Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, Band 17

IGCP 580

Magnetic Susceptibility and Gamma-Ray Spectrometry through time

Graz, 24-30th June 2012

ABSTRACT VOLUME

Editorial: KIDO, E., SUTTNER, T.J., PILLER, W.E., DA SILVA, A.C., CORRADINI, C. & SIMONETTO, L.

Impressum:

Medieninhaber, Herausgeber und Verleger: Institut für Erdwissenschaften,
Karl-Franzens-Universität Graz, homepage: www.uni-graz.at
Druck: Medienfabrik Graz GmbH, Dreihackengasse 20, 8020 Graz

Organization

Organizing Committee

Thomas J. SUTTNER (Graz, Austria)
Erika KIDO (Graz, Austria)
Werner E. PILLER (Graz, Austria)
Anne-Christine DA SILVA (Liège, Belgium)
Carlo CORRADINI (Cagliari, Italy)
Luca SIMONETTO (Udine, Italy)
Giuseppe MUSCIO (Udine, Italy)
Monica PONDRELLI (Pescara, Italy)
Maria G. CORRIGA (Cagliari, Italy)

Technical Staff

Gertraud BAUER (Graz, Austria)
Elisabeth GÜLLI (Graz, Austria)
Erwin KOBER (Graz, Austria)
Claudia PUSCHENJAK (Graz, Austria)
Georg STEGMÜLLER (Graz, Austria)

Scientific Committee

Jacek GRABOWSKI (Warsaw, Poland)
Leona KOPTÍKOVÁ (Prague, Czech Republic)
Damien PAS (Liège, Belgium)
Michael T. WHALEN (Alaska, USA)

Sponsors & Cooperation Partners

Preface

Within the frame of the 4th Annual Meeting of IGCP 580 (UNESCO) on the *application of magnetic susceptibility on Palaeozoic sedimentary rocks*, we intend to bring together scientists that apply geophysical methods working on different time slices. Knowledge of problems appearing through the entire data-gaining-procedure (from application to interpretation) of Magnetic Susceptibility (MS) & Gamma-Ray Spectrometry (GRS) signals and possible ways how to deal with them is one of the major tasks of this conference. A full understanding of these geophysical methods is crucial in order to use them as palaeoclimatic and palaeoenvironmental proxies. In this framework, this conference is organized in conjunction with the IGCP 596 project (*Climate change and biodiversity patterns in the Mid-Palaeozoic*). Additionally this meeting shall highlight the productive cooperation between IGCP 580 and NAP0017, one of its subprojects on *MS & GRS in the Carnic Alps*, which after two successful years will come to an end by 30.06.2012.

The Organizing Committee

Contents

- Abstracts -

- Field-Workshop -

Abstracts

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Magnetic susceptibility and geochemistry analysis of a Miocene fluviatile succession, J. Artsouma, Tunisia

BELGHITHI, H.[1,2], DA SILVA, A.C.[2], YAICH, C.[1] & BOULVAIN, F.[2]

(1) Sfax engineering school, sedimentary dynamic and environment, 3038 Sfax, Tunisia;
belghithihanene@gmail.com, *chokriyaich@gmail.com*
(2) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium;
ac.dasilva@ulg.ac.be, *fboulvain@ulg.ac.be*

Introduction

In Tunisia, the Miocene succession is mostly constituted of detrital sediments deposited in a coastal and fluviatile setting. The studied section is located in Djebel Khechem el Artsouma, in the center of Tunisia. The present study includes magnetic susceptibility (MS) combined with geochemical analyses.

Geological setting

The stratigraphic succession of the studied section (CASTANY, 1951; YAÏCH, 1984) shows the following formations (Fig. 1):

The base of the Beglia Formation, corresponding to coastal sand accumulations is interpreted as a seaward stepping (Serravallian–Tortonian age). The transition between the Beglia and Saouaf formations, represented by red clayey sands rich in gypsum, corresponds to a landward stepping. The top of the Saouaf Formation (Serravallian–Tortonian age) is the result of a seaward stepping.

Artsouma section

The section is 45 m and 98 samples have been collected for MS and calcimetry. Out of these 98 samples, 19 have been selected for further geochemical analyses (major and trace elements).

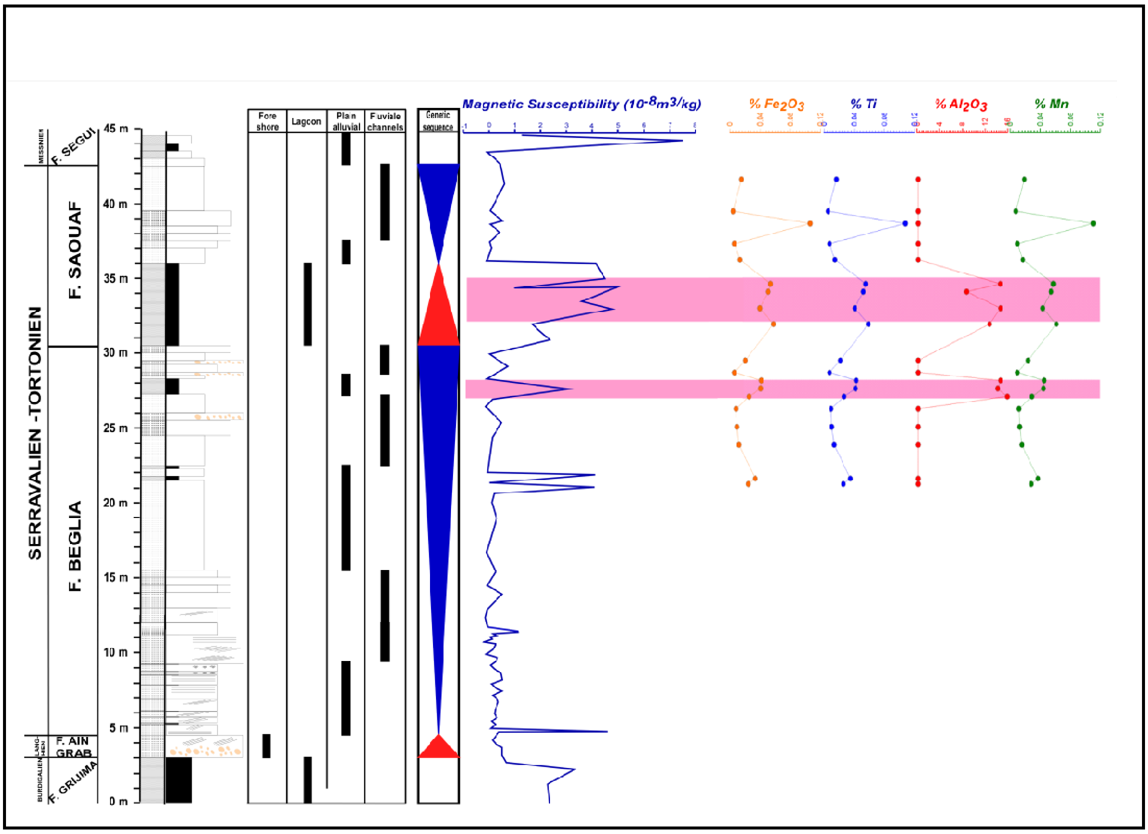


Fig. 1: Log, paleoenvironments, magnetic susceptibility and geochemical analysis of J. Artsouma, Tunisia.

Magnetic susceptibility of the Beglia-Saouaf Formation transition: MS values are between $-1.36.10^{-10}$ and $7.33.10^{-8}$ m^3/kg. The highest values are observed between 29 and 37 m, corresponding to the transgression phase at the base of the Saouaf Formation.

To be interpreted as related to lithogenic inputs, the magnetic susceptibility signal should show close relationship with other proxies such as selected major or trace elements. Although Zr (r=0.28), Rb (r=0.35), Ti (r=0.40) and Al_2O_3 (r=0.49) are considered as proxies for detrital inputs (RIQUIER et al., 2010) a positive correlation between these elements and the MS signal would be a good indicator that the MS signal is driven by detrital inputs. The highest MS values recorded at the base of the Saouaf Formation corresponding to clay layers are explained by the presence of iron oxides (Fe_2O_3, Mn, etc.).

References

CASTANY, G. (1951): Etude géologique de l'Atlas tunisien oriental.Annu. Mines. Géol. Tunis, n) 8: 895 p.

RIQUIER, L., AVERBUCH, O., DEVLEESCHOUWER, X. & TRIBOVILLARD, N. (2010): Diagenetic versus detrital origin of the magnetic susceptibility variations in some carbonate Frasnian–Famennian boundarysections from Northern Africa and Western Europe: implications for paleoenvironmental reconstructions. International Journal of Earth Sciences (Geologische Rundschau), (2010) 99 (Suppl 1): S57-S73.

YAICH, C. (1984): Etude géologique des chaînons du Cherahil et du Khechem el Artsouma (Tunisie Centrale). Thèse 3ème cy-cle, Univ. Besançon (n° 461).

Facies develpoment and MS across the Silurian/Devonian boundary in the Lake Wolayer area (Carnic Alps, Italy and Austria)

CORRADINI, C.[1], CORRIGA, M.G.[1], SUTTNER, T.J.[2], KIDO, E.[2], VODRÁŽKOVÁ, S.[3], KOPTÍKOVÁ, L.[4], DA SILVA, A.C.[5], PONDRELLI, M.[6] & SIMONETTO, L.[7]

(1) Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari (Italy); *corradin@unica.it*, *maria.corriga@unica.it*
(2) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; *thomas.suttner@uni-graz.at*, *erika.kido@uni-graz.at*
(3) Czech Geological Survey, P.O.B. 85, 118 21 Praha 1, Czech Republic and GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany; *stana.vodrazkova@seznam.cz*
(4) Institute of Geology ASCR, v.v.i., Rozvojova 269, Prague 6, 16500, Czech Republic; *koptikova@gli.cas.cz*
(5) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *ac.dasilva@ulg.ac.be*
(6) International Research School of Planetary Sciences, Dipartimento di Scienze, Università d'Annunzio, viale Pindaro 42, I-65127 Pescara, Italy; *monica@irsps.unich.it*
(7) Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; *luca.simonetto@comune.udine.it*

Upper Silurian and Lower Devonian sediments in the Lake Wolayer area are characterized by generally shallow water deposits. Two sections, a few hundred meters apart from each other, expose the Silurian–Devonian boundary: the Seewarte section (BANDEL, 1969; SUTTNER, 2007) and the Rifugio Lambertenghi Fontana III (RLF III) section (CORRADINI & CORRIGA, 2010).

The Seewarte section exposes rocks from upper Pridoli to Emsian. The Silurian part consists of 5 m of grey wackestones-packstones including interbeds of few centimetre-thick layers of densely packed bioclastic grainstones; common fossils are fragmented crinoids, bryozoans, brachiopods, corals and cephalopods. The S/D boundary coincides with the base of crinoidal limestone, often strongly dolomitized.

The RLF III Section exposes about 15 m of grey-reddish "*Orthoceras* limestones" of Pridoli–Lochkovian age, mainly represented by an irregular alternation of grainstones and wackestones-packstones. Crinoids are always very abundant, brachiopods are common; rare nautiloid cephalopods and trilobites have been observed in some levels. The S/D boundary is exposed in the upper part of the section, characterized by very shallow water sediments.

Conodont fauna allowed a good biostratigraphic characterization of the two sections, even if in the boundary interval the abundance is quite scarce.

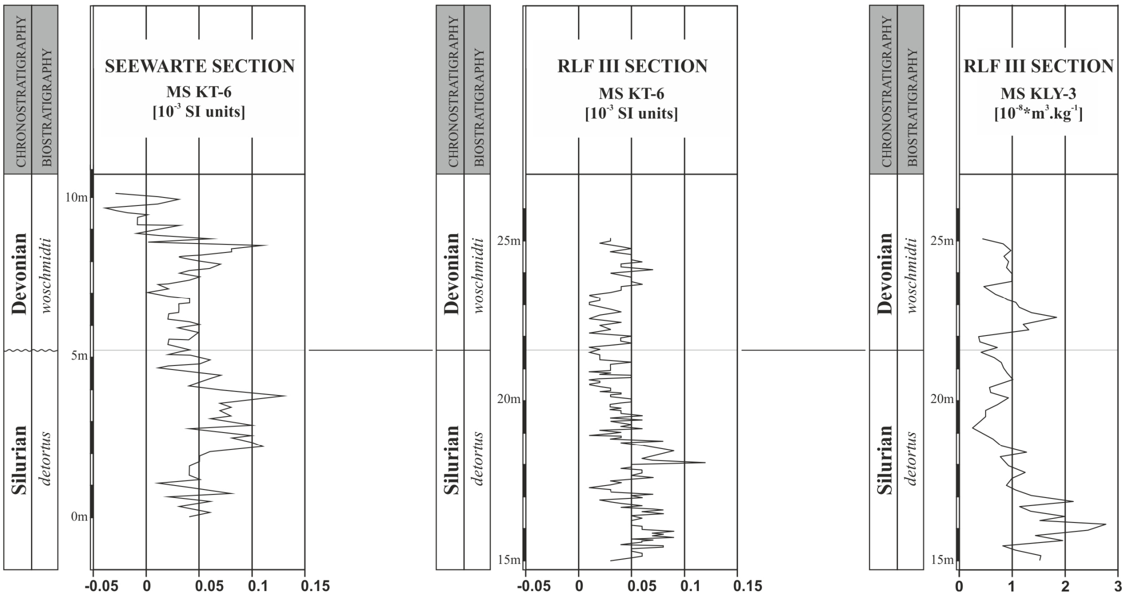


Fig. 1: Magnetic susceptibility across the S/D boundary of the Seewarte and RLF III sections.

In order to achieve a more precise correlation within the two sections, geochemical and geophysical methods were applied in the boundary interval.

As for geochemical analysis, the stable carbon isotopes were studied. The well known prominent $\delta^{13}C$ shift in the latest Pridoli, just below the basal Devonian “plateau”-like peak (SALTZMAN, 2002; BUGGISCH & MANN, 2004) is documented.

As for geophysical methods, the magnetic susceptibility was studied, both with field device (KT-6) and, for the RLF III section, measurements were also done on the Kappabridge laboratory device (KLY-3). The results especially of the field method show very similar trends for both sections, displayed by distinctive positive and negative shifts (Fig. 1). More precisely, three peaks are evident: two in the Silurian and one in the lowermost Devonian.

References

BANDEL, K. (1969): Feinstratigraphische und biofazielle Untersuchungen unterdevonischer Kalke am Fuß der Seewarte (Wolayer See, zentrale Karnische Alpen). Jahrbuch der Geologischen Bundesanstalt, 112: 197-234.

BUGGISCH W. & MANN U. (2004): Carbon isotope stratigraphy of Lochkovian to Eifelian limestones from the Devonian of central and southern Europe. International Journal of Earth Sciences, 93: 521-541.

CORRADINI, C. & CORRIGA, M.G. 2010. Silurian and lowermost Devonian conodonts from the Passo Volaia area (Carnic Alps, Italy). Bollettino della Società Paleontologica Italiana, 49 (3): 237-253.

SALTZMAN*,* M.R. (*2002):* Carbon isotope ($\delta^{13}C$) stratigraphy across the Silurian–Devonian transition in North America: evidence for a perturbation of the global carbon cycle. Palaeogeography, Palaeoclimatology, Palaeoecology, 189: 83-100.

SUTTNER, T.J. 2007. Conodont Stratigraphy, Facies-Related Distribution Patterns and Stable Isotopes (Carbon and Oxygen) of the uppermost Silurian to Lower Devonian Seewarte section (Carnic Alps, Carinthia, Austria). Abhandlungen der Geologischen Bundesantstalt, 59: 1-111.

The use of magnetic susceptibility in Palaeozoic rocks as a tool for correlations and paleoclimatic reconstructions: merits and pitfalls

DA SILVA, A.C.[1], DEKKERS, M.J.[2], DE VLEESCHOUWER, D.[3], CLAEYS, P.[3] & BOULVAIN, F.[1]

(1) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *ac.dasilva@ulg.ac.be*, *fboulvain@ulg.ac.be*
(2) Faculty of Earth Sciences, Department of Earth Science, Paleomagnetic Laboratory Fort Hoofddijk, Utrecht University, Utrecht, The Netherlands
(3) Earth System Sciences and Department of Geology, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium; *dadevlee@vub.ac.be*, *phclaeys@vub.ac.be*

Magnetic susceptibility (MS) is a commonly used tool in sedimentary rocks for paleoclimatic research and for high resolution correlations. These two applications are possible on the basis of the link between MS and detrital inputs, which are considered to have a higher magnetic susceptibility than carbonates. MS is ideal for this approach because data acquisition is fast, straightforward and provides the high amount of measurements required. However, the original paleo-environmental signal can be affected by different syn- or post-depositional processes, mostly in the case of Palaeozoic rocks.

In this contribution, we synthesize 10 years of research on the application and on the origin of the magnetic susceptibility signal in the Devonian record of Belgium. These sections are of particular interest because the biostratigraphy is well known and a relatively continuous record (over 20 My) exists through various paleoenvironments (platform, ramp, atoll), with different diagenetic maturity.

The first step was to compare MS with facies and to correlate the different sections (DA SILVA & BOULVAIN, 2002; DA SILVA et al., 2009). On the Frasnian platform sections, the MS increases towards shallower facies, in agreement with their depositional setting, closer to the detrital inputs sources. When considering ramp (Eifelian–Givetian) and atoll sections (Frasnian), the MS relationship with facies is opposite and MS increases towards the deepest facies. This was interpreted as related to the lower water agitation and lower carbonate production rate in the deeper environments that concentrated the detrital particles. Correlations were possible between the different coeval Frasnian atoll sections. Although, correlation with the coeval Frasnian carbonate platform was not possible, since the MS signals influenced by different parameters in both settings. Consequently, the depositional setting constitutes a key parameter influencing the way the original magnetic susceptibility signal is recorded and should be interpreted.

In order to identify some of the external parameters influencing the magnetic susceptibility signal, a MS curve from the Eiflian–Givetian ramp was selected for time-series analysis (DE VLEESCHOUWER et al., 2012). This spectral analysis highlights persistent high-frequency meter scale cycles that are interpreted as reflecting changes in flux of magnetic minerals, most likely controlled by monsoon rainfall-intensity. By combining chrono- and biostratigraphic information with theoretical knowledge of sedimentation rates in different depositional environments, these cycles are interpreted as astronomically driven (precession-dominated). In this case, the magnetic susceptibility signal reflects astronomical forcing, through variations in detrital inputs.

