopityoxylon	3	*Protosciadopityoxylon liaoxiense* Zhang et Zheng	Chaoyang, Lingyuan and Kazuo, Liaoning , J_1	Zhang, Zheng and Ding, 2001
			Protosciad opityoxylon jeholense (Ogura) Zhang et Zheng	Beipiao of Liaoning, J_1	Zhang, Zheng and Ding, 2000a
			Protosciadopityoxylon liaoningense Zhang, Zheng et Ding	Beipiao of Liaoning, J_1	Zhang, Zheng and Ding, 1999; Wang et al., 2006
	Xenoxylon	6	*Xenoxylon latiporosum* (Cramer) Gothan	Beipiao of Liaoning, J_1	Duan,1986; Du, 1982; Sze, 1951;
				Yanqing of Beijing, J_2, J_3	Ding, Zheng and Zhang, 2000;
				Jiayin of Heilongjiang, J_3	Zheng, 2004; Wang, Zhang and
				Qitai of Xinjiang, J_3	Saiki, 2000
			Xenoxylon ellipticum Schultze-Motel ex. Vogellehner	Beipiao of Liaoning, J_3	Ding, Zheng and Zhang, 2000; Zheng, Zhang and Ding, 2001
			Xenoxylon hopeiense Chang	Zhuolu of Hebei, J_3	Chang, C.Y., 1929;
				Beipiao and Chaoyang of Liaoning, J_1, J_2	Ding, Zheng et Zhang, 2000
			Xenoxylon peideense Zheng et Zhang	Mishan of Heilongjiang, J_3	Zheng and Zhang, 1982
				Kazuo and Tieling, Liaoning, J_1, J_3	Ding, Zheng and Zhang, 2000
			Xenoxylon japonicum Vogellehner	Chaoyang of Liaoning, J_1	Ding, Zheng and Zhang, 2000
			Xenoxylon conchylianum Fliche	Hebei, J_2	Li and Cui, 1995
	Scotoxylon	1	*Scotoxylon yanqingense* Zhang et Zheng	Lingyuan of Liaoning, J_3	Zhang, Zheng and Ding, 2000b
Incertae sedis	*Sahnioxylon*	2	*Sahnioxylon rajmahalense* (Sahni) Bose et Sah	Beipiao of Liaoning, J_2	Zhang et al., 2005;
			Sahnioxylon sp.		Philippe et al., 1999;

Notes: J_1 = Lower Jurassic; J_2 = Middle Jurassic; J_3 = Upper Jurassic

Available data clearly demonstrate that the Jurassic wood specimens are mainly recorded in the Northern Floristic Province; whereas in the Southern Floristic Province, fossil wood records are rare (Figs. 1, 3). The possible reason for this phenomenon may be because of insufficient specimen collection and investigation. Further work is therefore needed in the Southern province to improve the records of Jurassic fossil wood.

It is noteworthy that Jurassic wood and growth ring features in China provide informative evidence for palaeoclimatic reconstruction. Tree rings preserve a continuous record of environmental factors present during the life of a tree. Fossil tree rings are a unique source of detailed information about growth factors such as seasonality, annual growing conditions, water availability, limiting temperatures or forest productivity in the geological past (Creber and Francis, 1999). The occurrence of growth rings in nearly all of the woods analyzed indicates that the trees grew under a distinctly seasonal climate (e.g. Creber, 1977; Creber and Chaloner, 1984, 1985; Francis, 1984, 1986; Keller and Hendrix, 1997; Falcon-Lang, 2005).

Jurassic wood from Northern Floristic Province

As noted above, fossil woods are abundant in the Northern Floristic Province, ranging from the Early to Late Jurassic periods,

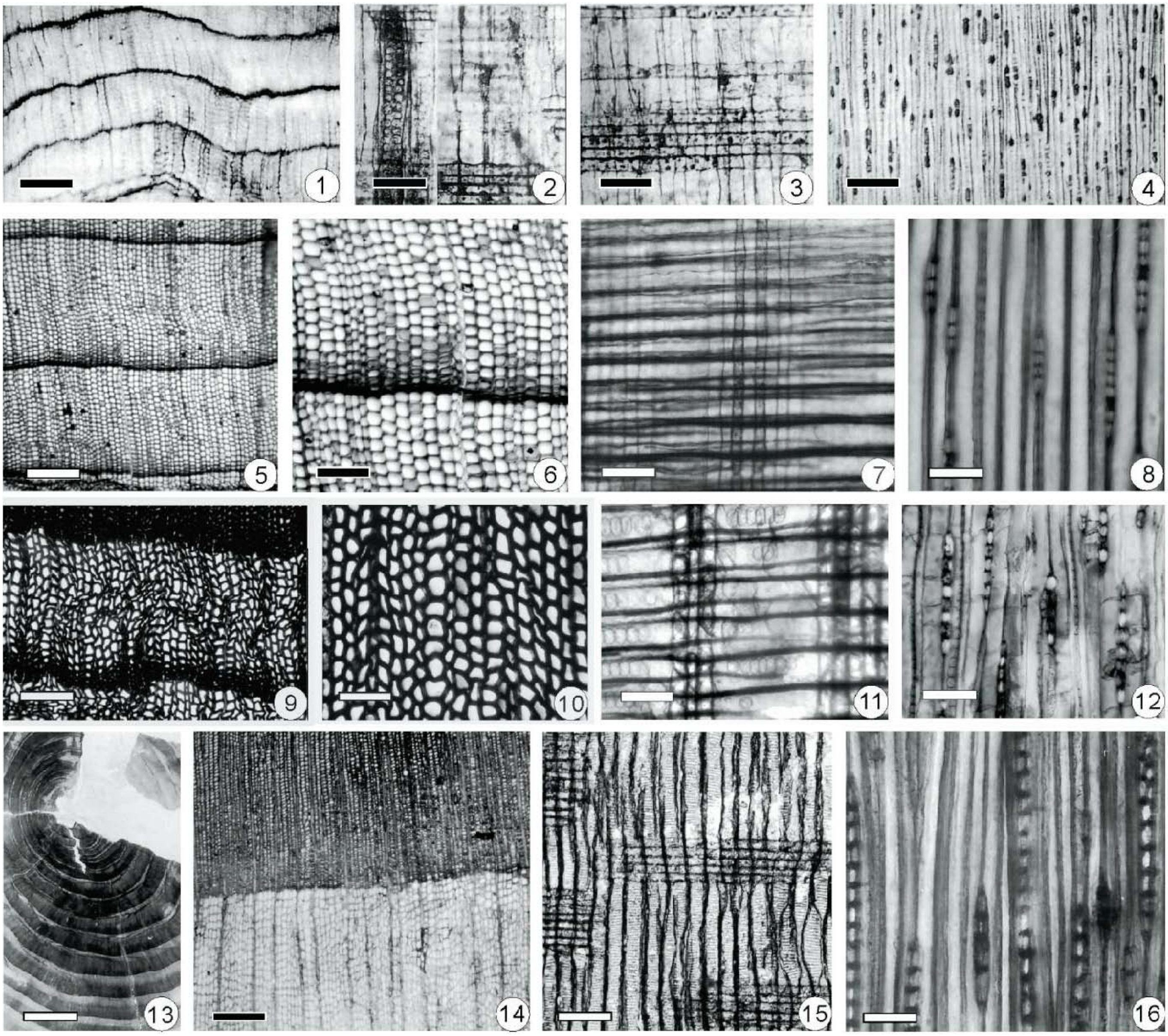

Figure 4. Selected fossil wood taxa from the Jurassic deposits of China. 1-4. Araucarioxylon batuense Duan, from the Middle Jurassic Tiaojishan Formation, Chaoyang, Liaoning Province. 1. Transverse section, showing growth rings, bar=125µm; 2-3. Radial section, showing the cross-fields and radial tracheids, bar=50µm; 4. Tangential section, showing the height of rays, bar=50µm. 5-8. Xenoxylon hopeiense Chang, 5, 6, 8 from the Middle Jurassic Tiaojishan Formation, Beipiao, Liaoning Province; 7 from the Upper Jurassic Houcheng Formation, Hebei Province. 5. Transverse section, showing the distinct growth rings, bar=312.5µm; 6. Transverse section, showing the variations of the tracheid, bar=167µm; 7. Radial section, showing the radial wall pits and cross-field pits, bar=43µm; 8. Tangential section, showing changes of the height of rays, bar=31µm. 9-12. Protosciadopityoxylon liaoningense Zhang, Zheng et Ding, from the Lower Jurassic Beipiao Formation, Beipiao, Liaoning Province. 9. Transverse section, showing the growth rings, bar=312.5µm; 10. Transverse section, showing the tracheids, bar=167µm; 11. Radial section, showing the cross-field and radial tracheids, bar=31µm; 12. Tangential section, showing the height of rays, bar=31µm. 13-16. Sahnioxylon rajmahalense (Sahni) Bose et Sah, from the Middle Jurassic Tiaojishan Formation, Beipiao, Liaoning Province. 13. Transverse section showing xylem cylinder, over 12 growth rings. Note the central empty pore is the space after pith decayed, bar=286µm; 14. Transverse section, showing distinct tracheids and growth rings, bar=286µm; 15. Radial section, showing radial wall scalariform pits and cross-field pits, 16. Tangential section, showing uniseriate rays and the variation of ray height, bar=57µm.

and are especially well documented in the horizons of the Middle and Late Jurassic (Fig. 3).

Lower Jurassic: The Lower Jurassic wood is reported only from the Beipiao Formation in Western Liaoning Province, corresponding to the Pliensbachian to Toarcian. This formation is notable for coal resources in Liaoning. Fossil woods from this horizon include the following taxa: *Protosciadopityoxylon liaoxiense* Zhang et Zheng, *P. liaoningense* Zhang, Zheng et Ding, *P. jehoense* (Ogura) Zhang et Zheng, *Sciadopityoxylon heizyoense* (Shimakura) Zheng et Zheng, *Xenoxylon latiporosum* (Cramer) Gothan, *Protophyllocladoxylon* *chaoyangense* Zhang et Zheng and *P. franconicum* Vogellehner (Zhang et al., 2000a). Growth rings are well developed in these woods with wider early wood and narrow late wood, normally 1-2 tracheids wide and maximum 5-6 tracheids. These anatomical features may imply that the climate in western Liaoning was warm and humid during the Early Jurassic with seasonal variations: long spring and summer seasons and a shorter winter season. The megaplant assemblages in the Beipiao Formation (Zhang and Zheng, 1987) show that ferns are the dominant group in the assemblages, with diverse *Cladophlebis* foliages of larger fronds. The ferns were growing under the canopy of an arborescent forest dominated by conifers and ginkgoaleans, which are tolerant of a warm and humid climate. The fossil woods in the Beipiao Formation were dominated by conifers, which are the coal-forming plants during the Early Jurassic.

Middle Jurassic: Middle Jurassic woods in this timespan are represented in the Tiaojishan Formation in western Liaoning and the Yima Formation in Henan Province. The latter is an early Middle Jurassic coal deposit, corresponding to Aalenian to Bajocian. Some fossil woods were reported from this formation, including the bennettitalean *Perisemoxylon* and conifer *Protocupressinoxylon*. These woods demonstrate distinct growth rings, implying that the palaeoclimatic conditions were warm and humid with seasonal variations.

The Middle Jurassic Tiaojishan Formation in Beipiao City, western Liaoning (corresponding to the Bathonian to Callovian) contains a variety of plant fossils including foliages and conifer woods (Wang et al., 2006). Abundant wood genera are recognized in this formation, including *Araucarioxylon batuense* Duan, *Haplomyeloxylon tiaojishanense* Zhang and Wang, *Protopiceoxylon chaoyangense* Duan, *Xenoxylon latiporsum* (Cramer) Gothan, *X. hopeiense* Chang, *Protosciadopityoxylon liaoningense* Zhang, Zheng and Ding. In addition, some fossil cycad-like stems belonging to *Lioxylon liaoningense* Zhang et al., have been found in this formation. The floristic signature of the Tiaojishan Formation indicates that subtropical to temperate warm and humid climates prevailed during the late Middle Jurassic in the Beipiao area. Growth ring pattern analysis of the fossil conifer wood demonstrates a consistent and distinct seasonal climate during this interval in western Liaoning (Wang et al., 2006). Additionally, fossil conifer woods have also been recorded from the Middle Jurassic in the Zhuolu, Hebei Province, close to western Liaoning, including *Cupressinoxylon fujeni* Mathews et Ho, *Protopiceoxylon extinctum* Gothan, and *Xenoxylon hopeiense* Chang. The distinct growth rings of these woods infer the same climatic conditions as those of western Liaoning during the Middle Jurassic.

Late Jurassic: There are various of fossil wood horizons in the Upper Jurassic of northern China. Among them, the Tuchengzi Formation (corresponding to Oxfordian to Kimmeridgian) is remarkable and representative of the palaeoclimate conditions. This is an extensively developed deposit composed of red and variegated calcareous and tuffaceous mudstones, sandstones and conglomerates. The lower part of this formation is lacustrine sediments formed in arid environments and fossils are sparse. The middle part of this formation is composed of red conglomerate with sandstone intercalations, represented by arroyo or wadi alluvial sediment containing no fossils; and the upper part is sand dunes composed of eolian sandstones. Interspersed locally there are desert oases lake deposits with a sparse xerophytic vegetation, such as the cheirolepidiaceous plants of *Brachyphyllum* and *Pagiophyllium* (Deng and Shang, 2002), as well as the conifers *Schizolepis*, *Pityolepis* and the czeknowskialean *Leptostrobus.* Fossil woods reported from this formation include *Protophyllocladoxylon franconicum*, *Xenoxylon ellipticum* and *X. latiporosum*. It is noteworthy that the foliages of the above conifers bear distinct xerophytic structures with small scale-like leaves and thick cuticles. The fossil woods contain obvious growth rings and false rings (Zheng et al., 2001; Zheng, 2004). The *Classopollis* pollen in this formation can reach over 86% (Pu and Wu, 1982). In general, the evidence from fossil plants, palynomorphs and fossil wood assemblages supports an arid and subtropical to warm temperate palaeoclimate in the Late Jurassic of western Liaoning that was characterized by distinct seasonality. Meanwhile, a potential terminal Jurassic monsoonal climate also affected this region, resulting in desert eolian sandstone deposits.

In northern Hebei, the Tuchengzi Formation is slightly different from that in western Liaoning in sedimentary features, characterized by fluvial deposits with regional lake fishes and bivalves. A petrified forest marked by *Xenoxylon latiporosum* (Cramer) Gothan and *Scotoxylon yanqingense* Zhang et Zheng has been reported (Duan, 1986; Zhang et al., 2000b). The cross section of these woods show distinct growth rings. Palynological evidence indicates that *Classopollis* pollen reached up to 15-91% in this formation in Xuanhua, Hebei (Zhang, 1989). Such evidence demonstrates that during the Late Jurassic period, the general climatic conditions in northern Hebei were similar to those in western Liaoning, but the aridity was less strong than there, probably indictaing a seasonal arid or semi-arid and semi-humid climate. However, there are no desert deposits in northern Hebei.

Jurassic wood from Southern Floristic Province

The Jurassic floras from southern China belong geographically to the Euro-Sinian Region, representing a subtropical vegetation (Zhou, 1995). However, the fossil wood specimens in this region are rare. Up to now, they have been reported only from two horizons of limited extent in Sichuan and Anhui provinces (Fig.3). *Araucarioxylon zigongensis* was documented in the Middle Jurassic Xintiangou and Xiashaximiao Formations in Zigong, Sichuan Province, and shows distinct growth rings (Duan and Peng, 1998). These two formations are composed mainly of purple-red mudstones, sandy mudstones with intercalations of siltstones and basal medium-grained sandstones with cross bedding. The fossil assemblages including ostracodes, bivalves, vertebrates and plants, and other sedimentary facies indicate that the fossil woods were growing in subtropical regions with a warm and cool climate as well as distinct seasonal aridity (Zhou, 1995).

Additionally, *Cupressinoxylon hanshanense* has been recognized from the Upper Jurassic in Anhui Province (Zhang and Cao, 1986). The taxon is characterized by a very narrow late wood (only 2-3 tracheids broad) with irregular growth rings. The wood specimens were found from the Hanshan Formation, which is composed of a series of dark purple-red, grayish-yellow sandstones and conglomerates with a thickness of 450 m. Fossil plant foliages were reported from the lower part of this formation, comprising fern fronds (such as *Klukia*), bennettitales (*Ptilophyllum*), as well as many conifers (represented by Cherolepidiaceae), and some twigs may belong to *Cupressinoxylon* (Cao, 1985). The above deposits and plant fossil assemblages imply arid and dry climate.

Conclusions

As an important proxy for palaeoenvironmental reconstruction, fossil wood increasingly improves our understanding of vegetation history and palaeoclimatic conditions. Fossil wood from the non-marine Jurassic deposits of China provides clues for investigation of terrestrial biodiversity and climatic variations. Diverse Jurassic fossil wood taxa are taxonomically referred to coniferales, cycadales and bennettitales. The horizons of the Jurassic wood range through Lower, Middle and Upper Jurassic intervals, and are especially abundant in Aalenian to Bajocian, Bathonian to Callovian and Oxfordian to Tithonian. Phytogeographically, the Jurassic woods from China occur mainly in the Northern Floristic Province. An analysis of growth ring features indicates distinct and seasonal climate variations in the Northern Floristic Province during the Early, Middle and Late Jurassic. This is of particular significance for exploring the Jurassic terrestrial vegetation history and climate change, and is therefore crucial for the regional and global correlations between the marine and non-marine Jurassic.

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Palynofacies in Lower Jurassic epicontinental deposits of Poland: tool to interpret sedimentary environments

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Diversified continental, marginal-marine and marine epicontinental deposits in Poland of Early Jurassic age yielded unusually rich palynomacerals. Numerous parameters, such as the presence of acritarchs and dinoflagellate cysts, spore/bisaccate pollen grain ratio, content of terrestrial phytoclasts, degree of oxidation, presence of tetrads and sporangia, degree of palynomorph alteration, presence and character of amorphous organic matter, presence of epibionts on palynomorphs, were collectively found as indicative of certain palynofacies. The ratio of spores and bisaccate pollen grains significantly depends on the climatic conditions where also seasonal changes may influence the local characteristics of palynofacies. However, the ratio also strongly reflects the local depositional environment which may vary regionally and spore/bisaccate pollen grain ratio can be taken as a general indicator of distance from the shore. Early Jurassic palynomacerals from the Polish Basin are strongly dominated by terrestrial elements, marine palynomacerals occur in significant quantities only in Pliensbachian deposits in Pomerania Western Poland. Charcoal is an important component of palynomacerals. Due to its resistance to biogenic degradation and buoyancy, charcoal produced by extensive wildfires was widely re-deposited and concentrated particularly in foreshore to shallow shoreface and delta plain environments. Three types of palynofacies inversions (abnormal palynofacies composition) are discussed. Six main palynofacies types linked to depositional systems previously determined by sedimentological studies have been distinguished providing a robust paleoenvironmental tool for recognition of palynofacies attributed to certain palaeoenvironments.

Introduction

Since the pioneering work of Muller (1959), distribution patterns of palynomorphs and other particulate organic matter has been used for facies recognition and palaeoenvironmental interpretation. Palynofacies forms a natural interface between palynology and sedimentology. The term palynofacies, introduced by Combaz (1964), embracing all HF resistant organic remains in sediments, involves recognition of different types of palynomorps, phytoclasts, amorphous organic matter, their proportions, size spectra and preservation states. Palynofacies analysis has been particularly developed by Batten (1973, 1996) and Tyson (1984, 1987, 1989, 1993, 1995) and other authors (Tschudy, 1969; Minshall et al. 1985, Bustin 1988, Van Bergen and Kerp, 1990, Williams, 1992). The definition of Powell *et al.* (1990) stating that palynofacies signify a distinctive assemblage of palynoclasts (or palynological matter, kerogen, palynomacerals), whose composition reflects a particular sedimentary environment was adopted by the present authors.

Unusually rich palynofacies of the epicontinental Lower Jurassic deposits of Poland, coupled with great range of palaeoenvironments, previously determined by detailed sedimentological studies (Pieñkowski, 2004), offered a good opportunity to study the palynofacies/palaeoenvironment interface in detail. The scope of this paper is to link sedimentary palaeoenvironments, interpreted based on detailed sedimentological studies, to the related palynofacies.

Geological, sedimentological and palaeoclimatological background

During the Early Jurassic, spanning some 24 million years (Gradstein et al. 2004), terrigenous, continental, marginal-marine and marine sediments reaching a maximum of 1400 m in thickness were deposited in a large epeiric basin extending across Poland (Figs. 1, 2). The sediments are defined as the Kamienna Group (Pieñkowski, 2004), that was subdivided into lithologic formations (Fig. 2), showing regional facies differentiation (Pieñkowski, 2004). The Mid-Polish Trough was an elongated, relatively narrow subsiding zone, which was superimposed on the south-western edge of the East European Craton and the north eastern boundary of the Variscides (Dadlez, 1997; Fig. 1). The Lower Jurassic deposits are dated with varied precision - marine deposits in Pomerania yielded Pliensbachian ammonites, in the other parts of the basin the less precise biostratigraphic divisions are based on megaspores (Marcinkiewicz, 1971), miospores (Pieñkowski 2004) and dinoflagellate cysts (Barski and Leonowicz, 2002; Pieñkowski, 2004).

Detailed studies performed in 35 cored boreholes and exposures integrated data from lithology, sedimentary structures, trace fossils,

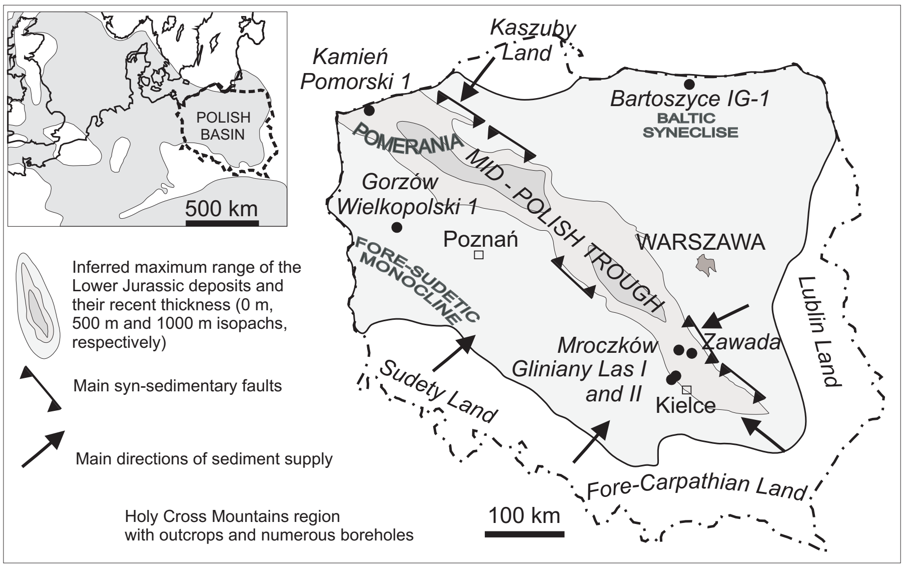

Figure 1. Paleogeographic map of the Early Jurassic epicontinental basin in Poland. Main parts of the basin (or regions) are indicated, as well as location of seven boreholes sampled for palynomacerals.

body fossils, boron content and petrology (Fig. 3). It allowed lithofacies description, palaeosalinity reconstruction, recognition of depositional systems, and sequence stratigraphic correlation (Pieñkowski, 2004) - Figs. 2, 3.

During the Early Jurassic, marginal-marine (mainly mesohaline), deltaic and continental sedimentation prevailed in the area of Poland. Marine (polyhaline) conditions occurred mainly in the Pliensbachian times (in Pomerania and briefly in the rest of the Mid-Polish Trough). Also some thin horizons within the Sinemurian and Toarcian sections in Pomerania show marine characteristics (Pieñkowski, 2004). The Early Jurassic Polish basins in (irrespectively of its marine or brackish-marine character) were generally not deeper than few tens of metres, most commonly their depth varied between 10 and 20 m (Pieñkowski, 2004). It means that the wave-base could reach the bottom of the basin and consequently dispersal of sediments and palynomacerals, enhanced by nearshore currents, was very extensive. Only the Early Pliensbachian sedimentation in Pomerania took place in a shelf basin attaining depth of about 100 m, below the storm wave base. Early Jurassic shallow marginal-marine, marine-brackish environments in Poland are characterised by a low diversity but abundant, mainly oligohaline-mesohaline biota. Brackish-water bivalves (mostly Cardiinidae and Mytiliidae) occur in the assemblages in high numbers but in low diversity, foraminifera are mostly represented by impoverished assemblages of agglutinated forms. Brackish marine trace fossil assemblages are generally richer and more diversified than fresh-water assemblages (Pieñkowski 1985), but locally terrestrial ichnoassemblages are rather diversified (Pieñkowski and Niedzwiedzki, 2007 *in print*).

Shallow brackish-marine or marine reservoirs were fringed by barrier-lagoon and deltaic environments. Deltas were both of fluvial-dominated (bird-foot) character or wave-dominated with fringing barrier and lagoons. Behind these marginal-marine facies belt (of deltaic/barrier-lagoon origin) alluvial plains developed. Alluvial environments were dominated by meandering and anastomosing river systems (Pieñkowski, 2004).

Sedimentation in the extensive and shallow Polish Basin was characterized by a great variety of rapidly shifting facies and depositional systems and reflects even minor fluctuations in sea level (Pieñkowski, 1991, 2004). This allowed a high-resolution sedimentological and sequence stratigraphic analysis (Pieñkowski, 1991, 2004) (Fig.3). Eleven sequences has been distinguished (Fig. 2), comparable to the number of global Early Jurassic sequences determined by Haq et al. (1987). Sequences are divided into parasequences (Fig. 3). Boundaries of sequences and most of the parasequences in the Lower Jurassic of Poland can be compared to the European standards (Hesselbo and Jenkyns, 1998; De Graciansky et al. 1998). Total number of parasequences in the Lower Jurassic of the Polish Basin is similar to the number of sequences (24) determined in British Lias by De Graciansky et al. (1998).

Traces of vegetation such as plant roots and palaeosol horizons are common in the Early Jurassic deposits. Palaeosols mark hiatuses in sedimentation and are often associated with tops of shallowing-upward sequences and parasequences (Fig. 3). Proximity of marsh/swamp area had a crucial impact on palynofacies. Numerous finds of macroscopic plant fossils have been helpful in interpreting of palaeoclimatic conditions (Makarewiczówna, 1928; Reymanówna, 1991; Wcislo-Luraniec, 1991), pointing generally to a warm and fairly humid climate, conductive for dense vegetation. It is concordant with general reconstruction of the Early Jurassic palaeoclimate (Chandler et al. 1992). The general miospore spectra with a domination of Matoniaceae and Dicksoniaceae-related spores, for the main part of the Polish Lower Jurassic deposits indicate a subtropical, generally warm and humid climate However, one should bear in mind that there were some climatic fluctuations, for example in earliest Hettangian (Warrington, 1970; Orbell, 1973; Hubbard and Boutler, 2000; Guex et al. 2004). In contrast to this, McElwain *et al*. (1999) suggested a fourfold increase of CO_2 at the T/J boundary and a global warming as a consequence. It is possible, however, that the long-term Hettangian warming effect followed a brief cooling event at the Triassic/Jurassic boundary. Another climate shift occurred in the Late Pliensbachian times, when the “greenhouse” climate may have been punctuated by sub-freezing polar conditions and the presence of limited polar ice is evidenced by dropstones and glendonites (Price, 1999). Paleotemperature variations of Early Jurassic seawater point to a sharp recurrent temperature drop during the Late Pliensbachian (Rosales et al. 2004). Such rapid drops in temperature could be associated with glaciations and rapid regressions, possibly providing onsets for the following warming phases, transgressions and anoxic events in the Early Toarcian (Morard et al. 2003; Rosales et al. 2004;. Hesselbo et al. 2007), coupled with increased humidity. It is now well-established that the Early Toarcian was characterized by major disturbances to the carbon cycle, as evidenced by large carbon-isotope excursions.

Materials and methods

Studies on the distribution of palynomorphs and other kerogen particles in various depositional systems have been performed on 226 samples derived from 7 selected boreholes (Figs. 1, 3) from

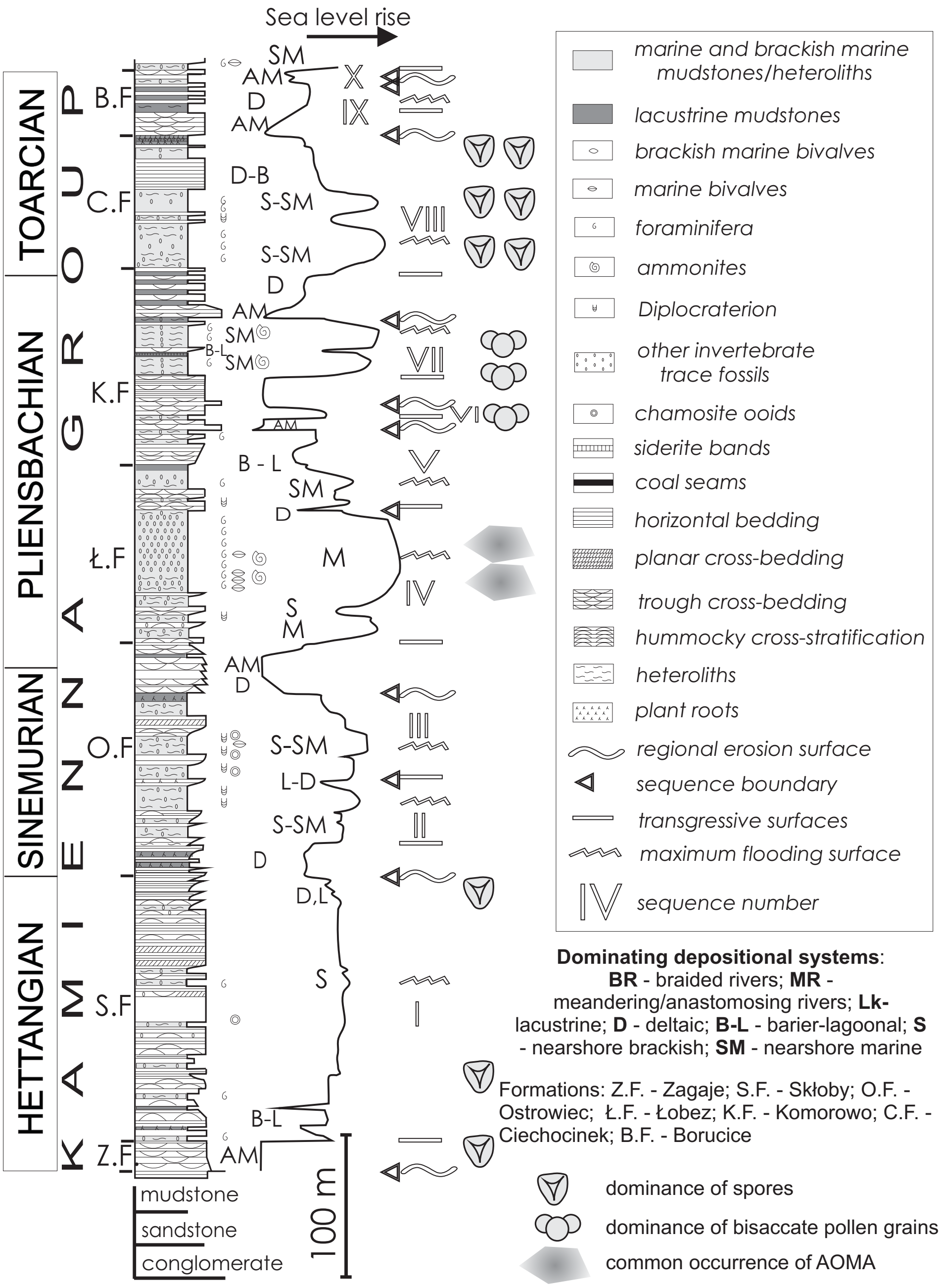

Figure 2. Synthetic profile of the Lower Jurassic of Poland (based on the Pomerania region), showing general facies, palaeoenvironments, sequence stratigraphy and general concentration in the profile of selected palynomacerals: spores, bisaccate pollen grains and AOMA (Amorphous Organic Matter of Aquatic Origin) in the profile, indicating the general palaeoclimatic and bathymetric conditions.

different regions and spanning stratigraphically entire Polish Early Jurassic. The following drillcores were included in this study: Gliniany Las 1 - Fig. 3, Gliniany Las II, Mroczków, Zawada 3, Gorzów Wielkopolski IG-1, Kamieñ Pomorski IG-1 and Bartoszyce IG-1. All samples derive from mudstone-claystone lithofacies (clay to silt size fraction, i.e. < 63 mm), as an uniform sampling tend to strongly reduce a “sediment fraction bias” (Rossignol 1969; Mudie, 1982). The samples were subsequently macerated in hydrofluoric acid. During the preparation of the organic residues, no chemical oxidation or deliberate physical separation was involved. The macerated residue was mounted in glycerine gel (at least three strew slides were prepared from one sample) and were subsequently studied in light transmission light microscope. Selected samples were additionally studied in SEM.