To understand the nature and origin of the magnetic susceptibility signal, it is crucial to identify the magnetic minerals that are carrying this MS signal (DA SILVA et al., 2012). Geochemistry and magnetic analyses (hysteresis and acquisition curves of the Isothermal Remanent Magnetic Saturation IRM) were performed on three sections (two Frasnian platform sections and one Eifelian Givetian platform section). Magnetic parameters show that the MS signal is mostly influenced by fine-small grained magnetites which were formed during a Variscan remagnetization event. This remagnetization occurred during the Carboniferous and is interpreted to be related to the smectite-illite transformation (releasing the iron for the magnetite formation). In two sections, the Eifelian Givetian platform section and one of the Frasnian platform, a strong link exists between the MS signal and TiO_2, Al_2O_3 and Zr concentrations, which are detrital proxies. This shows that despite the remagnetization, the MS signal is still related to detrital input, indicating that the newly formed magnetite probably remained associated with the original clay minerals, leading to a globally increased signal still reflecting the primary trends. In one section (Frasnian platform), there is no strong link between MS signal and detrital proxies, indicating that in this case the MS signal was affected by the remagnetization event (possibly in relation with fluid circulation).

In conclusion, MS appears as a convolved signal, related on one hand to primary parameters such as the amount of detrital inputs and this amount can be by influenced by orbital cyclicities. On the other hand, depositional parameters such as water agitation and carbonate production can also influence the way MS cycles are recorded. Furthermore, the diagenesis can also have a strong impact on the final signal. This clearly highlights the need to use magnetic susceptibility in conjunction with other techniques (comparison with other paleoenvironmental proxies or magnetic or geochemical analysis).

References

DA SILVA, A.C. & BOULVAIN, F. (2002): Sedimentology, magnetic susceptibility and isotopes of a Middle Frasnian carbonate platform: Tailfer section, Belgium. Facies, 46: 89-102.

DA SILVA, A.C., MABILLE, C. & BOULVAIN, F. (2009): Influence of sedimentary setting on the use of magnetic susceptibility: examples from the Devonian of Belgium. Sedimentology, 56: 1292-1306.

DA SILVA, A.C. DEKKERS, M.J., MABILLE, C. & BOULVAIN, F. (2012): Magnetic susceptibility and its relationship with paleoenvironments, diagenesis and remagnetization: examples from the Devonian carbonates of Belgium. Studia Geophysica et Geodaetica, 56 (2): in press; DOI: 10.1007/s11200-011-9005-9.

DE VLEESCHOUWER, D., DA SILVA, A.C., BOULVAIN, F., CRUCIFIX, F. & CLAEYS, P. (2011): Precessional and half-precessional climate forcing of Mid-Devonian monsoon-like dynamics. Climate of the Past, 7: 1427-1455. doi:10.5194/cpd-7-1427-2011

Preliminary results on the magnetic susceptibility records along the Frasnian–Famennian Fuhe section, China

DA SILVA, A.C.[1], WHALEN, M.[2], SLIWINSKI, M.[2], DEVLEESCHOUWER, X.[3], PETICLERC, E.[3], BOULVAIN, F.[1], BERTOLA, C.[1], PRASANNAKUMAR, V.[4], WANG, J.[5], ZENGHUI, G.[5] & CHEN, D.[5]

(1) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *ac.dasilva@ulg.ac.be*, *fboulvain@ulg.ac.be*
(2) Department of Geology and Geophysics, University of Alaska Fairbanks, Faribanks, AK 99775, U.S.A.; *mtwhalen@gi.alaska.edu*, *mgsliwinski@alaska.edu*
(3) Institut royal des Sciences naturelles de Belgique, rue Vautier, 29, B-1000 Bruxelles, Belgium; *Xavier.Devleeschouwer@naturalsciences.be*, *estelle.petitclerc@naturalsciences.be*
(4) University of Kerala, India; *prasannan@cgist.ac.in*
(5) Institute of Geology and Geophysics, Chinese Academy of Science, #19 Beitucheng Xilu, Chaoyang District, Beijing 100029, China; *dzh-chen@mail.igcas.ac.cn*, *wangjg04@gmail.com*, *guozenghui19890525@126.com*, *dzh-chen@mail.igcas.ac.cn*

Introduction

In 2010, the IGCP-580 meeting was held in Guilin, China and during this event a field trip team work (guided by Daizhao Chen) was organized in order to sample various key Palaeozoic sections. Our team focused on the Frasnian–Famennian boundary, in two different sections: the Detergent Factory section (shallow water deposits), 10 km south of Guilin and the Fuhe section (deep water deposits), about 40 km south of Guilin. The sequence stratigraphy of the Fuhe section was examined by CHEN & TUCKER (2003) and CHEN et al. (2005) documented carbon and strontium isotopic variations within a well-established conodont stratigraphic canevas.

Geological setting

Starting from the early Devonian, a main transgression progressively flooded Southern China and led to the deposition of deeper and deeper-water deposits, with increasing proportion of carbonates. The maximum transgression was reached during the Frasnian. Although, during the Givetian and Frasnian, active tectonic influenced patterns of sedimentation in different areas. The Fuhe section was located within the offshore spindle-shaped Yangshuo basin which was surrounded by shallow-water carbonate platforms and isolated from significant continental siliciclastic influx (CHEN et al., 2005).

Magnetic susceptibility

The section is 33 m thick and cuts through Early to Late *rhenana*, *linguiformis* and *triangularis* conodont zones. The first 27 m (Frasnian) was sampled every 50 cm and the upper 6 m, corresponding to the upper Kellwasser F–F interval was sampled every 10 cm. The sedimentation is mostly characterized by two main facies: (1) autochthonous pelagic nodular mudstones, with abundant sponge spicule networks and ostracods and with some clotted micrite; intercalated with (2) coarser intervals of allochthonous calciturbidites with lithoclastic grainstones beds or lenses, displaying oblique and convolute stratifications, grading into bioturbated mud-wackestones ($T_{c\text{-}e}$ Bouma subdivision). The mean MS value for the entire Fuhe section is $3.23.10^{-8}$ m³/kg, which is in the range the MS marine standard of 5.5×10^{-8}; the median value for ~11,000 lithified marine sedimentary rocks, including siltstone, limestone, marl and shale samples (ELLWOOD et al., 2011). The MS values range between $-1.46.10^{-9}$ and $9.25.10^{-8}$. The first part of the section (0-9 m) is dominated by turbiditic deposits and the MS values are relatively low (~ 9.10^{-9} m³/kg). Then, between 9 and 27 m, the facies are dominated by mudstone with *in situ* sponges (autochthonous sediments) and MS is higher ($6.45.10^{-8}$ m³/kg), with some sharp variations. The last 6 m, correspond to the upper Kellwasser event of the F–F interval (Fig. 1). Below the F–F boundary, facies alternate between autochthonous and allochthonous and the MS values decrease from $5.46.10^{-8}$ to $5.23.10^{-9}$ m³/kg. Above the F–F, autochthonous facies dominate once again and MS values sharply increase.

Gamma-Ray Spectrometry (GRS)

GRS measurements were made with a handheld apparatus every 50 cm between 7 and 27 m and every 20 cm in the upper 6 m, encompassing the upper Kelwasser F–F boundary. Concentrations in K are quite low (almost always below 2.2 %) with a mean value of 1.0 % for the whole section. There is a slight increase of the K concentrations from 7 m to 29 m until the maximum value (2.1 %) in the *linguiformis* Zone. After that, between 29 and 30.6 m, the K concentrations (< 0.65 %) are very low (end of the Frasnian) and there is a new increasing trend in the lower Famennian. Th concentrations are weak (below 12 ppm) with a mean value of 5.38 ppm for the whole section. Th concentrations seems to be stable during the Frasnian before a peak towards high Th concentration (11.38 ppm) in the *linguiformis* Zone followed by an interval of low Th concentrations (< 4.5 ppm) just before the F–F boundary. In the early Famennian, the Th concentrations are fluctuating but an increasing trend could be observed (similar to the increasing K concentrations). Concentrations of K statistically correlate moderately well with Th concentrations throughout the whole section (r=0.75). Th and K concentrations are usually related to the presence of aluminosilicates (illite and other clay minerals, potassium feldspars, micas) in carbonates. A good correlation between K and Th is considered to reflect a fine-grained siliciclastic admixture in carbonate rocks (EHRENBERG & SVANA, 2001; FABRICIUS et al., 2003).

The U/Th ratio is highly fluctuating between 0.2 and 1.1 ppm with a mean trend corresponding to decreasing values up-section. The mean value for U/Th ratio corresponds to 0.55. Six distinct peaks are present along the section with values above 0.75 indicating probably local dysoxic conditions (2.0-0.2 ml O_2/l, bottom-water oxygen level sensu TYSON & PEARSON, 1991). The last peak in U/Th values is contemporaneous with the low K and Th concentrations at the end of the Frasnian in the *linguiformis* Zone.

Geochemistry

Carbon isotopic analyses were performed in order to evaluate the relationship of our measured section with the published conodont zonation and carbon isotopic curve (CHEN & TUCKER, 2003; CHEN et al., 2005) and with the conodont zonation.

Geochemistry of major and trace elements were measured on the Fuhe section (upper 6 m) and it appears that there is a moderate positive correlation between elements which are proxies for lithogenic inputs and magnetic susceptibility (r = 0.6), showing that the MS signal is probably of primary origin, related to lithogenic inputs (e.g. RIQUIER et al., 2012; DA SILVA et al., 2012).

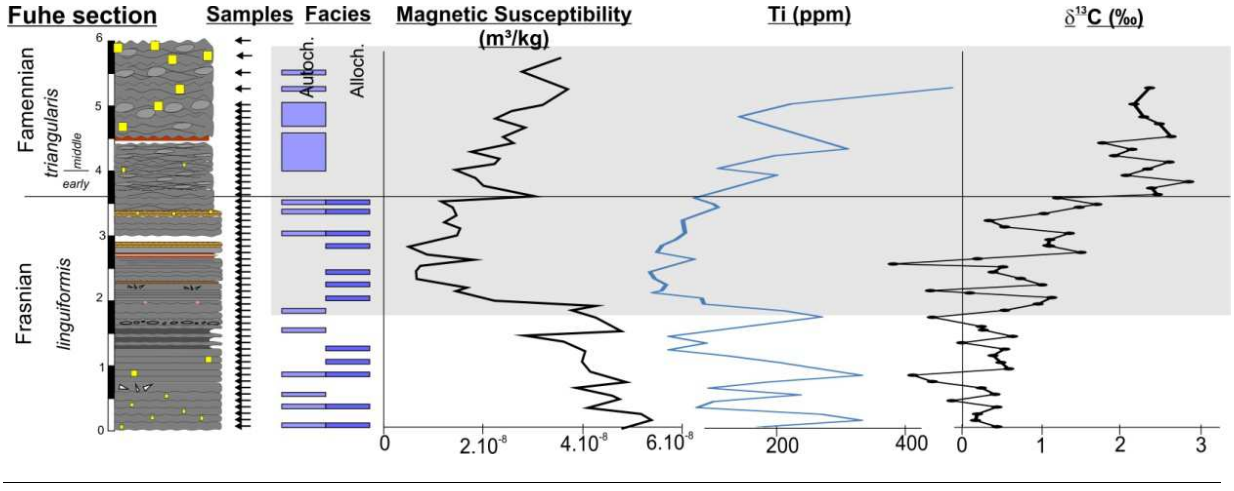


Fig. 1: Upper part of the Fuhe section (last 6 m) with the F–F boundary; position of sample (arrows), facies (autochthonous or allochthonous), magnetic susceptibility, Ti (ppm) and carbon isotopes. The conodont zonations are from CHEN et al. (2005) and the grey area corresponds to the upper Kellwasser interval.

References

CHEN, D. & TUCKER, M.E. (2003): The Frasnian–Famennian mass extinction: insights from high-resolution sequence stratigraphy and cyclostratigraphy in South China. Palaeogeography, Palaeoclimatology, Palaeoecology, 193: 87-111.

CHEN, D., QING, H. & LI, R. (2005): The Late Devonian Frasnian–Famennian (F/F) biotic crisis: Insights from $\delta^{13}C_{carb}$, $\delta^{13}C_{org}$ and $^{87}Sr/^{86}Sr$ isotopic systematics. EPSL, 235: 151-166.

DA SILVA, A.C. DEKKERS, M.J., MABILLE, C. & BOULVAIN, F. (2012): Magnetic susceptibility and its relationship with paleoenvironments, diagenesis and remagnetization: examples from the Devonian carbonates of Belgium. Studia Geophysica et Geodaetica, 56 (2): in press; DOI: 10.1007/s11200-011-9005-9.

EHRENBERG, S.N. & SVÅNÅ, T.A. (2001): Use of spectral gamma ray signature to interpret stratigraphic surfaces in carbonate strata: an example from the Finnmark carbonate platform (Carboniferous–Permian), Barents Sea. AAPG Bulletin, 85: 295-308.

ELLWOOD, B.B., TOMKIN, J.H., EL HASSANI, A., BULTYNCK, P., BRETT, C.E., SCHINDLER, E., FEIST, R. & BARTHOLOMEW, A (2011): A climate-driven model and development of a floating point time scale for the entire Middle Devonian Givetian Stage: A test using magneto-stratigraphy susceptibility as a climate proxy. Palaeogeography, Palaeoclimatology, Palaeoecology, 304: 85-95.

FABRICIUS, I.L., FAZLADIC, L.D., STEINHOLM, A. & KORSBECH, U. (2003): The use of spectral natural gamma-ray analysis in reservoir evaluation of siliciclastic sediments: A case study from the Middle Jurassic of the Harald Field, Danish Central Graben. Geological Survey of Denmark and Greenland Bulletin, 1: 349–366.

RIQUIER, L., AVERBUCH, O., DEVLEESCHOUWER, X. & TRIBOVILLARD, N. (2010): Diagenetic versus detrital origin of the magnetic susceptibility variations in some carbonate Frasnian–Famennian boundary sections from Northern Africa and Western Europe: implications for paleoenvironmental reconstructions. International Journal of Earth Sciences, 99: S57-S73.

TYSON, R.V. & PEARSON, T.H. (1991): Modern and ancient continental shelf anoxia: an overview. Geological Society of London, Special Publication, 58: 1-24.

Magnetic susceptibility of Early Cretaceous sediments from northwest China and its implications

DAI, S.[1], LIU, H.-J.[1], DA SILVA, A.C.[2], HUANG, Y.-B.[1], ZHU, Q.[3], ZHAO, J.[1], LIU, J.-W.[1], KONG, L.[1] & LIU, X.[1]

(1) Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China; *daisher@lzu.edu.cn*
(2) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *ac.dasilva@ulg.ac.be*
(3) Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

Magnetic susceptibility (MS) had been classically used to study paleoclimatic variations recorded into loess-paleosol successions or into marine sediments. The application of MS as a paleoclimatic tool is based on the link between the MS signal and the main magnetic minerals which are interpreted as mostly related to detrital inputs. However, the application of MS on fluvial and lacustrine sediments is still a matter of debate.

In the northwest of China, Cretaceous fluvial and lacustrine sediments are well exposed in different locations, corresponding to different sedimentary basins. These outcrops have the potential to document the different steps of the basin formation, as well as climatic changes through time. This work focuses on the Hekou and Liupanshan Basins located at 250 km apart. The sediments deposited in these two different basins are both from alluvial, fluvial and lacustrine settings. The Lower Cretaceous, Hekou Group in the Hekou basin and Liupanshan Group in the Liupanshan basin, are respectively 3570 and 1330 meters thick, corresponding to 139-106 Ma and 127-100 Ma (magnetostratigraphic dating). Mean mass MS value are respectively 8.65 m^3/kg and 7.35 m^3/kg, and the mass MS varies between 1.47 and 23.87 m^3/kg, and 0.29 and 75.03 m^3/kg in the Hekou and Liupanshan basin. For each settings, the mean mass MS values are different and are decreasing from alluvial to shore, shallow lake, (fan) delta and fluvial settings. Furthermore, mean MS also changes with the main lithology, with a decrease from the mudstones to sandstones, limestones and marls.

When comparing the MS profiles from the two basins, they appear very different and so very hard to correlate. In the Liupanshan Group, they are three levels of volcanic ashes, which are corresponding to abnormally high MS values in comparison to the rest of the curve. When removing these three portions with abnormally high values, some similarities are observed between the two sections, mostly in their lower part, showing also high values that we interpret as related to massive input of magnetite from the fast weathering of the granitic basement. Although after this lower portion, the MS curves in the two sections are relatively different and hard to correlate. The rock-magnetic investigation on the origin and nature of the magnetic minerals in the two basins shows that hematite dominates in the Hekou basin but magnetite and maghemite dominates in the Liupanshan basin. The origin and the variation of the amount of these minerals leading to the main changes in magnetic susceptibility are still unknown. Although it seems that as mentioned before, the sedimentary setting as a strong influence on the magnetic susceptibility signals. Furthermore, tectonic deformation also has an influence on the changes of the MS signal.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

The magnetic susceptibility as tool for environmental and paleoenvironmental prospections: case study coast of Sfax, southern Tunisia

ESSEFI, E.[1] & YAICH, C.[1]

(1) Sedimentary Dynamics and Environment (DSE) (Code 03/UR/10-03), National Engineering School of Sfax, University of Sfax, Road of Soukra, km 4. Sfax, 3038 Sfax, Tunisia; *hocinsefi@yahoo.fr*, *chokriyaich@gmail.com*

Introduction

The use of the magnetic susceptibility for environmental purposes has gained a noticeable popularity. The use of this tool allows inferring the natural conditions as well as the human induced activity. The aim of this work is twofold. On the one hand, it follows the contamination of surface sediments of the coast of Sfax (Fig. 1) by polluting materials such as heavy metals. On the other hand, it records the variation of depositional environment during the late Holocene.

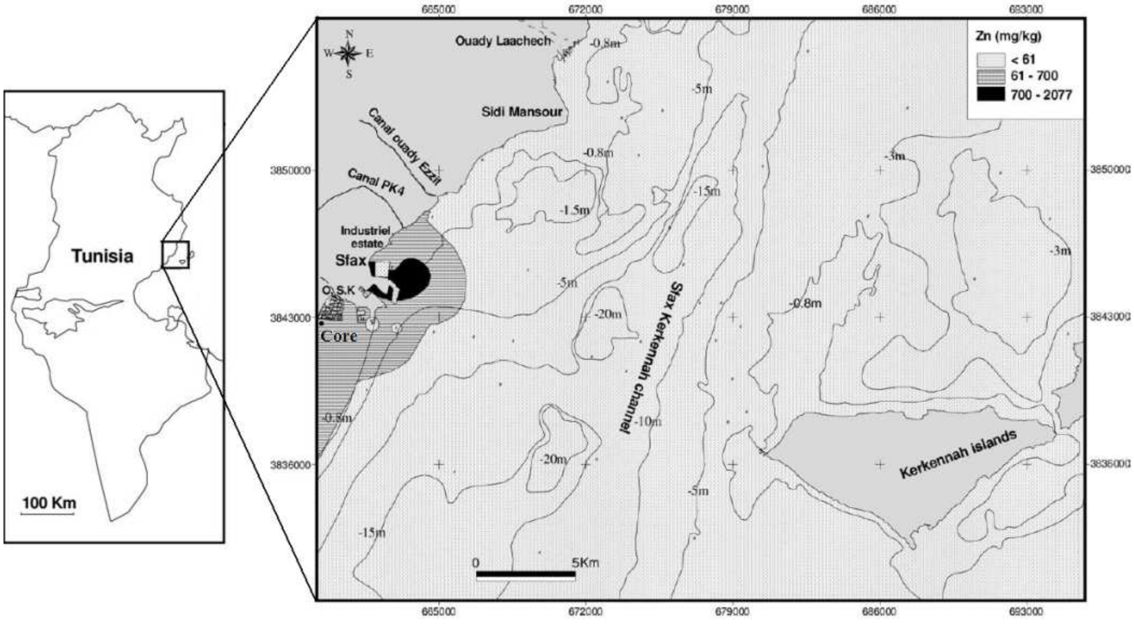


Fig. 1: Contamination of the coast of Sfax by zinc (GHANNEM et al., 2011).