Further definition of palynomacerals (or palynological matter) follows that of Powell et al. (1990), Batten (1996), with some amendments based on Van Bergen and Kerp (1990) and Tyson (1993, 1995).

Results

Generally, palynomacerals in the Lower Jurassic of Poland are rich and show strong dominance of terrestrial material (with exception of some Early Pliensbachian intervals in Pomerania). Palynomacerals found in the Lower Jurassic of Poland comprises the following elements:

1. Palynomorphs

1.1. - Spores – they are produced by pteridophyte, inhabiting usually more humid areas (Tyson, 1993). Only miospores are discussed in the present paper, the Early Jurassic megaspores of Poland (characterized by Marcinkiewicz, 1971) are statistically insignificant in the material studied. The most common miospores are represented by trilete fern spores (Pl. 1: 1, 2, 3, 4), sometimes they occur in tetrads (Fig. 4: 1) or sporangia.

1.2. - Bisaccate pollen grains - they are produced by a larger spectrum of plants than spores, particularly by conifers. These pollen grains have air sacs, which suggest wind pollination and is responsible for wide dispersion of these palynomorphs (Pl. 1: 3, 5). Occurrences of monosulcate pollen grains (mostly *Ovalipolis* sp. in the lowermost Hettangian) were sporadic and statistically insignificant in the material studied.

1.3 - Dinoflagellate cysts and acritarcha (Fig. 4: 2, 3) – they are primarily restricted to shelf environments and they had a meroplanctonic lifestyle similar to that of fossil and modern cyst-forming dinoflagellates (Dufka, 1990).

2 – Phytoclasts (STOM), for definition see Batten (1996). Structured organic matter – STOM - herein it means plant detritus, it comprises wood (translucent - brown and opaque - black), opaque charcoal (although assignation of charcoal is a matter of controversy - Tyson 1995; Batten, 1996) and other dark to opaque phytoclasts, cuticles and other non-cuticular tissues.

We follow the conclusion of Tyson (1995) that dark to opaque granular phytoclasts do not show good structural preservation,

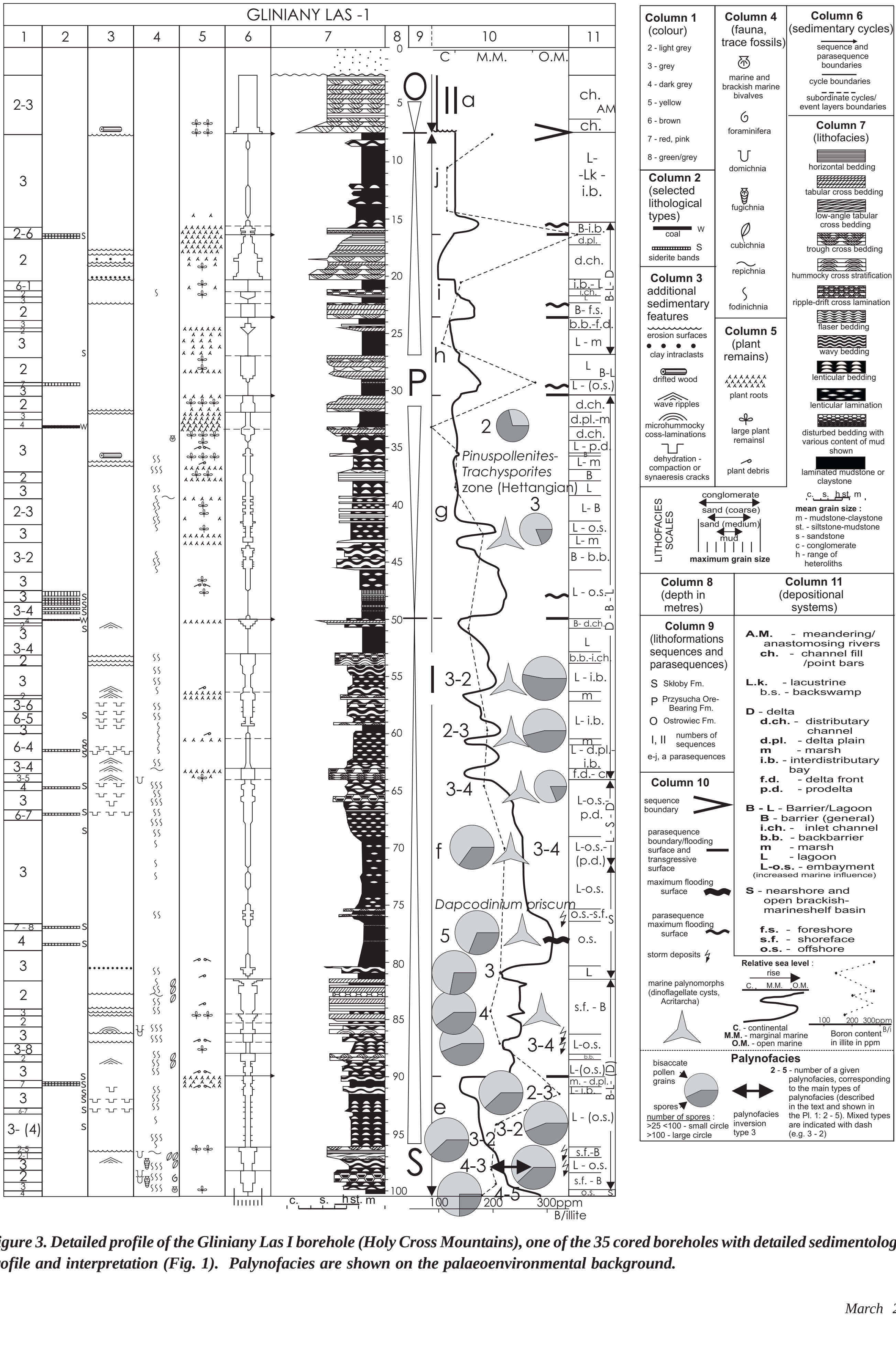

Figure 3. Detailed profile of the Gliniany Las I borehole (Holy Cross Mountains), one of the 35 cored boreholes with detailed sedimentological profile and interpretation (Fig. 1). Palynofacies are shown on the palaeoenvironmental background.

at least in the transmitting light studies. Therefore it is hard to distinguish STOM from amorphous organic matter of terrestrial derivation (AOMT). Opaque phytoclast material is mainly derived from the oxidation of translucent woody material during prolonged transport, post-depositional alteration or wild fires (charcoal) – Tyson (1993). Angular, lath-shaped fragments point to a structured phytoclasts, usually charcoal, which was proven in the SEM studies – Fig.4: 4.

3 - Amorphous organic matter (AOM) is divided into **AOMT** (amorphous matter of terrestrial derivation, dark and usually opaque, occurring most often in rounded fragments) and **AOMA** (amorphous organic matter of aquatic origin, mostly light and translucent). AOMT embraces heterogenous, fluorescent amorphous organic matter, humic gel and resin (Tyson, 1995). AOMA (amorphous matter of aquatic origin) is usually of planctonic/bacterial origin (Batten, 1996) and it shows "spongy", translucent structure and diffusive outlines (Pl. 1:6). Translucent AOMA dominate in the marine deposits (Tyson, 1995). It is not determined if it is of plant or animal origin.

Distribution of the Early Jurassic palynomacerals in Poland are related to the climatic conditions, regional palaeogeography/ palaeoenvironments and local palaeoenvironments (indicated in previous studies – Pieñkowski, 2004):

Climatic conditions: a high dominance of spores in the whole Polish Basin is observed in the Lower Toarcian (in average only 20% of bisaccate pollen grains against 80 % of spores), which is a striking contrast to the rest of the geologic profile (Fig. 2). Strong spore domination as observed in the Lower Toarcian sediments is obviously associated with palaeoclimatic factors – climate at that time must have been much warmer and much more humid (perhaps, with exception of the lowermost part of the *tenuicostatum* biochronozone) than during other Early Jurassic intervals. The bisaccate pollen grain/ spore ratio in the Lower Toarcian deposits in Poland is always strongly biased towards spores, which dominate even in the brackish-offshore settings. This is concordant with Morard *et al*. (2003) and Rosales et al. (2004) and also Wang (2002) noted that the youngest Early Jurassic (likely Toarcian) flora the Early Jurassic Hsiangchi Formation from China point to a particularly warm and humid climate. On the other hand, Wang et al. (2005) postulated warm but somewhat drier conditions for Toarcian of Quaidam Basin, but stratigraphic precision does not allow to distinguish between the Lower and Upper Toarcian strata. It is possible that local climatic changes may have caused observed floral changes in China.

To a lesser extent, also Hettangian deposits show in some sections higher abundance of spores.

On the other hand, Late Pliensbachian palynofacies is characterized by strong dominance of bisaccate pollen grains (in average some 70% of bisaccate pollen grains to only 30% of spores). Dominance of pollen grains in Late Pliensbachian deposits (particularly in Eastern Poland) is clearly associated with drier and colder climate (Fig. 2) as coniferous source areas were generally drier, colder or higher than the habitats of pteridophyta. Macroflora found in the outcrops of Late Pliensbachian deposits shows dominance of coniferous forests at that time, some trunks attain 1 m of diameter.

Seasonal changes are characteristic of certain types of climate and they may have had an impact on the Jurassic palynofacies. Pieñkowski (2004) indicated recurrent palynofacies alterations in some laminated, varve-like mudstones (lagoonal/interdistributary bay deposits) with altering light- and dark-grey laminae. Light-grey, more silty laminae contain sparse, oxidized phytoclasts, including charcoal fragments (Fig. 5). On the other hand, dark-grey laminae contain numerous and much larger, translucent phytoclasts (cuticleand some wood). Pollen grain/spore ratio is similar in both types of laminae. Varve-like lamination reflects probably seasonal changes - light laminae represent drier seasons with wild fires, better drainage in nearby swamps or marshes and contain abundant oxidized organic matter. The dark lamina with abundant translucent plant tissue likely correspond to a wet seasons with poor drainage (high water level) in nearby swamps or marshes and intense vegetation. This example shows a "micro-scale" palynofacies fluctuations determined by seasonal changes, although a bulk sample containing both light and grey lamina shows a typical "lagoon" palynofacies characteristics. However, by taking a sample from only a single lamina one can obtain a spurious picture of a general palynofacies character.

Regional palaeogeography: regional palaeogeographical/ palaeoenvironmental differences are observed: samples from Western Poland (particularly Pomerania region) contain relatively more spores, while samples from the Eastern Poland (particularly the Baltic Syneclise region) are relatively rich in bisaccate pollen grains (again, with exception of Lower Toarcian assemblages, where spores always dominate). This is probably associated with regional climate fluctuations, associated with proximity of the West European Sea (Pomerania), and, on the other hand more continental climate (and possibly higher altitudes) in the East (Fig. 1).

Local palaeoenvironment/depositional systems: taking in account the general background of the climatic changes and regional

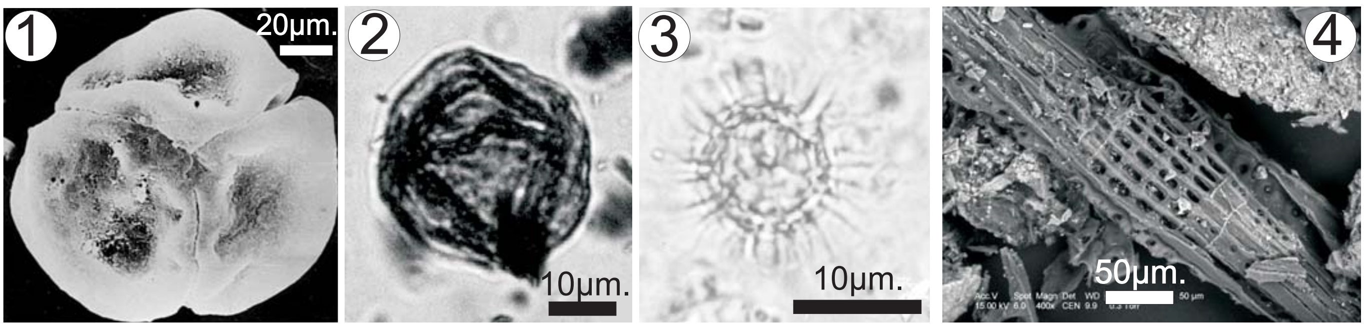

Figure 4. Selected palynomacerals: 1 – spore tetrad (SEM), Kamieñ Pomorski IG -1 borehole, depth 678.6 m, basal Hettangian; 2 – dinoflagellate cyst (light micograph), Kamieñ Pomorski IG-1 borehole, depth 180.3 m, Lobez Fm., Lower Pliensbachian; 3 – acritarch (light mocrograph), Kamieñ Pomorski IG 1 borehole, depth 253.9 m, Lobez Fm., Lower Pliensbachian; 4 – charcoal with characteristic structure (SEM, photo L. Marynowski), Kamieñ Pomorski IG-1 borehole

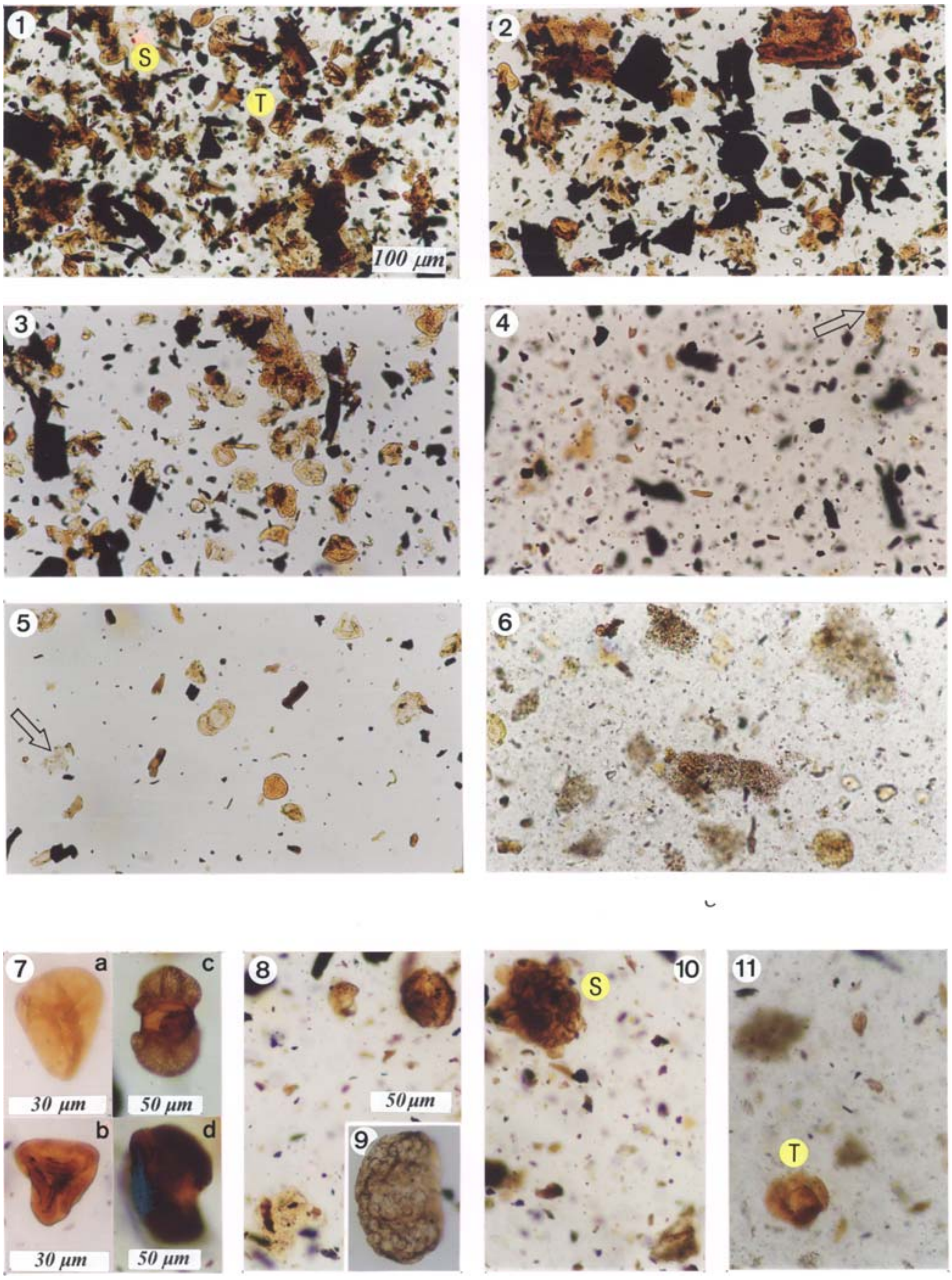

Plate 1. Typical palynofacies associations of the epicontinental Lower Jurassic of Poland. 1 – alluvial plain/lacustrine palynofacies (Zawada PA-3 borehole, depth 97.8 m, Zagaje Fm., Lower Hettangian) – very abundant STOM (both translucent and opaque), very abundant spores (with tetrads – T and sporangia – S); 2 – delta plain palynofacies (Gliniany Las 1 borehole – Fig. 3, depth 33.1 m, Przysucha Ore Bearing Fm., Upper Hettangian), abundant STOM (both translucent and opaque), relatively more opaque STOM and AOMT than in palynofacies 1, dominance of spores; 3 – lagoon palynofacies (Gliniany Las 1 borehole – Fig. 3, depth 80.8 m, Skloby Fm., Middle Hettangian), abundant translucent STOM (mostly cuticle), less frequent opaque STOM, numerous sporomorphs (in this sample bisaccate pollen grains dominate); 4 – foreshore-shoreface palyno-facies (Gorzów Wielkopolski IG-1 borehole, depth 1108,6 m, Skloby Fm., Middle Hettangian), dominance of fine, dispersed opaque STOM (with high occurrence of charcoal), palyno-morphs are mechanically corroded or destroyed (arrow indicates disintegrated bisaccate pollen grain); 5 – offshore/open brackish shelf (Gliniany Las I borehole – Fig.3, depth 77.4 m, Skloby Fm., Middle Hettangian, maximum flooding surface), very sparse STOM (mostly small opaque fragments), sparse pollen grains which dominate over spores, occurrence of dinoflagellate cysts (arrowed – disintegrated cyst) and acritarchs; 6 – offshore fully marine shelf (Kamieñ Pomorski IG-1 borehole, depth 279,2 m, Lobez Fm. with ammonites., Lower Pliensbachian) – dominance of spongy, translucent AOMA with diffused edges, rare pollen grains either disintegrated or covered with epibiont growths (the pollen grain at the lower edge of the photo), occurrence of dinoflagellate cysts and acritarchs. Scale for 1 to 6 – 100 µm, same as photo 1.

Palynofacies inversions: 7 - colour contrasts of the same sporomorph taxons: 7a, b – spore **Concavisporites intriastriatus** *(Nilsson) Ariang showing dark yellow (7a) or orange-brown colour (7b); 7 c, d – bisaccate pollen grain cf.* **Vitreisporites pallidus** *(Reissinger) Nilsson showing pale orange (7c) and dark-brown (7d) colours. All these sporomorphs showing wide range of colours derive from one sample (Kamieñ Pomorski IG-1 borehole, depth 400.2 m, Upper Sinemurian, brackish-marine embayment deposits); 8 – palynofacies inversion type 3 in the same sample – on the typical background of palynofacies 5 (brackish offshore-embayment) with translucent AOMA (lower left corner) the tetrad is visible (upper right corner); 9 – the same sample – epibiont (likely algae of fungal) growths on the surface of corroded bisaccate pollen grain, scale same as photo 8; 10 – palynofacies inversion type 3 (Kamieñ Pomorski IG-1 borehole, depth 277.5 m, Lower Pliensbachian, fully marine offshore shelf deposits with ammonites), palynofacies "6" with translucent spongy AOMA and with sporangium (S), scale same as photo 8; 11 - palynofacies inversion type 3 (Kamieñ Pomorski IG-1 borehole, depth 279.2 m, Lower Pliensbachian, fully marine offshore shelf with ammonites), typical palynofacies "6" with translucent spongy AOMA, tetrad (T) is visible, scale same as photo 8.*

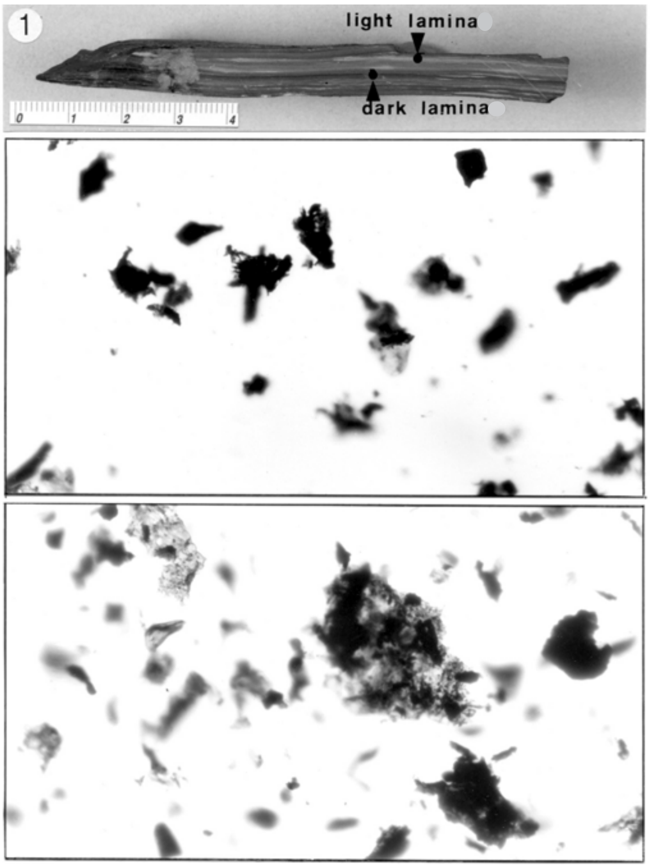

Figure 5. Laminated, varve-like mudstone (Kamieñ Pomorski IG 1 borehole depth 637.6 m, Lower Hettangian, Skloby Fm., lagoon/interdistributary bay environment), showing altering light and dark laminae, likely corresponding to seasonal changes. Palynofacies from the light lamina (upper photo) shows oxidized STOM (including numerous charcoal particles), sparse translucent STOM and sparse palynomorphs; these laminae contain more silt and less organic matter. Palynofacies of the dark lamina (lower photo) shows numerous translucent STOM (cuticle and wood), sparse oxidized organic matter and more palynomorphs; these lamina contain more clay and organic matter. Light laminae correspond probably to a dry season, while dark laminae represent wet seasons. Palynofacies show marked difference.

palaeogeographical differentiation, abundance and settling rate of palynomorphs and other kerogen elements is thought to be mainly controlled by local palaeoenvironmental conditions (sedimentary processes), thus the certain palynofacies can be attributed to certain palaeoenvironments. Generally, sporomorphs are most numerous in delta plain and fringing lagoonal deposits (Pl. 1: 2, 3). In the total material studied, bisaccate pollen grains show a slight dominance over spores (55% to 45%). The ratio pollen grain/spores in marginal-marine and marine environments is taken in this paper as one of palynofacies indicators of a distance from the shore, although it must be taken with caution. Spores show dominance (in average some 70% to 30%) in horizons with traces of vegetation (marshes with palaeosols and plant roots), which is expected in the places located near the parent pteridophyte flora. Spores are mainly produced in low lying swampy deltaic-alluvial plain areas and are common in palaeoenvironments situated close to these areas (Pl. 1: 1, 2, 3). This rule is well-known from previous works (Muir, 1964; Tyson, 1993, 1995; Batten, 1996; DeBusk, 1997). According to Reynolds et al. 1990, further distribution of sporomorphs is influenced primarily by water depth and current velocity. Presence of sporangia, including tetrads (Pl. 1: 1), points to a short distance of transport because of their vulnerability to dynamic factors such as currents or waves. Therefore they usually indicate proximity to vegetated areas - except for the case of palynofacies inversion discussed below. In high-energy environments (both fluvial and nearshore) sporomorphs are often mechanically destroyed (Pl. 1: 4), therefore in high-energy nearshore zones the spores are relatively more frequent than bisaccate pollen grains, because they are more robust than pollen grains and they can be positively selected by turbulent hydrodynamic conditions. On the other hand, the widespread distribution of bisaccate pollen grains (besides their generally higher frequency), reflects the fact that they are the most buoyant and most easily transported of all sporomorphs, therefore they can be found even in distal offshore settings (Pl. 1: 5, 6). According to many authors (Hopkins, 1950; Brush and Brush, 1972; Melia, 1984; Traverse, 1988; Horowitz, 1992; Rousseau et al. 2006) bisaccate pollen grains are suited to long distance dispersal by wind and become preferentially concentrated in more fine-grained and deeper water sediments, either of marine or lacustrine origin.

Both sporomorphs and bisaccate pollen grains which are found in quiet offshore environment (both brackish and fully-marine) frequently show biogenic corrosion or epibiont (likely fungal or algal) growths (Pl. 1: 6, 9).

Oxidized black STOM, including charcoal (Fig.4: 4) is widely distributed in deltaic and high energy foreshore-shoreface facies (Pl. 1: 2, 4). It is largely due to its buoyancy (Whitaker, 1984) and durability for decomposing. Charcoal produced by wildfires in the Lower Jurassic of Poland was found by Reymanówna (1993).

Wood is especially abundant in alluvial plains and in deltaic environment (Pl. 1: 1, 2). Coarse phytoclast material (>1 mm) is usually only dominant in high, first and second order, headwater streams (Minshall et al. 1985). Accumulations of medium to coarse grained plant detritus and recycled coal and lignite debris are apparently common in the swash zone of barrier beaches near the mouths of the Mississippi (Burgess, 1987), which is in concordance with observed high frequency of charcoal and oxidized wood fragments in delta plain and particularly foreshore-shallow shoreface environment (Pl. 1: 2, 4). Rounded opaque fragments of AOMT (Pl. 1: 5) can be also frequent in marginal marine and littoral facies – Bustin (1988).

Cuticle (Pl. 1: 2, 3) is most common in lagoonal and deltaic (marsh) deposits. Fisher (1980) considers that the cuticle is especially characteristic of facies resulting from the settling out of flotation and suspension loads under low energy conditions.

Acritarcha and dinoflagellate cysts – if appear – occur in statistically insignificant amount in the Early Liassic material from Poland. However, their appearance is of big qualitative significance as they point to marine influences. Most studies have consistently demonstrated that a relative abundance of small micrhystridid Acritarcha occurring in the material studied is most characteristic of shallow water marginal marine conditions (Prauss, 1989). This seems to occur mainly in brackish marginal facies. As far as dinoflagellate cysts are concerned, there is no simple relationship between their abundance, diversity and inferred "marinity" of the environment. Generally, they indicate marine or brackish-marine environment.

Light-brown to pale yellow and white AOMA of a spongy appearance (Batten, 1996) constitutes the most characteristic palynomaceral for fully-marine, offshore settings (Pl. 1: 6).

Last but not at least, frequency of certain palynomorphs may be influenced by redeposition (Batten, 1991). As indicated by taxonomic studies, number of sporomorphs derived from older (than Jurassic) systems was insignificant in the material studied. However, in places intraformational redeposition took place. This is of importance for colour of the sporomorphs (which will be discussed later), but still this process was not significant for quantitative properties of the Lower Jurassic palynofacies of Poland.

Based on the above characteristics, certain palynofacies have been linked to the prior determined palaeoenvironments (depositional systems). Six types of palynofacies have been distinguished:

1. Alluvial plain (Pl. 1: 1) - only mudstone/claystone samples were studied, thus they represent only alluvial plain fines deposited in lacustrine, distal crevasse or levee subenvironments. Generally, they show very abundant palynological matter, usually dominated by spores (in average 57% of spores to 43% of bisaccate pollen grains), presence of tetrads and sporangia (Pl. 1: 1). It should be noted that locally bisaccate pollen grains can show significant share, which largely depends on the local vegetation. Phytoclasts are very abundant and diversified, both translucent (cuticle, wood) and opaque (representing both oxidized "wood", charcoal or AOMT);
2. Delta plain (Pl. 1: 2) – abundant translucent (mostly cuticle and wood) to opaque phytoclasts (including more abundant charcoal than in the alluvial plain sediments), abundant sporomorphs, tetrads, sporangia, spores dominate over bisaccate pollen grains – in average 65% of spores to 35% of bisaccate pollen grains, sporadic presence of dinoflagellate cysts and acritarchs;
3. Lagoon (including delta front) - (Pl. 1: 3) - abundant sporomorphs, usually balanced pollen/spores ratio (in average 54% of bisaccate pollen grains to 46% of spores, but this ratio may vary considerably depending on the fluvial input), cuticle are abundant, moderate amount of other phytoclasts, relatively rare dark phytoclasts, rare dinoflagellate cysts and acritarchs;
4. Shoreface - foreshore (Pl. 1: 4) – common dispersed fragments of opaque phytoclasts (mostly charcoal), low to moderate content of sporomorphs, in lower energy environments bisaccate pollen dominate (in average 67% of bisaccate pollen grains to 33% of spores), while in high energy foreshore-shallow shoreface environment this ratio is usually reversed due to the more robust structure of spores resistant to mechanical destruction (Pl. 1: 4). Rare dinoflagellate cysts and acritarchs are observed;
5. Offshore brackish marine (Pl. 1: 5) – rare translucent AOMA, rare very small and rounded fragments of opaque phytoclasts (including charcoal), rare sporomorphs (bisaccate pollen grains dominate over spores – in average 67% of bisaccate pollen grains to 33% of spores), occasionally palynomorphs show biogenic corrosion and are covered by epibiont (likely algal or fungal) growths (Pl. 1: 9), relatively more common occurrences of dinoflagellate cysts and acritarchs;
6. Offshore marine (Pl. 1: 6) – common translucent, "spongy" AOMA with diffused edges, rare bisaccate pollen grains, spores absent or very rare - in average 73% of bisaccate pollen grains to 27% of spores (except for palynofacies inversions), palynomorphs often show biogenic corrosion and are covered by epibiont (likely algal or fungal) growths (Pl. 1: 6, 9), dinoflagellate cysts and acritarchs are relatively more common.

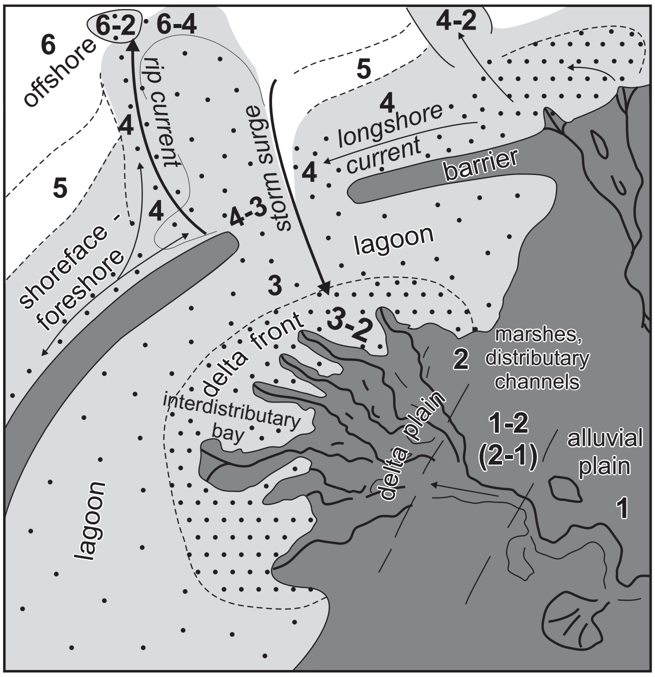

Figure 6. Sketch showing spatial distribution of main palynofacies associations on the palaeoenvironmental background. Dots represent concentrations of STOM (phytoclasts, including charcoal) and spores. The numbers represent successive palynofacies associations 1-6 (see text and Pl. 1).

Spatial distribution of six palynofacies on the generalised paleoenvironmental background is presented on Fig. 6.

Palynofacies inversions

The term palynofacies inversion was introduced by Pieñkowski (2004) and is further described herein to explain abnormal composition of palynomacerals (abnormal composition means significant difference both in content and appearance of certain palynomacerals from the typical "background" palynofacies, characterised as the 6 main palynofacies). Three types of palynofacies inversions have been distinguished (Fig. 7):

Inversion type 1 - contrasting palynomorph colour

This inversion is characterised by the presence of palynomorphs of coeval palynomorphs, having different colours (Pieñkowski, 2004). The colours are conventionally identified with TAI (thermal alteration index), thus the colours are related to the burial history of the palynomorphs (Marshall, 1991). The background "thermal" colour of Early Jurassic palynomorphs (except for few places in the maximum tectonic burial zones) is the dark yellow to pale orange colours (Pl. 1: 1-6). However, in some samples palynomorphs representing the same taxons may show much darker orange-brownish down to dark-brown colour (Pl. 1: 7). This is explained by the different early burial setting. The "background", dark-yellow palynomorphs were finally settled in the sediment just after their release from the parent plant and their colour reflects mostly a thermal history. Others, showing darker

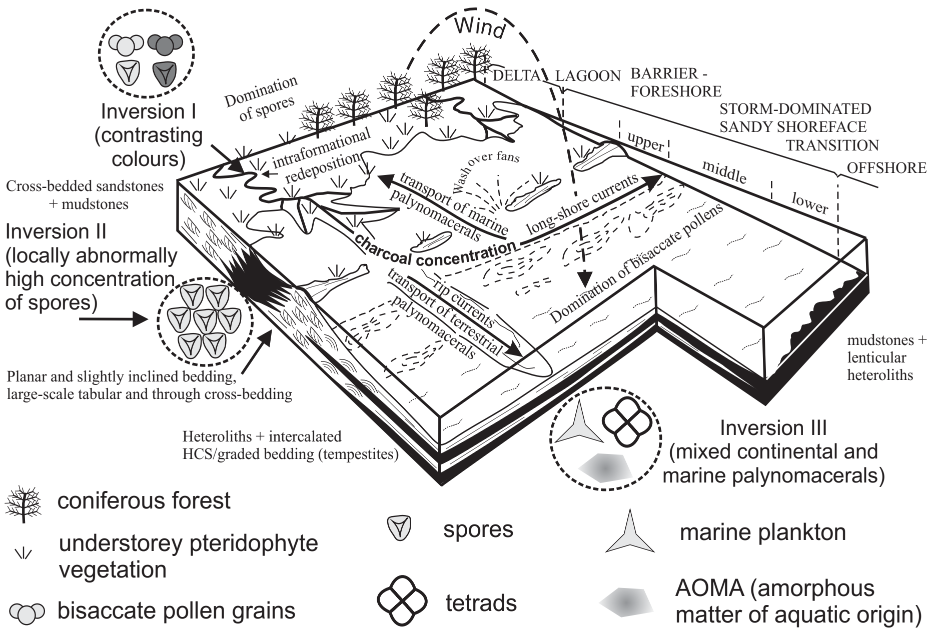

Figure 7. Three types of palynofacies inversions shown on the palaeoenvironmental background (depositional systems). The scheme shows also dispersion of some types of palynomacerals.

colours, went through diagenetic (oxygenation) cycle in the alluvial plain/delta plain swamp/marsh environment and after getting dark they were redeposited to be finally incorporated in the sediment. Transport must have been relatively short as the darkened palynomorphs show little or no mechanical corrosion (Pl. 1: 7b, d). The whole primary burial – oxygenation – redeposition process took a time insignificantly short from the geologic point of view (so called "intraformational" redeposition). Although the burial period in swamp/marsh deposits was short enough to consider the palynomorphs as practically contemporaneous, they were significantly transformed as far as concerns their colours. This type of inversion points to the sedimentary "cannibalism" processes, associated both with lateral migration of channels, shifting of delta lobes, high-energy marine erosion caused by waves and currents (for example at the transgression surfaces). Moreover, this inversion shows that in certain cases colour measurements must be taken with due caution, as they may indicate something else than TAI reflecting epigenetic "tectonic" burial history.

Inversion type 2 – abnormally high frequency of spores

Occasionally, in lagoonal settings (delta fringing lagoons), up to 3000 of spores were found in one sample (in regard to its average volume and density). Such abnormal quantity of spores is explained by rapid decrease of current velocity at the mouth of distributary channel entering the delta-fringing lagoon. As the main vector of sporomorph dispersal is river water (Muller, 1959) sporomorph concentrations capable of diluting all other palynomorphs are generally restricted to the vicinity of active fluvio-deltaic sources (Tyson, 1993). Additionally, existence of delta-fringing lagoons at the river (distributary channel) mouth greatly enhances mass deposition of spores. Such abnormal abundance can be also be due to an abundance in ferns in the ecosystem, but such an extraordinary amount of sporomorphs is occasionally observed only in lagoonal/lacustrine deposits and by an order exceeds average amount of spores observed in alluvial/deltaic plain sediments, even those associated with palaeosol horizons. Thus, it is interpreted that additional factor (hydrodynamic) must have been involved.

Inversion type 3 - presence of sporangia and tetrads in open marine deposits

This unusual mixture of different palynofacies elements (such as coexistence in one sample of spongy AOMA typical for offshore marine/brackish marine settings with tetrads and sporangia typical of alluvial-deltaic plains – Pl. 1: 8, 10, 11) is explained by influence of offshore-oriented currents, which could introduce terrestrial palynofacies into an open marine environment (Pieñkowski, 2004). Presence of tetrads and sporangia in offshore settings was usually associated with distal storm deposits (tempestites). Strong, offshore-directed currents are capable of transporting the sediment far away from shore (Davidson-Arnott and Greenwood 1976). Moreover, bulk of terrestrial material is transported during periods of high discharge in rivers (floods) associated with storms, which is connected with so-called "wash-out" effect. Storm transport provides a potential mechanism by which plant material from alluvial/deltaic settings, containing tetrads and sporangia, with may be occasionally flushed out and deposited in shelf environment (Hedges et al. 1988). Such possibility was also discussed by Tyson (1984, 1993): if the individual sporomorphs in a tetrad or sporangium are of low density, they should be capable of long distance flotation, and therefore other factors as the lower energy of the transporting and depositing mechanism play a crucial role in protecting the tetrad or sporangium from disaggregation. However, the clear association with storm deposits indicates that a high-energy agent could transport intact tertrads or sporangia. It seems that particularly a short time of flood/storm event was a key factor. It is also possible that sporangia and tetrads were transported offshore in large plant fragments and were released there in a post-storm, quiet weather conditions.

One should note that at many transgressive surfaces or flooding surfaces (smaller-scale transgressions at the parasequence boundaries) mixture of different palynomorphs can be also observed. Thus, transgression/flooding associated with regional sea-level rise can be also indicated as a process responsible for this kind of inversion, it is related to the reworking of previously deposited marginal-marine and alluvial plain sediments.

This type of inversion is by far the most common one in the Lower Jurassic of Poland. This is caused by the character of the shallow epicontinental basin, surrounded by deltaic or barrier-lagoonal facies, dominated by wave/current processes.

Conclusions

Rich palynomacerals obtained from the Polish Lower Jurassic deposits, together with precise sedimentological investigations, brought results useful for general palynofacies recognition – particularly in continental and marginal-marine environments. In general, ratio of spores and bisaccate pollen grains significantly depends on climate and the relatively cooler and drier Late Pliensbachian climate resulted in dominance of pollen grains, while very warm and humid climate in the Early Toarcian times (to lesser extent also Hettangian) resulted in high dominance of spores. Regional environmental conditions (related to the distance to the shore, palaeorelief and drainage factors) resulted also in regional variation in the bisaccate pollen grain/spore ratio. In the Lower Jurassic strata of Western Poland (Pomerania), spores are generally more frequent than in Eastern Poland (Baltic Syneclise, Holy Cross Mountains), where bisaccate pollen grains dominate (except of the Lower Toarcian, where spores always dominate). Taking into account, climatic and regional factors, the spore/bisaccate pollen grain ratio can be taken as a general indicator of distance to the shore. Spores tend to be relatively more abundant in alluvial plain and deltaic plain environments than in the nearshore, and particularly, offshore environments. Cuticles are particularly common in the lagoonal and delta plain deposits, while charcoal and oxidized wood fragments are relatively most common in the high energy, nearshore environment and in the delta plain environment due to its buoyancy and resistance to biological/chemical degradation. Translucent, spongy AOMA is present in offshore deposits, being less frequent in brackish marine and more frequent in fully marine shelf environment. Miospores occurring in offshore environment show epibiontic growths and traces of biodegradation.

Six typical palynofacies assocations, linked to previously determined palaeoenvironments, have been distinguished.

Palynological inversions (Pieñkowski, 2004) are further described and three types of such inversions are distinguished: type one is connected with intraformational redeposition resulting in contrasting colours of miospores, two others are related to sedimentary processes: hydrodynamic entrapment of spores in delta-fringing lagoons (type 2) or insertion of characteristic terrestrial palynomacerals into offshore-shoreface environment due to storm resuspension processes associated with rip currents (type 3). The type 3 inversion may be associated with transgressions (including parasequence flooding events) and related reworking/redeposition processes. The type 3 inversion is the most common one.

Palynological inversions must be taken into account in the interpretation of both colour and palynofacies composition. In such cases, the "background" palynofacies in their regional and palaeoclimatic context must be taken into account when performing correct palaeoenvironmental interpretations.

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by Clifford M. Nelson

The 16th International Geological Congress, Washington, 1933

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In 1933, the International Geological Congress (IGC) returned to the United States of America (USA) for its sixteenth meeting, forty-two years after the 5th IGC convened in Washington. The Geological Society of America and the U.S. Geological Survey (USGS) supplied the major part of the required extra-registration funding after the effects of the Great Depression influenced the 72nd U.S. Congress not to do so. A reported 1,182 persons or organizations, representing fifty-four countries, registered for the 16th IGC and thirty-four countries sent 141 official delegates. Of the total number of registrants, 665 actually attended the meeting; 500 came from the USA; and fifteen had participated in the 5th IGC. The 16th Meeting convened in the U.S. Chamber of Commerce Building from 22 to 29 July. The eighteen half-day scientific sections—orogenesis (four), major divisions of the Paleozoic (three), miscellaneous (three), batholiths and related intrusives (two), arid-region geomorphic processes and products (one), fossil man and contemporary faunas (one), geology of copper and other ore deposits (one), geology of petroleum (one), measuring geologic time (one), and zonal relations of metalliferous deposits (one)—included 166 papers, of which fifty (including several of the key contributions) appeared only by title. The Geological Society of Washington, the National Academy of Sciences, and the U.S. Bureau of Mines hosted or contributed to evening presentations or receptions. Twenty-eight of the 16th IGC's thirty new guidebooks and one new USGS Bulletin aided eight pre-meeting, seven during-meeting, and four post-meeting field trips of local, regional, or national scope. The remaining two new guidebooks outlined the USA's structural geology and its stratigraphic nomenclature. The 16th IGC published a two-volume monograph on the world's copper resources (1935) and a two-volume report of its proceedings (1936).

Prologue: The Invitation, 1929

The Union (now Republic) of South Africa had hosted the 15th IGC during 29 July–7 August 1929. One of the 15th IGC Council's duties involved selecting the location for the next Congress. Article II of the IGC's statutes adopted at the 13th IGC (Brussels, 1922) required Congresses to be held every three or four years.

When the 15th IGC's Council held its fourth meeting at Pretoria on 5 August, General Secretary Arthur Hall (Assistant Director of the Geological Survey of South Africa [GSSA]) read letters of invitation from the Union of Soviet Socialist Republics (USSR) and the United States of America (USA) to host the 16th IGC in 1932. In a letter dated 3 February 1928, Dimitri Mushketov, Director of the newly renamed All-Union Geological Committee at Leningrad (the former and future St Petersburg), and Mikhail Tetiaev, the Committee's Secretary General, described to the 15th IGC's Committee of Organization the "immense progress" made in understanding the geology of all the Russias since the 7th IGC held in St Petersburg in 1897 (Hall, 1930, p. 130). Charles Berkey (Columbia University), the Secretary of the Geological Society of America (GSA) since 1922, submitted an alternative request, supported by Charles Dawes, Vice President of the USA, in a letter of 21 June 1928 from the USA's ambassador to the Court of St James. They asked the Secretary of State for Foreign Affairs to transmit to the 15th IGC's President, Arthur Rogers (Director, GSSA), the offer, from the Chairman of GSA's Continuing Committee on Invitation and Organization of the IGC to the USA's Secretary of State Frank Kellogg, to hold the 16th IGC in the U.S. "under the auspices of the United States Government" (ibid., p. 131). The invitation from the USA, Berkey emphasized, "was as near a final one from the Government as was possible to obtain at this juncture" (ibid.). Berkey asked the Council's fifty-nine members present at the fourth meeting to consider it official. Bailey Willis (Stanford) seconded Berkey's motion and it passed "on a show of hands". Twenty-three members of the Council supported the USSR's offer while thirty-three voted to accept the USA's invitation (ibid.).

Planning and Financing, 1930–1932

The USA, as host for the 16th IGC, would, of course, have to find ways and means to pay for it. Initial discussions began within the GSA, for since 1891 it had been the organization that provided liaison and assistance for U.S. participation in the IGCs. Securing Federal funds, the U.S. organizers thought, would be easy because the USA's economy had continued to prosper through the 1920s, and, on 4 March 1929, the Republican Herbert Hoover succeeded Calvin Coolidge as the USA's 31st President. Hoover had assisted Waldemar Lindgren's U.S. Geological Survey (USGS) team in the Sierra Nevada while earning a BSc in geology at Stanford in 1895. Hoover, subsequently a successful mining entrepreneur and World War I humanitarian, also served as Secretary of Commerce (1921–1929) in the administrations of Republicans Warren Harding and Coolidge. In the national election of 1928, Hoover swamped his Democratic opponent and the Republicans increased their majorities in the House of Representatives and in the Senate. Hoover took his oath of office on 4 March 1929, one day after the 50th anniversary of the USGS' founding. He invited the USGS staff to a luncheon at the White House on 21 March to honor the agency's anniversary. The gathering was recorded in a group photograph taken on the grounds just outside the Rose Garden, where President Hoover, Secretary of the Interior Ray Wilbur, and USGS Director George Smith stood front and center. Hoover appointed Dawes ambassador to Britain, and he confirmed his predecessor's decision about the 16th IGC. Hoover agreed to serve as Honorary President.

However, neither of Hoover's twin presidencies nor funding for the 16th IGC proved easy. The USA, as a creditor nation, increased its gold reserves during the 1920s. Coolidge's administration continued a low-interest policy that failed to stem the specie flow and fuelled speculation in gold and other stocks, whose prices continued to rise after Hoover took office and into most of the summer of 1929. USA stocks declined in September and crashed heavily in October. By mid-November, as the financial panic continued, Wall Street's listed stocks had lost nearly US$30 billion in market value. As is well known, the effects from the burst bubble began to ripple through the national and global economies (see Fausold, 1984; Garraty, 1986; and Kennedy, 1999).

By the spring of 1930, as the American economic recession deepened, the GSA had arranged with the USGS to convene the 16th IGC in Washington in June 1932, accompanied by excursions in May, and others in June through early July, to take advantage of cooler weather and lower travel rates than those expected in Washington later in the summer. Walter Mendenhall (see Figure 1), who had joined the USGS in 1896 and worked in its geologic and groundwater-resources units before managing its Land Classification Board for a decade and then becoming Chief Geologist in 1922, agreed to serve as the 16th IGC's General Secretary. Henry Ferguson (USGS), who helped the U.S. Bureau of Mines (USBM) to prepare the USA's portion

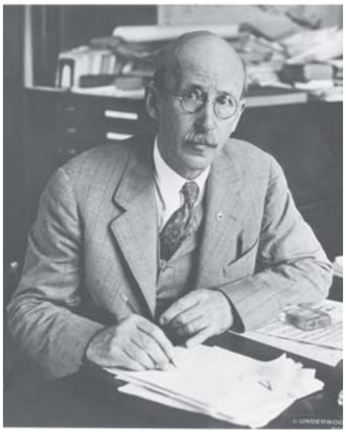

Figure 1. Walter Curran Mendenhall (1871–1957) in 1930; Director, USGS (1930–1943); NAS, 1932; General Secretary, 16th IGC (Library of Congress).

of the 15th IGC's report on the world's gold resources, chaired the Excursion Committee, whose members, and their colleagues from academia, government, and industry elsewhere in the USA, began preparing guidebooks. In October 1929, Mendenhall had called for greater support for basic geologic research in the USGS. "To apply science to human needs", Mendenhall asserted, "there must be science to apply. Research cannot be neglected in any field of science, geologic or other", he continued, "without jeopardizing its usefulness" (Mendenhall, 1929, p. 12). Funds from the USGS' new line-item of US$100,000 for "fundamental research in geologic science" (U.S. Statutes at Large, v. 46, p. 311, 14 May 1930), gained for the fiscal year 1930–1931, supported work by USGS geologists toward completing their contributions to the guidebooks, a new geologic map of the United States, and those of several of its States.

The 16th IGC's Committee on Organization, likewise selected under the 1913 rules, comprised Hoover and twenty-nine Members from academia, industry, and State and National governments. Lindgren (see Figure 2), USGS Chief Geologist during 1911–1912 and subsequently Rogers Professor of Geology at MIT, served as Chairman. Mendenhall (General Secretary), Ferguson and the USGS geologist Marcus Goldman (Assistant Secretaries), Edward Mathews (Johns Hopkins and General Treasurer), Olive Postley (USGS and

Figure 2. Waldemar Lindgren (1860–1939) in 1912; NAS, 1909; President, 16th IGC (Library of Congress).

Administrative Assistant), and Raymond Becker (Business Manager) joined Hoover and Lindgren as 16th IGC officers. The Organization Committee also included Foster Bain (Secretary of the American Institute of Mining and Metallurgical Engineers [AIMME]), Alan Bateman (Yale), Berkey, Eliot Blackwelder (Stanford), Isaiah Bowman (Director of the American Geographical Society, but later at Johns Hopkins University), Reginald Daly (Harvard), Arthur Day (Carnegie Institution Geophysical Laboratory), Everette DeGolyer (Amerada Petroleum), Arthur Keith (USGS), Andrew Lawson (Berkeley), Charles Leith (University of Wisconsin), Richard Penrose, Jr (Philadelphia), Sidney Powers (Tulsa), Wallace Pratt (Director, Humble Oil), William Wrather (Dallas), and David White (USGS: Chief Geologist, 1912–1922). The organizers appointed a six-person Executive Committee consisting of Bain, Berkey, DeGolyer, Lindgren, Mathews, Mendenhall, and White.

The Organization Committee's First Circular, issued in September 1930, listed program topics and field trips proposed for consideration by prospective attendees. To add to the list of world mineral resources—iron, coal, and gold—already discussed at recent IGCs and treated monographically as part of their reports, the 16th IGC's organizers selected petroleum and established a Petroleum Committee to join the existing Excursion, Finance, and Program groups. The Program Committee solicited comments and offers of papers on ten proposed subjects also of current interest. The Excursion Committee proposed offering seven trips before the sessions in Washington, several during the meeting, and four after the sessions. But two months later, in the USA's mid-term elections, the Republicans lost control of the House of Representatives and maintained only a one-seat margin in the Senate.

In December 1930, Mendenhall succeeded Smith as Acting Director of the USGS, after Hoover nominated Smith as Chairman of the Federal Power Commission. On 29 December, Mendenhall reported the additional progress made by the 16th IGC's organizers to the annual meeting of the GSA in Toronto. As national governments had financially supported recent IGCs, the Secretariat had "explored the possibility of securing [U.S.] Government grants for administrative expenses of the [16th] Congress and the publication of its proceedings" (Mendenhall, 1931, p. 178). The USGS sought from the 71st U.S. Congress approval of a House joint resolution intended to provide during fiscal 1931–1932 funds from the Interior Department to publish the guidebooks and the national geologic map, and money from State Department for administrative expenses and publishing the meeting's report and its petroleum monograph.

By the time the Second Circular appeared on 1 August 1931, the effects of the growing worldwide economic depression, the failure to pass the joint resolution on finances, and responses to the First Circular convinced the Organization Committee, now expanded to thirty-two members, to postpone the start of the 16th IGC until late June 1933. The Committee now specified seven principal topics for discussion—arid-region geomorphology, batholiths and related intrusives, fossil man and contemporary faunas, measuring geologic time, orogenesis, the Paleozoic's major divisions, and zonal relations of metalliferous deposits. These were selected "as especially important at this time" and papers invited for them (Mendenhall, 1933, p. 247). The Excursion Committee also planned nine pre-meeting excursions (eight between the Mississippi Valley and the Atlantic Coastal Plain and one from San Francisco to Washington), eight more near and in Washington during the sessions, and five post-meeting trips. The last group included two transcontinental excursions (one with optional side-trips and the other providing a general cross-section of U.S. geology), and one each on the glacial geology of the central states, Lake Superior metals deposits, and (by air) geomorphological features between Washington and San Francisco.

While planning continued in December 1931, the 72nd U.S. Congress reconsidered the Organization Committee's request for Federal financial support and the Senate confirmed Mendenhall as the USGS' fifth Director (see Rabbitt, 1986). Hoover and his Secretary of State Henry Stimson asked the legislators to approve the joint resolution reintroduced in the House, provide US$85,000 for the 16th IGC's expenses, and make US$35,000 of that sum available during fiscal 1932–1933. The anticipated US$240,000 required for the fourteen pre- and post-meeting excursions, would "be raised by the geological congress and its friends" (U.S. Congress, 1932a, p. 3). The remaining US$50,000 from the appropriation would be used during fiscal 1933–1934 to print and issue the 16th IGC's reports. Although Bowman, Day, Mendenhall, and Smith testified in hearings held by the House Committee on Foreign Affairs during February–March 1932 (U.S. Congress, 1932b), the legislators decided against giving Federal monetary support to the 16th IGC.

The GSA rescued the 16th IGC from further postponement or termination by supplying funds from its new Penrose Bequest. Richard Penrose, Jr, like Hoover a successful mining entrepreneur, had died in July 1931. His will, reflecting the advice he sought from Berkey and other colleagues, divided most of his estate of US$10 million equally between the American Philosophical Society and the GSA. In July 1932, GSA's Council decided to support the 16th IGC by donating "the income from Penrose's investments" accrued before his estate was settled (Eckel, 1982, p. 26). GSA's new Advisory Committee on Policies and Projects—Leith (Chairman), Frank Adams (McGill), Bowman, Rollin Chamberlin (University of Chicago), Morris Leighton (Illinois State Geologist), Lindgren, and John Reeside, Jr (USGS)—coevally decided, as one of a dozen recommendations, against aiding IGCs and other scientific meetings, except for the 16th IGC, as "probably never again financially feasible" (ibid., p. 27). The GSA's Council intended the US$90,000 grant to the 16th IGC "as further evidence of good will and co-operation in the advancement of the science" (Fairbanks and Berkey, 1952, p. 764). Although on 22 April the USGS saw its line-item funds for fundamental research in geology reduced from US$100,000 to US$40,000 for fiscal 1932–1933, the agency took US$50,000 from its US$110,000 appropriation for engraving and printing geologic and topographic maps during that year and directed it toward the cost of publishing the new geologic map of the United States. The American Association of Petroleum Geologists (AAPG) contributed an additional US$1,000.

The Third and Fourth Circulars, issued on 1 December 1932 and 1 May 1933, finalized the arrangements for the 16th IGC. During 8–22 July participants could register for US$5 at the GSA House on Columbia's campus in New York City (NYC), the California Division of Mines office in San Francisco's Ferry Building, or at the U.S. Chamber of Commerce Building (CCB, 1925; see Figure 3) at 1615 H Street, N.W., in Washington, just north of Lafayette Square (now Park) and the White House, and just east of Connecticut Avenue. The CCB also was within four blocks to the southwest of the USGS offices in the Interior Department Building (1917; now the General Services Administration), at 18th and F Streets. The circulars also invited attendees to participate in the meetings of four other scientific organizations—the Pan-Pacific Science Congress (Vancouver, Canada, 1–22 June), the American Association for the Advancement of Science (Chicago, 19–24 June), the AIMME (Chicago, 26–29 June), and the Society of Economic Geologists (Princeton, 7–8 July).

Twelve brief trips within NYC and to nearby locales, and the longer A-series of pre-meeting excursions from NYC and Washington, would occupy 6–20 July. The GSA House planned to serve afternoon

Figure 3. U.S. Chamber of Commerce (Chamber of Commerce).

tea daily and the American Museum of Natural History (AMNH) arranged to host a reception to honor the foreign guests on 21 July. Interested attendees could then use the printed guide when visiting the city's AIMME, the American Geographical Society, and its other scientific institutions before returning to the special-rate Taft (at 7th Avenue and 15th Street) or other hotels. They would leave by train for Washington at 6 p.m., at the two-thirds fare arranged by the Organization Committee for all rail (but not steamship) travel to and from the IGC. The general sessions and volunteered exhibits at Washington would begin at the CCB on the following day and continue through 29 July. The topics for discussion now included the original seven plus petroleum geology, after the Organization Committee selected copper as the subject for the 16th IGC's commodity volume and invited experts to send papers for evaluation by a separate committee chaired by consulting engineer Arthur Notman (NYC). Prospective authors for the general sessions were asked to submit abstracts (200 words maximum) of their papers to the General Secretary by 1 June and full typescripts (5,000 words maximum and ready for publication) by 1 July. All attending and non-attending registrants would receive the list of registrants, the program, the abstracts of papers, guides to the scientific institutions of NYC and Washington, the thirty IGC-excursion guidebooks, the new, four-sheet "Geologic Map of the United States" (1:2,500,000) by George Stose and Olaf Ljungstedt (USGS), and the final report. The Organization Committee also noted the deaths of three members—Penrose, Powers, and Benjamin Emerson (Smith College and USGS)—and the addition of Notman and James Dunn (State Department's International Conference Division).

Registration

By the time the 16th IGC met in July 1933, the American people had rejected Hoover and his failed policies, which favored loans to businesses rather than public-work projects, and elected Franklin Roosevelt as their new President. Roosevelt took office in January 1933, began work on the USA's economic and social recovery during his administration's first "Hundred Days" (see McJimsey, 2000), and joined Hoover as an Honorary President of the 16th IGC. Lindgren, Mendenhall, Mathews, Ferguson, Goldman, Postley, and Becker continued as 16th IGC officers. Berkey (Chair), DeGolyer (Secretary), Ferguson (Treasurer), Bain, and David White served as the Executive Committee of the now 32-member Organization Committee.

A reported 1,182 persons and organizations registered for the 16th IGC, the largest number yet recorded. They represented fifty-four countries and thirty-four of these nations sent 141 official delegates. Although only 665 of the members actually came to Washington, they formed the third highest total after those at the 14th IGC (Madrid, 1926) and the 7th IGC (St Petersburg, 1897). Five hundred persons from the USA came to the 16th IGC. Fifteen of the participants also attended the 5th IGC (see Nelson, 2006)—Adams, Charles Barrois (Lille), Whitman Cross (USGS and one of the Assistant Secretaries in 1891), Darton, Gerhard de Geer (Stockholm), Keith, Charles Keyes (Des Moines and Tucson), Alfred Lane (Tufts College), Lawson, Emmanuel de Margerie (Paris), Ezequiel Ordoñez (Mexico City), Timothy Stanton (USGS Chief Geologist since 1930), Edward Ulrich (U.S. National Museum and ex-USGS), David White, and Willis. Attendees at the 16th IGC, as at the 5th and other IGCs, represented a mix of aspiring as well as established geologists.

Accommodation and Communications

The Organization Committee secured special rates (on the European plan, with baths) for attendees at the Shoreham (now the Omni Shoreham) Hotel, the Meeting's headquarters. The Shoreham, at 2500 Calvert Street, N.W., just west of Connecticut Avenue, was about 2.7 kilometers northwest of the Chamber of Commerce Building, but could easily be reached by streetcar or taxi service. The Shoreham charged US$4 for a double (two-bed) room and US$3 for single-bed accommodation. The organizers expected that meals there and at other hotels or at restaurants in Washington would require less than US$2–$3 per day. The Committee asked that mail and telegrams for members of the 16th IGC be sent to the addresses in NYC, San Francisco, or Washington, but they also established "Intergeol Washington" for all cable and radio messages.

Opening Sessions

The Council's membership, specified by Article IX, included (no more than) six representatives from the Organization Committee—Bain, Berkeley, Blackwelder, Henry Kümmel (New Jersey State Geologist), Frederick Ransome (CalTech and ex-USGS), and David White—plus official delegates (from national governments and academies, and directors of national surveys and university institutions), and selectees (Charles Wright [the American Vice-Consul in Rome], Arthur Smith Woodward [Sussex and ex-British Museum of Natural History], B. P. Nekrasov, Dimitri Perkin, and Nikolai Svitalsky [all from the USSR's newly renamed All-Union Geological Exploration Administration], Ferguson, Goldman, and Mathews). The Council met initially at 9.30 a.m. on Saturday, 22 July, and each weekday thereafter at 9.40 a.m. As before, the Council approved the Officers (Bureau), including as Vice Presidents all government delegates. The opening meeting of the General Assembly followed at 11.00 a.m. on the 22nd. There, Past General Secretary Hall (representing Past President Rogers), U.S. Secretary of the Interior Harold Ickes, President Lindgren, GSA President Leith, and General Secretary Mendenhall welcomed the attendees and wished them a successful meeting. Lindgren, remarking on the day's heat and humidity, advised them follow the Roman practice of making haste slowly.

Scientific Sessions

The eighteen half-day scientific sections at the Chamber of Commerce Building comprised from one to four sequences of selected formal papers and discussions held at 10.00 a.m. each morning and 2.00 p.m. each afternoon. Ten of the sections ran concurrently in pairs to accommodate the 116 selected presentations; another fifty papers were given only by title. Presenters invited to speak for fifteen to twenty minutes received ten additional minutes for discussion; those limited to five or ten minutes were allocated five minutes of discussion.

Concurrent sections in the afternoon of 22 July evaluated Appalachian orogenesis and measuring geologic time. Franz Eduard Suess (Vienna) compared mountain systems in Europe and North America. Hans Stille (University of Berlin) contrasted tectonic regimes on those continents. And Arthur Bevan (Director, Virginia Geological Survey) and three other U.S. geologists described structures and times of orogeny in the northern and central Appalachians. Alfred Lane's

(MIT) “Rating the Geologic Clock,” began the section on measuring geologic time, to which Wilbur Foye (Wesleyan College), Jakob Johannes Sederholm (Geological Commission of Finland), Keyes, and Ernst Antevs (Auburn, Maine) evaluated measurements and correlations in the Precambrian and the Quaternary. Among that section’s six by-title papers were Gerard de Geer’s review of international geochronology, Ebba de Geer’s (Stockholm) “teleconnection of geochronology and historical time”, Johann Koenigsberger’s (Freiburg in Baden) discussion of remnant magnetism and time, and Iosef Starik’s (Academy of Sciences, Moscow) assessment of the “lead method” of isotopic geochronology.