Pollution of the coast of Sfax

The coast of Sfax has also witnessed ever increasing urbanising activities. Many studies (e.g., GHANNEM et al., 2011) have noticed the damage. The southern coast contains, in particular, a site of collecting wastes of the town of Sfax, the liquid and solid rejections of SIAPE, the basins of storage of the “margines” and the station of purification. The Tunisian government has taken serious measurements that heavily coasted on the national budget to clean the polluted northern coast of Sfax by funding the Taparura Project and the controlled zone of phospho-gypsum waste. But results of these remedial solutions are not guaranteed for sure. The first ten centimeters of the core are characterized by high values of magnetic susceptibility. These values are due the pollution of surface sediment with heavy metals. This contamination was recently discussed by GHANNEM et al. (2011).

Variation of the depositional environment during the late Holocene

Values of the magnetic susceptibility (Fig. 2) show also the transition from a marine depositional environment to a continental one. The marine domain (0 cm to 62 cm) is characterized by low values of the magnetic susceptibility; this domain records coarse sedimentary grain. Whereas the continental domain (62 cm to 154 cm) is characterized by high values of magnetic susceptibility. This high values are due the presence of red clays. Within these two different domains we find also minor oscillations indicating slight variability of the sea level and/or climatic change.

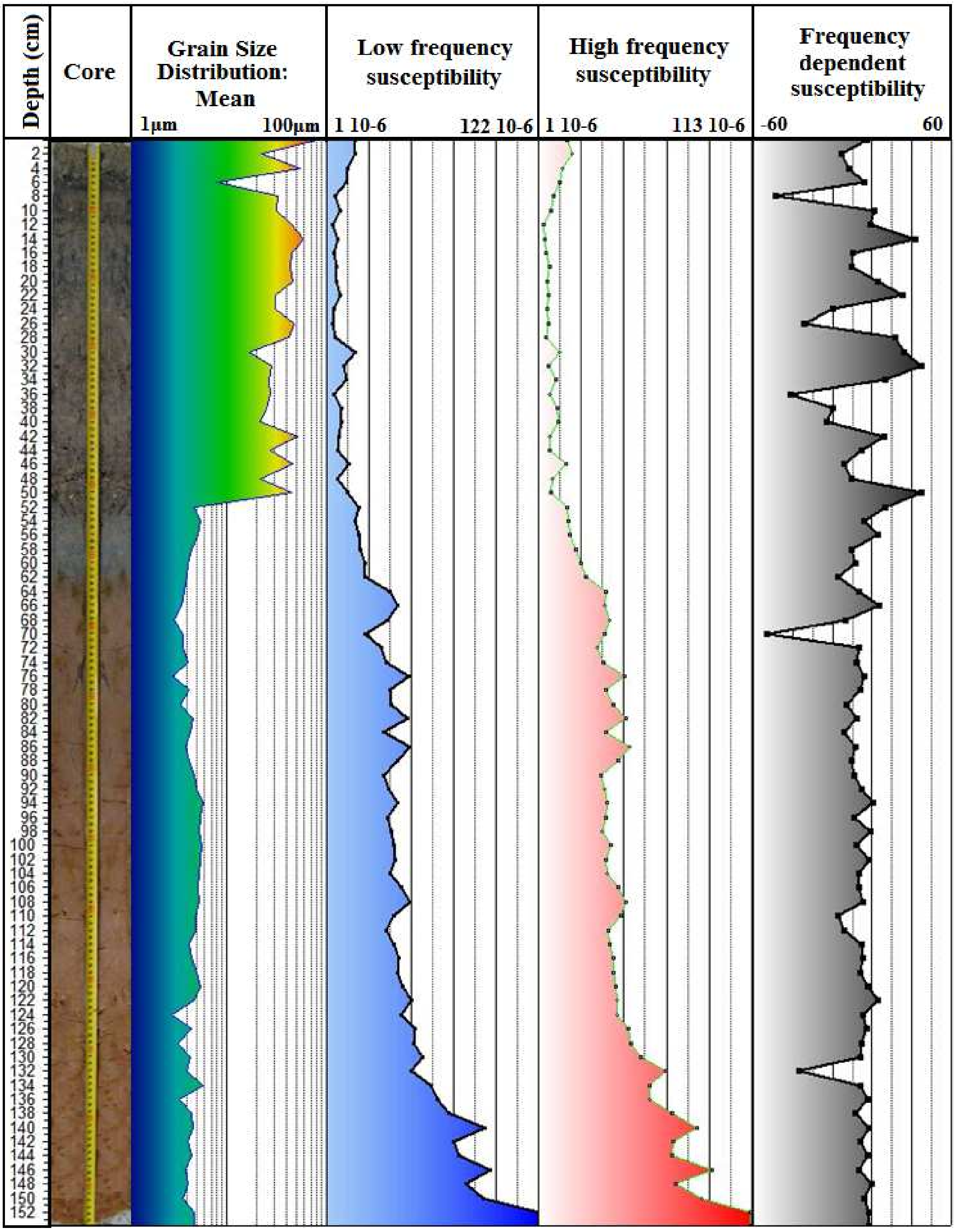


Fig. 2: Record of the mean of the grain size, low frequency magnetic susceptibility, high frequency magnetic susceptibility and independent frequency magnetic susceptibility along a core collected from the coast of Sfax.

References

GHANNEM, N., AZRI, C., SERBAJI, M.M. & YAICH, C. (2010): Spatial distribution of heavy metals in the coastal zone of “Sfax–Kerkennah” plateau, Tunisia. Environmental progress and Sustainable Energy, 30 (2). doi: 10.1002/ep.

Four warm and humid climatic events since the Pliocene inferred from the identification of sedimentary greigite (Fe_3S_4) in Lake Qinghai, China

FU, C.-F.[1,2], JAN, B.[3], QIANG, X.-K.[2] & AN, Z.-S.[2]

(1) Key Laboratory of Western Mineral Resources and Geological Engineering, Ministry of Education of China & Chang'an university, Xi'an, Shaanxi, 710054, China; *fuchaofeng@gmail.com*
(2) State Key Laboratory of Loess and Quaternary Geology, Institute of Earth and Environment, CAS, Xi'an, Shaanxi, 710075, China; *qiangxk@loess.llqg.ac.cn*
(3) Geomagnetism Lab, School of Environment Science, University of Liverpool, Oliver Lodge Building, Liverpool L69 7ZE, UK; *janbloemendal@gmail.com*

Qinghai Lake, located on the northeastern margin of the Qinghai-Tibet Plateau, is China's largest extant closed-basin lake, and is of considerable interest in the context of research on Asian climate and environment evolution and the recent uplift history of the Tibetan Plateau. A 626 m long core has been drilled in the southern basin of Lake Qinghai and which reveals a generally continuous sedimentary record consisting of aeolian silt at the base, overlain by lake sediments. Magnetostratigraphy dates the base of the sequence to about 5.1 Ma. The magnetic susceptibility record reveals the presence of four distinct peaks at depths of 431.99 – 419.24 m, 410.28 - 396.40 m, 47.43 - 43.89 m, and 17.23 - 16.41 m, and from which samples were chosen for detailed rock magnetic analysis, including thermomagnetic and hysteresis properties. The results indicate the presence of the authigenic ferrimagnetic sulphide greigite (Fe_3S_4) of stable single domain or pseudo-single-domain grain size and which we conclude is responsible for the enhanced magnetic susceptibility. Sedimentary greigite is most frequently found in rapidly deposited marine sediments, but it can also form in freshwater environments with a high organic loading (SNOWBALL & TORII, 1999). From the presence of the greigite, together with the results of sediment grain size and geochemical analyses, we infer that the four intervals represent episodes of relatively warm and humid climate. Based the magnetostratiographic-based age model they are dated as follows: 3.802 - 3.726 Ma, 3.620 - 3.592 Ma, 0.613 - 0.597 Ma and 0.174 - 0.168 Ma B.P.

Acknowledgements: This study was supported by the National Natural Science Foundation of China (Grants 40872114, 41140028).

References

SNOWBALL, I. & TORII, M. (1999): Incidence and significance of magnetic iron sulphides in Quaternary sediments and soils. 199-230. In: MAHER, B.A. & THOMPSON, R. (eds), Quaternary climates, environments and magnetism. Cambridge University Press.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Environmental context of the earliest tetrapod trackways: clues from MS and petrological studies (Eifelian, Holy Cross Mts., Poland)

GRABOWSKI, J.[1], NARKIEWICZ, M.[1] & DE VLEESCHOUWER, D.[2]

(1) Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warszawa, Poland; *jacek.grabowski@pgi.gov,pl*, *marek.narkiewicz@pgi.gov.pl*
(2) Earth System Sciences and Department of Geology, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium; *dadevlee@vub.ac.be*

The lower, track-bearing part of the investigated Zachełmie section (NARKIEWICZ & NARKIEWICZ, 2010; NIEDŹWIEDZKI et al., 2010) is composed of marly dolomitic mudstones and dolomitic shales with a common microbial lamination, dessication cracks, incipient palaeosol levels and evidence of (mostly vanished) evaporites. It grades upwards into bioturbated dolomite mudstones to wackestones, and, occasionally even grainstones with marine fossils, including crinoids and conodonts. MS in the lower part is carried mostly by hematite, whereas the grained dolomite varieties contain fine-grained magnetite. Moreover, MS signal appears to be controlled mainly by depositional pattern, with a few exceptional levels where it seems to be related to a secondary hematite mineralization. Time-series analysis of the MS data revealed a clear cyclicity that can be interpreted in terms of orbital/climatic cycles. The MS cycles are here compared to geochemical data, including elemental and stable isotopes (C, O, Sr) composition. Moreover, a comparison between MS data and bulk chemistry is intended to substantiate depositional controls on MS distribution. The environmental parameters, including redox conditions and palaeosalinity will be discussed.

Acknowledgements: Financial support of Polish Ministry of Science and Higher Education (research grant No.N307 323439 to MN and JG) and the Research Foundation – Flanders (FWO) for a Ph.D. fellowship (to DDV).

References

NARKIEWICZ, K. & NARKIEWICZ, M. (2010): Mid Devonian carbonate platform development in the Holy Cross Mts. Area (central Poland): new constraints from the conodont *Bipennatus* fauna. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 255, 3: 287-300.

NIEDŹWIEDZKI, G., SZREK, P., NARKIEWICZ, K., NARKIEWICZ, M. & AHLBERG, P.E. (2010): Tetrapod trackways from the early Middle Devonian period of Poland. Nature, 463: 43-48.

Magnetic susceptibility and gamma ray spectroscopy of the Jurassic/Cretaceous boundary section, Le Chouet (Vocontian basin, SE France)

GRABOWSKI, J.[1], PRUNER, P.[2], SCHNABL, P.[2], SCHNYDER, J.[3] & SOBIEŃ, K.[1]

(1) Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warszawa, Poland; *jacek.grabowski@pgi.gov.pl*, *Katarzyna.Sobien@pgi.gov.pl*
(2) Institute of Geology AS CR v.v.i., Rozvojova 269, 165 00 Praha 6, Czech Republic; *pruner@gli.cas.cz*, *schnabl@gli.cas.cz*
(3) University Paris VI, case 117, 4, pl. Jussieu, 75252 Paris Cedex 05, France; *johann.schnyder@upmc.fr*

Integrated biostratigraphic (ammonites, micro- and nannofossil) and magnetostratigraphic study is focused on LeChouet section (Vocontian basin, SE France), as one of key sections studied within a frame of Berriasian Working Group of ICS (WIMBLEDON et al., 2011). Additionally, detailed rock magnetic, magnetic susceptibility (MS) and gamma ray spectroscopy (GRS) are carried out in order to understand better the palaeoenvironmental changes in the Jurassic/Cretaceous boundary interval.

The section, ca. 30 m thick is situated about halfway between the Berrias type section in the west (GALBRUN, 1985) and the Western Alpine overthrust in the east. It comprises mostly thin – to medium bedded micritic limestones intercalated by a few horizons of brecciated limestones and slumps indicating slope instabilities (JOSEPH et al., 1988). The age of the sequence (Late Tithonian – Early Berriasian) is documented by calpionellids and ammonites (*Crassicollaria* – *Calpionella* calpionellid zones; *Durangites* – *Jacobi* ammonite zones), as well as magnetostratigraphy (M20n1r in the bottom of the section to M19n). MS (mass normalized), anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM) in 1T and -100 mT were measured for all magnetostratigraphically studied horizons (86 samples). GRS measurements were performed in 44 horizons. The most important magnetic mineral is magnetite, however hematite rich samples occasionally also occur. MS signal is very weak, close to diamagnetic, and generally decreasing between Tithonian and Berriasian (Fig. 1), which is a typical feature in that time interval (see GRABOWSKI, 2011 and references therein). It reveals a moderate correlation with IRM1T ($R^2 = 0.47$) which indicates that ferromagnetic minerals significantly contribute to MS. The correlation with ARM is worse ($R^2 = 0.263$, so fine grained (close to SD) magnetite is not a dominant carrier of MS. Samples with hematite are related to slumped horizons and reveal characteristically low natural remanent magnetizations (NRM) intensities, below 2×10^{-4} A/m, while the NRM of typical samples varies between 2 and 7×10^{-4} A/m. The results of GRS logging are not easy to interpret. The correlation between K and Th is low to moderate ($R^2 = 0.31$), while between those two elements and U even worse (R^2 close to 0). Both K and Th reveal a moderate correlation with MS, which confirms that the latter is mostly related to detrital lithogenic input. Maximum U content correlate well with slumped beds and hematite horizons. It might be speculated that slumped beds might have been originally rich in organic matter which was subsequently oxidized – therefore apparently unusual coexistence of U and hematite is now observed. The second explanation is that hematite and U might be linked to enhanced detrital inputs of specific mineral phases from the neighbouring continent. The Th/U ratio, disregarding the data from slumped beds which were affected by redeposition, show a slow increasing trend from slightly dysoxic (Th/U between 0.8 and 1.3) to oxic environment (Th/U above 1.3) in the topmost part of calpionellid zone A onto the base of zone B and encompassing the J/K boundary.

Acknowledgements: Studies were carried out within a frame of the Polish – French bilateral cooperation 7841/R09/R10 (“Polonium”) and funded by the Ministry of Science and Education (project No. 683/N-POLONIUM/2010/0).

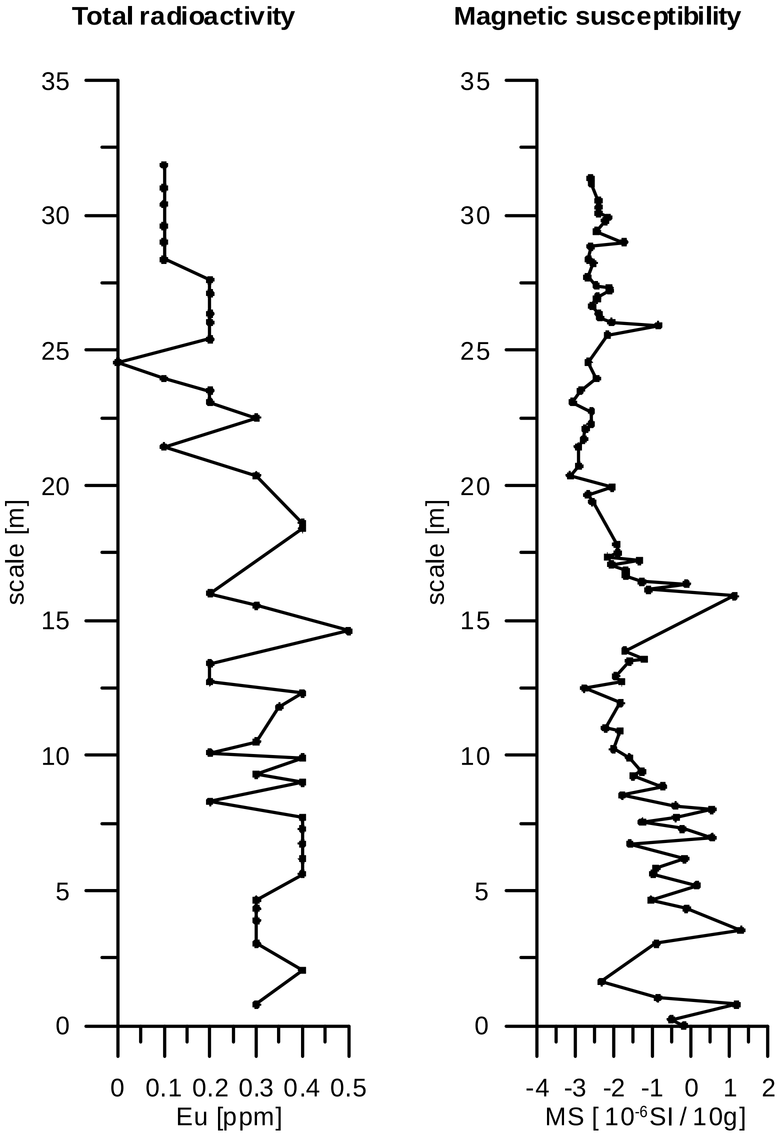


Fig. 1: Gamma-ray and MS logs of le Chouet section. Note that both GRS and MS decrease from Tithonian to Berriasian. Eu is total radioactivity recalculated as equivalent of Uranium.

References

GALBRUN, B. (1985): Magnetostratigraphy of the Berriasian stratotype section (Berrias, France). Earth and Planet. Science Letters, 74: 130-136.

GRABOWSKI, J. (2011): Magnetostratigraphy of the Jurassic/Cretaceous boundary interval in the Western Tethys and its correlations with other regions: a review. Volumina Jurassica, 9: 105-128.

JOSEPH, P., BEAUDOIN, B., SEMPERE, T. & MAILLART, T. (1988): Vallées sous-marines et systèmes d'épandages carbonatés du Berriasien vocontien (Alpes méridionales françaises). Bulletin de la Société Géologique de France, 8, IV, 3: 363-374.