Two morning sections on 24 July treated fossil man and contemporary faunas and the geology of petroleum. In the former section, after Victor Madsen (Geological Survey of Denmark) reported the work of the IGC’s Commission for the Study of Fossil Man, other colleagues reviewed human fossils and associated faunas on continents and individual countries—Arthur Smith Woodward for the “Old World,” Louis de Lóczy (Hungarian Geological Survey) for Hungary, Raymond Dart (University of Witwatersrand) for southern Africa, and Davidson Black (Geological Survey of China, Peiping [Beijing]) for China. Smith Woodward proposed that humans originated in Tanganyika (now Tanzania) and subsequently spread to Britain, China, Java, and other parts of Eurasia. John Merriam (President, Carnegie Institution) organized and summarized papers by Chester Stock (CalTech), Barnum Brown (AMNH), and Edwin C. Eckel (Washington, D.C. and ex-USGS) about post-Pleistocene occurrences, principally at Folsom and other sites in the southwestern USA and in the Appalachians. Jorge Broggi (Lima), Ivan Gubkin (of the USSR’s newly renamed All-Union Geological Exploration Administration), Irving Levorsen (Tulsa), Frank Clark (Mid-Kansas Oil and Gas), Tasia Stadnichenko (USGS), and Pratt discussed the tectonics, paleogeography, origin, and accumulation (in-place or migrant) of petroleum, but papers by Stanislav Zuber (Rome), Parker Trask (USGS), and Chitani Yoshinosuke (Imperial Geological Survey of Japan) on Ponto-Caspian occurrences, source beds, and Japan’s petroleum appeared only by title. Pierre Teilhard de Chardin, SJ’s (Geological Survey of China) evaluation of the “piedmont method” in continental geology led the afternoon’s eight miscellaneous, but mostly paleontological, papers. This section’s five by-title papers included Mushketov’s review of Soviet glaciology since 1913 and a description by S. K. Girin, and four colleagues, of Soviet geophysical-prospecting methods.

On 25 July, the program devoted single morning and afternoon sections to batholiths and related intrusive bodies. Hans Cloos’ (Bonn) discussion of pluton structure and orientation in relation to crustal movement began the morning’s sequence of seven papers, which also included presentations on the origin and derivations of granites, and reports on intrusives in the Belgian Congo and Norway. In the afternoon, Arthur Buddington (Princeton), Joe Peoples (Wesleyan University), and Norman Bowen (Carnegie Geophysical Laboratory) reviewed batholiths, phacoliths, sills, and other intrusions in the Appalachians, Montana, and Idaho; and Arnold Heim (Zürich) evaluated batholiths in Tibet. Key contributions about mechanics and differential anatexis by Franc Loewinsson-Lessing (Academy of Sciences, Leningrad) and by Pentti Eskola (University of Helsinki) appeared only by title. The twelve oral papers in concurrent morning and afternoon sections evaluated stratal sequences, boundaries, biotas, and correlation (mostly by fossils rather than unconformities) of major divisions of the Lower and Middle portions of the Paleozoic Era in Britain, Spain, Germany, Scandinavia, Japan, China, and North America by Otto Schindewolf (Prussian State Geological Survey, Berlin), Edward Ulrich (U.S. National Museum and ex-USGS), Kobayashi Teiichi (Tokyo Imperial University), Armand Renier (Director, Geological Survey of Belgium and University of Liège), Wilhelmus Jongmans (Netherlands Mines Bureau), Amadeus Grabau and Ting Ven King (Academia Sinica, Nanking [Nanjing]), and Raymond Moore (University of Kansas). Dimitri Nalivkin’s (Mining Institute, Leningrad) overview of the Soviet Paleozoic formed one of three by-title contributions.

The sections on 26 July offered thirteen miscellaneous papers. The morning’s initial three presentations discussed aspects of paleogeography, stratigraphy, and tectonics in Morocco, other French possessions (by the Ministry of Colonies’ Henry Hubert), and Hungary (by Lóczy). This section continued with assessments of U.S. cryptovolcanic structures (by the University of Cincinnati’s Walter Bucher), the role of bentonite-based correlations in the Ordovician of eastern North America, and how data from a 1932 earthquake in Nevada influenced ideas about the genesis of Basin-Range structure in western North America. Presentations during the afternoon focused on geologic maps. Stose reviewed his new map of the United States and Nelson Darton (USGS) discussed his in-progress revision of his coverage of the Washington area. Darton, with the late George Williams, had prepared a 1:62,500 geologic map of the Washington area for the 5th IGC (Nelson, 2006, p. 284). This map, updated in cooperation with Keith, appeared as the “Historical Geology Sheet” in 1901 in the Washington Folio of the *Geologic Atlas of the United States*. The USGS published Darton’s second revision on two sheets at 1:31,680 in 1947. Four European geologists then presented new coverage (at 1:500,000 to 1:2,000,000) of four parts of Africa—the Belgian (now Republic of) Congo, by Paul Fourmarier (Liège); Algeria, by Gaston Bétier (Algiers); Spanish Morocco (now Western Sahara), by Augustin Marin y Bertran de Lis (Madrid); and Eritrea, Somalia, and Ethiopia, by Giuseppe Stefanini (University of Pisa). Heim completed these reviews by discussing the 1932 geologic map of Switzerland, on four sheets, at 1:200,000.

Five papers in the third section on Paleozoic divisions, convened during the morning of 27 July, completed the review by analyzing the Upper Paleozoic. Arthur Walkom (Sydney) discussed the boundaries of the Permian in Australia; Alexander du Toit (Johannesburg) detailed the division of the Upper Paleozoic in Gondwanaland; Ting and Grabau assessed the Permian of China; David White described the American Permian; and Charles Schuchert (Yale) reviewed the correlation of “important” Permian sequences. The by-title papers included a summary of the Permo-Carboniferous in Australia, by William Edgeworth David (Sydney), and the Permian in the Urals, by biostratigrapher Georgii Fredericks.

The 16th IGC’s held its three remaining sections on orogenesis—with worldwide coverage of “crustal disturbance, regional correlations, and classifications of rock structures” (Mendenhall, 1933, p. 248)—two on 27 July and the third during the morning of the 29th. Fourmarier proposed a rule of symmetry for the architecture of Earth’s crust, Heim evaluated energy sources (solar, rotational, and axial) for the Earth’s crustal movements, and Tokuda Sadazaku (Tokyo) analyzed three types of mountain arcs. But most of the papers treated topics in countries, regions, or single continents. Only Heim and Tokuda mentioned global continental drift as an overriding concept. “Even if we do not accept A. Wegner’s theory in its entirety”, Heim observed, “certain displacements accompanied by compression in one region and by extension in another, as well as the apparent differences in the amount of displacement in latitude and longitude of different continental blocks, can hardly be explained otherwise than by accepting the idea of continental drift, at least in a restricted sense" (Mendenhall, and others, 1936, p. 914).

On 15 November 1926, the AAPG had convened in NYC, as part of its annual meeting, a symposium on the theory of continental drift as proposed by Alfred Wegener. Published initially in an article in 1912, Wegener expanded his model in four German editions (1915–1929) of a book-length version, of which the third (1922) appeared in English and French in 1924. Willem van Waterschoot van der Gracht, a former Director of the Netherlands Geological Service, but then Vice President of Marland Oil, introduced and summarized a sequence of presentations about the model's viability by nine American and four European geologists. Frank Taylor (who had proposed his own concept of continental displacement in 1910) strongly favored drift, but six of the other Americans—including Chamberlin, Chester Longwell (Yale), Schuchert, and Willis—rejected Wegener's ideas principally for lack of a workable propelling mechanism. Wegener thought their objections unjustifiable, but the proceedings, published in 1928, continued to influence opinions in America (see Oreskes, 1999). The 16th ICG's Program Committee invited Wegener to discuss his ideas of worldwide continental displacement at the meeting before they learned that he had died in November 1930 while returning from resupplying a scientific station on Greenland's ice-cap. Waterschoot van der Gracht, who might have tested opinion again in a larger international audience, left the USA in 1928 and became Director of the Netherlands Bureau of Mines in 1932. He submitted for the 16th IGC's orogenesis sections only a by-title analysis of the Late Paleozoic orogeny in North America.

While the second section on orogenesis convened in the afternoon of 27 July, a concurrent section discussed "geomorphogenic" processes and products in arid regions. Among its papers were Kenneth Sandford's (Oxford) analysis of the role of peneplains in the development of the Libyan Desert, Richard Russell's (Louisiana State University) analysis of the desert-rainfall factor in denudation, Nils Hõrner's (Geological Institute, Uppsala) description of physiographic processes on Central Asia's continental basins, Kirk Bryan's (Harvard) ideas about pediment formation, Blackwelder's "insolation" hypothesis of rock weathering, and George Barbour's (Geological Survey of China) discussion of China's loess. William Morris Davis' (Pasadena and ex-Harvard) views about desert "geomorphogeny" appeared only by title. While these two sections proceeded, other attendees met to form an "International Paleontologic Union", adopt a constitution and by-laws, appoint a ten-member organization committee (with Rudolf Richter [Frankfurt] as Chairman and Benjamin Howell [Princeton] as Secretary), and plan to meet at future IGCs.

Two additional sections, on the mornings of 27 and 29 July, evaluated the geology and zonal relations of copper and other metalliferous deposits. Their general papers included an analysis by William Emmons' (Director, Minnesota Geological Survey and Professor, University of Minnesota) of hypogene zoning in lodes, Svitalsky's views on zonal distribution of ore deposits, and Paul Niggli's (University of Zürich) by-title study of geochemistry as it related to this zoning. Five other presentations looked at zoning in specific mines and mining districts in North America and Europe. Teodoro Flores (Geological Institute of Mexico), Heim, Nekrasov, and Walter Weed (Scarsdale, NY) offered discussions of specific copper-ore districts in Mexico, Spain, the USSR, and the USA. The section closed with Jacques Thoreau's (Louvain) review of uranium ores from Shinkolobwe-Kasolo in the Belgian Congo's Katanga Province and Manuel Santellán's (Mexico City) twin presentations about beryllium and silver in Mexico.

Commissions and Committees

Ten International Commissions—Crust of the Earth, Distribution of the Karroo (Gondwana) System, Fossil Man (reestablished in 1929), Geologic Map of Africa, Geologic Map of Europe (1:500,000), Geologic Map of the World (1:5,000,000), Geophysics and Geothermics, Lexicon of Stratigraphy (volumes on Africa, America, Asia, Australasia, and Europe), *Paleontologica Universalis*, and Spendiarov Prize (see Milanovsky, 2004)—met during the 16th IGC to report progress and plan future work. The Council agreed to discontinue the IGC's Commission on Glaciers in favor of the equivalent committee of the International Geophysical Union. The Council also approved the formation of a new Commission on Authors' Abstracts. On 26 July, the 16th IGC's Spendiarov Committee—John Flett (Chairman and Director, British Geological Survey), Hall, Gubkin, Matthews, and Stille—awarded its Prize, established during the 7th IGC at St Petersburg in 1897 but given only four times since the initial award in 1903, to Thomas Nolan (USGS, see Figure 4) as the host country's most promising young geologist.

Figure 4. Thomas Brennan Nolan (1901–1992) in 1956; Spendiarov Prize, 16th IGC; Assistant Director (1944–1956) and Director (1956–1965), USGS; NAS, 1951; Vice President, IUGS, 1964–1972 (USGS).

Entertainment and Exhibits

The Chamber of Commerce provided afternoon tea daily between 4.30 and 5.30 p.m. Most talks and other evening activities in Washington were held at the Shoreham. On 22 July, the Geological Society of Washington reception featured Douglas Johnson's (Columbia) "A Geomorphic Traverse of the United States", followed by a "smoker". Dr and Mrs Whitman Cross hosted an afternoon garden party on 23 July at their home near Connecticut Avenue and just north of Chevy Chase Circle. That evening, Hellmut de Terra (Yale) discussed his scientific exploration of the Himalayas and the Karakoram Mountains. The USBM screened its new film about the evolution of the oil industry on 24 July. For attendees not participating in Excursions B-5 and B-6, which departed on the evening of 25 July, Frank Adams (McGill) evaluated the importance of Charles Lyell's work on the 100th anniversary of the publication of Volume III of his *Principles of Geology*. On 26 July, Victor van Straelen (Brussels) described the Albert National Park in the Belgian Congo. The NAS hosted on 27 July a reception for all attendees at its headquarters (1924) at 21st Street and Constitution Avenue, N.W. The Regents and the Superintendent of Virginia's Mount Vernon received attendees at the home of General and President George Washington at 5.00 p.m. on 28 July.

Sixty-eight women—forty-three from the USA and twenty-five from other countries—registered for the 16th IGC as members or accompanying members. In addition to Ebba de Geer's by-title paper, and Taisia Stadnichenko's presented paper, Florence Bascom (Smith and USGS), Winifred Goldring (New York State Museum), Anna Jonas (later Stose, USGS), and Eleanora Bliss Knopf (New Haven) co-authored four of the guidebooks. Julia Gardner (USGS), like Goldring, Jonas, and Knopf, one of Bascom's former students, also participated in the 16th IGC. The American Association of University Women's National Club extended to all women attendees the privileges of its National Club House at 1634 I Street, N.W. Special sightseeing excursions for them, organized by the thirteen-member Women's Local Entertainment Committee, chaired by Mrs. Charles Wright, departed in private automobiles from the Shoreham during 24–28 July for tours of Arlington National Cemetery, the Folger Shakespeare Library, the Lincoln Memorial, the National Cathedral, the Pan American Union, the Washington Monument, and other sites of historical and cultural interest in the greater metropolitan area.

The Chamber of Commerce Building provided space for attendees and organizations to exhibit their publications and scientific specimens. The USGS displayed aspects of its operations and products at a site in the Interior Department Building near its offices.

On 27 July, at 12.30 p.m., 355 of the attendees assembled (by prior notice) around Lindgren and Mendenhall in the CCB's courtyard (since built over) for a group photograph. That image appeared as a folding plate, facing the key on page 54 of the 16th IGC's Report (Mendenhall and others, 1936).

Guidebooks for Field Trips

The U.S Government Printing Office published (1932–1933) thirty guidebooks (G), to which 156 geologists contributed information, that aided nineteen local, regional, and national excursions by car, bus, rail, and (or) air before (A), during (B) and after (C) the meeting in Washington. Costs for these trips ranged from US$5 to US$360:

G1 / A-1:	Eastern New York and Western New England
G2 / A-2:	Mining Districts of the Eastern States
G3 / A-3:	Southern Appalachian Region
G4 / A-4:	The Paleozoic Stratigraphy of New York
G5 / A-5:	Chesapeake Bay Region [Coastal Plain]
G6 / A-6:	Oklahoma and Texas [oil fields]
G7 / A-7:	Geomorphology of the Central Appalachians
G8 / A-8:	Mineral Deposits of New Jersey and Eastern Pennsylvania
G9:	New York [City] and Vicinity
G9a:	New York [State] II
G10 / B-1,-2,-3:	Southern Pennsylvania and Maryland [mines and structure]
G11 / B-4,-5,-6:	Northern Virginia [geomorphology, stratigraphy, and structure]
G12 / B-7:	Southern Maryland [Coastal Plain]
G13 / C-1:	Western Texas and Carlsbad Caverns
G14 / C-1:	Ore Deposits of the Southwest
G15 / C-1:	Southern California
G16 / C-1;	Middle California and Western Nevada
G17 / C-1:	The Salt Lake Region
G18 / C-1, -2:	Colorado Plateau Region
G19 / C-1:	Colorado [State]
G20 / C-2:	Pennsylvanian of the Northern Mid-Continent
G21 / C-2:	Central Oregon
G22 / C-2:	The Channeled Scabland
G23 / C-2:	The Butte Mining District
G24 / C-2:	Yellowstone-Beartooth-Big Horn Region
G25 / C-2:	The Black Hills
G26 / C-3:	Glacial Geology of the Central States
G27 / C-4:	Lake Superior Region [copper and iron deposits]
G28:	An Outline of the Structural Geology of the United States
G29:	Stratigraphic Nomenclature in the United States
G30 / A-2, -6; C-1, -2, -3, -4:	The Baltimore & Ohio Railroad (New York–Washington–Cumberland–Chicago or St. Louis)

Berkey chaired a committee that arranged the A Series of field trips and he led A-8. Ferguson oversaw the planning for the B and C Series and the publication of all the guidebooks. Of the two month-long transcontinental excursions by special Pullman-equipped trains, Lindgren led C-1 and Richard Field (Princeton) led C-2. To further aid C-1, Darton (1933) prepared the sixth part—the Southern Pacific's route from New Orleans to Los Angeles—of the *Guidebook of the Western United States*, a series of volumes about the geology and topography of other railroad routes to and along the West Coast that also appeared as USGS Bulletins during 1912–1922. Leighton led C-3 and Leith co-led C4. The 16th IGC also published a guide to the scientific institutions of Washington, the latter to supplement three in-city excursions repeated each weekday—B-8a, the Smithsonian Institution, including the National Museum [1910]); B-8b, the National Bureau of Standards and the Carnegie Geophysical Laboratory and its Department of Terrestrial Magnetism; and B-8c, the Library of Congress, the Folger Shakespeare Library, and the Pan American Union.

Invitation for the 17th IGC

On 24 July, during the Council's second meeting, Lindgren called for invitations for the next IGC. Gubkin, in renewing the USSR's offer in 1929, invited the IGC to hold its next meeting in Moscow or Leningrad. Flett, speaking for the British delegation, but unable to offer a firm invitation, asked for time to consult more widely about holding the meeting in London in 1936 to mark the 100th anniversary of the BGS. When the Council met on 25 July, Mendenhall read Gubkin's letter of invitation. On July 28, the Council voted 32–0 to accept the invitation of the USSR, then the only definite offer, to hold the 17th IGC in Moscow.

Closing Session

The General Assembly convened for its closing meeting during the afternoon of 28 July. Mendenhall read President Roosevelt's greeting and his hope that the meeting was "proving to be enjoyable and constructive" (Mendenhall, 1936, and others, p. 77). Flett, Sederholm, and Lindgren (the last in four languages) expressed their thanks to the organizers of the 16th IGC, the USGS, and the GSA. Lindgren, "more than ever impressed with the value of contacts among geologists," said he was convinced that scientists were "working together harmoniously for the advancement of knowledge of this earth" (ibid., p. 92).

Epilogue: Financial Summary and Final Report, 1936

The 16th IGC balanced its financial books. The meeting's receipts totaled US$151,122, not counting the US$50,000 the USGS provided for preparing and printing the guidebooks and the geologic map of the United States. In addition to the sums received from the GSA and the AAPG, the American Geographic Society sent US$100 and individual donors gave US$2,885, registrations and excursions brought in an additional US$51,294, and publication sales, the Spendiarov Prize, and deposit interest yielded another US$5,843. Disbursements of US$144,152—US$10,733 for administration, US$79,175 for excursions, foreign guests, and meetings, US$54,912 for publications, and US$332 for the Spendiarov Prize and check tax—left a balance of US$5,970 for the estimated bills payable as of 26 March 1936.

Mendenhall published an interim summary of the 16th IGC in *Science* for 22 September 1933. The meeting issued its report on copper, edited by Notman's committee, in two volumes in 1935. The 16th IGC's two-volume Report appeared in 1936. It printed forty-five papers and forty-five abstracts, most being accompanied by illustrations, maps, discussions, and references. Since 1933, some authors had submitted papers to accompany their abstracts and others reduced their papers, already published elsewhere, to abstracts. The Report's second volume also contained the scientific reports of the IGC's Commissions, including those by Dart and other members of seventeen of the Commission on Fossil Man's twenty-four geographic subcommissions.

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The Global Boundary Stratotype Section and Point (GSSP) of the Guzhangian Stage (Cambrian) in the Wuling Mountains, Northwestern Hunan, China

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The Global boundary Stratotype Section and Point (GSSP) for the base of the Guzhangian Stage (Cambrian Series 3) is defined at the base of a limestone (calcisiltite) layer 121.3 m above the base of the Huaqiao Formation in the Louyixi section along the Youshui River (Fengtan Reservoir), about 4 km northwest of Luoyixi (4 km southeast of Wangcun), in northwestern Hunan, China. The GSSP is exposed in a road cut at a position of 28°43.20' N and 109º57.88' E. The GSSP level contains the lowest occurrence of the cosmopolitan agnostoid trilobite Lejopyge laevigata *(base of the* L. laevigata *Zone). Secondary global markers near the base of the stage include the appearance of either* L. calva *or* L. armata *just below the base of the stage, the appearance of conodonts associated with the base of the* Laiwugnathus laiwuensis *Zone, and the transgressive phase of a small eustatic event. Faunal turnovers close to the base of the Guzhangian Stage are recognized as near the base of the Boomerangian Stage in Australia, the base of the* Aldanaspis *Zone (polymerid trilobites) in Siberia, and the base of the* Paradoxides forchhammeri *Zone in western Avalonia. The horizon corresponding to the first appearance of* L. laevigata *is near the peak of a rather long negative* $\delta^{13}C$ *excursion of up to 0.58 ‰.*

Introduction

The International Subcommission on Cambrian Stratigraphy (ISCS) has recommended a subdivision of the Cambrian System into four series (Babcock et al., 2005; Peng, 2006; Peng et al., 2006). Within each series it is expected that two to three stages whose boundaries correspond to horizons that can be correlated with a high degree of confidence through all paleocontinents will be recognized. As emphasized by Geyer and Shergold (2000), communication of time-stratigraphic information will be maximized if the internal subdivisions of the system correspond to horizons recognizable on all paleocontinents. Traditional, regional stratigraphic schemes, based principally on unit stratotypes, do not meet this goal, and it is for this reason that the ISCS is now engaged in further developing our understanding of key horizons for correlation within the Cambrian, and newly defined series and stages that are readily traceable among Cambrian regions. The newly defined chronostratigraphic units are based on the principle of boundary stratotypes, in which the base of one unit (marked by a Global boundary Stratotype Section and Point, or GSSP) automatically delimits the top of the underlying unit. So defined, these intervals differ in substance from unit stratotypes, which have been variously defined in Cambrian regions (Geyer and Shergold, 2000; Peng et al., 2004a, 2006; Babcock et al., 2005). Apart from the Guzhangian Stage (discussed here), the boundary positions relevant to the Cambrian (Figure 1) that have been ratified are: 1, the conterminant base of the Paleozoic Erathem, Cambrian System, Terreneuvian Series, and Fortunian Stage (Brasier et al., 1994; Landing, 1994; Gehling et al., 2001; Landing et al., 2007); 2, the base of the Drumian Stage (Babcock et al., 2007); 3, the base of the Furongian Series and Paibian Stage (Peng et al., 2004a); and 4, the base of the Ordovician System (Cooper et al., 2001).

At least 11 candidate horizons for global chronostratigraphic correlation have been identified in the upper half of the Cambrian System, based on the first appearance datum (FAD) horizons of intercontinentally distributed agnostoid trilobites (Geyer and Shergold, 2000). To date, three of them have been chosen as the primary stratigraphic tools for correlation of the bases of stages, i.e. the FAD of *Ptychagnostus atavus* for the Drumian Stage, the FAD of *Lejopyge laevigata* for the Guzhangian Stage, and the FAD of *Glyptagnostus reticulatus* for the Paibian Stage. The FAD of the intercontinentally distributed agnostoid trilobite *Lejopyge laevigata* is one of the most

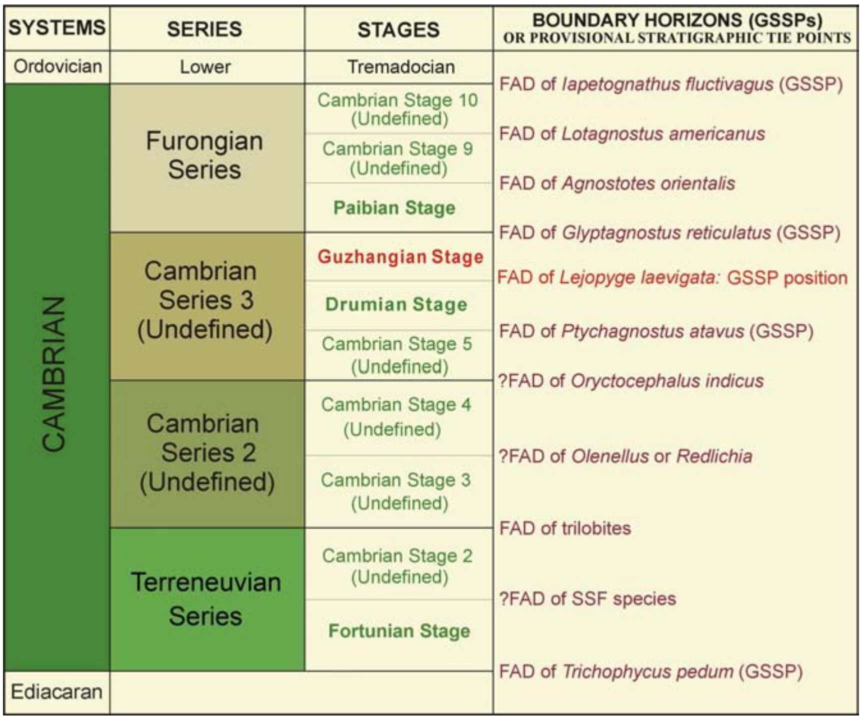

Figure 1. Chart showing working model for global chronostratigraphic subdivision of the Cambrian System, indicating lower boundary of the Guzhangian Stage (modified from Babcock et al., 2005).

recognizable levels in the Cambrian (Geyer and Shergold, 2000; Peng and Babcock, 2001; Peng et al., 2001, 2004a; Babcock et al., 2005). A position corresponding closely to the first appearance of *L. laevigata* is recognizable in strata of Gondwana, Baltica, Laurentia, Kazakhstan, and Siberia (e.g., Öpik, 1961, 1979; Ergaliev, 1980; Robison, 1984, 1994; Laurie, 1989; Geyer and Shergold, 2000; Peng and Robison, 2000; Peng and Babcock, 2001; Peng et al., 2001, 2006; Shergold and Geyer, 2003; Babcock et al., 2005, Axheimer et al., 2006), and can be identified with precision using multiple lines of evidence.

The purpose of this paper is to announce ratification of the Guzhangian Stage, the base of which coincides with the FAD of the cosmopolitan trilobite *Lejopyge laevigata*. The GSSP for the base of the new stage is 121.3 m above the base of the Huaqiao Formation in the Louyixi section (formerly called the Wangcun South section; Peng et al., 2004c; Peng, 2005; Peng et al., 2005) along the Youshui River (Fengtan Reservoir), about 4 km northwest of Luoyixi (4 km southeast of Wangcun), in northwestern Hunan, China; Figs. 3, 5, 6, 10). Of the methods that should be given due consideration in the selection of a GSSP (Remane et al., 1996), biostratigraphic, chemostratigraphic, paleogeographic, facies-relationship, and sequence-stratigraphic information is available (e.g., Peng and Robison, 2000; Peng et al., 2001, 2004b), and that information is summarized below. The section is easily accessible, and access for research is unrestricted. It is located on public land under permanent protection by the government of Guzhang County, Hunan. Government protection of this area, a well-known tourist area with a National Geo-Park, ensures continued free access to the site for research purposes.

For comparative purposes, the FAD of *L. laevigata* in another excellent section, the Wangcun section, located on the north bank of the Youshui River (opposite the Luoyixi section), Yongshun County, Hunan Province, China (Peng et al., 2001), is also discussed. The FAD of *L. laevigata* occurs 121.3 m above the base of the Huaqiao Formation in the Wangcun section (Peng et al., 2001, 2004b, 2004c). The boundary interval containing the FAD of *L. laevigata* in the Wangcun section also fulfills all of the geological and biostratigraphic requirements for a GSSP, and is located along a roadcut for which free access for research purposes is granted.

Stratigraphic Rank of the Boundary

The base of the Guzhangian Stage (Figs. 1, 2) will be embraced by a Cambrian series to be named at a future date. Currently the unnamed series is referred to as undefined Cambrian Series 3 (Babcock et al., 2005, 2007; Peng et al., 2006; Figs. 1, 2). The Guzhangian Stage is the third (uppermost) of three stages included in Cambrian Series 3. The base of the stage automatically defines the top of the Drumian Stage, and limits the Drumian to four globally recognized agnostoid trilobite zones, the *Ptychagnostus atavus* Zone, the *Ptychagnostus punctuosus* Zone, the *Goniagnostus nathorsti* Zone, and the *Lejopyge armata* Zone. The boundary is a standard stage/age GSSP.

Geography and Physical Geology of the GSSP

Geographic Location

The Luoyixi section (Peng et al., 2006) is exposed along a roadcut situated on the south bank of the Youshui River, (Fengtan Reservoir), in the Wuling Mountains (Wulingshan). A number of counties, including Guzhang County, border the river in northwestern Hunan Province, China. The Youshui River forms the boundary between Guzhang County (to the south) and Yongshun County (to the north) in this area (Figs. 3, 4). The roadcut along the opposite bank of the river, which contains the same succession of strata, is referred to as the Wangcun section. Previously, the Luoyixi section was referred to informally as the Wangcun South section (Peng et al., 2004c, 2005). The position of the section is in a roadcut delimited by a cliff represented on topographic map H49 G 0790032, 1:10,000 scale (Surveying and Mapping Bureau of Hunan Province, 1991, 1:10,000 scale; Figure 3D). The Luoyixi section exposes the uppermost part of the Aoxi Formation and more than 200 m of the overlying Huaqiao Formation. The boundary stratotype for the base of the Guzhangian Stage is in the lower portion of the Luoyixi section. The GSSP is exposed in a roadcut at a position of 28°43.20´ N latitude and 109º57.88´ E longitude (determined by handheld Garmin GPS), and at an elevation of approximately 216 m.

Geological Location

The Cambrian geology of northwestern Hunan, the site of the GSSP section, has been summarized in a number of publications, most notably Peng et al. (2001) and papers contained and cited therein. An overview of Cambrian paleogeography, biotic provinces, and

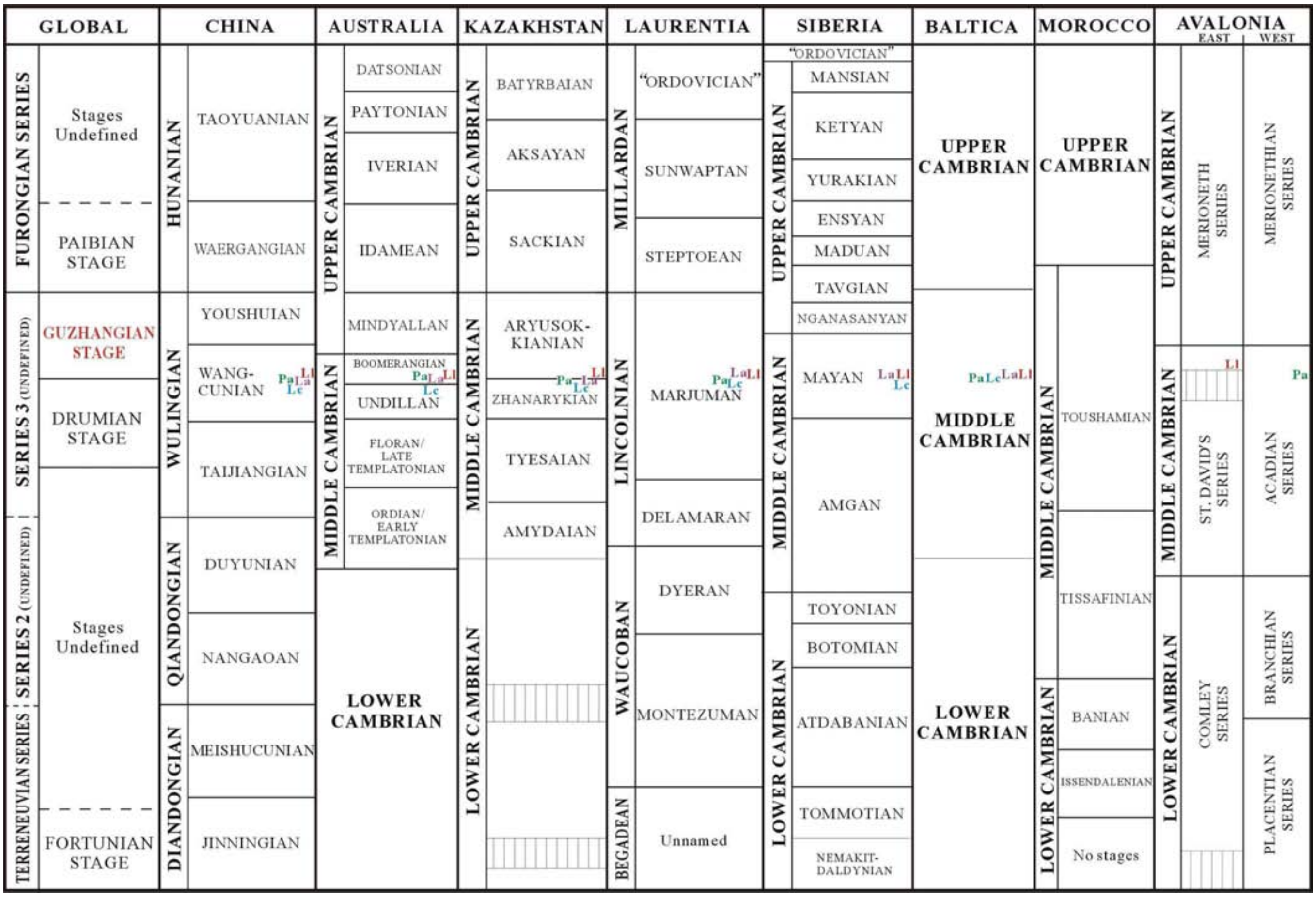

Figure 2. Correlation chart of the Cambrian showing the global chronostratigraphic stages compared to regional usage in major areas of the world (modified from Peng et al., 2004a). Ll indicates the presence and horizon of **Lejopyge laevigata** *in a region; La indicates the presence and horizon of* **Lejopyge armata** *in a region; Lc indicates the presence and horizon of* **Lejopyge calva** *in a region; Pa indicates the presence and horizon of* **Ptychagnostus aculeatus** *in a region. Chart compiled from numerous sources, summarized principally in Geyer and Shergold (2000) and Babcock et al. (2004).*

geologic history of the region is contained in Peng and Babcock (2001).

The Wuling Mountains consist of an extensive series of folded and thrusted slices resulting from post-Devonian compressional tectonics that extend through parts of northwestern Hunan, eastern Guizhou, and southeastern Sichuan provinces, China (Guizhou Bureau of Geology and Mineral Resources, 1987; Hunan Bureau of Geology and Mineral Resources, 1988). The Luoyixi section is situated on the southeast limb of an undulating syncline, the Liexi-Zhuitun Syncline. Cambrian strata of South China are assigned to three major depositional environments along a platform-to-basin transition (e.g., Pu and Ye 1991; Peng and Robison 2000; Peng and Babcock 2001). Relatively shallow environments of the Yangtze (South China or Southwest China) Platform were flanked by deeper environments of the Jiangnan Slope Belt, and still deeper environments of the Jiangnan Basin. The GSSP occurs within the Huaqiao Formation, which consists of a thick succession of carbonate beds deposited in the outer part of the Jiangnan Slope Belt (e.g., Pu and Ye, 1991; Rees et al. 1992; Peng and Robison, 2000; Peng and Babcock, 2001).

Location of Level and Specific Point

The first lenticular calcisiltite limestone layer of the Huaqiao Formation that contains the cosmopolitan agnostoid trilobite *Lejopyge laevigata* occurs 121.3 m above the base of the Huaqiao Formation in the Luoyixi section. The species is rare in this bed, but becomes more abundant upsection.

Stratigraphic Completeness

Detailed correlation of Cambrian Series 3 strata through northwestern Hunan, coupled with detailed biostratigraphy (Peng and Robison, 2000; Peng et al., 2004a, 2004b), sedimentology (Fu et al., 1999; Zuo, 2006; Zuo et al., 2006), and carbon-isotope chemostratigraphy (Zuo, 2006; Zuo et al., 2008; Figures 6, 7), demonstrates the stratigraphic continuity of the basal interval of the Guzhangian Stage in the Luoyixi section. Biostratigraphic studies within Hunan Province and globally demonstrate that the succession of trilobite species (e.g., Westergård, 1946; Daily and Jago, 1975; Öpik, 1961, 1967, 1979; Robison et al., 1977; Ergaliev, 1980; Egorova et al., 1982; Rowell et al., 1982; Robison, 1964a, 1964b, 1984, 1994; Laurie, 1988, 1989; Geyer and Shergold, 2000; Axheimer et al., 2006; Peng et al., 2006) and conodont species (Peng et al., 2006) in the Luoyixi section is undisturbed. The section lacks synsedimentary and tectonic disturbance in the GSSP boundary interval, although minor bedding-plane slippage, which is expected in an inclined succession of strata, occurs along some beds. Bedding-plane-slip surfaces do not appear to have resulted in any loss or repetition of stratigraphic

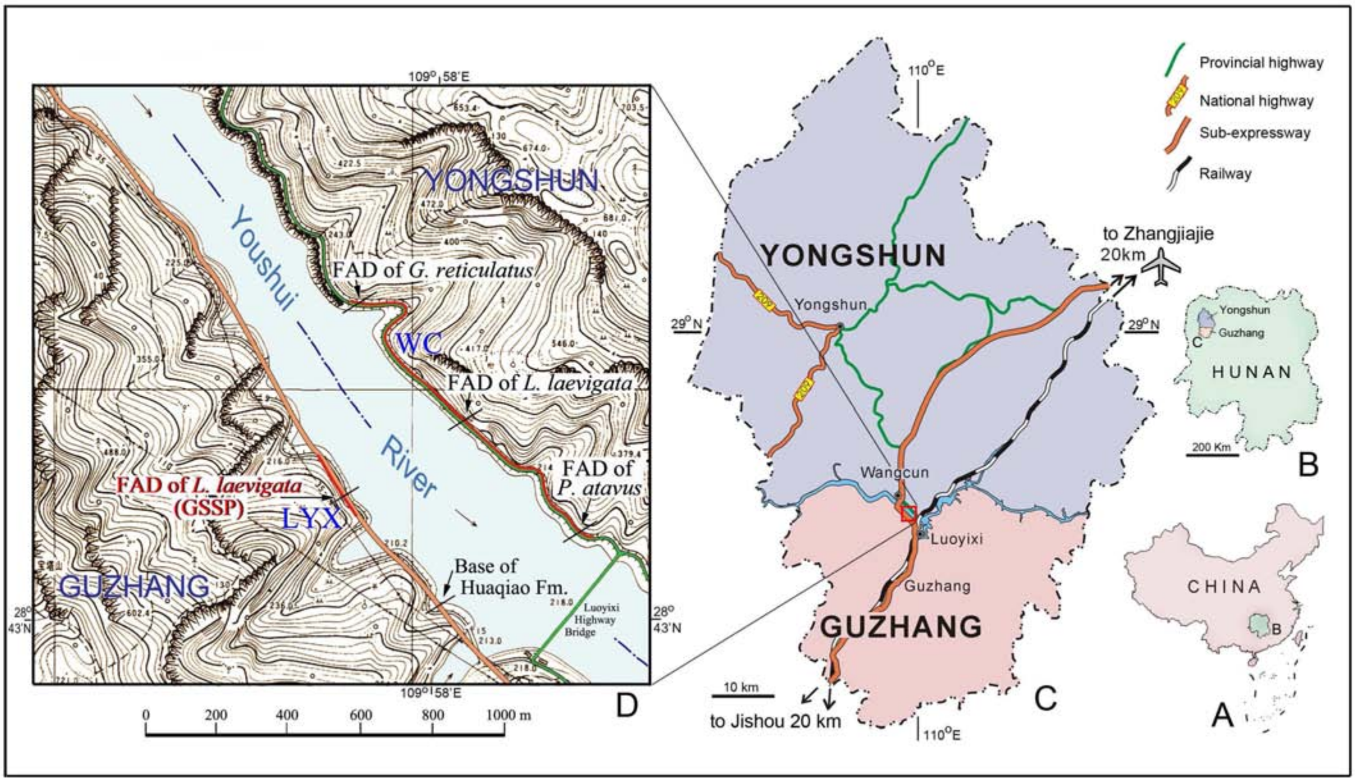

Figure 3. Topographic map of part of northwestern Hunan Province, China, along the Youshui River (Fengtan Reservoir), showing the position of the Luoyixi section (LYX, in northern Guzhang County) and the Wangcun section (WC, in southern Yongshun County). Part D of the figure is from topographic map H49 G 0790032 (Surveying and Mapping Bureau of Hunan Province, 1991, 1:10,000 scale). The position of the GSSP coincides with the FAD of **L. laevigata** *in the Luoyixi section.*

thickness, and the biostratigraphic succession in the section is unaffected. There appears to be no evidence of faulting resulting in either loss or repetition of section along the present exposure of the formation. Distal carbonate turbidite beds are present in the section, but weak turbidity currents do not appear to have disrupted the stratigraphic distribution of fossil taxa in the stratotype. Evidence of metamorphism and strong diagenetic alteration is absent.

Thickness and Stratigraphic Extent

In the Luoyixi section (Figure 5), the Huaqiao Formation consists of a succession of dark, thin-bedded, thinly laminated lime mudstones, argillaceous limestones, and fossiliferous limestone lenses; light-colored ribbon limestones are present in places. In the Wangcun-Luoyixi area, the Huaqiao Formation includes fine-grained carbonate turbidites and autochthonous carbonate sediments, mostly fine-grained, leading to the interpretation that it was deposited in the lower part of an outer slope-apron environment (Fu et al., 1999).

The basal contact of the Guzhangian Stage, marked by the FAD of *Lejopyge laevigata*, occurs in a mostly monofacial succession of dark gray to black limestones (lime mudstones, or calcimicrites and calcisiltites), and fine-grained argillaceous limestones interbedded with lenses of fossil-rich limestone (calcisiltite). The point where *L. laevigata* first appears occurs is the lower part of a 0.82 m-thick layer of dark gray, thinly laminated calcisiltite, overlying another layer of thinly laminated, dark-gray calcisiltite (Figure 5C, D). The basal contact of this bed in the Luoyixi section is observable up to the height of the roadcut. The total bedding plane length of the bed is approximately 28 m.

Provisions for Conservation, Protection, and Accessibility

The exposure containing the GSSP is not subject to building, landscaping, or other destruction. It is located on public land along a road leading to some popular tourist destinations, such as the Fengtan Reservoir, the Hongshiling (Forest of Red Rocks) National Geo-Park, and the historic town of Wangcun. The roadcut is to be permanently managed by the government of Guzhang County.

Access to the outcrop is essentially unrestricted in all seasons. Travel to Hunan is open to persons of all nationalities, and travel for scientific purposes is welcomed. Ordinary vehicles can be driven along the length of the section, and can be parked adjacent to the GSSP point.

Motivation for Selection of the Boundary Level and of the Stratotype Section

Principal Correlation Event (marker) at GSSP Level

The agnostoid trilobite *Lejopyge laevigata* (Figure 9H-J) has one of the broadest distributions of any Cambrian trilobite (e.g., Westergård, 1946; Pokrovskaya, 1958; Öpik, 1961, 1979; Palmer, 1968; Khairullina, 1970, 1973; Robison et al., 1977; Yang, 1978, Ergaliev, 1980; Egorova et al., 1982; Robison, 1984, 1988, 1994; Laurie, 1989; Lu and Lin, 1989; Yang et al., 1991; Dong , 1991; Tortello and Bordonaro, 1997; Geyer and Shergold, 2000; Peng and Robison, 2000; Jago and Brown, 2001; Babcock et al., 2004, 2005; Axheimer et al., 2006; Peng et al., 2006), and its first appearance has

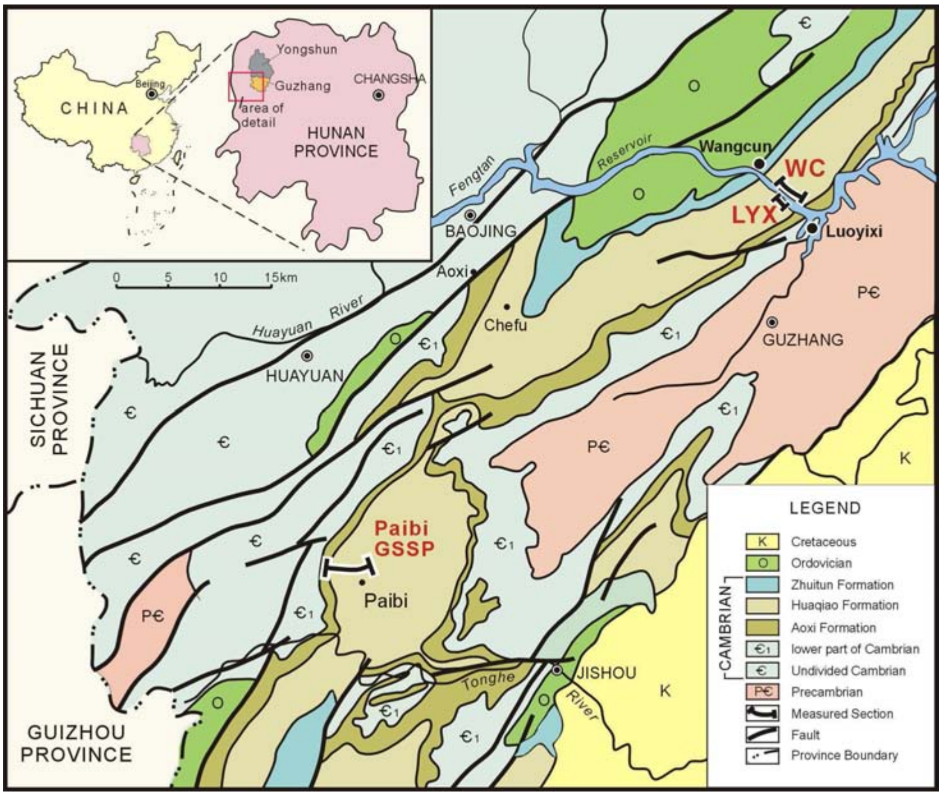

Figure 4. Map of part of northwestern Hunan Province (location of Hunan inset), China, showing location of the stratotype section for the Guzhangian Stage (Luoyixi section, south side of the Fengtan Reservoir, Youshui River; indicated as LYX). Location of the Wangcun section (north side of the Fengtan Reservoir, Youshui River) is indicated as WC. For reference, location of the Paibi section, stratotype of the Furongian Series and Paibian Stage (indicated as Paibi GSSP), is also indicated. Map modified from Peng et al. (2004b).

been acknowledged as one of the most favorable levels for a GSSP defining the base of a global Cambrian stage (e.g., Robison et al., 1977; Rowell et al., 1982; Robison, 1999, 2001; Geyer and Shergold, 2000; Shergold and Geyer, 2001; Babcock et al., 2004; Peng et al., 2006). Agnostoid trilobites provide the best and most precise tools for intercontinental correlation in the upper half of the Cambrian System (e.g., Robison, 1984; Peng and Robison, 2000). Recent recalibration of radiometric ages for the Cambrian (Grotzinger et al., 1995; Davidek et al., 1998; Landing et al., 1998, 2000), scaled against the number of agnostoid zones recognized in the upper half of the Cambrian, indicates that the average duration of an agnostoid-defined biochron is about one million years (Peng and Robison, 2000). *Lejopyge laevigata* has been identified from Argentina, Australia, China, Denmark, England, Germany (in glacial erratics), Greenland, India, Kazakhstan, Norway, Poland, Turkestan, Uzbekistan, Russia, Sweden, and the United States, and has been used as a zonal guide fossil in deposits of Baltica, Gondwana, Kazakhstania, Siberia, Laurentia, and eastern Avalonia (e.g., Westergård, 1946; Cowie et al., 1972; Robison, 1976, 1984; Öpik, 1979; Shergold et al., 1985; Geyer and Shergold, 2000; Peng and Robison, 2000; Axheimer et al., 2006; Peng et al., 2006). The base of the Boomerangian Stage in Australia corresponds to the base of the *L. laevigata* Zone (Öpik, 1967; Shergold et al., 1985; Geyer and Shergold, 2000; Axheimer et al., 2006). In western Avalonia, the base of the *Paradoxides forchhammeri* Zone corresponds approximately to the base of the *L. laevigata* Zone (Geyer and Shergold, 2000). By using the first appearance of *L. laevigata*, rather than its local abundance, the base of the Scandinavian *L. laevigata* Zone can be extended downward so that the revised *L. laevigata* Zone in Scandinavia embraces the traditional *Solenopleura? brachymetopa* Zone (Axheimer et al., 2006).

Stratigraphically, the first appearance of *Lejopyge laevigata* (Figures 5B-D, 6, 7) always succeeds the first appearance of at least one other species of *Lejopyge*. In China, Kazakhstan, and Tasmania, where three *Lejopyge* species are present, the stratigraphic order of appearance is *L. calva* (at times assigned to *Pseudaphalacroma dubium* or *Pseudophalacroma?* sp.), followed by *L. armata*, and then followed by *L. laevigata* (Jago, 1975, Ergalieva, 1980, Peng and Robison, 2000). In Antarctica, *L. calva* is also followed by *L. armata* (Cooper et al., 1996). In Laurentia, however, the order of succession is *L. calva* followed by *L. laevigata*, followed by *L. armata*. The reason for the discrepancy in the first appearance of *L. armata* in Laurentia is unknown, but it may relate to limits on the exposure of favorable biofacies and stratigraphic occurrence. Morphological features of *L. calva* suggest it may be an ancestor of both of *L. armata* and *L. laevigata*. Species of *Lejopyg*e always succeed the FAD of the agnostoid *Goniagnostus nathorsti*, which is the eponymous guide fossil for the *G. nathorsti* Zone, and they always succeed the FAD of *Ptychagnostus punctuosus*, which is the eponymous guide fossil for the *P. punctuosus* Zone. It is desirable to select the position of a GSSP in a section showing a complete succession from the *P. punctuosus* Zone (or the *G. nathorsti* Zone and the *L. armata* Zone if recognized regionally) through the *L. laevigata* Zone. In a complete succession, the LADs of both *L. calva* and *L. armata* should fall within the *L. laevigata* Zone, and *L. calva* should be in the lowermost part of the zone. Selection of the FAD of *L. laevigata* as the primary correlation tool for the base of a Cambrian stage ensures that the boundary will fall within a stratigraphic interval bearing agnostoid trilobites, many of which are phylogenetically related. Globally, the stratigraphic interval bearing the overlap between *L. calva*, *L. armata*, and *L. laevigata* is relatively narrow but widely recognizable. Together, the narrow stratigraphic overlap of *Lejopyge* species (if more than one species is present), and the stratigraphic disappearance of both *P. punctuosus* and *G. nathorsti*, allows the boundary to be tightly constrained as long as ptychagnostid-bearing strata are present in a region.

Selection of a GSSP in an open-shelf to basinal deposit, and particularly in one from a low-latitude region such as the South China (Yangtze) Platform, is desirable because it provides faunal ties and correlation with low-latitude open-shelf areas, high-latitude open-shelf areas, and low- or high-latitude, slope-to-basinal areas. In the latter half of the Cambrian, stratification of the world ocean according to temperature or other factors that covary with depth (e.g., Cook and

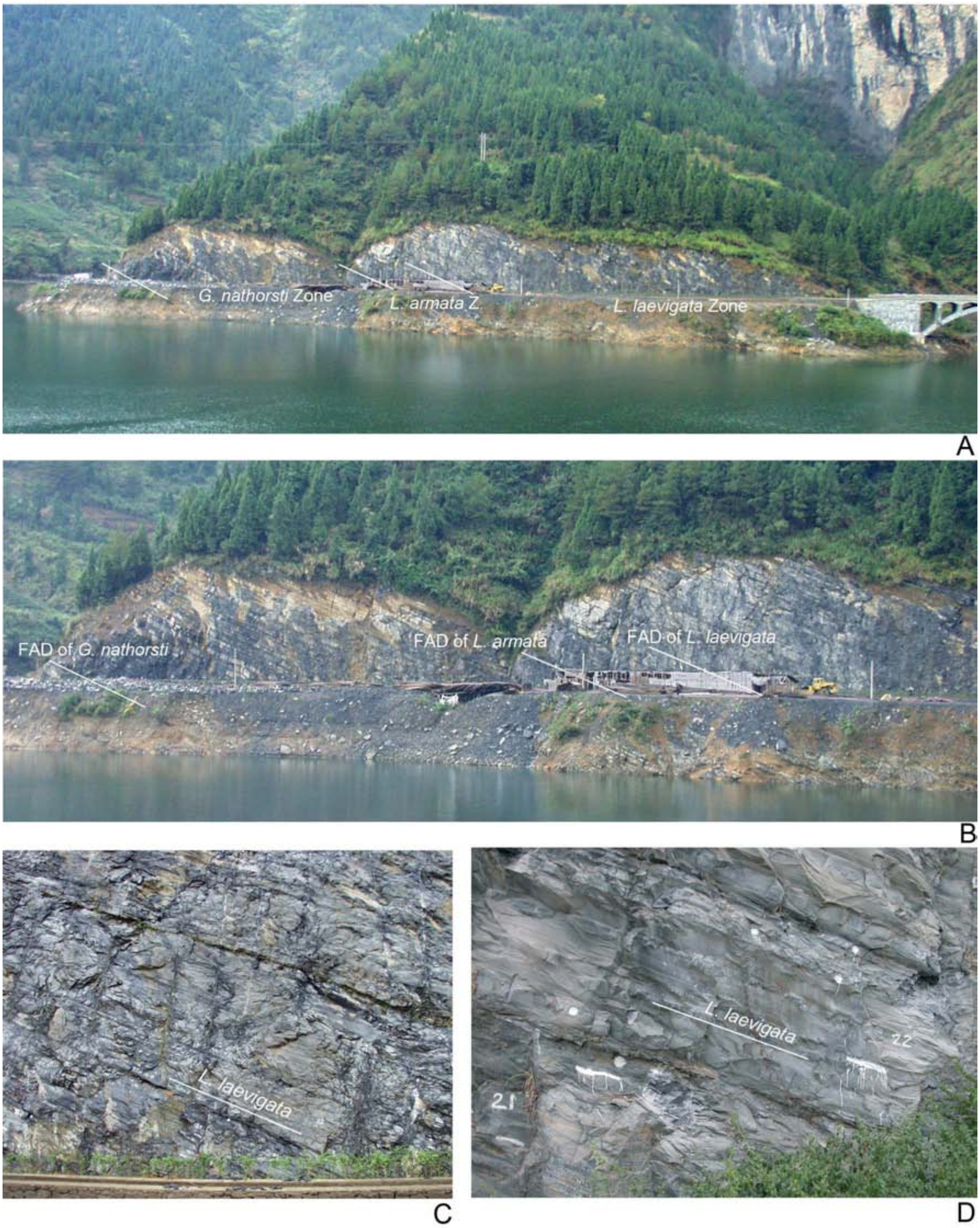

Figure 5. Exposure of the GSSP for the base of the Guzhangian Stage (coinciding with the FAD of* Lejopyge laevigata*) in the Huaqiao Formation, Luoyixi section, Guzhang County, Hunan Province, China. Strata underlying the Guzhangian GSSP belong to the Drumian Stage. A, Southwestern bank of Youshui River (Fengtan Reservoir) showing the Luoyixi section. B, Lower part of the Luoyixi section. C, D, Progressively closer views of the Luoyixi section showing the FAD of* L. laevigata *(marked by a white line), 121.3 m above the base of the Huaqiao Formation.

Taylor, 1975, 1976; Babcock, 1994) led to the development of rather distinct trilobite biofacies in shelf and basinal areas. Low-latitude shelf areas were inhabited mostly by endemic polymerid trilobites and some pan-tropical taxa. High-latitude shelf areas, and basinal areas of low and high latitudes, were inhabited mostly by widespread polymerid trilobites and cosmopolitan agnostoid trilobites. Slope areas are characterized by a combination of some shelf-dwelling taxa and basin-dwelling taxa. A combination of cosmopolitan agnostoids, which have intercontinental correlation utility, shelf-dwelling polymerids, which mostly allow for intracontinental correlation, and pan-tropical polymerids, which allow for limited intercontinental correlation, provides for precise correlation of the base of the *L. laevigata* Zone through much of Gondwana. Likewise, the combination of these taxa provides for precise correlation of the base of the zone into areas of

Baltica, Siberia, Laurentia, Kazakhstan, and eastern Avalonia, and reasonably good correlation into western Avalonia (Hutchinson, 1962; Geyer and Shergold, 2000).

Stratotype Section

The FAD of *L. laevigata* in the Luoyixi section, Hunan Province, China (Figures 3, 5, 6), occurs in the Huaqiao Formation at a level 121.3 m above the base of the formation (Figures 5C, 5D, 6). At this section, and in the Wangcun section as well, the Huaqiao Formation rests on the Aoxi Formation. The Aoxi-Huaqiao contact is inferred to be a sequence boundary representing a major eustatic rise (transgressive event). Agnostoid trilobite zonation of the Huaqiao Formation in the measured section reveals a complete, tectonically undisturbed, marine succession through much of the Drumian Stage (lower part of the *P. atavus* Zone through the *P. punctuosus*, *G. nathorsti* and *L. armata* zones), through all of the Guzhangian Stage, and into the overlying Paibian Stage (Furongian Series). The Huaqiao Formation in the Luoyixi section is a mostly monofacial succession of dark, fine-grained limestones (Figure 5). Small truncation surfaces, and slide surfaces reflecting distal turbidite deposition are rare in the section and absent near the GSSP, suggesting deposition in an outer slope to carbonate apron environment (Rees et al., 1992).

The GSSP in the Luoyixi section lies within a long, apparently complete stratigraphic succession beginning in the uppermost part of the Drumian Stage and containing an assemblage of agnostoid trilobites, most of which are phylogenetically related ptychagnostid species. Successive stratigraphic levels show a succession beginning with *Goniagnostus nathorsti* (79.4 m above the base of the Huaqiao Formation) and continuing through the FADs of *L. armata* (111.9 m above the base of the formation), *Lejopyge laevigata* (121.3 m, marking the base of the Guzhangian Stage), and *Proagnostus bulbus* (215.7 m). The section appears to be continuous through the entire *L. laevigata* Zone, the *Proagnostus bulbus* Zone, the *Linguagnostus reconditus* Zone, and the *Glyptagnostus stolidotus* Zone to the base of the Paibian Stage (marked by the base of the *Glyptagnostus reticulatus* Zone). In the bed containing the lowest *L. laevigata* in the section (121.3 m), the species is rather rare. *L. laevigata* remains uncommon through the first 40 m of its range in the Luoyixi section.

Observed ranges of trilobites across the stratigraphic interval containing the GSSP are summarized in Figure 6. Besides *L. laevigata*, a number of other guide fossils, important for intercontinental correlation, help to constrain the boundary position. They include the LADs of *L. calva* and *G. nathorsti*, both of which occur below the FAD of *L. laevigata*. *Ptychagnostus atavus* ranges from the base of the Drumian Stage through the lowermost part of the *L. laevigata* Zone (lowermost part of the Guzhangian Stage). The FADs of *Clavagnostus trispinus*, *Linguagnostus kjerulfi*, and *Ptychagnostus aculeatus* occur slightly below the base of the *L. laevigata* Zone, whereas the FAD of *Utagnostus neglectus* occurs in the lowermost part of the *L. laevigata* Zone.

Observed ranges of polymerid trilobites, some of which have utility for correlation on a regional scale, serve as secondary biostratigraphic correlation tools for identifying the base of the Guzhangian Stage (Peng et al., 2004b, 2006). A diverse assemblage

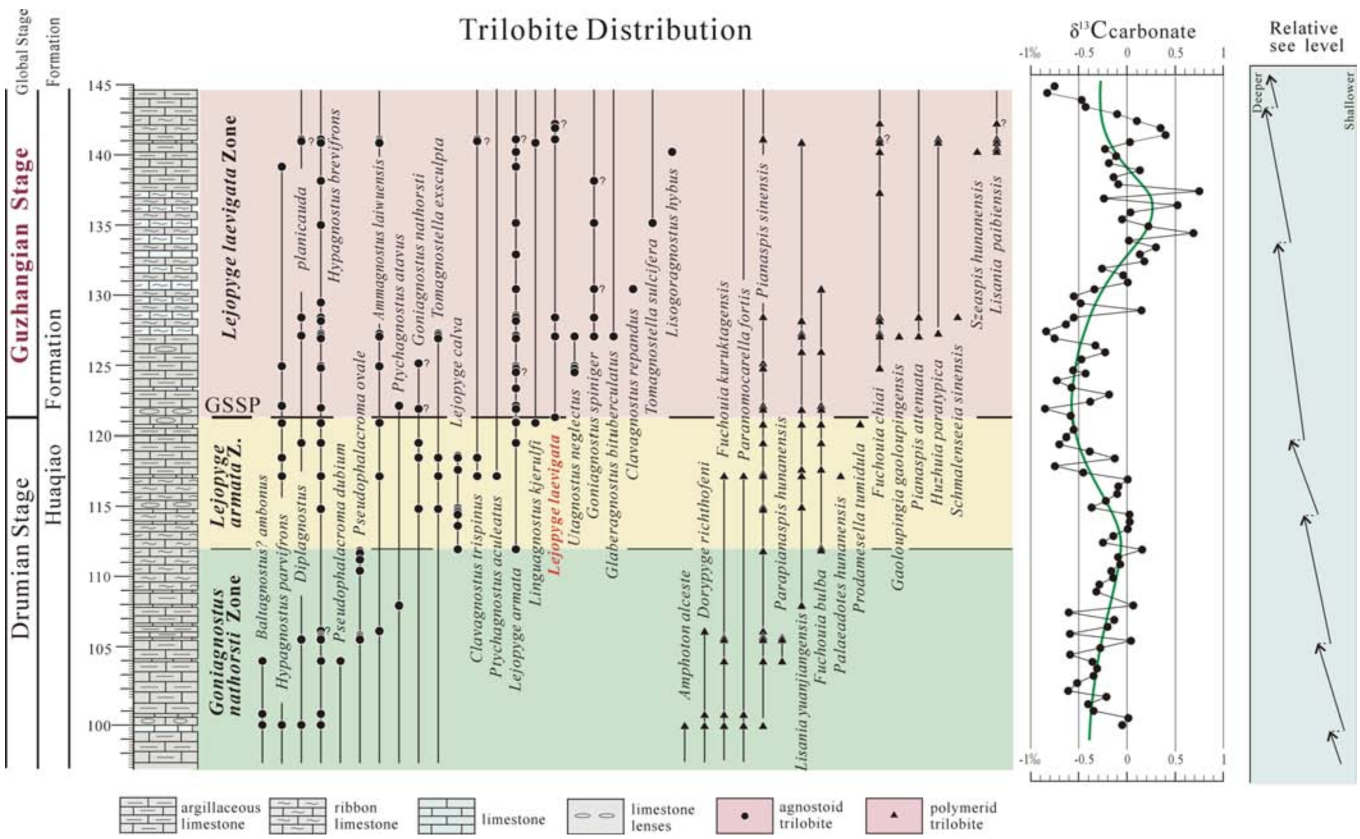

Figure 6. Observed stratigraphic distribution of trilobites in the Huaqiao Formation near the base of the Lejopyge laevigata *Zone, Luoyixi section, Guzhang County, Hunan Province, China. The GSSP coincides with the base of the* L. laevigata *Zone in this section. An interpretive sea level history, reflecting small-scale regional or eustatic changes, is added for comparison. Also added for comparison is a curve of $\delta^{13}C$ isotopic values, derived from samples collected from the Luoyixi section.*

of polymerid trilobites belonging to the *Pianaspis sinensis* Zone range through the *G. nathorsti* Zone and into the *L. laevigata* Zone. *P. sinensis*, *Fuchouia chiai*, *Lisania yuanjiangensis*, *Lisania paratungjenensis*, *Amphoton alceste* and *Prodamesella tumidula* disappear before the FAD of *L. laevigata*. The LADs of *Fuchouia bulba* and *Qiandongensis convexa* are in the lowermost part of the *L. laevigata* Zone.