WIMBLEDON, W.A.P., CASELLATO, C.E., REHAKOVA, D., BULOT, L.G., ERBA, E., GARDIN, S., VERREUSSEL, R.M.C.H., MUNSTERMAN, D.K. & HUNT, C.O. (2011): Fixing a basal Berriasian and Jurassic/Cretaceous (J/K) boundary – is there perhaps some light at the end of the tunnel? Rivista italiana di paleontologia e stratigrafia, 117: 295-307.

Gamma ray stratigraphy of the middle Silurian Mulde Event in the Bartoszyce IG1 borehole (NE Poland)

JAROCHOWSKA, E.[1], MUNNECKE, A.[1] & KOZŁOWSKI, W.[2]

(1) GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany; *e.jarochowska@student.uw.edu.pl*, *axel.munnecke@gzn.uni-erlangen.de*
(2) Faculty of Geology, University of Warsaw, 93 Żwirki i Wigury Str., 02-089 Warsaw, Poland; *woko@uw.edu.pl*

The Mulde Event (Wenlock, Silurian) is recorded globally in low to mid-latitudes as a double-peaked positive stable carbon isotope excursion, and is associated with an extinction affecting selectively pelagic and hemipelagic fauna, particularly conodonts, graptolites and marine phytoplankton. With respect to graptolites, this extinction, affecting approximately 95 % species, is known as the *lundgreni* event. The biotic crisis precedes the onset of the stable carbon isotope excursion and is recorded as three stepwise extinction events, referred to as Datum points 1, 1.5 and 2 with respect to conodonts (CALNER & JEPPSSON, 2003; JEPPSSON & CALNER, 2003) and corresponding to the (1) *Cyrtograptus lundgreni*, (2) *Testograptus testis*, and (3) *Monograptus flemingii-Pristiograptus dubius* graptolite extinctions (PORĘBSKA et al., 2004). The survival interval immediately following the final step of the extinction is characterized in diverse sections by abrupt lithological changes and the dominance of low-diversity disaster fauna.

In the Paleozoic Baltic Basin developed on the East European Craton, a detailed record of the *lundgreni* event has been provided by PORĘBSKA et al. (2004) based on the Bartoszyce IG1 borehole, drilled in the Peribaltic Syneclize, NE Poland. The rocks represent outer shelf facies: grey, sparsely bioturbated marlstones. The middle Silurian deposits accessible in this borehole have been formed in times of a rapid subsidence rate, providing a thick and continuous sedimentary record of this interval. Data from different sections in the same basin, as well as global eustatic curves, indicate very rapid regression coincident with the extinction interval. The stepwise character of the extinction might reflect not only the temporal structure of the biotic crisis, but may also result from staggering dynamics of the sea-level fall. However, apparent facies homogeneity hinders direct sequence-stratigraphical interpretations.

In order to gain insight into the changing dynamics of the deposition rate and influx of terrigenous material, we have performed spectral gamma-ray measurements on the core interval spanning the *lundgreni* to *Colonograptus praedeubeli* graptolite zones (approx. 75 m). Depending on the core completeness, measurements were collected at the resolution of one to three data points for each core meter, using a portable gamma-ray spectrometer placed in a lead-screened container. Preliminary results revealed a very low variability of K concentration in the studied interval (average 39.38 % of the total dose, SD 4.00 %) and, consequently, its low correlation with Th concentration (average 31.44 % of the total dose, SD 7.01 %). The concentrations of Th and U (average 29.04 % of the total dose, SD 7.5 %) allowed to distinguish metre-scale cycles characterized by mirrored concentrations trends: decreasing U content and increasing Th content, interpreted as shallowing-upward cycles capped with progradational surfaces. At the bottom of the *testis* biozone we have identified a pronounced flooding surface, and a major progradational surface at the boundary between the *testis* and the *flemingii-dubius* biozones, suggesting that the entire *testis* biozone corresponds to deposits of a highstand systems tract or, alternatively, of a forced regression systems tract. This interpretation would place the sequence boundary predicted by CALNER et al. (2006) at the LAD of *T. testis.* The following *flemingii-dubius* to lowermost *dubius* interval, which precedes the onset of the $\delta^{13}C$ excursion, is characterized by low total dose rates and low (depleted) Th and (baseline) U contents and the presence of laminated deposits rich in organic matter.

Through an application of spectral gamma-ray logging to provide a rough sequence-stratigraphic framework, we aim to integrate existing geochemical and biostratigraphical data with an interpretation of sea-level dynamics during the Mulde Event.

References

CALNER, M. & JEPPSSON, L. (2003): Carbonate platform evolution and conodont stratigraphy during the middle Silurian Mulde Event, Gotland, Sweden. Geological Magazine, 140: 173-203.

CALNER, M., KOZŁOWSKA, A., MASIAK, M. & SCHMITZ, B. (2006): A shoreline to deep basin correlation chart for the middle Silurian coupled extinction-stable isotopic event. GFF, 128: 79-84.

JEPPSSON, L. & CALNER, M. (2003): The Silurian Mulde Event and a scenario for secundo-secundo events. Transactions of the Royal Society of Edinburgh: Earth Sciences, 93: 135-154.

PORĘBSKA, E., KOZŁOWSKA-DAWIDZIUK, A. & MASIAK, M. (2006): The *lundgreni* event in the Silurian of the East European Platform. Palaeogeography, Palaeoclimatology, Palaeoecology, 213: 271-294.

Geochemical and geophysical records of the Middle Devonian sequence in the Carnic Alps

KIDO, E.[1], SUTTNER, T.J.[1], PONDRELLI, M.[2], CORRADINI, C.[3], CORRIGA, M.G.[3], SIMONETTO, L.[4], VODRÁŽKOVÁ, S.[5] & KOPTÍKOVÁ, L.[6]

(1) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; *erika.kido@uni-graz.at*, *thomas.suttner@uni-graz.at*
(2) International Research School of Planetary Sciences, Dipartimento di Scienze, Università d'Annunzio, viale Pindaro 42, I-65127 Pescara, Italy; *monica@irsps.unich.it*
(3) Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari (Italy); *corradin@unica.it*, *maria.corriga@unica.it*
(4) Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; *luca.simonetto@comune.udine.it*
(5) Czech Geological Survey, P.O.B. 85, 118 21 Praha 1, Czech Republic and GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany; *stana.vodrazkova@seznam.cz*
(6) Institute of Geology AS CR, v.v.i., Rozvojova 269, 16500 Prague 6, Czech Republic; *koptikova@gli.cas.cz*

The late Eifelian Kačák Event (HOUSE, 1985) is a period of global anoxia coincident with widespread deposition of black shale and chert documented in sedimentary sequences of hemipelagic, pelagic and some neritic facies globally. The event-interval is constrained to the *kockelianus-ensensis* conodont zones (HOUSE, 1985) and associated with the faunal changes and extinctions. A significant negative $\delta^{13}C$ excursion and a broad depression in the magnetic susceptibility (MS)-curve have been recognized in the late Eifelian, which are related to the Kačák Event (HLADIL et al., 2002). In our study we focus on the Middle Devonian units of the Carnic Alps (Austria-Italy) and aim to define the Kačák Event by using microfacies analysis, biostratigraphy based on conodonts and the application of stable isotope geochemistry and magnetic susceptibility.

Selected units observed are the Hoher Trieb Formation (Eifelian–Frasnian) of Mt. Pizzul, Lanza (Italy) and the Valentin Limestone of Wolayer Glacier section (Austria). The former unit is characterized by gray to dark gray flaser and platy limestone which are intercalated by black shale and chert layers with silicified corals bearing breccia levels framing the interval. Slope settings are assumed for deposits of this formation which accumulated at the distal part of the fore reef. Totally 64 rock samples were collected for the study from the unit outcropping at Zuc di Malaseit Basso (ZMB; sampled interval 4.5 m). A depression in MS-values (55.73 to -2.44) is observed between sample nos. ZMB34 middle2 and ZMB7 middle, with a distinctive negative shift in carbon isotope from 2.2 (ZMB23 top1) to 0.1 (ZMB20-1), which corresponds with the Kačák event-interval.

The Valentin Limestone consists of highly condensed sediments, which were accumulated in a pelagic environment. According to SCHÖNLAUB (1985), the upper part of the Eifelian is unconformably overlain by beds of Givetian age, with the boundary allocated between bed-no. 70 and 71. We collected 15 limestone samples across the Eifelian–Givetian interval within gray tentaculite wacke- and packstones (bed-no. 69 to 72; in total, an interval of about 25 cm) for the MS (laboratory device KLY-3, Institute of Geology AS CR) and drilled 124 samples from the bulk-rock for the carbon and oxygene isotope analyses. MS-patterns show a trend that documents a decrease in values (47.45 to 27.71) between bed-nos. 69 top to 70a top, where a 5 mm or less thick dark limestone-level is intercalated (70a middle). Across this interval, carbon isotopes shift slightly (2.0 to 1.8), whereas oxygen values show a distinctive positive shift (-8.9 to -6.8). This slight excursion might correspond with the Kačák Event.

A next step of our study will be the correlation of isotopes and MS patterns across the Eifelian–Givetian boundary with deposits of the carbonate platform to clarify whether the Spinotti Limestone, *Amphipora* Lst or Kellergrat Reef Lst might represent the coeval neritic equivalent to the pelagic deposits across the Kačák Event.

Acknowledgements: Research is funded by FWF P23775-B17 and project 334000 of the Czech Geological Survey. This is a contribution to IGCP 580, NAP0017 and IGCP 596.

References

HOUSE, M.R. (1985): Correlation of mid-Palaeozoic ammonoid evolutionary events with global sedimentary perturbations. Nature, 313: 17-22.

HLADIL, J., PRUNER, P., VENHODOVÁ, D., HLADILOVÁ T. & MAN, O. (2002): Toward an exact age of Middle Devonian Čelechovice corals - Past problems in biostratigraphy and present solutions complemented by new magnetosusceptibility measurements. Coral Research Bulletin, 7: 65-71.

SCHÖNLAUB, H.P. (1985): Das Paläozoikum der Karnischen Alpen. 34-52. In: Arbeitstagung der Geologischen Bundesanstalt, 1985, Wien.

Petrophysical record of the Middle Devonian Basal Choteč event in different palaeogeographical settings (Perigondwanan Perunica microcontinent, Laurussia and Zeravshan-Gissar Mountain Region in Central Asia): a reflection of global palaeoclimatic changes?

KOPTÍKOVÁ, L.[1], HLADIL, J.[1], SLAVÍK, L.[1], FRÝDA, J.[2,3], MANDA, Š.[2], ČÁP, P.[2] &
VODRÁŽKOVÁ, S.[2,4]

(1) Institute of Geology ASCR, v.v.i., Rozvojova 269, Prague 6, 16500, Czech Republic; *koptikova@gli.cas.cz*, *hladil@gli.cas.cz*, *slavik@gli.cas.cz*
(2) Czech Geological Survey, P.O.B. 85, 118 21 Prague 1, Czech Republic; *bellerophon@seznam.cz*, *stana.vodrazkova@seznam.cz*
(3) Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6 – Suchdol, 165 21, Czech Republic
(4) GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany

Petrophysical record of the Basal Choteč event (BCE) interval close above the Emsian–Eifelian boundary has been studied in three different palaeogeographical settings: Perigondwanan Perunica microcontinent in the Barrandian Area, Prague Synorm (Czech Republic), Laurussia in the Central Great Basin (USA, Nevada) and Central Asian settings in South Tien-Shan Folded Area in the Zeravshan-Gissar Mountain Region (Kitab, Uzbekistan). Magnetic susceptibility (MS) and gamma-ray spectrometry (GRS) were applied.

Studied interval embraces roughly *Polygnathus costatus patulus* to *Polygnathus costatus costatus* conodont zones.

Similar features of the logs were revealed. Elevated input of shallow-water detritus skeletal material and increased turbidite activity mark the critical interval and the incipient environmental changes. GRS logs are characterized by elevated concentrations of U at the expense of Th concentration (total GRS is driven by the U content) at the event interval whereas U and Th concentrations below and above become closer or Th concentrations prevail (Prague Synform, CZ and Central Great Basin, NV). MS log shows attenuated oscillations and a delicate to distinct decrease in the values at the very event datum with no regard to the lithology. This might be indicative of calming down of the processes (atmospheric circulation, ocean currents etc.) which control the input of detrital material and drive the MS signal.

Following projects are acknowledged: IGCP 580, 596, GAP210/10/2351, GAP210/12/2018, ME08011, AV0Z30130516, RVO: 67985831.

Spectral gamma-ray correlations controlled by other stratigraphic methods – case studies from a Silurian carbonate platform and periplatform settings, East European Craton (Poland, Ukraine)

KOZŁOWSKI, W.[1], ŁUCZYŃSKI, P.[1], SKOMPSKI, S.[1] & SOBIEŃ, K.[2]

(1) University of Warsaw, Faculty of Geology, Żwirki I Wigury 93, 02 089 Warsaw, Poland; *woko@uw.edu.pl*
(2) Polish Geological Institute - National Research Institute, 4 Rakowiecka Street, 00-975 Warsaw, Poland; *Katarzyna.Sobien@pgi.gov.pl*

The Silurian sedimentary rocks covering the south-western margin of the East European Craton represent a low-latitude, carbonate platform to periplatform setting (KALJO & JURGENSON, 1977). Recently, the basin is a subject of interest of oil industry, due to its high shale-gas potential. The Silurian succession is well dated by graptolites and conodonts, however the biostratigraphical data are often incomplete or insufficient in drillcore sections. One of the methods that can potentially be used for improvement of stratigraphical resolution in the basin is spectral gamma-ray. However, prior to its implementation in drillcore sections, the method needs to be tested in well dated and easily correlable outcrop sections. Here presented are two case studies, revealing different applicability potential of the method in inshore and offshore settings.

In the first case, an attempt has been made, to correlate the inner carbonate platform sections of Konovka to Sokol formations (early Ludlovian), exposed in the Dnister river escarpment, between Woronowica and Konovka vilages, in Podolia (Ukraine). The studied interval, which both, vertically and horizontally, contain various facies, records a regressive event with distinct palaeobathymetric changes; however without significant emersion in the studied profiles. Laterally continuous outcrops of horizontally lying strata enables to track beds and horizons laterally across different facies, which allows to construct a stratigraphic framework independent from the gamma-ray record. The radiometrically measured element contents (eK, eTh, eU), and their ratios, do not reveal any reliable isochronous levels at longer distances (>several hundreds metres) and are strictly dependent on lateral or vertical facial changes. The local concentrations of potasium and thorium seem to be controlled by various admixtures of clay minerals, whereas uranium content is elevated in organic matter bearing rocks.

In the second case, a long distance (~150 km) correlation between the mid-Ludfordian sections of the Mielnik IG1 and Gołdap IG 1 boreholes (North-eastern Poland) is presented. The correlation is controlled biostratigraphically and independently by the mid-Ludfordian Carbon Isotope Excursion and by the rocks magnetic susceptibility. In this offshore example, the eK and eTh generally mirrors the eU content. The horizons with low eK and eTh contents, and with high eU content, show coincidence with the appearances of highly diversified graptolite assemblages and probably mark flooding surfaces, which allows the correlation of parasequences framework between the sections. This correlation is possible however only due to wide facies unification in the offshore setting and thanks to synchronous facies changes controlled by sea-level fluctuations.

The basic conclusion emerging from the comparison of the two cases is that the spectral-gamma ray studies may be used mainly to describe and to identify spectral-gamma (chemo-) facies. As any other facies, the vertically observed changes in the spectral gamma-ray record are often diachronous in proximal shelf setting and isochronous in offshore areas.

References

KALJO, D. & JURGENSON, E. (1977): Sedimentary facies of the East Baltic Silurian. 122-148. In: KALJO, D. (ed.), Facies and fauna of the Baltic Silurian, Institute of Geology, Academy of Sciences of the Estonian SSR, Tallinn.

Susceptibility data from Upper Triassic beds in Turkey: implications on climatic changes

LUKENEDER, S.[1] & LUKENEDER, A.[1]

(1) Geological and Palaeontological Department, Natural History Museum Vienna, Burgring 7, A-1010 Vienna, Austria; *susanne.lukeneder@nhm-wien.ac.at*, *alexander.lukeneder@nhm-wien.ac.at*

The section at Aşağiyaylabel, located within the Taurus Platform Units (Turkey, Anatolia), comprises an Early to Late Carnian platform drowning sequence, yielding an ammonoid mass occurrence ("*Kasimlarceltites* nov. gen. beds"), deposited during the Carnian Crisis (Upper Triassic), which is also known as the Carnian Pluvial Event. Furthermore the Julian/Tuvalian boundary (= Lower/Upper Carnian boundary) is well observable at Aşağiyaylabel, proven by detailed facies analysis (LUKENEDER et al. 2011). Recent investigations on the ammonoid fauna, as well as gamma-ray-, and susceptibility measurements strengthen this assumption.

Subsequently the sequence at Aşağiyaylabel represents a key section concerning the environmental changes during the Early to Late Carnian. Gamma-log values at Upper Carnian beds are 2 times higher than values of Lower Carnian beds, and furthermore show a general slightly increasing tendency from the Lower Carnian (0.015-0.019 cps) to the Upper Carnian (0.026-0.040 cps). Contrastingly, susceptibility measurements indicate some distinct peaks, most of them well interpretable: The sequence starts with Lower Carnian shallow water limestones bearing susceptibility values between -0.011 x 10^{-3} SI and 0.035 x 10^{-3} SI. The abrupt drowning of this carbonate platform is indicated by deeper-water limestones ("*Kasimlarceltites* gen. nov. beds") which appears with susceptibility values between 0.033-0.108 x 10^{-3} SI. The mentioned *Kasimlarceltites* (former "*Orthoceltites*") mass-occurrence at Aşağiyaylabel could also be detected in Karapinar (2 km NNE of Aşağiyaylabel). Not only the facies analogy between both mass-occurrences, but also the susceptibility and gamma-ray values, enables a correlation between both localities. The biggest peak concerning susceptibility values can be traced at the Julian/Tuvalian boundary. Pelagic sediments from the top (wacke- to packstones, Julian) indicate susceptibility values between 0.011 x 10^{-3} SI and 0.088 x 10^{-3} SI, whilst the lowermost layers of the Tuvalian show susceptibility values between 0.126 x 10^{-3} SI and 0.340 x 10^{-3} SI (approx. 2.5 times higher). The Lower Tuvalian at Aşağiyaylabel is marked by a delayed carbonate productivity crisis, which occurred much earlier (about 2 Ma) in other western Tethys sections (LUKENEDER et al., 2011). Climatic changes, due to more humid conditions, seem to be the reason for the change from carbonatic sediments to marly sediments and later on to shaly sediments, what has been well proved by Susceptibility measurements. Susceptibility measurements and resulting trends within the values, although attained by hand-held facilities, obtain reliable implications for lithological changes, displayed by siliciclastic or terrigenous input caused by variations in climatic conditions.

Acknowledgements: This study is funded by FWF P22109-B17.

References

LUKENEDER, S., ZUSCHIN, M., HARZHAUSER, M. & MANDIC, O. (2011): Spatiotemporal signals and palaeoenvironments of endemic molluscan assemblages in the marine system of the Sarmatian Paratethys. Acta Palaeontologica Polonica, 56 (4): 767-784.

Magnetic susceptibility of the Much Wenlock Limestone Formation (Homerian) of the English Midlands and Wenlock Edge

MARSHALL, C.[1]

(1) Geosystems Research Group, School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, B15 2TT, UK; Present address: VNG Norge AS. Postboks 720 Sentrum, NO-4003 Stavanger, Norway; *Carly.Marshall@vng.no*

Magnetic susceptibility data are presented for two composite sections from the English Midlands, spanning much of the Homerian (Silurian). Micrite samples from the uppermost Coalbrookdale, Much Wenlock Limestone and basal Lower Elton formations) were collected at 0.5 m intervals from a limestone mine, a borehole core and surface outcrops in the Dudley area, West Midlands. An equivalent set of samples were collected from outcrops along the Homerian type locality, Wenlock Edge, Shropshire. The formation generally comprises of two shallow water limestones (Lower Quarried Limestone and Upper Quarried Limestone members), separated by a deeper water nodular limestone and silty mudstone-rich interval (Nodular Beds Member). Deposited on the Midland platform, both sections are considered to span the upper *lundgreni* to *nilssoni* biozones, but are associated with mid-shelf and shelf–basin-margin settings respectively.

Detailed correlation of the Formation across the Midland Platform now involves bentonite geochemical fingerprinting, carbon isotope and integrated sequence stratigraphic studies. RAY & THOMAS (2007) and RAY et al. (2010) established a robust sequence stratigraphic framework, identifying thirteen parasequences between the base of the Much Wenlock Limestone Formation and the lower most part of the Lower Elton Formation. However specific details of the correlation between the West Midlands and Wenlock Edge and the extent to which the lower and upper boundaries of the Formation may be diachronous are not entirely clear, largely as a result of lateral facies variations between the two areas as a result of differing positions on the Midland Platform. Recent $\delta^{13}C_{carb}$ studies suggest that not all changes occurred simultaneously in the two areas, despite their close proximity (MARSHALL et al., 2009). High resolution magnetic ssusceptibility data are presented alongside stable carbon isotope ratios and inorganic geochemical analysis in an attempt to further refine the inconsistencies that have arisen in correlation of the formation across the Platform further.

References

MARSHALL, C., THOMAS, A. T., BOOMER, I. & RAY, D.C. (2009): High resolution δ13C stratigraphy of the Homerian (Wenlock) of the English Midlands. 55-6. In: Palaeontological Association, Annual Meeting Abstracts, University of Birmingham.

RAY, D.C., BRETT, C.E., THOMAS, A.T. & COLLINGS, A.V.J. (2010): Late Wenlock sequence stratigraphy in central England. Geological Magazine, 147: 123-144.

RAY, D.C. & THOMAS, A.T. (2007): Carbonate depositional environments, sequence stratigraphy and exceptional skeletal preservation in the Much Wenlock Limestone Formation (Silurian) of Dudley, England. Palaeontology, 50: 197-222.

Sedimentary development of a continuous Middle Givetian to Lower Carboniferous section from the fore-reef fringe of the Brilon reef-complex (Rheinisches Schiefergebirge, Germany)

PAS, D.[1], DA SILVA, A.C.[1], CORNET, P.[1], BULTYNCK, P.[2], KÖNIGSHOF, P.[3] & BOULVAIN, F.[1]

(1) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *dpas@ulg.ac.be*, *ac.dasilva@ulg.ac.be*, *fboulvain@ulg.ac.be*
(2) Department of Paleontology, Royal Belgian Institute of Natural Sciences, rue Vautier 29, BE-1000 Brussels, Belgium; *pierre.bultynck@naturalsciences.be*
(3) Senckenberg, Forschunginstitut und Naturmuseum Frankfurt, Senckenberganlage 25, 60325 Frankfurt, Germany; *peter.koenigshof@senckenberg.de*

The Brilon-reef complex is one of the biggest Devonian carbonate buildups (~80 km²) of the Rheinisches Schiefergebirge. The Burgberg section is located in the south-eastern fore-reef area of the Brilon reef-complex and exposes a succession of strata (117 m thick) which extend from the Middle Givetian (middle *varcus* conodont zone) to the Lower Carboniferous. This outstanding outcrop offers the opportunity to investigate the main phases of development, demise and drowning of the Brilon reef-complex from a fore-reef setting. Field and microfacies observations led to the definition of five lithological units (1-5) and nine microfacies which are integrated into a sedimentary model divided into off-reef, intermediate fore-reef and proximal fore-reef sedimentary domains (SD). SD1 is the most distal setting observed and is characterized by fine-grained sediment, dominated by pelagic biota and the local occurrence of storm and gravity flow deposits. SD2 is characterized by a mixture of biota and sediments coming from both deeper-water and shallow-water sources and is influenced by storm and gravity flow currents. In this domain *Renalcis*-mound like structures could develop locally. Finally, SD3 corresponds to the most proximal setting which is strongly influenced by gravity flow currents derived from the reef and the back reef of the Brilon reef-complex, bringing significant proportion of reef-builders remains. The microfacies stacking pattern through the Middle Givetian to Carboniferous of the Burgberg section indicates five main palaeoenvironmental trends corresponding to the lithological units (U1-5). From the base to the top of the section, these units are: (U1) - initial development of reef building upon submarine volcanoclastic deposits during the Middle Givetian (middle *varcus* zone); (U2) - the significant seaward growth of the reef from the Middle Givetian to the Early Frasnian, marked by the high increase of reef derived material to the fore-reef area; the maximum development of the Brilon reef-complex to the south extending from the *disparilis* to the *falsiovalis* conodont biozones; (U3) - the stepwise withdrawal of the reef influence from the Middle to the Late Frasnian (*jamiae* conodont biozone) characterized by a progressive decrease in shallow-water derived materials and increase in fine-grained sediments and deep-water biota; (U4) - demise and drowning of the Brilon reef-complex as a result of the Late Frasnian Kellwasser events (upper *rhenana* and *triangularis* conodont biozones) and development of a submarine rise characterized by nodular and cephalopod limestone deposits extending from the Late Frasnian to the Late Famennian; (U5) - significant deepening of the Burgberg area starting in the Late Famennian, marked by pelagic shales overlying the nodular limestone deposits.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Multi-disciplinary research on long-term Middle to Upper Devonian fore-reef successions from Germany and Austria

PAS, D.[1], DA SILVA, A.C.[1], CORNET, P.[1], SUTTNER, T.J.[2], KÖNIGSHOF, P.[3], BOULVAIN, F.[1] & BULTYNCK, P.[4]

(1) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *dpas@ulg.ac.be*, *ac.dasilva@ulg.ac.be*, *fboulvain@ulg.ac.be*
(2) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology and Paleontology), Graz, Austria; *thomas.suttner@uni-graz.at*
(3) Senkenberg, Forschunginstitut und Naturmuseum Frankfurt, Senkenbergganlage 25, 60325 Frankfurt, Germany; *peter.koenigshof@senckenberg.de*
(4) Department of Paleontology, Royal Belgian Institute of Natural Sciences, rue Vautier 29, BE-1000 Brussels, Belgium; *pierre.bultynck@naturalsciences.be*

Introduction

Despite the interest for the reconstruction of environmental changes over a long period of time, long-term successions have been relatively poorly investigated, using a mutli-disciplinary approach, compared to short-term intervals such as Kačák, Taghanic, punctata, Kellwasser and Hangenberg events. Recently, BOULVAIN et al. (2010) compared two km-thick Eifelian–Frasnian sections from Belgium and Czeck Republic using magnetic susceptibility (MS) technique. Despite a very different context regarding palaeogeography, sedimentary rate, facies and local sea-level changes history, a remarkable similarity in the MS trends can be observed between these two sections. Such similarities brought questions on the nature of the long-term forcing parameters that were active at the inter-regional scale.

In order to get a better understanding of the factors responsible for the inter-regional forcing, a detailed records of microfacies analyses, MS measurements, selected trace and major elemental concentrations and conodonts biostratigraphy have been performed on two Middle to Upper Devonian sections from Germany (Sauerland, Burgberg) and Austria (Carnics Alps, Freikofel).

Conodont biostratigraphy

In the Burgberg section, conodont biostratigraphy led us to confirm that the studied section extend from the Middle Givetian to the Lower Carboniferous. In the Freikofel section, it allowed to precisely identify the Eifelian–Givetian and the Frasnian–Famennian boundaries.

Sedimentology

The field and microfacies observations allowed us to reconstruct the sedimentary environment and to highlight several major variations of this environment. In the Middle Devonian, both sections are mainly characterized by fore-reef sediments. In the Burgberg section, those fore-reef sediments mainly correspond to bioclastic grainstone and rudstone related to gravity flow deposits derived from the shallow-water area. In the Freikofel section, the fore-reef area is dominated by breccia sediments suggesting a strong debris flow influence. Through the Upper Devonian, the sedimentary setting evolves towards an off-reef pelagic environment in both sections and even a basinal setting in the Burgberg section. Sediments are then dominated by thin-bedded and nodular limestone. In this Upper Devonian part, debris coming from the shallow-water area are still observed locally in both sections.

Magnetic susceptibility and geochemistry

The mean MS values for the Burgberg and Freikofel sections are respectively $1{,}88 \times 10^{-8} m^3/kg$ and $7{,}72 \times 10^{-9} m^3/kg$. Compared to the $MS_{marine\ standard}$ of $5.5 \times 10^{-8} m^3/kg$ defined by ELLWOOD et al. (2011) on the basis of ~11,000 marine rocks samples, our values are low, mostly in the Freikofel section. This could indicate a low terrestrial influx seaward during the Middle and Upper Devonian. Regarding the magnetic susceptibility curves from these two sections, several large-scaled trends can be highlighted. The evolution curves of some selected clastic input proxies such as Zr, Si, Al, Ti, Sr display similar large-scaled trends. This indicates that clastic input proxies and MS are inherently linked and MS techniques can then be used here as a proxi for changes in source or amount or type of weathering (RIQUIER et al., 2010).

Most of the long-term MS variations occurring in both sections are interpreted as being related to second order eustatic variations (T-R Cycles).

Through this multi-disciplinary investigation, we would like to get a better idea about what causes long-term trends in MS variations and to document the sedimentary changes in response to these long-term variations. Further aim is to develop the application of MS techniques as a correlation tool.

References

BOULVAIN, F., DA SILVA, A.C., MABILLE, C., HLADIL, J., GERSL, M., KOPTIKOVA, L. & SCHNABL, P. (2010): Magnetic susceptibility correlation of km-thick Eifelian–Frasnian sections (Ardennes and Moravia). Geologica Belgica, 13/4: 309-318.

ELLWOOD, B.B., ALGEO, T.J., EL HASSANI, A., TOMKIN, J.H. & ROWE, H.D. (2011): Defining the timing and duration of Kačák Interval within the Eifelian/Givetian boundary GSSP, Mech Irdane, Morocco, using geochemical and magnetic susceptibility patterns. Palaeogeography, Palaeoclimatology, Palaeoecology, 304: 74-84.

RIQUIER, L., AVERBUCH, O., DEVLEESCHOUWER, X. & TRIBOVILLARD, N. (2010): Diagenetic versus detrital origin of the magnetic susceptibility variations in some carbonate Frasnian–Famennian boundary sections from Northern Africa and Western Europe: implications for palaeoenvironmental reconstructions. International Journal of Earth Sciences, 99: 57-73.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

First report of magnetic susceptibility records of Tertiary sediments at Thiruvallam, Kerala, India

PRASANNAKUMAR, V.[1], RAJESH R.[1], RAJESH, S.[1] & PRATHEESH, P.[1]

(1) Department of Geology, University of Kerala, Trivandrum, Kerala, India-695 581; *prasannan@cgist.ac.in*

Introduction

The Tertiary sedimentary Formations of Kerala extend as narrow, discontinuous bodies along the coast and unconformably overlie the Precambrian crystalline rocks. Both marine and nonmarine sediments are found in the basin. The sediments, ranging in age from Late Eocene to Mio–Pliocene (RAHA et al.,1983), form three divisions, such as the Warkalli Formation, Quilon Formation and Vaikom Formation. The Warkalli Formation, composed of alternate layers of sands and clays with intercalations of lignite beds, get to a thickness of nearly 80 m while the Quilon Formation which underlies the Warkallis and having a maximum thickness of 70 m and consisting of fossiliferous limestone, sands and clays (KING, 1882), as a whole, represents a period of reduced supply of terrigenous clastics owing to the planation of the provenance. The Vaikom Formation underlies the Quilon Formation and consists of gravel, coarse to very coarse sand with greyish clay and carbonaceous clay with thin seams of lignite and attains a maximum thickness of 100 m (RAGHAVA RAO, 1976). Laterite is found as the cap rock above the Tertiary sediments.

Geological Background

The Warkalli Formation extends over 2000 km^2 and is also encountered in the nearshore regions at depths of over 6 fathoms during offshore drilling (PRABHAKAR RAO, 1968). Sticks and nodules of marcasite, impregnated in carbonaceous clays and in lignite towards the base of the Formation (PADMALAL et al., 1995), indicates reducing environment. Sands, varying in size from coarse to fine are angular and poorly sorted. The lithology and the spatial associations indicate that the Warkalli sediments are shallow water shoreline littoral and/or lacustrine to meandering river deposits (PRABHAKAR RAO, 1968). The faunal assemblages found in the clay beds and peat lenses represent a mixed ecological scenario stretching from low land-freshwater- to sandy beach environment with high organic input experiencing warm, humid climate with heavy rainfall (KUMARAN et al., 1995).

Three sets of geofractures with NW-SE to WNW-ESE, NNW-SSE to N-S and NE-SW trends have been recorded in between the Tertiary basin (VARADARAJAN & NAIR, 1978). The first set, parallel to the granulite trend, might have controlled the sedimentation. The second set is associated with the Western Ghat movement from Paleocene onwards while the third set with landward dips affects laterites and Recent sand bars at Varkala and Cochin. It is suggested that a reactivation rendered foundering of the sedimentary basin between the mainland and Laccadives. The Cenozoic tectonics of this region and surrounding areas played an important role in the deposition and distribution of the sediments within the basin. The rejuvenation of the source regions along with the tectonic uplifts of the Western Ghats and the adjoining areas resulted in varying conditions of sedimentation in a broad framework of basin margin deltaic environment.

The Tertiary sediments have already received much attention in terms of stratigraphical and palaeontological characters while the sedimentological and geochemical characters are studied only to a limited extend. The magnetic properties of the Tertiary sediments of Kerala coast are not dealt with hitherto. The present study aims to highlight the potential of magnetic susceptibility variation in interpreting the Tertiary sediments of the Kerala basin.

Thiruvallam section

A well developed section of Warkalli Formation (Fig. 1), capped by laterite and lateritic soil, is exposed at Thiruvallam, south Kerala. In a broad frame work, the section encompasses alternating layers of varying types of sand and clay with a lignite bed at the bottom. Sand layers vary in thickness from 20 cm to 2 m while clay layers vary from 2 m to 4 m. Minor ferrugenous layers (10-20 cm) and a suspected layer of laterite are also found in the section.

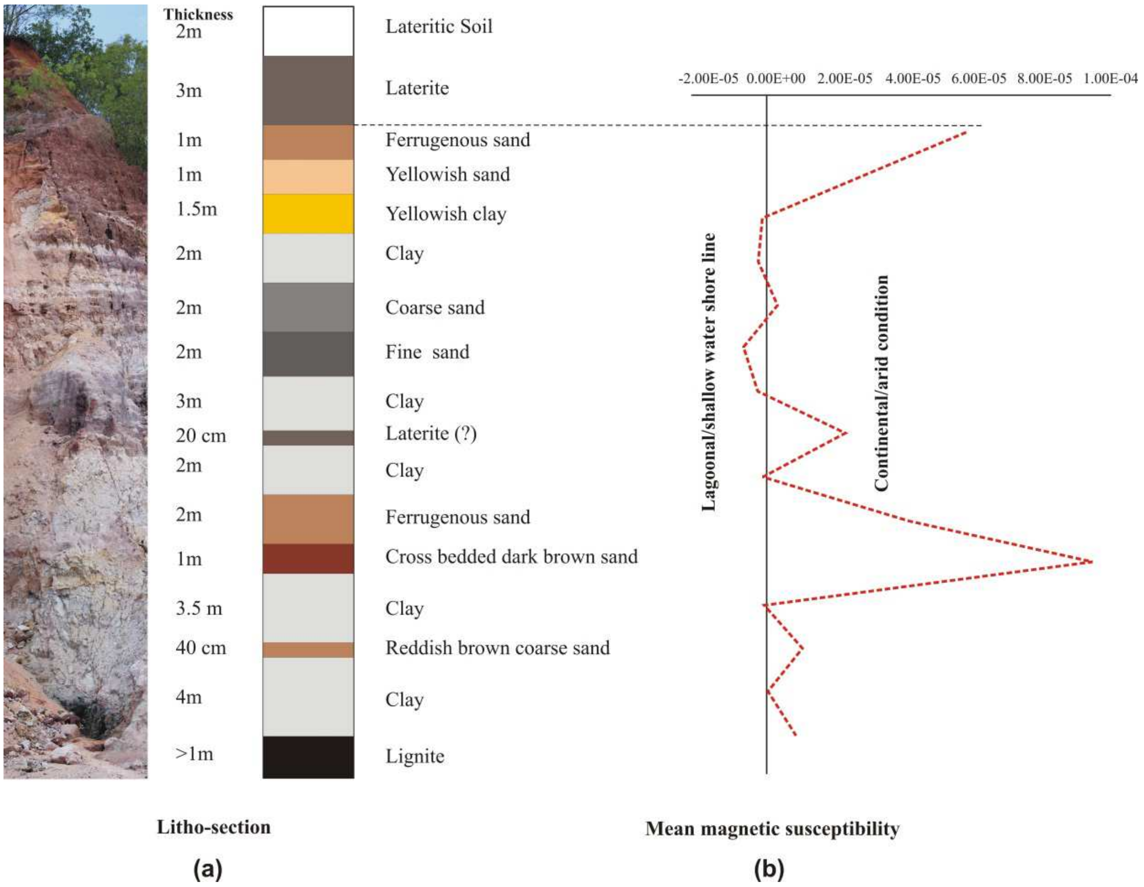


Fig. 1: (a) Lithosection at Thiruvallam cliff; (b) mean MS variation in the Thiruvallam section.