Conodonts (Figure 11) help to constrain the base of the Guzhangian Stage in the Luoyixi section, the stratotype (Figures 7, 10), although the zonation is not as precise as that afforded by trilobites. The first observed elements of *Shandongodus priscus* (the eponymous species of the *S. priscus* Zone) in the Luoyixi section occur in the lower part of the *L. laevigata* Zone.

Regional and Global Correlation

A position at or closely corresponding to the FAD of *L. laevigata* in the Luoyixi section is one of the most easily recognizable horizons on a global scale in the Cambrian (e.g., Geyer and Shergold, 2000; Figure 2). Suitability of the FAD of this species for marking a global stage and series boundary has been summarized principally by Geyer

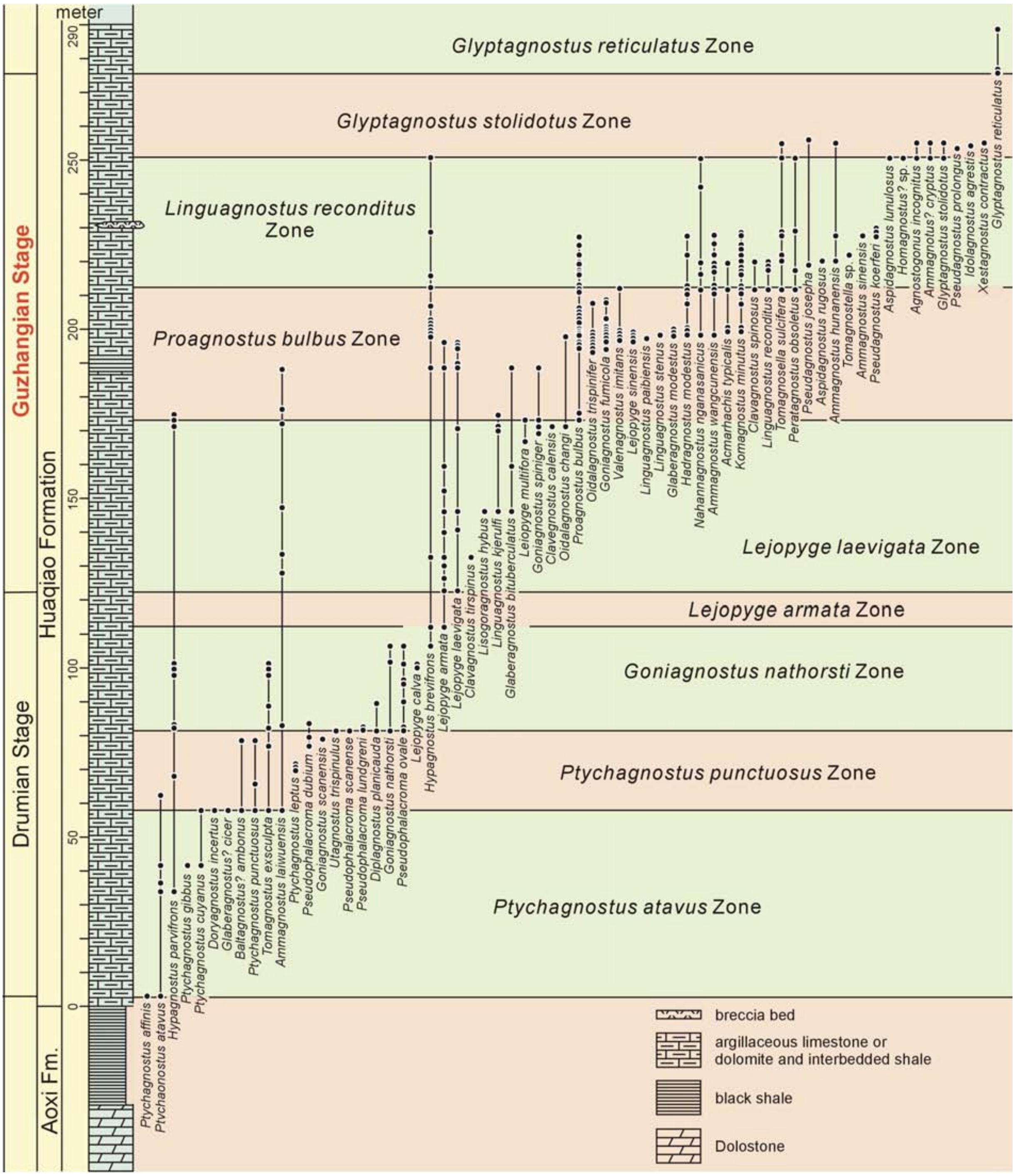

Figure 7. Observed stratigraphic distribution of agnostoid trilobites in the Huaqiao Formation, Wangcun section, on the northeastern bank of the Youshui River, Yongshun County, Hunan Province, China, added for comparison with the Luoyixi section, which is on the southwestern bank of the same river (modified from Peng and Robison, 2000).

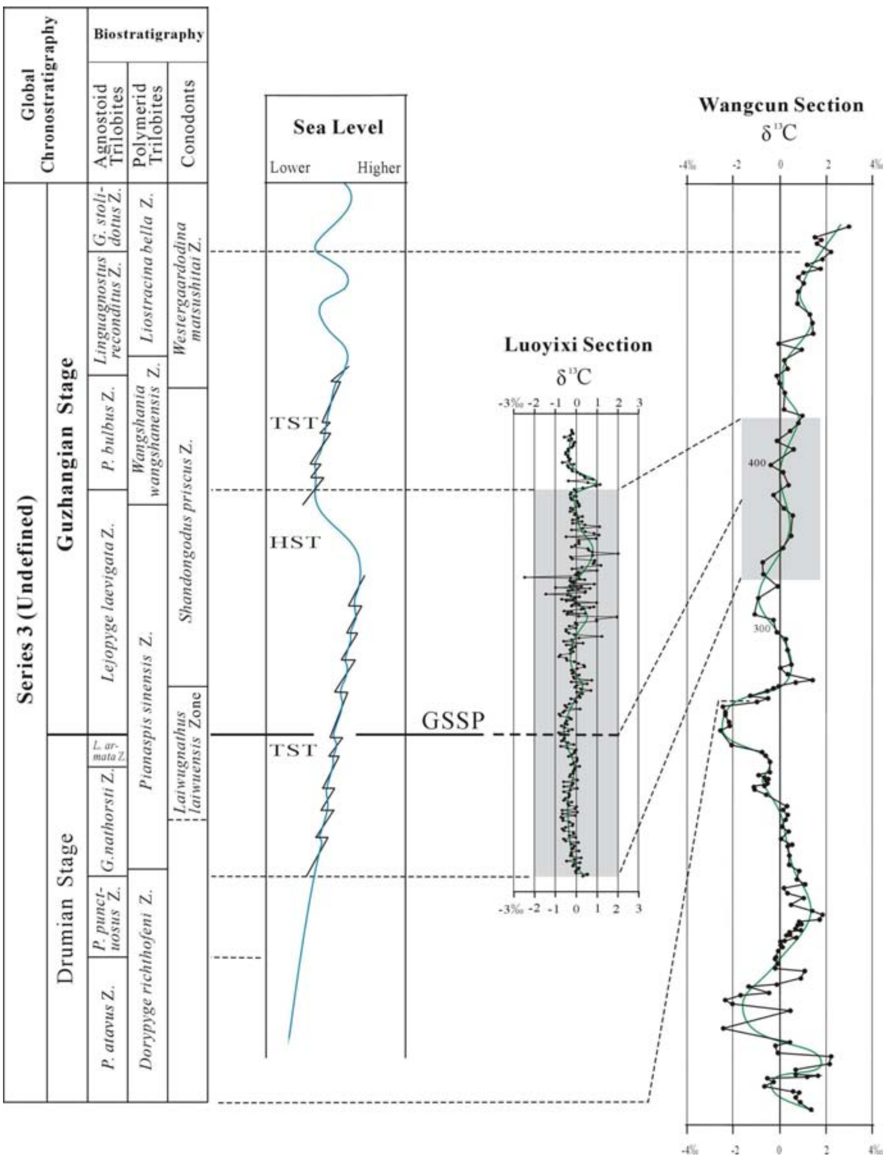

Figure 8. Summary of primary and secondary stratigraphic indicators for the base of the Guzhangian Stage of the Cambrian System. Major stratigraphic tools used to constrain the GSSP of the Guzhangian Stage are the zonation of agnostoid trilobites (Peng and Robison, 2000; Peng et al., 2006), the zonation of polymerid trilobites (Peng et al., 2004b; Peng et al., 2006), the zonation of conodonts (Peng et al., 2006), carbon isotope chemostratigraphy (records from the Luoyixi and Wangcun sections from Zuo, 2006; Zhu et al, 2004), and sequence stratigraphy (Zuo, 2006). All these techniques can be applied in the Luoyixi section, the stratotype. Two orders of inferred sea level history are illustrated: third order (in blue) and fourth order (in black).

and Shergold (2000), and Peng et al. (2004c, 2006). Key correlation tools are described in the following subsections.

Agnostoid Trilobite Biostratigraphy

Lejopyge laevigata has been recognized worldwide (e.g., Westergård, 1946; Pokrovskaya, 1958; Öpik, 1961, 1979; Demokidov, 1968; Palmer, 1968; Khairullina, 1970, 1973; Robison et al., 1977; Yang, 1978, Ergaliev, 1980; Egorova et al., 1982; Robison, 1984, 1988, 1994; Laurie, 1989; Lu and Lin, 1989; Yang et al., 1991; Dong, 1991; Tortello and Bordonaro, 1997; Geyer and Shergold, 2000; Peng and Robison, 2000; Jago and Brown, 2001; Babcock et al., 2004, 2005; Peng et al., 2004b, 2006; Axheimer et al., 2006; Figure 2), having been identified from rocks of Argentina, Australia (western Queensland, Tasmania), China (Guizhou, Hunan, Sichuan, Xinjiang, Zhejiang), Denmark (Bornholm), England, Germany (erratics), North Greenland, India (Ladakh), Kazakhstan (Malyi Karatau), Kyrgyzstan, Norway, northern Poland, Russia (southern and northeastern Siberian Platform), Sweden, Turkestan, Uzbekistan, and the United States (Nevada, Alaska). The species has been used as a zonal guide fossil in deposits of Baltica, Gondwana, Kazakhstan, Siberia, Laurentia, and eastern Avalonia (e.g., Westergård, 1946; Cowie et al., 1972; Robison, 1976, 1984; Öpik, 1979; Ergaliev and Ergaliev, 2000; Geyer and Shergold, 2000; Peng and Robison, 2000; Ergaliev and Ergaliev, 2000, 2001; Axheimer et al., 2006). Co-occurrences with other trilobites allow for a close correlation into western Avalonia (near the base of the *Paradoxides forchhammeri* Zone; Geyer and Shergold, 2000).

Polymerid trilobite Biostratigraphy

The base of the *L. laevigata* Zone coincides with a change in polymerid trilobite faunas recognized near the base of the Boomerangian Stage in Australia (Öpik, 1967; Geyer and Shergold, 2000; Figure 2) and the base of the *Aldanaspis* Zone in Siberia (Egorova et al., 1982). It also approximately coincides with a faunal change associated with the base of the *Paradoxides forchhammeri* Zone in western Avalonia (Geyer and Shergold, 2000).

Conodont Biostratigraphy

Two conodont zones are recognized in the Luoyixi section, with terminology adapted from North China usage (An, 1982). A position near the base of the *L. laevigata* Zone corresponds with a change in conodont faunas (Figure 10). The interval from 117.2 m to 121.0 m, assigned to the *Laiwugnathus laiwuensis* Zone, is characterized by the first appearances of paracondonts such as *Yongshunella polymorpha*, *Furnishina bigeminata*, *F. kleithria*, and *F.* cf. *alata*. The eponymous guide fossil *Laiwugnathus laiwuensis* occurs immediately below the FAD of *L. laevigata*. The lower boundary of the *Shandongodus priscus* Zone is in the lower quarter of the *L. laevigata* Zone in the stratotype section. In the Wangcun section, conodont faunas show an increase in diversity above the lower boundary of the *S. priscus* Zone (Dong and Bergström, 2001).

Chemostratigraphy

The base of the *L. laevigata* Zone is not marked by a distinctive shift in carbon isotopic values (Figure 6), although its position can be recognized from a longer sequence of $\delta^{13}C$ values. The horizon

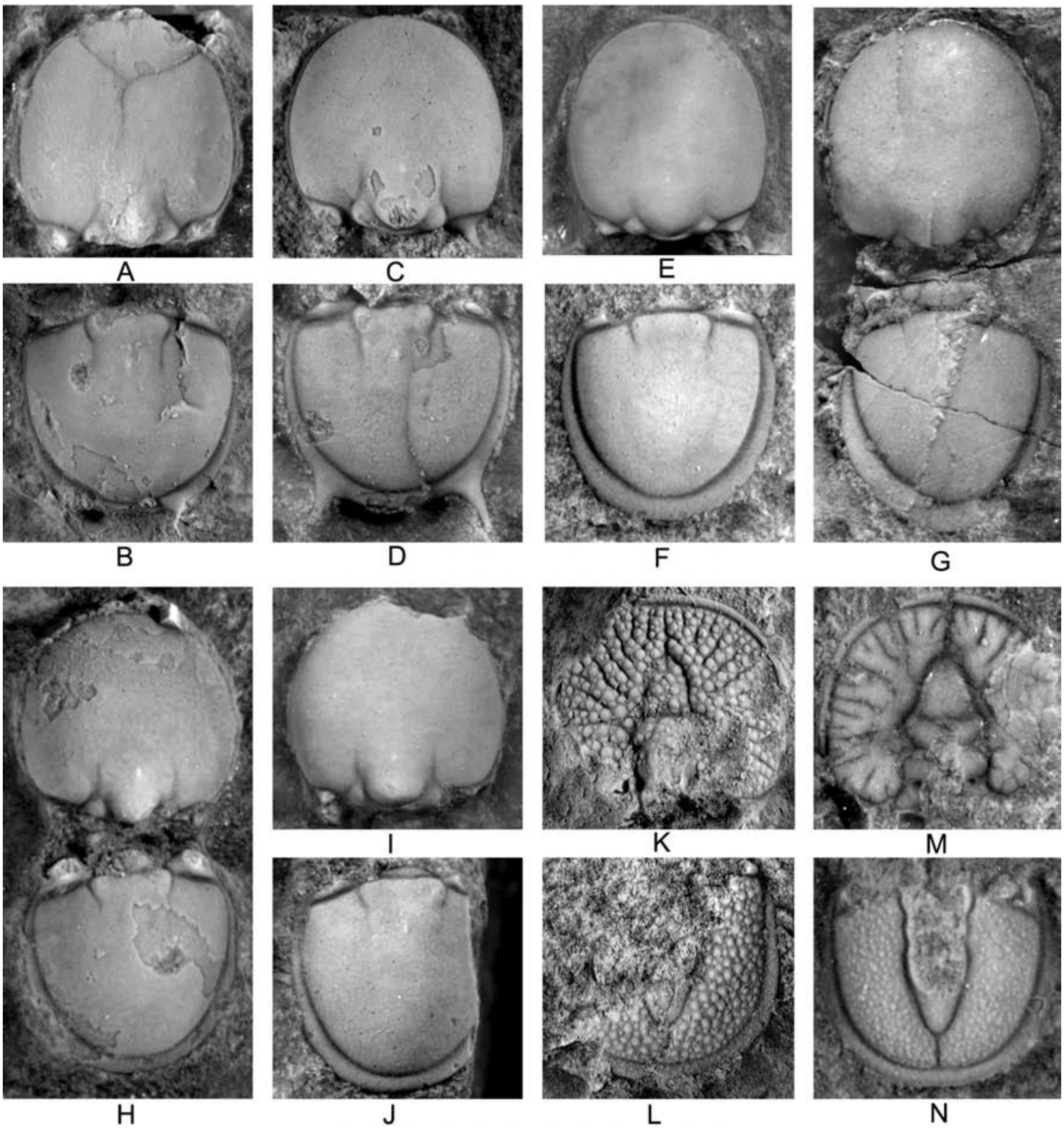

Figure 9. Key agnostoid trilobite species used for recognition of the base of the Guzhangian Stage. Numbers with the prefix LYX (for Luoyixi section) indicate collecting horizons in meters above the arbitrary 0 m position. All dorsal views. A-D, **Lejopyge armata** ***(Linnarsson, 1869), a series of primitive and derived forms. A, cephalon, LYX12.50, 111.9 m above the base of the Huaqiao Formation, x 6; B, pygidium, LYX21.45, 120.85 m above the base of the Huaqiao Formation, x 10; C, cephalon, LYX27.65, 127.05 m above the base of the Huaqiao Formation, x 8; D, pygidium, LYX27.65, 127.05 m above the base of the Huaqiao Formation, x 8; E-G,*** **Lejopyge calva** ***Robison, 1964. E, cephalon, LYX 15.4, 114.8 m above the base of the Huaqiao Formation, x 8; F, pygidium, LYX15.15, 114.55 m above the base of the Huaqiao Formation, x 10; G, exoskeleton, LYX19.05, 118.45 m above the base of the Huaqiao Formation, x 10; H-J,*** **Lejopyge laevigata** ***(Dalman, 1828), a series of primitive and derived forms. H, exoskeleton, LYX21.9, 121.3 m above the base of the Huaqiao Formation, x 9; I, cephalon, LYX64.40, 163.8 m above the base of the Huaqiao Formation, x 10; J, pygidium,. LYX64.40, 163.8 m above the base of the Huaqiao Formation, x 10.5; K, L,*** **Ptychagnostus aculeatus** ***(Angelin, 1851). K, incomplete cephalon, LYX54.75, 154.15 m above the base of the Huaqiao Formation, x 7; L, fragmentary pygidium, LYX17.75, 117.15 m above the base of the Huaqiao Formation, x 7; M, N.*** **Goniagnostus nathorsti** ***(Brøgger, 1878). M, LYX15.40, 114.8 m above the base of the Huaqiao Formation, x 11; N, pygidium, LYX15.40, 114.8 m above the base of the Huaqiao Formation, x 15.***

corresponding to the first appearance of *L. laevigata* is near the peak of a rather long negative $\delta^{13}C$ excursion of up to 0.58 ‰ (Figures 6, 7). Strata in the upper part of the Drumian Stage are characterized by slightly negative $\delta^{13}C$ values (reaching a maximum of 7.6 ‰). A small positive shift, which peaks at about 0.15 ‰, coincides with the base of the *L. armata* Zone, and this is followed by a longer negative shift, the peak of which nearly coincides with the base of Guzhangian Stage. Oscillations in the $\delta^{13}C$ curve through the rest of the unnamed stage are minor, usually ranging between -1 and +1 ‰ (Figure 6). The next most distinct position in the $\delta^{13}C$ curve is the base of the SPICE excursion, one of the largest positive $\delta^{13}C$ excursions known from the Paleozoic, which coincides with the base of the Paibian Stage

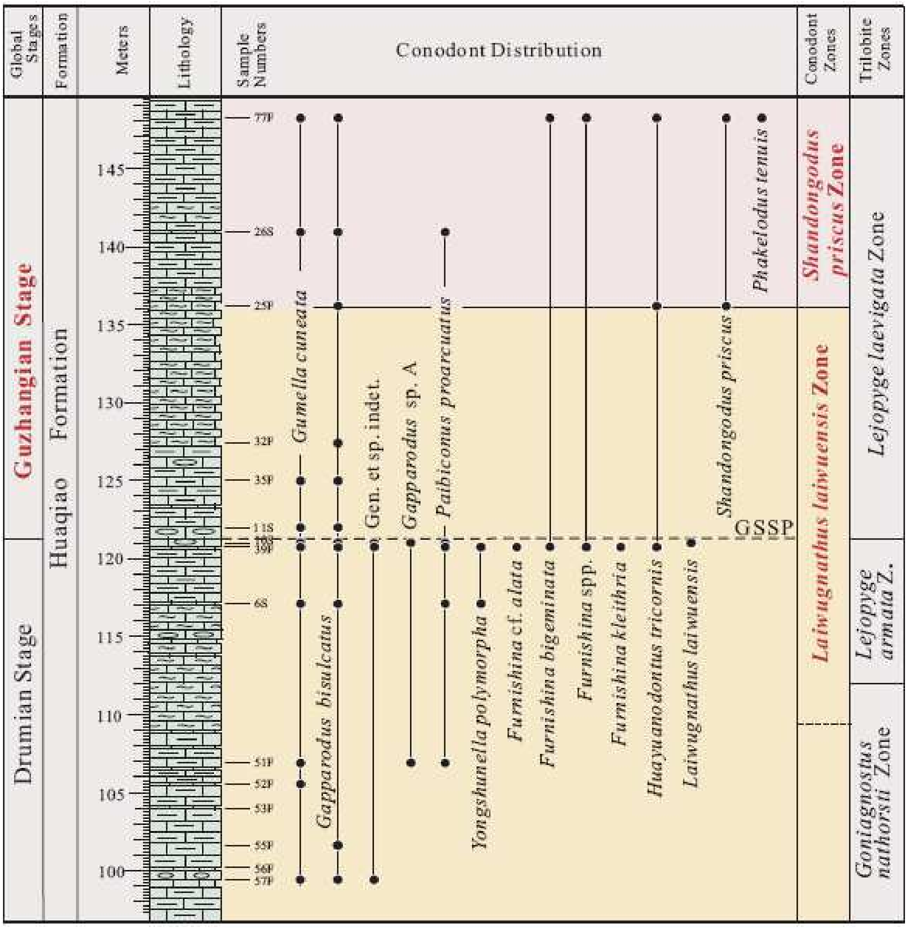

Figure 10. Observed stratigraphic distribution of conodonts in the Huaqiao Formation near the base of the* Lejopyge laevigata *Zone, Luoyixi section, Guzhang County, Hunan Province, China.

(Brasier and Sukhov, 1998; Montañez et al., 2000; Zhu et al., 2004).

Sequence Stratigraphy

Work in the Wuling Mountains of Hunan shows that the base of the *L. laevigata* Zone is associated with the early part of a transgressive event (Figures 6, 7). Overall, the Huaqiao Formation is inferred to have been deposited during eight third-order cycles (Zuo, 2006). Superimposed on these long-term cycles are a series of smaller scale transgressive-regressive cycles. Within the first third-order cycle, Zuo (2006) recognized 11 fourth-order cycles, and within the second fourth-order cycle he recognized 9 fifth-order cycles. In the Luoyixi section, the FAD of *L. laevigata* is associated with one of the small scale transgressive events, the lower part of the sixth fourth-order cycle (almost coinciding with the top of the first fifth-order cycle; Zuo et al., 2006, fig. 4). The species first appears less than 20 cm upsection of a surface inferred to represent a deepening event of small magnitude. Comparative work on sections elsewhere in Hunan Province, China (Paibi and Wangcun), and in the Great Basin, USA, shows that *L. laevigata* first appears in outer-shelf and slope lithofacies of Gondwana and Laurentia at an early stage of a transgressive event. The transgression with which the FAD of *L. laevigata* is associated is interpreted to be of eustatic scale.

Reference Section

Another excellent reference section exposing the Huaqiao Formation in general, and the lower part of the *L. laevigata* Zone in particular, is located near Wangcun (across the Youshui River from the Luoyixi section), Hunan Province, China. There seems to be little difference between the Luoyixi section and the Wangcun section. The Luoyixi section was selected as the stratotype section because it has been more intensively collected in the boundary interval, making the position of the first appearance of *L. laevigata* more tightly constrained.

Estimate of Age

The base of the Guzhangian Stage is estimated to be 503.0 ± 1 Ma. This figure is derived from extrapolation between the estimated age of the base of the traditional Upper Cambrian (~500 Ma) (Shergold, 1995), which is closely correlative to the base of the *Linguagnostus reconditus* Zone of South China (Peng and Robison, 2000; Ahlberg, 2003; Ahlberg et al., 2004), and the estimated age of the base of the traditional Middle Cambrian (510.0 ± 1.0 Ma). The age of the base of the traditional Middle Cambrian is well constrained by U-Pb ages on zircons from an ash bed in the Hanford Brook Formation, southern New Brunswick (Landing et al., 1998; Bowring and Erwin, 1998). These estimates provide a duration of about 10 Ma for the traditional Middle Cambrian. In South China, seven to nine biozones are recognized in the traditional Middle Cambrian (i.e., the Taijiangian and Wangcunian stages; Peng and Babcock, 2001, Yuan et al., 2002; Peng, 2003). In Australia, the same interval is covered by eight biozones (Geyer and Shergold, 2000). The average duration, then, for each zone is a little more than 1 million years. This suggests that the base of the Guzhangian Stage, coinciding with the base of the *Lejopyge laevigata* Zone, a level two or three biozones above the *P. punctuosus* Zone, is close to an age of 503.0 Ma (possibly slightly younger). This estimate accords well with a mean SHRIMP age on zircons of 503.2 ± 3.8 Ma (Perkins and Walshe, 1993) for an interval probably equivalent to the *Goniagnostus nathorsti* Zone through the basal part of the *L. laevigata* Zone in the Southwell Sub-group of the Mt. Read Volcanics, Tasmania (Jago and McNeil, 1997).

Encarnación et al. (1999) provided dates from volcanic tuffs in the Taylor Formation, Antarctica, that provide broad support for an age close to 503.0 Ma for the base of the Guzhangian Stage. U-Pb ages on zircons recovered from slightly above and below *Nilsonia*- and *Amphoton*-bearing carbonate beds yielded a weighted mean age of 505.1 ± 1.3 Ma. The sampled strata were interpreted as equivalent to the Floran-Undillan interval as used in Australia (Shergold et al. 1985; Shergold, 1995), but biostratigraphic control on the Taylor Formation is poor. Based on occurrences of trilobites in Australia, China, and Siberia, the sampled beds seem to be in a position near the base of the *Ptychagnostus punctuosus* Zone (equivalent to the Floran-Undillan boundary).

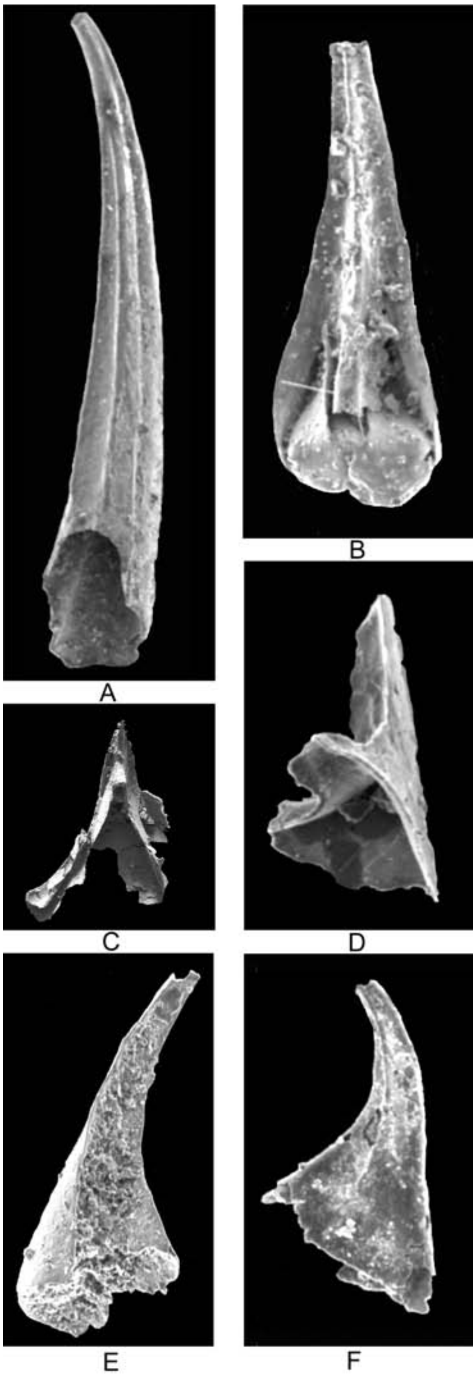

Figure 11. Conodonts used for recognition of the base of the Guzhangian Stage. A, **Gapparodus bisulcatus** *(Müller, 1959): sample 51F, 106.9 m above the base of the Huaqiao Formation, posterolateral view, ×53; B,* **Laiwugnathus laiwuensis** *An, 1982: sample 10S, 121.0 m above the base of the Huaqiao Formation, posterior view, ×72; C,* **Furnishina kleithria** *Müller and Hinz, 1991: sample 39F, 120.8 m above the base of the Huaqiao Formation, posterior view, ×28; D,* **Shandongodus priscus** *An, 1982: sample 25F, 136.25 m above the base of the Huaqiao Formation, posterolateral view, ×207; E,* **Yongshunella polymorpha** *Dong and Bergström, 2001: sample 6S (117.15 m above the base of the Huaqiao Formation), lateral view, ×83; F,* **Yongshunella polymorpha** *Dong and Bergström, 2001: sample 6S (117.15 m above the base of the Huaqiao Formation), lateral view, ×82.*

Acknowledgements

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Hydrological Extremes in Small Basins-The 12th Biennial Conference of the Mediterranean Network of Experimental and Representative Basins (ERB)

Cracow, Poland, September 18-20, 2008

The Mediterranean Network of Experimental and Representative Basins (ERB) is an open association of hydrologists from twenty European countries carrying out their research in well-instrumented, small drainage basins. The ERB was recommended by the European Council and established in 1986. The main objectives of the network are:

- to establish and maintain relationships among member countries and research teams by means of information exchange, mobility, and regular conferences;
- to initiate and enable co-operation among members and other organizations;
- to maintain databases of small-scale research and experimental basins.

It is much easier to comprehend and follow the complex hydrological processes that influence river dynamics, flood formation, low flows, and their consequences in small basins than in large ones. Generally, large basins have many more hydrological factors, and they are more spatially dispersed. A similar pattern applies to the physical and chemical characteristics of water arising from factors of a different nature: geological, climatic, and anthropogenic. Small research basins occur in various climatic and plant cover zones, with different geological characteristics and geomorphology. Some of them represent pristine environments, whereas others have environments that have been strongly changed by farming practices or urbanization. Hence, the scope of hydrological research in small basins is very wide: from surface-water and ground-water monitoring to studies in runoff generation, hydrological and environmental modelling, biogeochemical processes, hydrological extremes, uncertainties in data and model concepts, effects of natural and man-made changes, erosion, sedimentation, hill-slope processes, and so on.

Biennial conferences are one of the forms of the ERB's activities. The first was held in 1986 in Aix en Provence (France). It was followed by conferences in Perugia (Italy), Wageningen (The Netherlands), Oxford (UK), Barcelona (Spain), Libice (Czech Republic), Ghent (Belgium), Demanovska Dolina (Slovakia), Turin (Italy), and Luxemburg (Luxemburg). The last conference in September 2008 took place in Cracow (Poland) at the Institute of Geography and Spatial Management of Jagiellonian University. The conference theme focused on hydrological extremes. The rising intensity of extremes has been connected with global environmental changes during recent decades. The topics discussed were: predictions of stream-flow response in controlled and uncontrolled catchments, the calibration of hydrological models, hydro-chemical and geomorphological responses to the extremes, interactions between surface-water and ground-water, extreme value statistics, and model data-time-step dependency on basin characteristics. As usual, one of the sessions was devoted to new ideas in hydrological research. The conference started with the address by the ERB International coordinator, Piet Warmerdam of the Wageningen University (The Netherlands), who briefly reviewed the ERB's objectives. Then the Director of the Institute of Geography and Spatial Management in Cracow, Boleslaw Domanski, presented a short introduction to the history of the Jagiellonian University, where the first chair in geography in Central Europe was founded in 1849.

The first session (Prediction of Hydrological Response based on Different Quality Measurement Data) was chaired by Andreas Herrmann of the Technical University Braunschweig (Germany). The presentations concerned the modelling of hydrological extremes using gauge and radar-driven model predictions, the methods of delineation of small basins prone to flash floods, the importance of accurate catchment-averaged evapo-transpiration for flood forecasting and extreme flood simulation using two-dimensional hydraulic model, engineering perspective of flood protection using dry-dams, and the use of isotopic tracers in studying hydrological response in small catchments.

The second session (Hydrological Model Calibration for Extreme Conditions) was chaired by Joao de Lima of the University of Coimbra (Portugal). The presentations concerned river flow modelling under different catchment conditions: glaciated, urbanized, mountainous, forested, and granitic. Also, a deterministic-stochastic model for the area of the former USSR's basins situated in different climatic zones was presented.

The third session (Hydro-chemical and Geomorphological Response to Hydrological Extremes) was preceded by the keynote lecture by Maciej Zalewski of the European Regional Centre for Eco-hydrology (Poland). His lecture was focused on the implementation of ecological biotechnologies in integrated water resources management. It was followed by five presentations on hydrochemistry dynamics under extreme conditions in basins of different land-use. One of them dealt with sediment transport during river flow extremes. Another one was devoted to threshold values of rainfall causing surface runoff and sheet erosion on slopes. This presentation was also an introduction to the next day's field excursion to the Jagiellonian University's Research Station in the Carpathian Foothills. The last presentation of the session concerned sea-water intrusions and their influence on lake-water chemical composition on the Baltic Sea coast.

The fourth session (Extreme Value Statistics) took place on the second day of the conference and was chaired Piet Warmerdam. The session consisted of three presentations only. They were focused on the statistical characteristics of extreme events, especially during the low flow periods. Four presentations were delivered during the next session (Surface-water-Ground-water Interface under Extreme Conditions) conducted by Daniel Viville of the C.N.R.S (France). The keynote lecture by Zbigniew Kundzewicz of the Polish Academy of Sciences concerned the prediction and scenarios of changes in water circulation affected by the climate change. Other lecturers presented the results of studies on the interaction among the rainfall, groundwater levels, and runoff formation.Over sixty posters were presented during the poster session. For two hours, the authors had the opportunity to discuss the research results with other conference participants. The result of the best poster competition was announced by the Conference Scientific Committee. Scientific value, well-considered design, clarity of figures and descriptions, and general aesthetic impression were taken into consideration. The poster entitled 'Multi-temporal Analysis of Land Cover Change for Flood Discharge Studies in the Nyando River Basin using Land-Sat Images', presented by Olang Luke Omondi and co-authors of the BOKU University (Austria), was judged to be the best on display. The authors received a diploma and a set of reproductions of old maps from the map collection of the Jagiellonian University Library.

After the poster sessions, the participants made a half-day excursion to the Research Field Centre of the Jagiellonian University (JU) in Lazy (in the Carpathian Foothills) and its experimental basins. Despite the cold

and rainy weather, the participants explored the meteorological station, the stream-gauging site, and soil erosion experimental plots. Wojciech Chelmicki (JU) explained the history of hydrological research in the Carpathian Foothills. An outline of the environmental and hydrological issues of the area was given by Janusz Siwek (JU). The methodology of soil erosion measurements was outlined at the site by Jolanta Swieüchowicz (JU). Finally a brief summary of studies of streamwater chemistry and water circulation during flood events was given by Joanna Siwek (JU). The field-trip ended with a conference dinner served at the Royal Castle in Niepolomice near Cracow. During the dinner there was an opportunity to thank Piet Warmerdam for his six-year service as ERB International Coordinator. The new coordinator, Ladislav Holko of the Slovak Academy of Sciences, was introduced to the ERB members.

On the third day, the prediction of streamflow and streamwater characteristics during extreme events was strongly emphasized. The session 'Extreme Flow Prediction in Ungauged Basins' conducted by Joanna Pociask-Karteczka (JU) started with the keynote lecture by Ian Littlewood (United Kingdom). He described progress in the methodology of the unit hydrograph based models and their application to engineering and environmental hydrology. The last two sessions, conducted by Wojciech Chelmicki and Ian Littlewood, gave an overview of new ideas and developments in small-basin research. The presentations concerned engineering structures and water management systems in small basins, the methodology of natural tracers in water and suspended sediment circulation, and the application of neural networks to river-flow modelling during floods. The conference concluded with the ERB General Assembly conducted by Piet Warmerdam and the new ERB International Coordinator, Ladislav Holko. The place and date of the next ERB Conference was announced: Austria, 2010.

A book containing the abstracts of the oral and poster presentations was published and may be downloaded from the conference webpage (http://www.geo.uj.edu.pl/erb2008). The Proceedings of the Conference, based on the oral presentations, will be published in 2009 in the IHP-UNESCO Technical Documents in Hydrology. The papers based on the keynote lectures will be published in late 2008, in the journal of the Folia Geographica, series Geographica-Physica. The Proceedings based on the posters will be published in the same journal in 2009. The organizers wish to thank the keynote lecturers for their valuable contribution to the conference, and UNESCO for the financial support granted to some young researchers participating in the event.

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GeoMod2008

Florence, Italy, September 22-24, 2008

This conference was the third edition of the International GeoModelling Conference and followed the two previous meetings held at ENI-Agip headquarters in Milan, Italy (RealMod2002) and Emmetten-Lake Lucerne, Switzerland (GeoMod2004). GeoMod2008 was organized by researchers of the Institute of Geosciences and Earth Resources of the National Research Council of Italy and the Department of Earth Sciences of the University of Florence. It was convened under the auspices of the International Year of Planet Earth and Regione Toscana and funded by both Italian (Cassa di Risparmio di Firenze, Istituto Nazionale di Geofisica e Vulcanologia, Department of Earth Sciences of the University of Florence, National Institute of Oceanography and Experimental Geophysics-OGS) and international (Tectonic Lab Vrije Universiteit Amsterdam, Netherlands Research Centre for Integrated Solid Earth Science, International Lithosphere Program) sponsors.

The conference consisted of three days of oral and poster presentations. It was preceded by a modelling workshop on Sunday 21 September and followed by a two-day field trip (25-26 September). More than 180 researchers from all five continents took part in the conference. Participants were predominantly from Europe (mainly France, Italy, Germany, Switzerland, Spain), but there were also twenty attendees from the Americas (eleven from USA and Canada and nine from Central and South America), eleven from Asia, eight from Australia and New Zealand and two from Africa. More than 150 extended abstracts were submitted and were published in a special volume of Bollettino di Geofisica Teorica e Applicata. More than 20,000 individual visits were registered by the conference website (www.geomod2008.org), from which users could (and still can) download congress material such as the extended abstract volume and the field-trip guide book.

The conference venue was Villa La Pietra, an exclusive fifty-seven-acre estate located on one of the foothills surrounding Florence. Composed of five villas and one of the most beautiful gardens in Italy, La Pietra is the home of New York University in Florence. Technical sessions were held in Villa Sassetti, La Pietra's International Conference and Events Center. A modelling workshop preceded the GeoMod2008 conference on Sunday 21 September, with more than seventy researchers attending. It was organized and coordinated by Susanne Buiter (Geological Survey of Norway, Trondheim) and Guido Schreurs (University of Bern, Switzerland). It focused on both analogue and numerical modelling of tectonic processes. Six invited talks investigated technical aspects of modelling (e.g., natural and model rheology, advances in analogue materials and numerical techniques, quantification of results, etc.). As in the previous GeoMod2004 workshop, the analogue and numerical results of a benchmark experiment were presented and discussed with about thirty laboratories participating in this comparison. Guido Schreurs illustrated the comparison of analogue models, while Susanne Buiter compared the results of the numerical modelling. The workshop was closed by discussion and comparison of the analogue and numerical models (moderated by Taras Gerya and Jean-Pierre Brun). It progressively shifted to a more general and philosophical discussion of geological modelling.

The conference was opened on 22 Monday, with welcome remarks by Professor Ernesto Abbate, representative of the Department of Earth Sciences of the University of Florence and Secretary General of the 32nd International Geological Congress, and Dr Giovanni Gianelli, Director of the Institute of Geosciences and Earth Resources of the National Research Council of Italy. An introductory speech by Dr Giacomo Corti, on behalf of the Organizing Committee, summarized the history of the International GeoModelling Conference and gave an overview of GeoMod2008, illustrating the scientific programme and the conference statistics. Chairman Giorgio Ranalli opened the first scientific session and introduced the first speakers. The themes treated in the different sessions covered all the main aspects and different scales of the deformation and evolution of the lithosphere/asthenosphere system. Six sessions consisted of three invited plenary lectures and poster presentations. One additional session consisted of poster presentations only. This conference format allowed the invited speakers to present a detailed state-of-the-art account of the results in their discipline, and prompted extensive, fruitful discussions after the talks.

The first day focused on modelling the large-scale deformation processes, with Session 1 investigating the rheology of the lithosphere and its relation with deformation patterns and the second focusing on subduction and mantle dynamics. Talks in the first session were given by Luigi Burlini, Evgeni Burov and James Jackson. Burlini illustrated the inferences on the rheology of the lithosphere based on the experimental deformation of rock samples, whereas Burov

and Jackson presented opposite views of the lithosphere rheology resulting in different strength profiles-the so-called 'jelly sandwich' (where strength mainly resides in the crust and mantle) or 'crème-brûlée' (where the mantle is weak and the strength is limited to the upper crust). Dubbing the classical 'jelly sandwich' view of lithosphere strength stratification, the 'weak mantle' view, illustrated by Jackson (Figure 1), stimulated a hot debate among the participants. The invited talks in the Subduction session were given by Carlo Doglioni, Francesca Funiciello, and Taras Gerya. Doglioni showed kinematic models of subduction, highlighting the role of the westward drift of the litho-sphere on the architecture of subduction zones, in particular the differences between W-directed and E-directed subductions. Funiciello reviewed small-scale analogue modelling studies of subduction, with special reference to the extensive experimental work conducted at the tectonic modelling laboratory of the University of Roma Tre. Gerya presented an overview of results and open questions resulting from recent numerical geodynamic modelling projects conducted within the Geophysical Fluid Dynamics Group at ETH-Zurich.The second day was dedicated to the development and evolution of orogens and rift zones, with the analysis of mountain building and thrust systems (Session 3) and lithospheric extension (Session 4). The invited speakers for the mountain building session were Jean-Pierre Burg, Onno Oncken, and Jacques Malavielle. Burg's talk focused on the structure and evolution of the Himalayan orogeny, illustrating how both analogue and numerical simulations can help in deciphering the evolution and lateral variations in structure of this complex orogen. Oncken investigated the evolution of another major compressional system, the Andes, summarizing recent work from an integrated research programme hosted by the Berlin and Potsdam Earth science research units. Lastly, Malavielle reviewed recent analogue modelling investigations of the evolution of orogens and thrust systems, with particular reference to the role of erosion and sedi-mentation on the evolution of deformation and kinematics of mountain belts. The invited talks in the lithospheric extension session were given by Jean-Pierre Brun, Roger Buck, and Luc Lavier. Brun approached the analysis of the extensional process by using examples from a natural laboratory, the Aegean system, illustrating the mechanics and evolution of extension and the developments of typical structures, such as the metamorphic core complexes. Buck presented recent numerical modelling calculations that investigate the role played by magma injection on extension and suggest the strong weakening effect of dyking on the extending lithosphere, which may eventually lead to its break-up. Lavier illustrated the results of numerical simulations that show how improving the rheological parameterization of the lithosphere rheology by introducing a semi-brittle media in the continental crust profoundly affect the evolution of rifting and the thinning of the continental crust.

The second day of the conference ended with a social dinner, organized in a typical restaurant downtown Florence, where about ninety participants could enjoy a great variety of Tuscan food and wines.

The third and final day was focused on basins, sediments and surface processes, with Session 5 investigating basins and sedimentary budget and Session 6 analyzing surface processes and their influence on tectonics. Session 7, with poster presentations only, was devoted to the analysis of methods and techniques for both analogue and numerical modelling. Talks on the Basins session were given by Roy Gabrielsen, Paola Ronchi, and Bruno Vendeville. Gabrielsen gave an overview of advances in the modelling of basin development, sediment distribution and the processes that take place in the basin after deposition, illustrating examples from the Norwegian margin. Ronchi discussed diagenesis in carbonate reservoirs, showing an integrated study, from conceptual to numerical modelling, which allow the prediction of the distribution of the dolomite bodies (potential hydro-carbon reservoirs) in the subsurface. Vendeville ended the session with an overview of the experimental model-ling works investi-gating the role of weak stratigraphic layers made of rock salt or over-pressured shale on deformation. The invited speakers for the Surface Processes session were Stephane Bonnet, Jean Braun, and Sean Willett. Bonnet reviewed recent advances in the laboratory analogue modelling of erosion and landscape dynamics, focusing on the need to go beyond steady-state behaviour to fully understand natural topographies and landscape evolution. Braun used the results of three-dimensional numerical experiments simulating erosion during crustal shortening to highlight the complex interactions between contractional structures and the loading/unloading produced by the surface processes. Finally, Willett closed the session (and the confe-rence) with a review of coupled geodynamic and surface process models, with special reference to the parameterization of mass redistribution processes that have been used in models of lithosphere deformation and landscape evolution over million year timescales.

The conference was followed by a two-day field-trip (on 25-26 September) attended by thirty-two participants. The field trip, led by Federico Sani, Marco Bonini, and Giacomo Corti, crossed the whole Northern Apennines thrust-and-fold belt, from its innermost sectors (on the Tyrrhenian side of northern Tuscany) to the most external parts (the Emilia Po Plain). The transect was planned to follow an ideal trip from the deepest structural units, widely exposed in the Apuan Alps metamorphic core, to the active thrusting at the Pede-Apennine margin of Po Plain, thus giving the participants a general but comprehensive overview of the Northern Apennines geology. Worth noting were the magnificent panoramas of the Apuan Alps, with the famous Carrara marble quarries, as well as the stop at the mud volcanoes field in the Nirano area (at the active thrust front of the Po Plain margin), where participants could observe the ongoing mud and fluid emissions (Fig.2).

For further information, see: www.geo-mod2008.org.

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GIRAF 2009 – An overview of Geoscience InfoRmation across AFrica

Windhoek, Namibia, 16-20 March 2009

Between 16 and 20 March 2009 97 participants from 26 African nations, plus four European countries and representatives from UNESCO, ICSU and IUGS-CGI held a workshop at the Namibian Geological Survey in Windhoek. The workshop – GIRAF 2009 – Geoscience InfoRmation In Africa – was organised by the Federal Institute for Geosciences and Natural Resources (BGR) and the Geological Survey of Namibia (GSN) at the Namibian Ministry for Mines and Energy and was mainly financed by the German Federal Ministry for Economic Cooperation and Development (BMZ), supported by the IUGS Commission for the Management and Application of Geoscience Information (CGI) and was mainly financed by the German Federal Ministry for Economic Cooperation and Development (BMZ). The participants came to Namibia to discuss one of the most topical issues in the geological domain – geoscience information and informatics. A prime objective was to set up a pan-African network for exchanging knowledge about geoscience information.

Fig.1. GIRAF-2009 logo

Fig.2. GIRAF countries in March 2009.

GIRAF 2009 builds on the results of a preparatory workshop organised by the CGI and funded by the IUGS, which was held in June 2006 in Maputo at the 21st Colloquium on African Geology – CAG21. This preparatory workshop concentrated on identifying general problems and needs of African geological institutions in discussion with representatives of African geological surveys, universities, private companies and non-governmental organisations. The GIRAF 2009 workshop used the results of this discussion to plan and design its programme.

Aims

In detail the aims of the GIRAF2009 workshop were:

- to bring together relevant African authorities, national experts and stakeholders in geoscience information;
- to initiate the building of a pan-African geoscience information knowledge network to exchange and share geoscience information knowledge and best practice;
- to integrate the authorities, national experts and experts across Africa into global geoinformation initiatives;
- to develop a strategic plan for Africa's future in geoscience information;
- to make Africa a more active part of the international geoscience information community.

The programme for the GIRAF 2009 workshop was designed to explore each of these aspects to improve the way geoscience information contributes to improve the health and prosperity of the people in Africa.

The Programme

After welcome speeches from the Namibian Minister of Mines, the German Ambassador for Namibia and the workshop organizers Dr. Gabi Schneider (GSN) and Dr. Kristine Asch (BGR, CGI), the workshop commenced with a series of keynote presentations, including Professor Sospeter Muhongo (ICSU) on the status of and the need for a network on geoscience Information in Africa, Dr. Felix Toteu (CRGM, Cameroon)

The breakout sessions

Monday

Group 1	Training and retraining of staff
Group 2	Lack of technical infrastructure (internet, hard and software)
Group 3	Inaccessibility of the data and project
Group 4	No enthusiasm in government and organisations

Thursday

Group 1	Data access, licencing and pricing
Group 2	How do we make Africa a part of the international geoscience information network
Group 3	How do we build an African (cross-border) geoscience information
Group 4	What strategies can be adopted to assist the very poor nations of Africa develop their geoscience information capabilities

Questions of the day

Tuesday - What 3 practical steps could GIRAF take to help you and your organisation?

Wednesday - If you could change 3 things in your organisation what would they be?

Thursday - How do you think the GIRAF initiative should continue in the future?

on the reasons for a Geoscience Workshop in Africa, Sarah Gaines (UNESCO) on UNESCO Earth Science Initiative in Africa and Ian Jackson (BGS, CGI) on the global OneGeology initiative. The aim of the week, however, was to better understand the reality of the status of geoscience information management, delivery, and systems from the perspective of the practitioners and projects across Africa. To do that the GIRAF workshop adopted three different approaches:

1 projects and initiatives in the national geological survey organisations across Africa were presented by the participants and their presentations discussed;

2 two sets of breakout sessions were held, allowing more detailed discussion of specific issues;

3 on each of three days, a novel "Question of the day" was posed, where feedback from individuals was sought on three pointed questions.

These exercises ensured that every attendee was able to contribute his/her views and experiences. The results were intense discussion of the issues which the participants felt were key to developing and improving the way geoscience information could be managed and delivered in Africa. The very tangible outcome of a hardworking but fruitful week was the unanimous endorsement of a series of practical recommendations – the GIRAF Strategy and Agreement.

In conclusion

The view of all the participants was that the GIRAF 2009 workshop was not only productive and beneficial but enjoyable, too. Our week together provided new and valuable experience and new contacts, networks and friendships and most importantly the base for a sustainable initiatitive to improve the way geoscience information will be managed and delivered in Africa. We now look forward to taking those important recommendations forward.

The GIRAF Agreement

Participants agreed the following 15 recommendations:

1. A small GIRAF management group is set up to coordinate the work and ensure that GIRAF is sustained. This small group will comprise a core executive and regional representatives.
2. GIRAF, through BGR, will set up a permanent but dynamic web which will include national contact details, news of progress and upcoming meetings and links to useful documentation, an informal message board. GIRAF will also aspire to produce a Newsletter quarterly.
3. Participants will communicate the outcomes of this meeting to the African geoscience organisations not present at GIRAF 2009 and encourage them to take part and embrace these recommendations and become a part of the GIRAF community
4. GIRAF will establish a network (and focal point) within Africa to connect geological survey institutions, support North-South partnerships in research and develop linkages to other related bodies, projects and initiatives.
5. GIRAF will encourage the nomination of African delegates to international bodies as to IUGS-CGI Council and the OneGeology Operational Management Group. These delegates will represent Africa at these two committees and communicate developments in IUGS-CGI and OneGeology back to African geoscience organisations.
6. The GIRAF community will seek support especially for those nations who have demonstrated a severe lack of capacity and capability and requested aid.
7. The GIRAF community will seek funding and sponsorship to support its work and goals and develop an initial case and proposal in order to bid for funds.
8. A second GIRAF Workshop should be organised in two years time and continue biannually. Tanzania/SEAMIC have agreed to host the next workshop.
9. GIRAF will encourage all African geoscience organisations (e.g. OAGS, Geological Society of Africa and other participating organisations) to communicate their collaboration through reports to their organisations, presentations at conferences, web pages, press releases and other means.
10. The GIRAF community will use all opportunities to lobby politicians, (including where possible ministerial briefings), using for example the occasions of INDABA, UNECA, NEPAD).
11. Training and scholarships will be pursued and regional offices for geoscience informatics proposed at existing university campuses.
12. GIRAF will approach the organisers of the next Colloquium on African Geology (CAG)/ Capetown to propose a session on geoscience information and volunteer to organise that session.
13. GIRAF will approach the organisers of the 34th IGC in Australia to propose the concept of a Special Symposium on African geoscience information and volunteer to organise that Symposium and to seek Geohost funding in particular for African participants.
14. The progress of GIRAF and its recommendations will be presented at the IGC in Australia in 2012.
15. We, the GIRAF community, will develop strategies to provide mutual assistance to implement GIRAF aims and build participant capacity to ensure the success of our endeavour.

This agreement was produced and unanimously endorsed by participants at the GIRAF 2009 Workshop in Windhoek, Namibia, 20 March 2009

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Further information

For more information on GIRAF please email or write to the address below and visit the GIRAF website www.GIRAF2009.org. We would be most pleased to hear from African nations who were not able to attend the GIRAF 2009 Workshop.

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Permo-Triassic ultra-high temperature metamorphism, Mesozoic magmatism and Pleistocene volcanism and gold mineralization in the Kyushu Island, SW Japan: An excursion

Fukuoka, Kyushu, Japan, November 11-13, 2007

The 4th International Symposium on 'Gondwana to Asia' was held in Fukuoka, Japan from 8 to 10 November, 2007. After the symposium, a field excursion was held in the Kyushu Island, which started from Fukuoka city (Figure 1) on the 11 November 2007 and lasted three days until the 13th. The excursion was led by M. Owada, A. Kamei, K. Watanabe and Y. Osanai. Twenty-one geologists from fifteen countries, including Australia, Brazil, France, Germany, India, Italy, Japan, Russia, Sri Lanka, South Africa, South Korea, Thailand, UK., USA. and Vietnam participated, making a longitudinal traverse covering most part of Kyushu (Figure 1), and enabling the participants to observe pre-Tertiary basement terranes of the Japanese islands which are interpreted in the global tectonic framework of eastern Asiatic continent and Gondwanaland, and the Pleistocene Aso volcanoes and gold mineralization of the Hishikari Gold Mine (Figure 1). On the first day, the participants stayed in the Jigoku Onsen (spa) of the Aso area and on the second day at Yuno-Onsen (spa) in the Hishikari area. About ten localities (Figure 1) were visited during the excursion. The participants were provided with an excursion guidebook (Owada et al., 2007) carrying an overview of recent understanding of geology of the areas of excursion with details of locations visited. The island of Kyushu in southwest Japan is geologically important as it consists of fragments derived from NE Asia and Gondwana, and late Mesozoic to Neogene terranes which are thought to have originated as accretionary complexes, Quaternary active volcanoes and the gold mineralization hosts the world's highest grade gold-bearing quartz veins. The Japanese islands have been an active convergent plate margin since the late Palaeozoic.

The first day of the excursion was devoted to examining the ultra high temperature pelitic granulites and associated rocks of the Higo metamorphic complex and the Cretaceous Shiraishino granodiorite of the Higo plutonic complex in the western part of the central Kyushu (Figure 1). M. Owada, A. Kamei and Y. Osanai explained the geological, metamorphic and tectonic evolution of the Higo terrane, which has an E-W extension of about 40 km with a maximum N-S width of about 20 km. The terrane consists of Permian Mizukoshi Formation, the Cretaceous Mifune Group, and three metamorphic complexes (Osanai et al., 2006). In addition the terrane is intruded by the Higo plutonic rocks. In the Higo terrane three distinct metamorphic complexes have been identified (Osanai et al., 2006). These terranes, from north to south, are: (i) the Manotani metamorphic complex; (ii) the Higo metamorphic complex; and (iii) the Ryuhozan metamorphic complex (Osanai et al., 2006). The Higo plutonic rocks, which consist of the Manzaka tonalite, the Shiraishino granodiorite, the Miyanohara tonalite and hornblende gabbro, have intruded the Higo and Ryuhozan metamorphic complexes (Osanai et al., 2006). The boundary between the Manotani and Higo metamorphic complexes is a thrust contact accompanied by ultramafic intrusions (now mostly serpentinites), while that between the Higo and Ryuhozan metamorphic complexes is not well exposed as it is masked by the intrusions of Miyanohara tonalite and Shiraishino granodiorite (Osanai et al., 2006; Owada et al., 2007). The Higo metamorphic complex seems to be an imbricate crustal section with a metamorphic gradient from north to south. The grade of metamorphism increases towards the lower crustal levels (Osanai et al., 2006).

The first outcrop (Stop 1 in Figure 1) was located about 3 km south of Matsubase in Kumamota and exposes the highest grade metamorphic rocks reported from Japan represented by sapphirine-bearing granulites. These rocks occur as irregular blocks from 0.5 to 10 m within ultramafic rocks that have intruded along shear zones. The main rock types observed at this locality are exposed in scattered boulders, and the participants enthusiastically hunted for rocks with ultra-high temperature assemblages. These are highly aluminous sapphirine-corundum-spinel and garnet-corundum granulites and serpentinite. The rocks have been metamorphosed under P-T conditions of 0.78-0.90 GPa and 900-960°C (Osanai et al., 2006), are restitic in nature and have been transported from the deeper granulite facies zone to the present shallower level (amphibolite facies zone) by ultramafic magma now exposed as serpentinite or metamorphosed peridotite. Here the aluminous granulites occur only as scattered boulders and no proper outcrop was observed. The origin of these ultra-high temperature granulites was discussed at length, the most plausible explanation being that the granulites were metamorphosed at depth and were probably brought to the surface as xenoliths in the ultramafic magma from which the serpentinite and peridotite were formed. The possibility of occurrence of diamond- and coesite-bearing UHP metamorphic rocks in the Higo metamorphic terrain, similar to those found in the Dabie and Sulu terranes in China (Osanai et al., 2006) was also discussed.

The second locality visited (Stop 2 in Figure 1) is located about 10 km SE of Matsubase and exposed garnet-cordierite-sillimanite-biotite gneiss, characterised by the presence of large porphyroblasts of garnet. The gneiss is exposed at a road-cutting and consists of garnet, cordierite, sillimanite, spinel, staurolite, biotite, K-feldspar, plagioclase, and quartz. Leucocratic material occurs in the gneiss either parallel to the gneissic foliation or as veins. The leucocratic layers with garnet, cordierite, plagioclase and quartz are a product of an anatectic melt formed during the peak metamorphism (Osanai et al., 2006), whereas the veins seem to be related to a subsequent event. The gneiss is very similar to cordierite-sillimanite-bearing pelitic gneisses in many Gondwana terranes, such as, for example, the Wanni Complex of Sri Lanka and the Kerala Khondalite Belt of India. The garnet in the gneiss is zoned, and its core, including the core inclusions, has yielded a Sm-Nd internal isochron age of 278.8±4.9 Ma, which reflects timing of the prograde metamorphism, while its rim and included minerals at the rim give a Sm-Nd internal isochron age of 226.1±28.4 Ma, indicating the age of peak metamorphism (Osanai et al., 2006). One of the major topics discussed was the origin(s) and ages of the different terranes in the Kyushu Island. The Higo terrane records inherited Palaeoproterozoic zircon ages (2155-1790 Ma from the Higo metamorphic complex), Cambrian-Devonian zircon core ages (550-450 Ma from the Higo and Ryuhozan metamorphic complexes), Early Permian Sm-Nd internal isochron ages (279-261 Ma from the Higo metamorphic complex) for prograde metamorphism, Late Permian to Triassic ages (258-206 Ma from the Higo and Ryuhozan metamorphic complexes) reflecting the age of the main metamorphism, Late Triassic to Early Cretaceous ages (ca. 180-210 Ma) from the Manotani metamorphic complex reflecting a period of retrogression and Early Cretaceous intrusive ages (ca 100-120 Ma) of the Higo plutonic rocks (Osanai et al., 2006). Although the source regions of inherited Palaeoproterozoic and Cambrian-Devonian zircon ages are unknown, it is believed that zircon has been derived from nearby Gondwana terranes. Based on similar metamorphic and igneous characteristics, protoliths, and on similar metamorphic and igneous ages, Osanai et al. (2006) have correlated the Higo metamorphic complex, together with the Manotani metamorphic complex and similar rocks in the Sefuri Montains in northern Kyushu, with the Permo-Triassic metamorphic rocks in the north Dabie and Sulu terranes in China. It was suggested that the Higo and Manotani metamorphic complexes were parts of the Permo-Triassic collisional zone between the North China and South China cratons and that they moved southward as a nappe structure before the intrusion of the 120 Ma Shiraishino granodiorite. The origin of the Manotani metamorphic complex was not clear to the participants. However, based on the lithological association of this complex, such as mafic schists derived from MORB-type basalt with minor amount of pelitic/psammitic schist, red chert, gabbro and serpentinite (Osanai et al., 2006), it was discussed that the complex might have originated as part of an obducted oceanic crust, now thrust over the Higo metamorphic complex.

The last outcrop (Stop 3 in Figure 1) visited on the first day was located about 15 km east of Matsubase. Here the participants were able to observe the early Cretaceous Shiraishino granodiorite and the overlying welded tuff from the Pleistocene Aso volcano, which is situated about 30-40 km NNE of this locality. The granodiorite at this locality is homogeneous and pale in colour and is medium- to fine-grained. It consists of plagioclase, quartz, biotite, hornblende and K-feldspar as major minerals and titanite, apatite, zircon, rutile as minor phases. Rb-Sr whole rock age reported from the Shiraishino granitoid is 122±14 Ma (see Owada et al., 2007 and references therein). It was suggested that the granodiorite is characterised by high concentration of Sr, slightly higher Na_2O and lower K_2O, Rb, and Y. This chemistry contrasts with that of other Cretaceous granitic rocks in the Kyushu Island (Owada et al., 2007). The participants discussed the possible origin of the granodiorite and agreed with the most plausible model presented by Kamei (2004). According to Kamei (2004) the Shiraishino granodiorite was intruded as an adakitic pluton, with magma thought to be derived from partial melting of younger subducted oceanic crust produced by the collision of the Kula-Pacific ridge at the eastern margin of Asian continent during the Early Cretaceous. Beautiful columnar joints (Figure 2) and flow structures in the overlying welded tuff from Aso volcano were clearly visible at this locality.

The participants stayed overnight at a

Japanese style hotel at Jigoku-Onsen, a spa-village in the Aso caldera, where they enjoyed Japanese bathing, foods and traditional accommodation. The second day of the excursion started in Aso (Stops 4-7 in Figure 1). The participants first visited the currently active Naka-dake volcano, which is a stratovolcano of basaltic andesite to basalt. On the way to the Naka-dake, we were able to observe the cinder cones of Kami-Kometsuka and Kometsuka in the Aso caldera. The Aso volcano, one of the active volcanoes in Japan, is well-known for its huge caldera (Figure 3), which is the largest caldera in the world. The caldera is 25 km across N-S and 18 km across E-W and was formed by the outflow of four huge pyroclastic flows in the late Pleistocene (see Owada et al., 2007). The caldera has a circumference of about 120 km and contains the city of Aso (Figure 3) as well as Aso Takamori-cho and South Aso-mura. The central cone group of Aso consists of five peaks: Mt. Neko, Mt. Taka, Mt. Naka, Mt. Eboshi, and Mt. Kishima. The highest point is the 1592 m of Mt. Taka. The crater of Mt. Naka-dake, the west side of which is accessible by road, contains an active volcano which continuously emits smoke and has occasional eruptions.

K. Watanabe explained the geological, tectonic and eruption histories of the Aso volcano and the origin of the Aso caldera. The present Aso caldera formed as a result of four huge caldera eruptions that occurred over a range of 90,000-270,000 years ago. These eruptions (Aso-1, Aso-2, Aso-3 and Aso-4) were associated with large-scale pyroclastic flows. K-Ar dating of volcanic rocks from the four eruptions yielded an age of 270,000 years for Aso-1, 140,000 years for Aso-2, 120,000 years for Aso-3 and 90,000 years for Aso-4 (Matsumoto et al., 1991). The total volume of the four pyroclastic flow deposits has been estimated to be more than 300 km^3. The basement rocks of this area are Palaeozoic to Mesozoic, with metamorphic rocks and Cretaceous granites. During and after the formation of the caldera, three large lakes existed in the caldera, in which thick lacustrine sediments were deposited (Owada et al., 2007). K. Watanabe explained that both the pre- and post-caldera rocks of Aso volcano range from basalt to rhyolite in composition and that they are characterized by high alkali contents.