The mean magnetic susceptibility values (K_m) in the section range from -8.51E-06 to 9.94E-05 and the P' values range from 1.016 to 3.668. The magnetic susceptibility in the different layers is mainly produced by the paramagnetic and diamagnetic minerals. Mean MS value shows maximum of 9.94E-05 in the cross bedded dark brown sand, which is approximately of 1 m thickness. Ferrugenous layers including the suspected laterite layer in the section is marked by progressive susceptibility while the clay layers show a sudden decrease in susceptibility. The ferrugenous sediments indicate arid/oxidising condition with fluvial influx, while the clay layers might have deposited in a lagoonal-brackish-nearshore environment. Altogether the fluctuating MS values indicate a cyclic change from arid/oxidising to non-arid climatic extremes in the Tertiary period. Detailed analysis of the magnetic susceptibility from similar sections exposed at different parts of Kerala is being attempted for broad startigraphic and environmental correlations.

References

KING, W. (1882): General sketch of the geology of Travancore State. Rec. Geol. Surv. India, 15, Part 2: 93-102.

KUMARAN, K.P.N., SOMAN, K., KAMBLE, C.V. & ANCY, J. (1995): Palynofloral analysis of sections from Bharathi and Kundara clay mines of Kerala Basin: Palaeoecological and tectonic perspective. Current Science, 69 (12): 1023-1027.

PADMALAL, D., SANTHOSH, S. & SURESH BABU D.S. (1995): Trace metal contents of Iron sulfide minerals from the Tertiary carbonaceous clays of Kerala. Journal of the Geological Society of India, 46: 263-268.

PRABHAKAR RAO, G. (1968): Age of the Warkalli Formation and the emergence of the present Kerala coast. Bull. Nat. Inst. Sci., 38 (1): 449-456.

RAGHAVA RAO, K.V. (1976): Groundwater exploration, development and long term aquifer management in Kerala. Proc. Symp. Mineral Resources of Kerala and their utilization, Trivandrum: 30-36.

RAHA, P.K., SINHA ROY, S. & RAJENDRAN, C.P. (1983): A new approach to the Lithostratigraphy of the Cenozoic sequence of Kerala. Geological Society of India Journal, 24 (7): 325-342.

VARADARAJAN, K. & NAIR, K.M. (1978): Stratigraphy and structure of Kerala Tertiary Basin. Journal of the Geological Society of India, 19: 217-220.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Magnetic susceptibility as a versatile investigation tool in different geocontexts: from Palaeozoic rocks to Recent sediments. An overview of three case studies

RĂDAN, S.-C.[1] & RĂDAN, S.[2]

(1) Geological Institute of Romania, 1 Caransebes St., RO-012271 Bucharest, Romania; *sc.radan@yahoo.com*
(2) GeoEcoMar, 23-25 Dimitrie Onciul St., RO-024053 Bucharest, Romania; *radan@geoecomar.ro*

Based on measurements on different types of rocks and sediments, various applications of the magnetic susceptibility (MS) in geology, geophysics and geoecology are presented. These have originated from outcrops, quarries or exploration wells, and respectively, from deltaic, lagoonal or marine sedimentary environments. Temporally, it is covered an interval between ca 380 Ma and Recent, and spatially, from Southern Carpathians to Danube, and from western Dacic Basin to Danube Delta and Northwestern Black Sea.

The first case regards an application of the magnetic susceptibility in geology (RĂDAN & RĂDAN, 1980a). Starting from more than 50,000 MS values obtained for cores extracted from 37 exploration wells in the Iazuri – Vlădeasa area (Poiana Ruscă Mountains, Southern Carpathians), a series of magnetic susceptibility models were carried out for the Devonian epimetamorphic schists. The MS vertical variations were illustrated by diagrams associated with each bore hole and by vertical sections supported by 6 to 9 exploration wells, placed along 3 profiles (RĂDAN & RĂDAN, 1980b). On the other side, several susceptibility maps were drawn, in two versions (RĂDAN & RĂDAN, 1981). All these models gave useful information concerning the two complexes of rocks of the "Ghelar series", which are characteristic for the Iazuri perysinclinal structure: the green tufogene schists (Middle Devonian) and the sericito-chlorito-quartzose schists (Upper Devonian). The magnetite bearing mineralisation distribution within the first complex is clearly outlined by means of the petromagnetic patterns. Besides, some tests for the magnetic susceptibility anisotropy of the epimetamorphic schists were performed (RĂDAN & RĂDAN, 1981). Finally, there are discussed the maps with susceptibility contours carried out at the lower, middle and upper levels of the main tuffogenous horizon of the tuffogenous greenschist complex (Middle Devonian), and also for the whole main horizon. The augmented Fe contents seem to be determined by the proximity of some important submarine volcanoes (MUREŞAN, 1973*).* The MS distribution pattern allows the identification of several supply palaeodirections of the volcanogenic material and of the associated iron minerals. The existence of a submarine volcanic activity in the vicinity of the Iazuri-Vlădeasa area, pointed out by petrographical methods (MUREŞAN, 1973), acquires thus a geophysical support, yielded by the magnetic susceptibility data.

The second case is dealing with the magnetic properties of the Pliocene coal bearing formations from the Western Dacic Basin (WDB), Southwestern Romania. Actually, it is a case history of the various signatures (*i.e.*, geophysical, geological and geochemical) which were discovered in this area and that provide evidence of past "coal fires" (RĂDAN & RĂDAN, 2012). The rock magnetic signal that is characteristic for the "original" clays (not affected by coal fires), sampled in the WDB ("Jilţ Sud" and "Lupoaia" lignite quarries), is defined by a low amplitude. The initial magnetic susceptibility (k_{in}) exhibits values rarely exceeding $75x10^{-6}x4\pi$ SI. During thermal demagnetisation works, as a result of some mineralogical transformations produced, we remarked an increasing of the magnetic susceptibility when temperatures higher than 300°C were applied (RĂDAN, 1998). The hematite appearance is possible, at the expense of the goethite or pyrite, but also the presence of the greigite is not excluded, in agreement with the first condition mentioned by KRS et al. (1990): the existence of the finely dispersed organic material and of some greater floristic and faunistic fragments, which favours a reducing environment. The presence of the vegetal material inside of several samples described as coaly clays, in one of them the gypsum being observed as well, stands for arguments for the possible appearance of the greigite. It can be added that during the palaeomagnetic stability tests, at the temperature steps of 300°C, 320°, 340°, 360°, 380° and 400°C it was easily established the sulfur release as volatile compounds, in fact a process taking place during the natural baking of the clays (S. RĂDAN, in RĂDAN, 1998). The rock magnetic signal, sent by the "baked clays", is changed in comparison with the signal received from the "original" clays. High and very high MS amplitudes were recorded for porcellanites and porcellanite-like clays: the k_{in} values range between $200x10^{-6}x4\pi$ SI and $1500x10^{-6}x4\pi$ SI, sometimes reaching $12800x10^{-6}x4\pi$ SI. Besides, the enhancement of several magnetic susceptibility anisotropy parameters was observed: e.g., the magnetic foliation (F) and the anisotropy degree (P) record values between 1.10 – 1.20, sometimes as high as 1.30 – 1.40, while for the thermally un-affected clays, a range of 1.03 – 1.05 was achieved for F and P. Instead, the features of the spatial distribution of the principal susceptibilities were generally preserved. So, the magnetic fabric is defined by similar characteristics with those obtained for the "original"/"fresh" clays. This remark is consistent with the data published by PERARNAU & TARLING (1985). The remanent magnetisation and the palaeogeomagnetic signatures are also comparatively analysed ("baked" *vs* "fresh" clays). The porcellanite deposits are able to produce significant magnetic anomalies; in the investigated area, amplitudes up to 1880 nT were measured.

The last case presented in the paper regards the use of the magnetic susceptibility as an investigation tool in aquatic sedimentary environments. A vast enviromagnetic archive of recent sediments from Danube Delta (DD), Razim (Razelm) – Sinoie Lagoonal Complex (RSLC), Black Sea Littoral Zone (BSLZ) and Northwestern Black Sea (NWBS) has been sampled over about 35 years (RĂDAN & RĂDAN, 2011). The most extended data bank belongs to the deltaic – lagoonal system (DD – RSLC) and is based on thousands of (sub)samples collected during the cruises carried out in the 1976 – 2011 period. To calibrate the modern sediments and to compare different magnetic fingerprints recovered from the various aquatic environments, a "magnetic susceptibility scale" (RĂDAN & RĂDAN, 2007) is used. The integrated magnetic susceptibility-lithological patterns associated with 10 deltaic lakes emphasize the allochthonous sedimentation, predominantly detrital in the lacustrine ecosystems that are directly influenced by the Danube River, comparing with the dominantly autochthonous sedimentation in the distal zones, where the organic component is mostly present. As regards the RSLC area, the MS data bank comprising around 1800 k values measured on bottom sediment samples (cores included) was systematized relating to 3 time periods in which the all four main lakes of the lagoonal complex were investigated: 1976 – 1978, 2002 – 2004 and 2007 – 2010. Based on the calibration of the lake sediments to the magnetic susceptibility scale, the data interpretation in a hydrodinamic context proved the sedimentogenetic capabilities of this versatile investigation tool. The quality of proxy environmental parameter of the magnetic susceptibility was even more demonstrated by a series of examples presented for the modern sediments sampled in four lakes of the Black Sea Littoral Zone, as well as in the Northwestern Black Sea. In conclusion, we remark that the validity of the VEROSUB & ROBERTS (1995) statement, *i.e.* "*many types of studies that are now classified as environmental magnetism have been in existence for some time*", is clearly proved by the enviromagnetic archives recovered from the modern sediments (RĂDAN & RĂDAN, 2011), sampled during 1976-2011 period, in various aquatic environments from the Danube – Danube Delta – Black Sea macro-system.

References

KRS, M., KRSOVA, M., PRUNER, P., ZEMAN, A., NOVAK, F. & JANSA, J. (1990): A petromagnetic study of Miocene rocks bearing micro-organic material and the magnetic mineral greigite (Sokolov and Cheb basins, Czechoslovakia). Physics of the Earth and Planetary Interiors, 63: 98-112.

MUREŞAN, M. (1973): The epimetamorphic formations from the northwestern part of the Poiana Ruscă Massif (Southern Carpathians) (in Romanian). Anuarul Institutului Geologic, XLII, Bucureşti.

PERARNAU, A. & TARLING, D.H. (1985): Thermal enhancement of magnetic fabric in Cretaceous sandstones. Journal of the Geological Society, London, 142: 1029-1034.

RĂDAN, S.-C. (1998): Contributions to the study of the magnetic properties of rocks in geophysical and geological context. Ph.D. Thesis (in Romanian), Central University Library of Bucharest: 332 p.

RĂDAN, S. & RĂDAN, S.-C. (1980a): An application of the magnetic susceptibility in Geology. Rev. Roum. Géol. Géophys. Géogr. – Géophysique, 24, 2, Bucarest: 269-275.

RĂDAN, S.-C. & RĂDAN, M. (1980b): Some petromagnetic methodological alternatives applied to the magnetic susceptibility study of epimetamorphic schists from the Poiana Ruscă Mountains (I). Patterns of vertical distribution of the susceptibility (in Romanian, with an English abstract). St. Cerc. Geol. Geofiz. Geogr. – Geofizică, 18, Bucureşti: 139-150.

RĂDAN, S.-C. & RĂDAN, M. (1981): Petromagnetic methodological alternatives applied to the magnetic susceptibility study of epimetamorphic schists from the Poiana Ruscă Mountains. (II) Patterns of areal and intrinsic distribution of susceptibility (in Romanian, with an English abstract). St. Cerc. Geol. Geofiz. Geogr. – Geofizică, 19, Bucureşti: 109-121.

RĂDAN, S.-C. & RĂDAN, S. (2007): A magnetic susceptibility scale for lake sediments; inferences from the Danube Delta and the Razim – Sinoie lagoonal Complex (Romania). Geo-Eco-Marina, 13, Bucureşti: 61-74.

RĂDAN, S.-C. & RĂDAN, S. (2011): Recent sediments as enviromagnetic archives. A brief overview. Geo-Eco-Marina, 17, Bucureşti – Constanţa: 103-122.

RĂDAN, S.-C. & RĂDAN, S. (2012): Chapter 17. Paleo-Coal Fires in the Western Dacic Basin, Romania. In: STRACHER, G.B., PRAKASH, A. & SOKOL, E.V. (eds), Coal and Peat Fires: A Global Perspective, Volume 2, Photographs and Multimedia Tours, Elsevier (accepted for publication).

VEROSUB, K.L. & ROBERTS, A.P. (1995): Environmental magnetism: Past, present, future. Journal of geophysical research, 100 (82): 2175-2192.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Magnetic susceptibility distribution in lake sediments inferred from short cores collected in the Danube Delta and Razim – Sinoie Lagoonal Complex. I. Results from deltaic lakes

RĂDAN, S.-C.[1], RĂDAN, S.[2] & CATIANIS, I.[2]

(1) Geological Institute of Romania, 1 Caransebes St., RO-012271 Bucharest, Romania; *sc.radan@yahoo.com*
(2) GeoEcoMar, 23-25 Dimitrie Onciul St., RO-024053 Bucharest, Romania; *radan@geoecomar.ro*, *catianis_irina@yahoo.com*

The composite paper (in two parts) is focused on the enviromagnetic results obtained on short cores collected from deltaic and lagoonal lakes, located in the very important wetlands of the Southeastern Romania, *i.e*. the Danube Delta and Razim (Razelm) – Sinoie Lagoonal Complex. Hence, by using a transparent Hydro-Bios corer, sediments up to ca 56 cm depth were sampled from various aquatic ecosystems. The sedimentary environments investigated in the Danube Delta are located in the interdistributary depressions from both the Fluvial Delta Plain (e.g., *Lungu L*., *Cuteţchi L*., *Uzlina L*., *Isacova L*., *Matiţa L*., *Babina L*.) and the Fluvio-Marine Delta Plain (e.g., *Puiu L*. and *Roşu L*.). As regards the lagoonal complex, the magnetic susceptibility (MS) was measured for a series of short cores that were taken out from its four main lakes, *i.e*. *Razim* (*Razelm*) *L*., *Goloviţa L*., *Zmeica L*. and *Sinoie L.* The results from the deltaic lakes are only under attention in this first part of the composite paper.

The sediment cores were cut at an adequate number of slices in order to study the vertical distribution of the magnetic susceptibility, by measuring this enviromagnetic parameter in the laboratory, for each sediment packet collected from the respective sampling intervals.

Firstly, the results reveal the reliable correlation between the lithological description of the core sediments, made on board of the research vessels, and the MS regime determined in the lab. Also, the data make possible to compare the magnetic susceptibility characterisation of the bottom sediments, sampled with the grab sampler (e.g., RĂDAN & RĂDAN, 2009, 2010), with the MS data associated with the first 10-30 cm of sediments collected from the upper half of the cores, taken out from the same places within a lake. More interesting, yet, are the variations in the magnetic susceptibility regime along the cores, in many cases being observed the increasing of the enviromagnetic parameter “intensity” from the upper towards the lower parts (an example, in Fig. 1a). Even in the lakes characterised by “confined sedimentary environments” (RĂDAN & RĂDAN, 2009, 2010), k values assigned to the MS classes III, IV and V (k scale, in RĂDAN & RĂDAN, 2007; see also Fig. 1f) were measured on the sediments sampled from the depth interval 35 – 55 cm, while for those collected from the first 10 – 30 cm, the magnetic regime showed a lower k “intensity” level (defined by the MS classes I and II). Such data demonstrate the capability of the investigated magnetic parameter as sedimentogenetic indicator, the higher k values being possible to be correlated with the interception of a underwater sandy bar. On the other side, the lower k values measured on the sediment samples collected from the upper part of the cores are usually related to the muds with fine vegetal (organic) detritus and/or with shell fragments (e.g., RĂDAN & RĂDAN, 2010). Based on the values of the enviromagnetic parameter (k) and of the contents of the lithological components (i.e., TOM – Total Organic Matter; CAR – Carbonates; SIL – Mineral/Siliciclastic fraction), achieved for the samples collected from the different levels of the cores (Fig. 1a, b, c), several correlation coefficients (r) were calculated (an example, in Fig. 1d, e).

Beside of these applications, the vertical distribution of the magnetic susceptibility associated with the cores clearly illustrates the particular characteristics of the two main “sedimentary environments” that are developed within the Danube Delta lakes: the “confined sedimentary environments” *vs* the “dynamic sedimentary environments”. The magnetic susceptibility data base, obtained by the investigation of the cores collected during the last five years, and which will be further completed, is also useful to make attempts to carry out lithological correlations inside of a lake or between the lakes. The future results will give complementary contributions in this respect. At the same time, the MS regimes achieved for the numerous short cores make possible to compare the sedimentary environments characterising the deltaic lakes with those from other aquatic areas, e.g. from the lagoonal lakes, where a series of results have been achieved as well (to be presented in the part II of the composite paper).

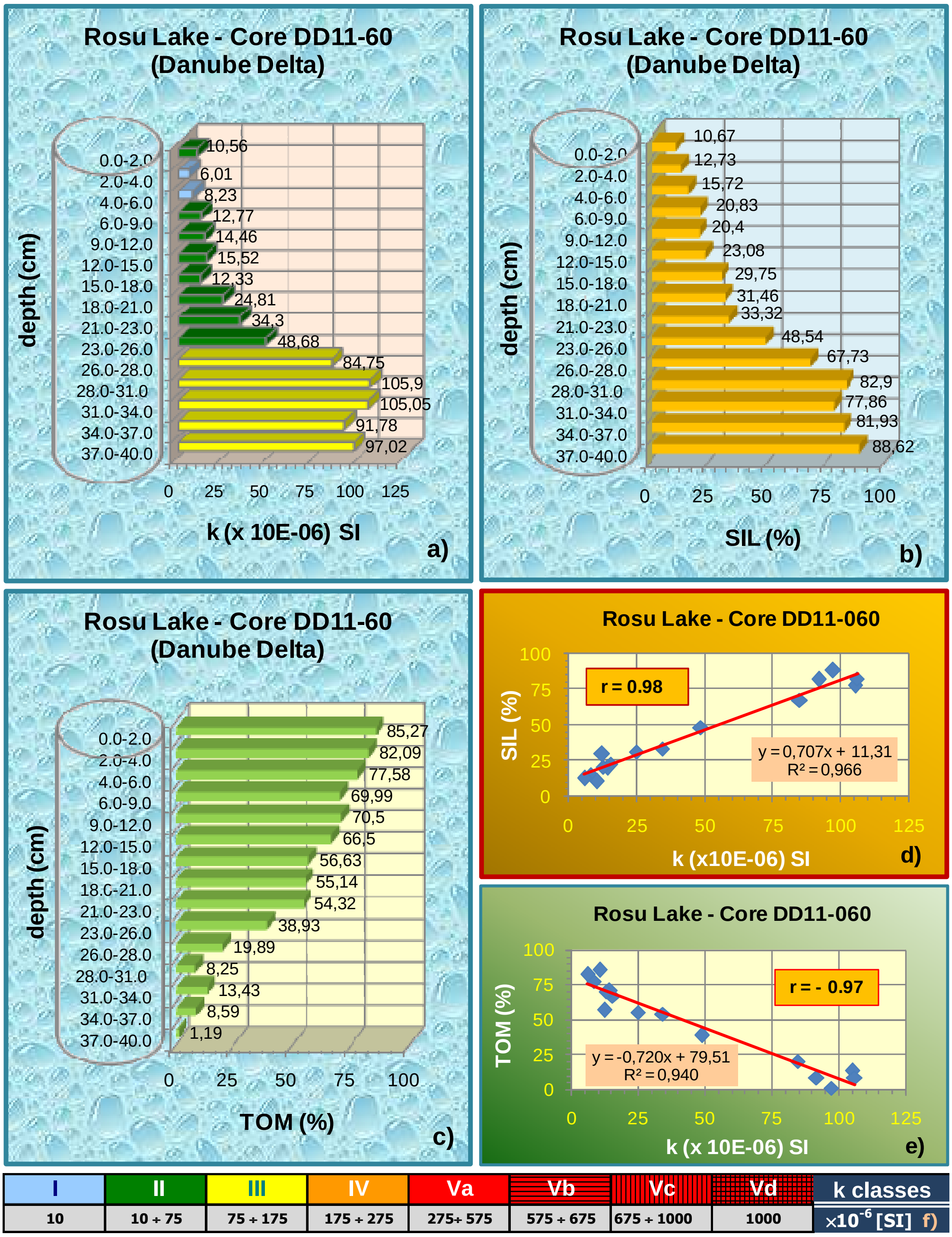


Fig. 1: An example of magneto-lithological model showing the vertical distribution of magnetic susceptibility [k] (a) and of two lithological components (b; c) along a short sediment core (DD 11-60) collected from the Roşu Lake, during the 2011 cruise in the Danube Delta. d) and e) correlation coefficients (r) for SIL vs. k and respectively, TOM vs. k; f) magnetic susceptibility scale (RĂDAN & RĂDAN, 2007), used to calibrate the recent sediments. Note: SIL – Mineral/Siliciclastic fraction; TOM – Total Organic Matter (see text).