After reaching the crater area of the Naka-dake volcano, the participants, some for the first time, enjoyed seeing one of the most active volcanoes in the world. We were able to see the three-fold structure of the Naka-dake volcano with the old and young volcanic edifices and the youngest cone. The active crater of the youngest cone consists of seven craterlets aligned N-S. Of these seven craterlets, only the northernmost one is active at present since 1933. At the time of our visit, the Naka-dake volcano was emitting a dense cloud of volcanic gases (Figure 4), which almost covered the light green-coloured hot water pool occupying the bottom of the craterlet. From the observation point for the Naka-dake, the participants had an excellent view of the layers of volcanic rocks showing historical and recent eruptions and the geometry of the craterlet (see left part of Figure 4). Welded driblet layers of basaltic andesite were visible around the southern-most craterlet, which were intercalated in layers of explosion breccia, pyroclastic surge deposits, and fine ash fall deposits as described by K. Watanabe. According to him the Naka-dake volcano has erupted more than 100 times since 553 AD, and in more active periods as in 1933, 1974, 1979, and 1989-1990, large amounts of fine ash of olivine-pyroxene basaltic andesite composition were erupted. About seven people have been killed since 1980 after inhalation of volcanic gases. After seeing the active Nake-dake volcano, we visited the Aso volcano museum to learn more about the history of the volcanic system.

The last outcrop (Stop 8 in Figure 1) of the second day was located at a village called Hachiman-daki, about 10 km S of Yatsushiro. The outcrop exposes garnet-clinopyroxene mafic granulite and serpentinite on the right bank of the Kuma River. At this outcrop, the garnet-clinopyroxene mafic granulite dominates over the serpentinite, which occurs between blocks of the former. The mafic granulite is medium-grained with a weak foliation and greenish grey in colour. The presence of chlorite in strongly sheared parts in the rocks suggests that they have undergone retrograde metamorphism. The peak and retrograde metamorphic conditions are 870-970ûC, 1.0-1.2 GPa and 720-820ûC, 0.5-0.6 GPa, respectively (Osanai et al. 2000). Some boulders of mafic rocks observed at this outcrop contains xenoliths of limestone and a felsic rock. Here the discussions were centred at the possible origin of the rocks, which belong to the Kurosegawa tectono-stratigraphic terrane in SW Japan. These rocks have been interpreted to form a tectonic mélange unit. However, some participants believe that they probably represent parts of an ophiolitic sequence.

One of the key issues discussed was the tectonic origin of the Kurosegawa terrane, which is subdivided into three units as (i) Kurosegawa Tectonic Zone, (ii) late Palaeozoic to early Mesozoic accretionary complex and (iii) Palaeozoic to Mesozoic covering sedimentary rocks (Yoshikura et al., 1990). In addition to these, Lower Cretaceous cover sequences consisting of fluvial and shallow marine deposits unconformably overlying the above units (Owada et al., 2007). The metamorphic and igneous rocks in the Kurosegawa terrane occur as blocks and clasts in the above units (i) and (ii). The igneous rocks are diorite to granite with granodiorite being the dominant rock. They are associated with high-grade metamorphic rocks having granulite facies mineral assemblages. The P-T conditions of this granulite facies metamorphism inferred from the Grt-Cpx mafic granulite are 1.0-1.2 GPa and 800-950°C (Osanai et al., 2000). The U-Pb zircon age of 450 Ma for post-metamorphic granitic rock reported from the Kurosegawa terrane (Hada et al., 2000), and 489 Ma Sm-Nd internal isochron age of garnet amphibolite (Osanai et al., 2000) may provide the youngest time limit for the major metamorphism. One of the tectonic models proposed to explain the origin of this terrane is that high-grade metamorphic rocks and granitic rocks formed a landmass, called Kurosegawa landmass, derived from the Gondwana supercontinent (Yoshikura et al., 1990). During the middle Palaeozoic, this landmass was situated near palaeo-equatorial regions, far south of the present position of Japan (see Owada et al., 2007). The same model suggests that the landmass, with the late Palaeozoic accretionary complex, eventually collided with the Eurasian plate by early Cretaceous time.

On the last day of the excursion, we visited the Hishikari gold mine (Stop 9 in Figure 1) to see the world's highest grade gold-bearing quartz veins (Figure 5). The mine is owned and operated by the Sumitomo Metal Mining Co. Ltd, Japan. The geology of the gold mineralization was explained by K. Watanabe, and the mining methods and extraction processes were demonstrated by the company's engineers. The gold content in the veins is extremely high, being ten times higher than the world average and about twice that of the silver in the same mineralization. The gold-bearing quartz veins occur as fissure-filling epithermal veins in Cretaceous sedimentary rocks and Pleistocene volcanic rocks and are composed mainly of quartz and adularia with smectite. The mineralization consists of two major ore zones, known as the Honko-Sanjin zone and the Yamada zone, and occurs in a NE-SW trending area 2.4 km long by 0.8 km wide. The gold-bearing quartz veins strike in a N 50°E direction and dip to the NW at 70°-90°. The average grade of the mineralization is 39.4 grams of gold per ton, and the estimated total resource is more than 300 tons of gold, of which more than half has already been mined. The host rocks of the vein mineralization are a Cretaceous flysch sequence with sandstone and shale belonging to the Shimanto Supergroup and the Pleistocene Hishikari Lower Andesite

(Figure 5). The age of the mineralization has been dated by K-Ar and Ar-Ar methods to have started at 1.15 Ma, about 500,000 years after the initiation of the volcanic activity in the area (see Owada et al., 2007 and references therein) and ended at 0.60 Ma. One of the problems discussed was the source of Au, and it was agreed that the source was the magma of the Pleistocene volcanic rocks.

The mining company reported that it maintains an environmental friendly policy by monitoring the quality of the water and air in the mine, noise levels etc. Part of the hot water from the mine is supplied to local villages for hot spring business and the rest is discharged to the nearby river after cooling.
Wilbert Kehelpannala thanks Professor Y. Osanai, Chairman of the organizing committee of the symposium for inviting him to deliver a keynote address, and the Kyushu University, Japan and the Japanese Society for Promotion of Science (JSPS) for financial assistance for participating in the workshop.

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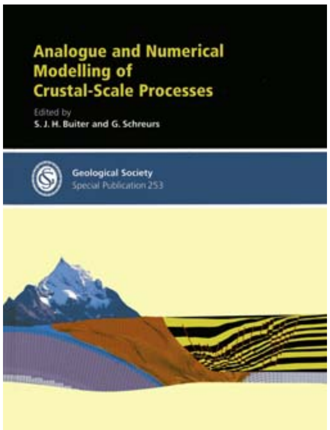
Analogue and numerical modelling of crustal-scale processes

Edited by S.J.H. Buiter and G. Schreurs

Geological Society Special Publications
No. 253, London, 2006, 456 pp.,
Price List: £85.00, US$170
ISBN 1-86239-191-2



Earth science began with the observation of the Earth materials and processes, then asking specific questions, proposing and testing hypotheses, formulating general concepts and theories, and finally experimenting and modelling. On a larger scale, this has been the pattern of Earth science history; and on a smaller scale this also is how a comprehensive Earth science research project proceeds. Experimentation, modelling and simulation are relatively recent developments in Earth science, and in this regard Earth scientists have a long way to go compared with their colleagues in physics and chemistry. But serious steps have been taken in recent decades. This new book is a testimony to these developments in the field of tectonic modelling. The book is a valuable addition to similar volumes published previously by the Geological Society of London, notably *Modern Insights into Structural Interpretation, Validation and Modelling* (edited by P. G. Buchanan and D. A. Nieuwland, 1996) and *New Insights into Structural Interpretation and Modelling* (edited by D. A. Nieuwland, 2003). *Analogue and Numerical Modelling of Crustal-Scale Processes* is the outcome of an international meeting, GeoMod2004, held in Switzerland in 2004; it is edited by Susanne Buiter of the Geological Survey of Norway and Guido Schreurs of the University of Bern, Switzerland.

There is no complete consensus on the usage of the terms "modelling," "simulation," and "experimentation" (or even "analysis") among Earth scientists. The editors of this volume define "model" to mean "an approximation of a physical process that will help further our understanding of the process itself, the measurable or observable structure that result from it, and the parameters that control it." They go on to remark that "models allow us to set the boundary conditions, study the effects of parameter variations and perform sensitivity analyses. By their nature, they are, however, always a simplification of reality."

This volume contains two sets of "modelling" studies: (1) Numerical modelling which is "a mathematical description of the natural situation, whereby aspects of processes are chosen that are of interest and can also feasibly captured in equations;" and (2) Analogue modelling which "represents a scaled analogue of a natural structure, scaling not only the dimensions, but also the forces and material (for example, sand or clay). The latter is what a physicist or a chemist might call "experimentation" and one of the challenges in Earth science experiments (aside from simplification of the actual material, structure or process) is scaling. For the upper crustal-level structures, one cm in the sandbox models is often assumed to represent one kilometer in nature.

Of the 23 papers included in this volume, 10 are numerical modelling, 9 are analogue modelling (experiments), and 4 are mixed (integrated) analogue-numerical modelling studies. Eventually and ideally, in Earth science we will need to compare and contrast the results of research on a specific problem obtained from three different methods: Observation, Experimentation (analogue modelling), and Numerical modelling. Towards this end, this volume offers some interesting case studies. The volume opens with a chapter on "Analogue benchmarks of shortening and extension experiments" (by the editors and 20 other authors) which compares the results of scaled analogue experiments on a brittle thrust wedge (structural shortening) and a brittle viscous normal faulting (structural extension) to test the reproducibility of the model outputs among 10 different laboratories around the world.

The second chapter ("The numerical sandbox" by Buiter et al.) is another international collaborative study, which compares the results of analogue experimentation and numerical modelling for a structural shortening and a structural extension case study. The rest of the papers in the volume are categorized under four headings: (1) Models of Orogenic Processes (7 papers), (2) Models of Sedimentary Basins (6 papers), (3) Models of Surface Processes and Deformation (3 papers) and (4) Models of Faults and Fluid Flow (5 papers). In terms of the geographic coverage of the case studies the following areas are studied: Northern Apennines, Italy (Chapter 3, Corti et al.), the Superior Province, Canada (Chapter 4, Cruden et al.), South Pyrenees, Spain (Chapter 6, Koyi and Sans), Sierra de Albarracin, Spain (Chapter 7, Marten et al.), Nankai Trough, Japan (Chapter 9, Yamada et al.), the Gulf of Cointh, Greece (Chapter 11, Mattioni et al., and Chapter 12, Le Pourhiet et al.), Weald basin, England (Chapter 14, Sandiford et al.), the Nepal Himalayas (Chapter 18, Godard et al.), the Norwegian margin North Sea (Chapter 19, Bjorlykke), the Marmara Sea, Turkey (Chapter 21, Muller et al.), West Carpathians, northern Europe (Chapter 22, Nemcok and Henk), and San Andreas fault, California (Chapter 23, Provost and Chzry).

With 59 reviewers listed in the acknowledgement, this is a well-refereed volume. Statoil is acknowledged for financially supporting some of the costs of producing this volume. I hope that the tradition of oil companies sponsoring research publications will be enhanced because the petroleum business is mainly a technological enterprise that relies on geoscience. And given the increasing demand for petroleum and other forms of energy, petroleum companies, which are enjoying high prosperity in these days of high oil prices, need to drastically increase their support for research and development ventures in geoscience. Three papers in this volume specifically deal with petroleum. Clarke et al. (Chapter 10) present the results of a 4-D numerical modelling of basin architecture and hydrocarbon migration. Bjorlykke (Chapter 19) discusses the effects of sediment compaction on fault stress and hydrocarbon flow in examples from the North Sea. Nemcok and Henk (Chapter 22) present a study of petroleum reservoirs in the West Carpathian thrust belt/foreland basin (with Early Cretaceous-Oligocene sediment filling and Late Oligocene Early Miocene thrust movements) in which numerical stress modelling is compared with the geometry of balanced cross sections, and thus fault-related oil migration pathways are identified. The upper crust of the Earth is where we observe mountains, cratons, and basin, and where our settlements and natural resources are located. Therefore, geoscientific investigation and modelling of the upper crust is crucial for our science and society, and this book offers many important papers for researchers and educators in geoscience.

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Tectonic Aspects of the Alpine-Dinaride-Carpathian System

Siegesmund, S., Fügenschuh, B. & Froitzheim, N. (Eds.)

Geological Society Special Publication, 2008, vol. 298, viii + 448 pp.
ISBN 978-1-86239-252-6, £90.00.

This Geological Society Special Publication, dedicated to one of the most respected experts on Alpine Geology, Professor Stefan Schmid, on the occasion of his 65th birthday comprises a collection of data and results from studies on the structural, tectonic, metamorphic and sedimentary evolution of distinct parts of the Alpine-Dinaride-Carpathian System. It represents the continuation of a series of Geological Society Special Publications on the evolution of the Alps and related orogenic belts, starting with the famous issue on "Alpine Tectonics" edited by Coward, M.P., Dietrich, D., and Park, R.G. in (Geological Society Special Publication, vol. 45). The current volume contains chapters concerning the pre-Alpine heritage and reactivation of pre-Alpine structures during Alpine orogeny, the Mesozoic paleogeography and Alpine subduction and collision processes, the processes of orogen-parallel, lateral extrusion and the linkage from the Eastern Alps towards the Carpathians and the Pannonian Basin, orogen-parallel and orogen-perpendicular extension, the record of orogeny in sediments captured in foreland basins, the tectono-metamorphic evolution, and the relations between the Alps, Apennines and Corsica. Major portions of this wide area were reexamined during the last decade, resulting in many new insights and models both for the pre-Alpine evolution and Alpine geodynamics.

The Alps, Carpathians and Dinarides are parts of the much larger system of Circum-Mediterranean orogens, forming a continuous, highly curved orogenic belt, which encircles the Pannonian Basin. The volume comprises 18 individual contributions covering a wide range of topics on the evolution of this orogenic belt, which has been the goal of intense detailed research since a long time. These studies are provided by different international working groups with fundamental experience in Alpine geology. Together, the data presented in these studies provide knowledge on the current structure of the orogen. The fact that 13 of these contributions handle studies on the evolution of the Alps documents that this orogen, although said to be the best investigated one worldwide, still provides many open questions. However, fundamental questions on the evolution of this orogenic system can only be answered in the Carpathians, Dinarides, and in the orogens forming the continuation of this orogenic belt towards the southeast.

This volume is therefore a useful tool to present recent data and models on the evolution of this part of the earth and to trigger discussion, evaluation and future research, particularly in the Dinarides, but in the Carpathians as well. As long as a modern comprehensive textbook on the geology of the Alps and its adjacent orogens is still missing, this volume will appeal to a wide range of readers thanks to contributions covering wide areas of the ALCAPA-system, and many geological techniques. It therefore represents a worthwhile addition to the library on Alpine geology, with the potential of impact to studies on other orogens.

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Note: Please see IUGS website for more detailed list of meetings.

● **Signifies the first announcement of the meeting in *Episodes* or an amended entry.**

2009

April

13–21 April 2009
THE MACQUARIE ARC 2009 CONFERENCE—AN INTERNATIONAL CONFERENCE ON ISLAND ARC CONTINENT COLLISIONS AND MINERAL DEPOSITS IN ACCRETED ARCS. (Four days of talks and four days of field trips), Turners Vineyard Convention Centre, Orange, Australia. (Contact: Convenor: Dr Richard Glen. Website: http://www.dpi.nsw.gov.au/aboutus/news/events/minerals).

14–17 April 2009
3RD INTERNATIONAL MAAR CONFERENCE (IAVCEI–CVS–IAS), Malargüe, Argentina. (Contact: Prof. Dr. Corina Risso. 31MC Secretariat, Departamento de Geologia, FCEN–Universidad de Buenos Aires, Pabellón 2, Ciudad Universitaria, C1428 EHA Buenos Aires, Argentina. Tel: +49-931-31-6019; Fax: +49-931-31-2378; E-mail: imc3@cenpat.edu.ar; Website: www.3imc.org)

15–18 April 2009
GEOFLUIDS VI CONFERENCE, Venue: Adelaide, Australia. (Contact: Website: http://www.adelaide.edu.au/geofluids/; E-mail:geofluids@adelaide.edu.au).

19–23 April 2009
ProGEO MEETING WG3—NORTHERN EUROPE GEODIVERSITY, GEOHERITAGE & NATURE AND LANDSCAPE MANAGEMENT, Drenthe, the Netherlands. (Contact: E-mail: info@geocheritage.nl)

20–23 April 2009
HYDROECO'2009—2ND INTERNATIONAL MULTIDISCIPLINARY CONFERENCE ON HYDROLOGY AND ECOLOGY, Vienna, Austria. (Contact: Website: http://www.natur.cuni.cz/hydroeco2009/).

28–30 April 2009
● ***ECOFORUM CONFERENCE & EXHIBITION—INCORPORATING THE 2ND ANNUAL CONFERENCE OF THE AUSTRALIAN LAND & GROUNDWATER ASSOCIATION (ALGA)***, Sydney, Australia. (Contact: Website: www.ecoforum.net.au/2009).

29–30 April 2009
● ***THE AUSIMM NEW LEADERS' CONFERENCE 2009: MINING OUR GENERATION—THE FUTURE OF THE MINING INDUSTRY,*** Brisbane, Queensland, Australia. (Contact: Website: http://www.ausimm.com/

May

6–7 May 2009
● ***FIRST INTERNATIONAL SEMINAR ON SAFE AND RAPID DEVELOPMENT MINING***, Perth, Australia. (Contact: Website: http://www.srdm.com.au/).

24–27 May 2009
THE MEETING OF THE AMERICAS, Toronto, Ontario, Canada. Sponsors: CGU, GAC, IAHCNC, MAC, AGU. (Contact: AGU Meetings Department, 2000 Florida Avenue, NW, Washington DC 20009 USA, Phone: +1 202 462 6900, N. America: (800) 966-2481.)

June

1–4 June 2009
24TH INTERNATIONAL APPLIED GEOCHEMISTRY SYMPOSIUM 2009, New Brunswick, Canada. Contact: Website: http://www.unb.ca/conferences/IAGS2009/).

4–5 June 2009
NORTH QUEENSLAND EXPLORATION CONFERENCE NQEM 2009, (Contact:Kaylene Camuti. E-mail: lantana@beyond.net.au).

6–8 June 2009
GSAQ—AIG FIELD CONFERENCE (Starts from Townsville after NQEM, Charters Towers District–Charters Towers, Mt Coolon site visits), Townsville, Australia. (Contact: d.young@findex.net.au).

7–10 June 2009
AAPG (AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS) ANNUAL CONVENTION AND EXHIBITION, Denver, Colorado, USA. (Contact: Tel: 918-560-2600; Fax: 918-560-2684; E-mail: rreeder@aapg.org).

8–10 June 2009
6TH IWA/GRA SPECIALIZED CONFERENCE ON ASSESSMENT AND CONTROL OF MICROPOLLUTANTS/ HAZARDOUS SUBSTANCES CONTROL IN WATER, San Francisco, USA. (Contact: Website: http://www.grac.org/micropol.asp).

8–10 June 2009
GROUNDWATER FOR THE AMERICAS, Panama City, Panama. (Contact: Website: http://www.ngwa.org).

8–11 June 2009
71ST EAGE CONFERENCE & EXHIBITION, Amsterdam, The Netherlands. (Contact: Website: www.eage.org/events/).

14–16 June 2009
THE 1ST INTERNATIONAL CONFERENCE ON CIVIL ENGINEERING—TOWARDS A BETTER ENVIRONMENT, Coimbra, Portugal. (Contact: Professor Isabel Pinto, Conference Chairperson, University of Coimbra, Polo II–Pinhal de Marrocos, 3030-290 Coimbra, Portugal; CE 09 Conference Secretariat: CI-PREMIER PTE LTD, 150 Orchard Road #07-14, Orchard Plaza, Singapore 238841, Tel: +65 67332922; Fax: +65 62353530; E-mail: cipremie@singnet.com.sg; Website: http://www.cipremier.com).

14–20 June 2009
XIV INTERNATIONAL CLAY CONFERENCE, Castellaneta Marina, Italy. (Contact: Tel: +39 0971.427294; Fax: +39 0971.427295; E-mail: secretariat@14icc.org; Website: www.14icc.org).

15–18 June 2009
SIAM CONFERENCE ON MATHEMATICAL & COMPUTATIONAL ISSUES IN THE GEOSCIENCES (GS09), Helmholtz-Zentrum für Umweltforschung Leipzig, Germany. (Contact: Website: http://www.siam.org/meetings/calendar.php?id=601).

22–26 June 2009
GOLDSCHMIDT 2009—CHALLENGES TO OUR VOLATILE PLANET, Davos, Switzerland. (Contact: E-mail: info@goldschmidt2009.org; Website: http://www.gsa.org.au/events/www.goldschmidt2009.org)

27 June–8 July 2009
● ***INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS (IUGG) 2011—EARTH ON THE EDGE: SCIENCE FOR A SUSTAINABLE PLANET***, Melbourne, Australia. (Contact:Website: http://www.iugg2011.com/).

July

6–11 July 2009
● ***7TH INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY (ANZIAG)*** Ancient Land-scapes-Modern Perspectives, Melbourne, Australia. (Contact: www.geomorphology2009.com)

7–12 July 2009
7TH INTERNATIONAL GEOMORPHOLOGY CONFERENCE, Melbourne, Australia. (Contact: Website: www.geomorphology2009. com).

9–13 July 2009
GEOLOGY FOR SOCIETY - ASSOCIATION OF EUROPEAN GEOLOGICAL SOCIETIES. Cluj-Napoca, Romania. (Contact: http://bioge.ubbcluj.ro/maegs).

August

11–15 August 2009
ASIA OCEANIA GEOSCIENCES SOCIETY 6TH ANNUAL MEETING, Singapore. (Contact: AOGS Secretariat Office Meeting Matters International, 25 Hindoo Road, Singapore 209116, Tel: +65 6341 7229; Fax: +65 6341 7269; E-mail: info@asiaoceania.org; Website: www.asiaoceania.org).

17–20 August 2009
SOCIETY FOR GEOLOGY APPLIED TO MINERAL DEPOSITS (SGA 2009), Townsville, Australia. (Contact: Website: http:// sga2009.jcu.edu.au/; E-mail: sga2009@jcu.edu.au).

19–21 August 2009
INTERNATIONAL SYMPOSIUM ON "RHEOLOGY OF CEMENT SUSPENSION SUCH AS FRESH CONCRETE", Reykjavik, Iceland. (Contact: Prof. O Wallevik. E-mail: wallevik@ru.is).

23–28 August 2009
IAMG2009—INTERNATIONAL ASSOCIATION FOR MATHEMATICAL GEOLOGY ANNUAL CONFERENCE, Stanford, California, USA. (Contact: Jef Caers, Chairman. Website: http://iamg09.stanford.edu/).

23–30 August 2009
IAGA 11TH SCIENTIFIC ASSEMBLY, Sopron, Hungary. (Contact: Conference Secretariat, Diamond Congress Ltd, Attila Varga, POB 48, Budapest Hungary H-1255 ; Tel: +36-1-214-7701; Fax: +36-1-201-2680; E-mail: iaga2009@iaga2009sopron.hu; Website: www.iaga2009sopron.hu/)

September

7–12 September 2009
SUSTAINABLE DEVELOPMENT AND MANAGEMENT OF GROUNDWATER RESOURCES OF HARD ROCK TERRAINS—Joint IAH/IAHS International Convention combining 37th IAH Congress and 8th IAHS Scientific Assembly, Hyderabad, India. (Contact: E-mail: iahs@ensmp.fr *or* w.struckmeier@bgr.de).

9–11 September 2009
IAEG 2009—INTERNATIONAL SYMPOSIUM 'GEOLOGICAL ENGINEERING PROBLEMS IN MAJOR CONSTRUCTION PROJECT'. Chengdu, China. (Contact: http://www.iaeg2009.com/)

9–11 September 2009
FIFTH INTERNATIONAL CONFERENCE ON SUSTAINABLE WATER RESOURCES MANAGEMENT. Malta. (Contact: Website: http://www2.wessex.ac.uk/09-conferences/waterresources-management-2009.html).

19–26 September 2009
- ***JOINT 61ST ICCP- 26TH TSOP MEETING—ADVANCES IN ORGANIC PETROLOGY AND ORGANIC GEOCHEMISTRY***, Gramado/Porto Alegre, Brazil. (Contact: International Committee for Coal and Organic Petrology (ICCP), The Society for Organic Petrology (TSOP). Website: www.ufrgs.br/ICCP_TSOP_2009/).

20–23 September 2009
27TH MEETING OF SEDIMENTOLOGY Alghero, Sardinia, Italy. (Contact: Dr. Vincenzo Pascucci, Institute of Geology and Mineralogy, University of Sassari. E-mail: pascucci@uniss.it. Website: www.ias2009.com)

23–26 September 2009
SUSTAINABILITY OF THE KARST ENVIRONMENT—DINARIC KARST AND OTHER KARST REGIONS. Plitvice Lakes, Croatia. (Contact: E-mail:jadranka.pejnovic@gs.t-com.hr).

27–30 September 2009
- ***CLEANUP 09, COMPRISED OF THE 5TH INTERNATIONAL WORKSHOP ON CHEMICAL BIOAVAILABILITY 24-25 SEPTEMBER AND THE 3RD INTERNATIONAL CONTAMINATED SITE REMEDIATION CONFERENCE***, Adelaide Hilton, Australia. (Contact: Website: http://www.cleanupconference.com/papers.htm).

29 September–1 October 2009
- ***BROKEN HILL EXPLORATION INITIATIVE 2009—BHEI***, Broken Hill Entertainment Centre, NSW, Australia. (Contact: Website: www.dpi.nsw.gov.au/minerals/geological/bhei2009).

October

5–9 October 2009
2ND INTERNATIONAL SYMPOSIUM ON THE GEOLOGY OF THE BLACK SEA, Ankara, Turkey. (Contact:SGB Secretary, General Directorate of Mineral Research & Exploration, 06520 Ankara. Tel: 90-312-287 91 93; Fax: 90-312-287 91 93; E-mail: isgb@mta.gov.tr).

12–16 October 2009
GEOETHICS: THE INTERNATIONAL SECTION OF THE MINING PRIBRAM SYMPOSIUM 2009, Pribram, Czech Republic. (Contact: Email: lidmila.nemcova@quick.cz *or* marcinikova@diamo.cz).

18–21 October 2009
GEOLOGICAL SOCIETY OF AMERICA (annual meeting), Boulder, CO. USA. (Contact: GSA Meetings Dept., P.O. Box 9140, Boulder, CO, 80301-9140, USA. Tel: +1 303 447 2020; Fax: +1 303 447 1133; E-mail:meetings@geosociety.org; Website: http://www.geosociety.org.meetings/index.htm)

18–23 October 2009
VIII INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL GEOCHEMISTRY, Ouro Preto/MG, Brasil. (Contact: Website:http://www.12cbgq.ufop.br/12cbgq/principaleng.htm).

21–25 October 2009
MODELCARE 2009, Wuhan, China. (Contact: Yanxin Wang, China University of Geosciences. E-mail: yx.wang@cug.edu.cn)

26–30 October 2009
- ***MINERALS COUNCIL OF AUSTRALIA'S SD09 CONFERENCE***, Adelaide, Australia. (Contact: E-mail: events@minerals.org.au; Website: http://www.sd09.com.au/).

26–31 October 2009
INTERNATIONAL CONFERENCE ON GEOSCIENCE FOR GLOBAL DEVELOPMENT, Dhaka, Bangladesh. (Contact: Ms. Afia Akhtar, Director General, Geological Survey of Bangladesh. E-mail: afia@agan.com or gsb@agni.com).

November

8–13 November 2009
- ***SGGMP—KANGAROO ISLAND 2009***, Kangaroo Island, Australia. (Contact: Website: http://sggmp.gsa.org.au/events.html).

2010

February

1–5 February 2010
- ***SPECIALIST GROUP IN TECTONICS & STRUCTURAL GEOLOGY—BIANNUAL FIELD CONFERENCE***, The Glasshouse, Port Macquarie, Australia. (Contact: Website: http://www.sgtsg.gsa.org.au/).

1–5 February 2010
6TH INTERNATIONAL BRACHIOPOD CONGRESS, Melbourne, Victoria, Australia. (Contact:http://www.deakin.edu.au/conferences/ibc/).

4–7 February 2010
SIXTH INTERNATIONAL DYKE CONFERENCE, Varanasi, India. (Contact: Prof. Rajesh K. Srivastava, Convener, IDC-6, Igneous Petrology Laboratory, Department of Geology, Banaras Hindu University, Varanasi 221 005, India. E-mail: 6idc2010@gmail.com *or* rajeshgeolbhu@gmail.com; Website: http://icc6.igpetbhu.com).

March

24–26 March 2010
INTEGRATED WATER RESOURCES MANAGEMENT AND CHALLENGES OF THE SUSTAINABLE DEVELOPMENT, Agadir, Morocco. (Contact: E-mail: lbouchaou@yahoo.fr).

April

6–9 April 2010
- ***13TH QUADRENNIAL IAGOD SYMPOSIUM 2010—GIANT ORE DEPOSITS DOWNUNDER***, Adelaide, Australia. (Contact: Website: www.geology.cz/iagod/activities/symposia/adelaide-2010).

13–18 April, 2010
ASSOCIATION OF AMERICAN GEOGRAPHER'S (AAG) ANNUAL MEETING, Washington DC, USA. (Contact: Rachel S. Franklin, PhD, Deputy Director, Association of American Geographers, 1710 Sixteenth St. NW, Washington, DC20009. Tel: (+1 (202)234–1450; Fax: +1 (202) 234–2744; Website: www.aag.org)

20–22 April 2010
- ***CAVING 2010: SECOND INTERNATIONAL SYMPOSIYM ON BLOCK AND SUBLEVEL CAVING ACG AUSTRALIAN CENTRE FOR GEOMECHANICS***, Perth, Australia. (Contact: Website: http://www.caving2010.com/).

July

4–8 July 2010
20TH AUSTRALIAN GEOLOGICAL CONVENTION, Canberra, Australia. (Contact: Website: www.gsa.org.au).

August

21–27 August 2010
20TH GENERAL MEETING OF THE INTERNATIONAL MINERALOGICAL ASSOCIATION, Budapest, Hungary. Bonds and Bridges. Mineral Sciences and their applications: Everything on natural and analogous solid matter and its interactions. (Contact: Ekkehart Tillmanns, E-mail: ekkehart.tillmanns@univie.ac.at; Fax: +43 1 4277 9532; Tel: +43 1 4277 53226. Tamas G. Weiszburg, E-mail: weiszburg@ludens.elte.hu; Fax: +3613812110; Tel: +36 1 3 812205; Website: http://www.univie.ac.at/Mineralogie/IMA_2010/

September

5–9 September 2010
- ***5TH INTERNATIONAL ARCHEAN SYMPOSIUM***, Perth, Australia. (Contact: Website: http://www.5ias.org/).

5–10 September 2010
11TH IAEG INTERNATIONAL CONGRESS—'GEOLOGICALLY ACTIVE', Auckland, Aotearoa New Zealand. (Contact: http://www.iaeg2010.com/)

26 September–1 October 2010
18TH INTERNATIONAL SEDIMENTOLOGICAL CONGRESS, Mendoza, Argentina. (Contact: Eduardo Piovano, GIGES, Dpto. Quimica, Facultad de Ciencias, Avda. Velez Sarsfield 1611, X5016GCA, Cordoba, Argentina. E-mail: secretary@isc2010.com.ar, *or* epiovano@efn.uncor.edu; Website:http://www.isc2010.com.ar/)

2012

June

IAVCEI 2012, Alaska, USA. (Contact; Steve McNutt and John Eichelberger. Tel: +1-907-474-7131; Fax: +1-907-474-5618; E-mail: steve@giseis.alaska.edu)

August

5–15 August 2012
34TH INTERNATIONAL GEOLOGICAL CONGRESS, Brisbane, Australia. (Contact: Dr Ian Lambert, Geoscience Australia. Tel: +61 2 62499556; Fax: +612 62499983; E-mail: lan.Lambert@ga.gov.au; Website: www.ga.gov.au/igc2012)

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Page number references to Volume 31 are listed. Abbreviations: A, article; BR, book review; CP, classical paper; CR: conference report; E: editorial; IYPE: International Year of Planet Earth 2007–2009; NR: news report; P: profile.