References

RĂDAN, S.-C. & RĂDAN, S. (2007): A magnetic susceptibility scale for lake sediments; inferences from the Danube Delta and the Razim – Sinoie lagoonal Complex (Romania). Geo-Eco-Marina, 13, Bucureşti-Constanţa: 61-74.

RĂDAN, S.-C. & RĂDAN, S. (2009): Integrated magnetic susceptibility and lithological studies on lacustrine recent sediments from the Danube Delta. Geo-Eco-Marina, 15, Bucharest: 177-197.

RĂDAN, S.-C. & RĂDAN, S. (2010): The use of the magnetic susceptibility to study hydrosedimentary environments and processes in Danube Delta. Geo-Eco-Marina, 16, Bucureşti-Constanţa: 37-46.

MS as a correlation tool on an isolated Oligocene–Miocene carbonate platform (Maiella, Abbruzzi, Italy)

REUTER, M.[1], PILLER, W.E.[1], BRANDANO, M.[2] & HARZHAUSER, M.[3]

(1) Institute of Earth Sciences, University of Graz, 8010 Graz, Austria; *markus.reuter@uni-graz.at*, *werner.piller@uni-graz.at*
(2) Department of Earth Sciences, University of Rome “La Sapienza”, 00185-Rome, Italy; *marco.brandano@uniroma1.it*
(3) Geological-Paleontological Department, Natural History Museum Vienna, 1010 Vienna, Austria; *mathias.harzhauser@nhm-wien.ac.at*

The Maiella (Abruzzi, S-Apennine, Italy) represents an isolated and tectonically relative stable oceanic platform in the central Mediterranean Sea. Due to its position this carbonate platform is well suited to identify local processes possibly overprinting regional or global signals in neritic carbonates. The 120-m-thick Decontra section is composed of bryozoan and corallinacean limestones of Oligocene–Miocene age frequently representing contourites interlayered with distinct planktonic foraminiferal carbonates. Due to the small terrigenous influence, the recorded magnetic suceptibility (MS) values are very low. Nonetheless, the MS signal broadly reflects relative sea-level changes in a mostly outer neritic setting. Winnowing processes usually concentrate high-density magnetic minerals. However, the lowest MS values occur in the shallowest high energetic facies due to oxidation of magnetic particles in a well-aerated environment and/or increased biogenic carbonate sedimentation diluting the fine-clastic carriers of the MS signal. Apart from that the MS trends always correlates with relative sea-level changes. MS minima correspond to deep hemipelagic facies while the maxima coincide with slightly shallower contourite facies. The relative high MS values in the cross-bedded contourite facies display condensation processes on the proximal outer ramp. There, a low aphotic carbonate production and permanent sediment reworking prevented dilution effects and favoured the precipitation and concentration of iron-bearing glauconite.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Magnetic susceptibility and sedimentology techniques applied to unravel the interaction between eustasy and tectonic activity from the Jurassic Kashafrud Formation (Koppeh Dagh Basin, NE Iran)

SARDAR ABADI, M.[1], DA SILVA, A.C.[1], AMINI, A.[2] & BOULVAIN, F.[1]

(1) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium;
Mehrdad.SardarAbadi@student.ulg.ac.be, *ac.dasilva@ulg.ac.be*, *fboulvain@ulg.ac.be*
(2) University of Tehran, Department of Geology, Tehran, Iran

Introduction

The Kashafrud Formation was deposited in an active extensional basin (Koppeh-Dagh Basin) during the Late Bajocian to the Late Bathonian. This extensional setting allowed the deposition of exceptional thickness of sediments during limited time. Surprisingly, despite being one of the probable source rocks for Gonbadli and Khangiran Gas fields in the north east of Iran and having great potential to improve our knowledge on the Jurassic evolution of the Kopeh-Dagh basin, this Formation has been the subject of limited sedimentological research. The Pole-Gazi type section of the Kashafrud Formation, selected for this work, is a 1616-m-thick interval exposed along the Kashafrud river valley. This work proposes to use a combination of magnetic susceptibility (MS) and lithological and facies description, in order to get a better understanding of facies evolution and a palaeogeographic model of the land/basin system, and in order to decipher the influence of tectonic activity and eustasy.

Sedimentology

Facies analysis reveals that the Formation was deposited in shallow marine, slope to basinal settings. Along the Kashafrud Formation, a major transgressive-regressive cycle was recorded, including flood dominated delta to deep basin deposits (transgressive phase, see Fig. 1), followed by siliciclastic shoreface and mixed carbonate-siliciclastic shoreface (regressive phase, see Fig. 1). During the transgressive phase, sedimentary structures typical of hyperpycnal feeder currents are observed. These hyperpycnal currents are interpreted as mainly developed during high tectonic activity phases (MUTTI et al., 1996). During the regressive phase, carbonate production increase and the alternation of carbonate and silicate cycle could be explained by eustatic sea level fluctuations (ZUFFA et al., 1995). Indeed, tectonism and eustasy were apparently the main factors controlling the sediment supply, accommodation and depositional style in this case.

Magnetic susceptibility

In the lower to the middle parts of the Formation where the hyperpycnal currents fed the basin, strong tectonic variations occurred because of the strong uplift across the land during the opening of the basin (POURSOLTANI et al., 2007; TAHERI et al., 2009). This strong tectonic activity was responsible for stronger erosion and higher amount of siliciclastic inputs into the basin which led to a high magnetic susceptibility signal (mean value of 3.78×10^{-8} m³/kg) (Fig. 1). Conversely, in absence of strong tectonic variations in the upper parts, bulk MS seems to be controlled by sea level variations. Actually, decreasing bulk MS values (mean value of 1.09×10^{-8} m³/kg) to the narrowing the land sources and carbonate production during one stage of sea level fall (Fig. 1).

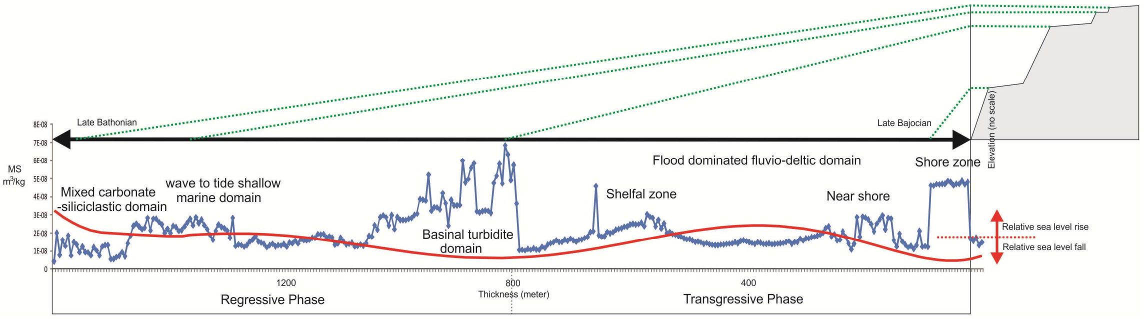


Fig. 1: Diagramatic relationship between tectonism (uplifted coastal terraces), magnetic susceptibility (MS), relative sea level changes and facies associations (sedimentary domains) with time.

In this study, high frequencies variations of MS coincide to the flood influenced deposits related to the modifications in hinterland/source system due to the high tectonic activity. In contrast, low MS frequencies are inferred to relaxation periods.

References

MUTTI, E., DAVOLI, G., TINTERRI, R. & ZAVALA, C. (1996): The importance of fluvio-deltaic systems dominated by catastrophic flooding in tectonically active basins. Memorie di Scienze Geologiche, 48: 233-291.

POURSOLTANI, M.R., MOUSSAVI-HARAMI, R. & GIBLING, M.R. (2007): Jurassic deep-water fans in the Neo-Tethys Ocean: The Kashafrud Formation of the Kopet-Dagh Basin, Iran. Sedimentary Geology, 198: 53-74.

TAHERI, J., FÜRSICH, F.T. & WILMSEN, M. (2009): Stratigraphy, depositional environments and geodynamic significance of the Upper Bajocian–Bathonian Kashafrud Formation, NE Iran. The Geological Society of London, 312: 205-218.

ZUFFA, G.G., CIBIN, U. & DI GIULIO, A. (1995): Arenite Petrography in Sequence stratigraphy. The Journal of Geology, 103: 451-459.

Is magnetic susceptibility a reliable proxy for detrital supply? - A case study of the Upper Devonian carbonates from the Holy Cross Mountains

SOBIEŃ, K.[1] & RAKOCINSKI, M.[2]

(1) Polish Geological Institute - National Research Institute, 4 Rakowiecka Street, 00-975 Warsaw, Poland; *Katarzyna.Sobien@pgi.gov.pl*
(2) University of Silesia, Faculty of Earth Sciences, Bedzińska Str. 60, 41–200 Sosnowiec, Poland; *mrakocin@us.edu.pl*

Two Upper Devonian sections (Janczyce 1 borehole and Kowala Quarry), located in the Holy Cross Mountains were selected for detailed analyses of magnetic susceptibility (MS) signal and rock magnetic properties. In order to distinguish MS carriers several tests were performed, such as: isothermal and anhysteretic remanent magnetization (IRM, ARM), S-ratio, thermoanalysis, hysteresis measurements. In addition, natural gamma ray signal was tested as well as geochemical analyses were performed for selected samples.
Relatively long Frasnian and Famennian interval (about 450 meters) of the Janczyce 1 borehole was sampled. Clear, large-scale magnetic susceptibility (mean value $18.8*10^{-9}$ kg/m^3) changes are in agreement with a total gamma ray record. Geochemical analyses of Zr, Ti and Al content confirmed that MS signal is mostly of terrigenous origin, therefore can be indirectly correlated with postulated T-R cycles. It can be also traced in other local sections as well as in distant outcrops.

Uppermost Devonian (ranging from *annulata* through *Hangenberg* shales) and Lower Tournaisian interval (39 meters) of Kowala Quarry, comprises black bituminous shales, marly shales, sometimes with carbonate nodules, micritic and wavy nodular limestones. A mean MS value is 48 $*10^{-9}$ kg/m^3. Marls and marly shales are dominated by paramagnetic minerals, which contribute significantly to MS signal. High positive correlation (0.82) between MS and ARM, and the lack of MS-IRM correlation is clearly visible in black bituminous shales, what indicates that fine grained magnetite is the dominant magnetic mineral in this kind of rocks. Moderate positive correlation between MS and ARM is noted in wavy nodular limestone and micritic limestone (0.61 and 0.30, respectively). In this case also some admixtures of high coercivity minerals (hematite) influenced MS signal. The presence of hematite-rich horizons, positive S-ratio, with values close to 1, was also confirmed by more detailed studies of rock magnetic properties. Secondary hematite is related to Permo–Triassic remagnetization episode of Devonian carbonates postulated by some authors (see SZANIAWSKI et al., 2011).
The complex nature of magnetic susceptibility signal and of carbonate magnetic mineralogy makes it difficult to draw direct conclusions related to detrital input, basing only on small scale MS changes. More detailed analyses are important, because the presence of secondary minerals and their influence on MS signal should not be omitted.

References

SZANIAWSKI, R., KONON, A., GRABOWSKI, J. & SCHNABL, P. (2011): Palaeomagnetic age constraints on folding and faulting events in Devonian carbonates of the Kielce Fold Zone (southern Holy Cross Mountains, Central Poland), Geological Quarterly, 55 (3): 223-234.

Contributions of different components to magnetic susceptibility of Ili Loess, central Asia

SONG, Y.-G.[1] & LI, C.-X.[1]

(1) State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, No 10 Fenghui Nan Road, Xi'an, Shaanxi 710075, China; *syg@ieecas.cn*

Magnetic enhancement mechanisms of loess on the Chinese Loess Plateau (CLP) have been well studied. It has been widely accepted that ultrafine magnetic grains produced during pedogenesis (ZHOU et al., 1990) are responsible for the enhancement of magnetic susceptibility (MS) from the CLP. And MS has been extensively used as a proxy of East Asian summer monsoons intensity on the CLP (AN et al., 1991). In contrast, loess magnetic enhancement mechanisms from outside the CLP in China have not been fully understood. Recent rock magnetism on the loess in the Ili basin, Central Asia have revealed the magnetic properties of Ili loess (e.g. magnetic mineral composition, concentration and granularity) are different with those of loess in the CLP (SONG et al., 2010). The enhancement mechanism and paleoclimatic significance of Ili loess MS are still unclear by now (SONG et al., 2008 & 2010). Here, we report the contributions of different components such as organic matter, carbonate, soluble salt on MS of the Ili loess, central Asia.

Total 12 loess samples were collected from ZSP section (80.25° E, 42.69° N) near the boundary of China and Kazakhstan and TLD section (43.15° N, 83.1° E) in the Ili basin, Xinjiang, China. Every sample was subdivided into five equal portions. We kept one without any pretreatment, and other 4 subsamples were pretreated by distilled water for diluting soluble salt, by 10 % perhydrol (H_2O_2) for dissolving organic matter, by 10 % acetic acid (AA) for removing secondary carbonate, by 10 % hydrochloric acid (HCl) for removing both carbonate and possible iron silicate, respectively. Magnetic susceptibility of all subsamples were measured with a Bartington MS2B meter at frequencies of 470 Hz and 4700 Hz in the state key laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences.

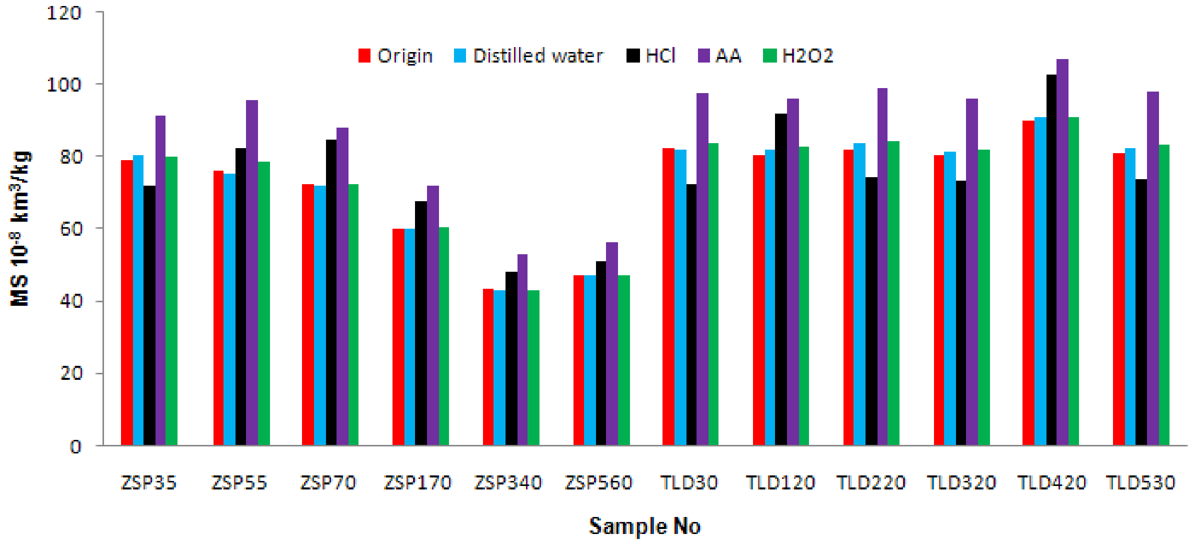


Fig. 1: Low-field magnetic susceptibility (MS) changes of the Ili loess samples pretreated by different methods.

The results of comparative analyses are showed in Figure 1 and Figure 2. Compared with the original samples, both low-field mass MS (Fig. 1) and frequency dependent susceptibility (χ_{fd}) (Fig. 2) of subsamples pretreated by the AA increase obviously, which indicates that the weak acid AA can leach the carbonate components in the Ili loess, but has little effect on silicates or iron oxides. In other words, the carbonate minerals can dilute the concentration of magnetic minerals, which causes the lower MS. Changes of MS and χ_{fd} pretreated by HCl are complicated. MS of near half subsamples increase, but most of χ_{fd} decrease after they are pretreated by HCl. These facts indicate strong acid HCl not only can remove carbonate, but also can react with Fe ion of ferrous silicate minerals. The MS and χ_{fd} values may be related with the balance between the degree of carbonate diluting and Fe Ion reaction with HCl. χ_{fd} is usually used as a tool to estimate the content of superparamagnetic particles (SP) .The decrease of χ_{fd}, may be caused by the dissolving of SP under strong acid solution. The MS of subsamples pretreated by distilled water and H_2O_2 have little changes (< 4 %) (Fig. 1), which implies that both soluble salt and organic matter have little effect on MS, most of χ_{fd} values of distilled water and H_2O_2 subsamples decreased obviously, which suggests that soluble salt and organic matter have contribution to SP of loess in some extent. However, further mineralogy and rock magnetism works are necessary to test the above conclusion.

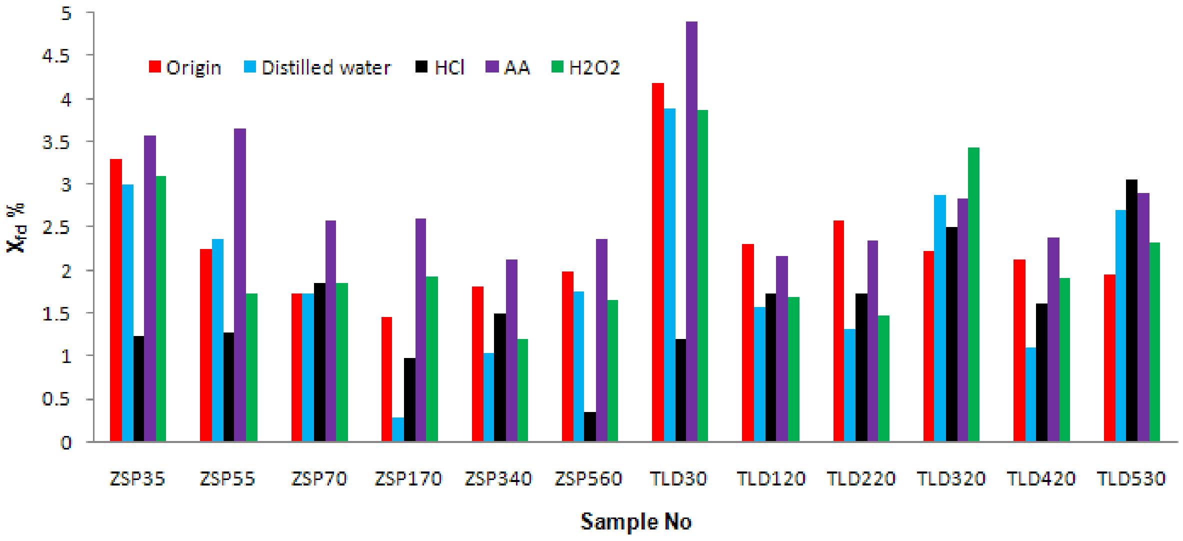


Fig. 2: Frequency-dependent susceptibility (χ_{fd}) changes of the Ili loess samples pretreated by different methods.

Acknowledgements: This work was funded by the Natural Science Foundation of China (Nos: 41172166 and 40972230).

References

AN, Z., KUKLA, G.J., PORTER, S.C. & XIAO, J. (1991): Magnetic susceptibility evidence of monsoon variation on the Loess Plateau of central China during the last 130,000 years. Quaternary Research, 36: 29-36.

SONG, Y.-G., SHI, Z.-T., DONG, H.-M., NIE, J.-S., QIAN, L.-B., CHANG, H. & QIANG, X.-K. (2008): Loess magnetic susceptibility in Central Asia and its paleoclimatic significance. Geoscience and Remote Sensing Symposium, 2: 1227-1230.

SONG, Y.-G., SHI, Z.-T., FANG, X.-M., NIE, J.-S., NAOTO, I., QIANG, X.-K. & WANG, X.-L. (2010): Loess magnetic properties in the Ili Basin and their correlation with the Chinese Loess Plateau. Science China Earth Sciences, 53: 419-431.

ZHOU, L.-P., OLDFIELD, F., WINTLE, A.G., ROBINSON, S.G. & WANG, J.T. (1990): Partly pedogenic origin of magnetic variations in Chinese loess. Nature, 346: 737-739.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Magnetic susceptibility across the Frasnian–Famennian boundary at the Boulongour Reservoir (Northwest Xinjiang-Uygur Autonomous Region, China)

SUTTNER, T.J.[1], KIDO, E.[1], CHEN, X.-Q.[2], WATERS, J.A.[3], MAWSON, R.[4] & FRÝDA, J.[5]

(1) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; *thomas.suttner@uni-graz.at*, *erika.kido@uni-graz.at*
(2) State Key Laboratory of Palaeobiology & Stratigraphy, Nanjing Institute of Geology and Palaeontology, Nanjing, China, 39 East Beijing Road, Nanjing 210008, China; *xqchen@nigpas.ac.cn*
(3) Department of Geology, Appalachian State University, Boone, NC 28608, USA; *watersja@appstate.edu*
(4) Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW, 2109, Australia; *rmawson37@gmail.com*
(5) Czech Geological Survey, P.O.B. 85, 118 21 Prague 1, Czech Republic/Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6 – Suchdol, 165 21, Czech Republic; *bellerophon@seznam.cz*

In general, the Late Devonian sequence at the Boulongour Reservoir (NW Xinjiang, China) is represented by tuffs, volcaniclastic deposits, limestones, shale, marls, chert, silt- and sandstones. In that sequence the Frasnian–Famennian boundary is identified by conodonts (CHEN et al., 2009) within the lowermost part of the limestone bearing unit (Hongguleleng Formation). The sedimentary sequence across the upper part of the *linguiformis* and *triangularis* zones consists of bioclastic limestone beds alternating with green shale on centrimetric to decimetric scale. The limestones have yielded an abundant macrofauna (principally brachiopods and crinoids). These faunas show very rapid rebound from the F/F biotic crisis. We see no sedimentologic evidence, such as black shale, of the global Upper Kellwasser Event in order to compare this section with others globally. In quest of additional evidence of the Kellwasser Event, we took bulk rock samples of each bed for geochemical and geophysical analyses.

Magnetic susceptibiliy (MS) was measured on 10 cm^3 samples with a Bartington MS3 magnetic susceptibility meter and MS2B dual frequency sensor. The resulting MS values show a distinctive negative trend which starts shortly before the Frasnian–Famennian boundary. Below the stage boundary, values vary between 1.59E-04 and 3.19E-04 before shifting to values below 1.00E-04 within the uppermost portion of the *linguiformis* Zone (ca. 2.4 m above the formation-base) which consecutively decrease to values around 6.81E-05 during the lower part of the *triangularis* Zone (up to ca. 6 m above the formation-base). This trend is consistent with sea-level rise across the F/F-boundary which is also supported by microfacies and geochemical data.

Acknowledgements: This study was supported by NAP0017.

References

CHEN, X.-Q., MAWSON, R., SUTTNER, T.J., TALENT, J.A., FRÝDA, J., MATHIESON, D., MOLLOY, P. & BERKYOVÁ, S. 2009. Late Devonian (latest Frasnian–Famennian) faunas from the 'Hongguleleng Formation' and the F–F boundary in northern Xinjiang, NW China. Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, 14, 18-20.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Geochemical, magnetic susceptibility, and carbon isotopic records across the Frasnian–Famennian boundary at Fuhe, China

WHALEN, M.[1], DA SILVA, A.C.[2], SLIWINSKI, M.[1], DEVLEESCHOUWER, X.[3], PETICLERC, E.[3], BOULVAIN, F.[2], BERTOLA, C.[2], PRASANNAKUMAR, V.[4], WANG, J.[5], ZENGHUI, G.[5] & CHEN, D.[5]

(1) Department of Geology and Geophysics, University of Alaska Fairbanks, Faribanks, AK 99775, U.S.A.; *mtwhalen@gi.alaska.edu*, *mgsliwinski@alaska.edu*
(2) Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; *ac.dasilva@ulg.ac.be*, *fboulvain@ulg.ac.be*
(3) Royal Belgian Institute f Natural Sciences, Geological Survey of Belgium, Rue Jenner 13, B-100 Brussels, Belgium; *Xavier.Devleeschouwer@naturalsciences.be*, *estelle.petitclerc@naturalsciences.be*
(4) Department of Geology, University of Kerala, Trivandrum, Kerala, India-695 581; *prasannan@cgist.ac.in*
(5) Institute of Geology and Geophysics, Chinese Academy of Science, #19 Beitucheng Xilu, Chaoyang District, Beijing 100029, China; *wangjg04@gmail.com*, *guozenghui19890525@126.com*, *dzh-chen@mail.igcas.ac.cn*

The Late Devonian Frasnian–Famennian (F–F) Event is one of the five most severe biotic crises in Earth history, recording a significant step-wise decline in marine biodiversity. In many basins worldwide the F–F event is recognized by two of organic carbon-rich black shale intervals referred to as the Lower and Upper Kellwasser Events (LKE & UKE). These units commonly record several geochemical anomalies, including positive δ^{13}C excursions and accumulation of redox-sensitive trace-metals implying deposition under low oxygen conditions.

We report here the results of δ^{13}C (C_{carb} and C_{org}) analyses coupled with determinations of major and trace element geochemistry, total organic carbon (TOC) and magnetic susceptibility (MS) for an F–F boundary section in Fuhe, (south central China) that provides insight into this event. A team from IGCP 580 evaluated this section, and a short interval near the top of the section was sampled at 10 cm intervals to document geochemical and MS variations at high resolution across the UKE. Various elemental proxies for oceanographic and biotic processes were measured by wavelength dispersive X-ray fluorescence spectroscopy at the Advanced Instrumentation Laboratory, University of Alaska Fairbanks. MS measurements were conducted at the University of Liege. Proxies for paleo-redox conditions (Mo, V, U), primary productivity (Ba, Cu, Ni, P, TOC), and detrital input (Al, Si, K, Ti, Zr) were measured from carbonate facies at Fuhe and compared with MS and δ^{13}C records to better understand the F–F event in south China.

The Fuhe section was located within the offshore, spindle-shaped Yangshuo basin that was surrounded by shallow-water carbonate platforms and appears to have been isolated from significant continental siliciclastic influx (CHEN et al., 2005). The mean MS value for the upper Fuhe section is $2.80.10^{-8}$ m³/kg, with a maximum value of $5.46.10^{-8}$ near the base of the section and a minimum value of $8.69.10^{-9}$ less than a meter below the F–F boundary. In the interval below the F–F boundary, facies alternate between autochthonous mudstones and allochthonous calciturbidites. Above the F–F, autochthonous mudstone facies dominate once again and MS values increase sharply from the minimum up to $3.71.10^{-8}$ near the top of the section. Elemental proxies for detrital input largely follow the trend in MS with higher values near the base of the section, a broad low interval spanning the F–F boundary interval and higher values above, implying that MS is largely controlled by detrital input.

Our δ^{13}C data largely reproduces results originally reported by CHEN et al. (2005) but with higher resolution. The UKE at Fuhe, as is common around the world, is characterized by a significant positive carbon isotope excursion (CIE) in both $\delta^{13}C_{carb}$ (3.8 ‰) and $\delta^{13}C_{org}$ (3.3 ‰). The CIE progresses in several steps with minor negative excursions during the dominantly positive trend. The $\delta^{13}C_{carb}$ maximum occurs about one meter higher in the section than the $\delta^{13}C_{org}$ maximum.

Unlike other localities around the world, values for TOC and elemental proxies for paleoredox conditions do not display appreciable enrichments at the level of the UKE at Fuhe. TOC is generally less than 0.25 wt.% with a minor enrichment, up to 0.32 wt.%, associated with the positive CIE. The U and Mo paleoredox proxies show no clear trend as most values fall below analytical detection limits (~1 ppm). Only V displays appreciable enrichment with a very narrow peak with a maximum value of

18 ppm associated with the positive CIE. This implies that there was likely a very short interval of suboxic conditions associated with the UKE but that oxic conditions prevailed over most of the time recorded by the section. Bioproductivity proxies Ba, Ni, and P record minor enrichments associated with the positive CIE but Cu does not.

The record of the UKE in south China, with very low TOC and detrital input and lack of evidence for anoxia, differs from many of the other records worldwide. Several studies at other localities have pointed toward increased rates of biological productivity fostered by the influx of weathering products associated with the expansion of terrestrial flora as a potential driver for the F–F event. The geochemical (detrital and redox proxies), TOC, and MS records from the Fuhe section imply that such processes may not have been active in south China or that the Yangshuo basin was effectively isolated from the effects of ongoing terrestrial processes.

References

CHEN, D., QING, H. & LI, R. (2005): The Late Devonian Frasnian–Famennian (F/F) biotic crisis: Insights from $\delta^{13}C_{carb}$, $\delta^{13}C_{org}$ and $^{87}Sr/^{86}Sr$ isotopic systematics. EPSL, 235: 151-166.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Lower–Middle Devonian boundary successions in the Holy Cross Mountains (central Poland): magnetic susceptibility as a tool for a short to long distance correlation

WÓJCIK, K.[1]

(1) University of Warsaw, Faculty of Geology, Żwirki i Wigury 93, 02-089 Warsaw, Poland;
krystian.karol.wojcik@student.uw.edu.pl

The reconstruction of the facies development of the Kielce Unit (southern part) of the Holy Cross Mountains (HCM) during the early stage of the Devonian transgression is the subject of the project. The magnetic susceptibility (MS) record is used as a tool for precise correlation between several 40-90 m thick shallow-marine carbonate successions to track the step-by-step evolution of the Holy Cross Mountains basin during the latest Emsian and early Eifelian.

The main changeover in the sedimentation over the HCM area occurred during the Early–Middle Devonian interval, when ‘Ic’ pulse of transgression broke the continental to coastal clastic sedimentation and initiated the development of the carbonate platform (SZULCZEWSKI, 1995). Before the shallow-marine carbonate facies unified over the whole area, the great diversification of sedimentary environment occurred during the early Emsian/Eifelian boundary interval. It has been expressed in visible lithological variability (geographical distribution of facies and time of their appearances) even between nearby successions.

The appearances of conodonts controlled by the facies changes, limit the use of biostratigraphy as a precise correlation tool. It permits, however, to build the general biostratigraphic framework as the base to place the MS record in selected successions. The high-resolution MS measurement (in 10 cm intervals) of about 3500 rock samples (10 to 70 g weight) was carried on in five sections from the eastern and western part of the Kielce Unit of the HCM. The MS record was used in following ways:

(1) to trace the Emsian/Eifelian boundary over the HCM area. The MS record of the conodont-marked boundary interval (traced in the Zbrza section) allowed to find the corresponding deposits in other HCM successions, where biostratigraphic data are less precise (Brzeziny and Porzecze sections). The finding of the boundary was possible within different shallow-marine facies by the identification of the corresponding MS zones. The MS record of the Emsian/Eifelian boundary from the HCM does not agree with German susceptibility magnetostratotype and records of other sections investigated by ELLWOOD et al. (2006). This seems to be caused by different MS response on sea-level fluctuations in different sedimentary environments (MABILLE & BOULVAIN, 2007; DA SILVA et al., 2009). This limits the using of the MSEC method as facies-independent stratigraphic tool.

(2) to high-resolution correlation of the HCM Upper Emsian and Lower Eifelian deposits. In generally decreasing MS magnitude (progress of Ic transgression pulse), several third (>1 Ma) to fifth order (>10 ky) trends were distinguished within 5 sections. They were correlated in agreement with conodont framework.

References

ELLWOOD, B.B., GARCIA-ALCALDE, J.L., EL HASSANI, A., HLADIL, J., SOTO, F.M., TRUYOLS-MASSONI, M., WEDDIGE, K. & KOPTIKOVA, L. (2006): Stratigraphy of the Middle Devonian Boundary: Formal Definition of the Susceptibility Magnetostratotype in Germany with comparisons to Sections in the Czech Republic, Morocco and Spain. Tectonophysics, 418: 31-49.

DA SILVA, A.C., MABILLE, C. & BOULVAIN, B. (2009): Influence of sedimentary setting on the use of magnetic susceptibility: examples from the Devonian of Belgium. Sedimentology, 56: 1292-1306.

MABILLE, C. & BOULVAIN, F. (2007): Sedimentology and magnetic susceptibility of the Couvin Formation (Eifelian, south western Belgium): carbonate platform initiation in a hostile world. Geologica Belgica, 10: 47-67.

SZULCZEWSKI, M. (1995): Depositional evolution of the Holy Cross Mts. (Poland) in the Devonian and Carboniferous – a review. Geological Quarterly, 39: 471-488.

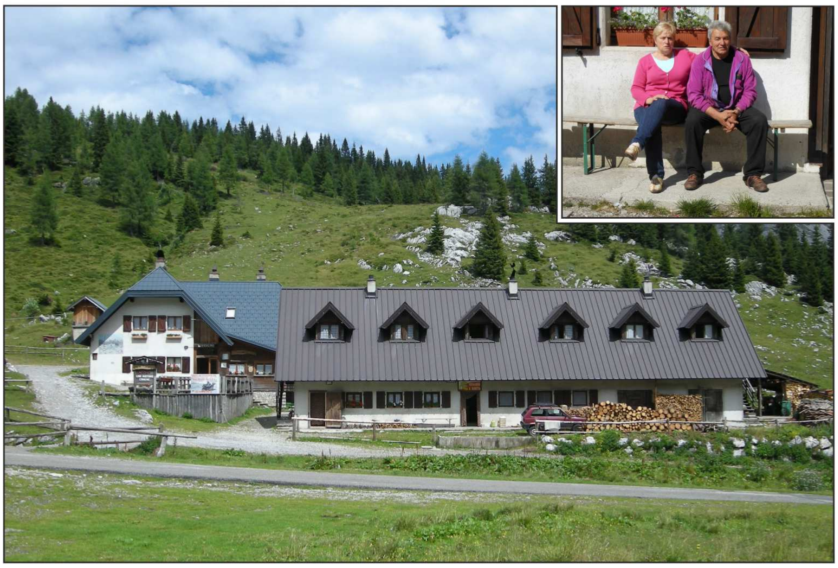
Field-Workshop

Field-Workshop: Infrastructure

Visitors Centre GeoPark Carnic Alps
Austria
email: office@geopark-karnische-alpen.at

Contact
Gerlinde Ortner & Hans Peter Schönlaub
Visitors Centre GeoPark Carnic Alps
A-9635 Dellach/Gail 65
phone: +43471830117

Webpage
www.geopark-karnische-alpen.at



Agriturismo Malga Cason di Lanza
Italy
33027 Paularo (Udine), Friuli Venezia Giulia

Contact
Francesca Cossetti
Via Cabia, 143/b
33022 Arta Terme (Udine)
phone: +39 0428 90928
mobile phone: +328 328 0052 710
(Silvio Cescutti)

Webpage
http://www.ersa.fvg.it/theme-oriented-areas/dairy-and-cheese-sector/alpine-cheese-huts-in-fvg/carnia/malga-cason-di-lanza

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Scientific research in the Geopark Carnic Alps – a never ending story

SCHÖNLAUB, H.P.[1]

(1) Geopark Carnic Alps, A-9636 Dellach/Gail, Austria; *hp.schoenlaub@aon.at*

Keywords: *Carnic Alps, Austria, Geoscience, Palaeozoic*

Active scientific research, as exemplified in the Geopark Carnic Alps, is a backbone of every Geopark. Management and administration are important activities, the role that geologists and other Earth scientist play are however much more important assets of a Geopark. Thus, it seems rather logical that every Geopark employs at least one geoscientist as member of its staff; otherwise geoscientists from outside have to be encouraged to undertake Earth science-related studies. Fortunately, the majority of EGN Geoparks has recruited at least one Earth scientist as permanent staff member.

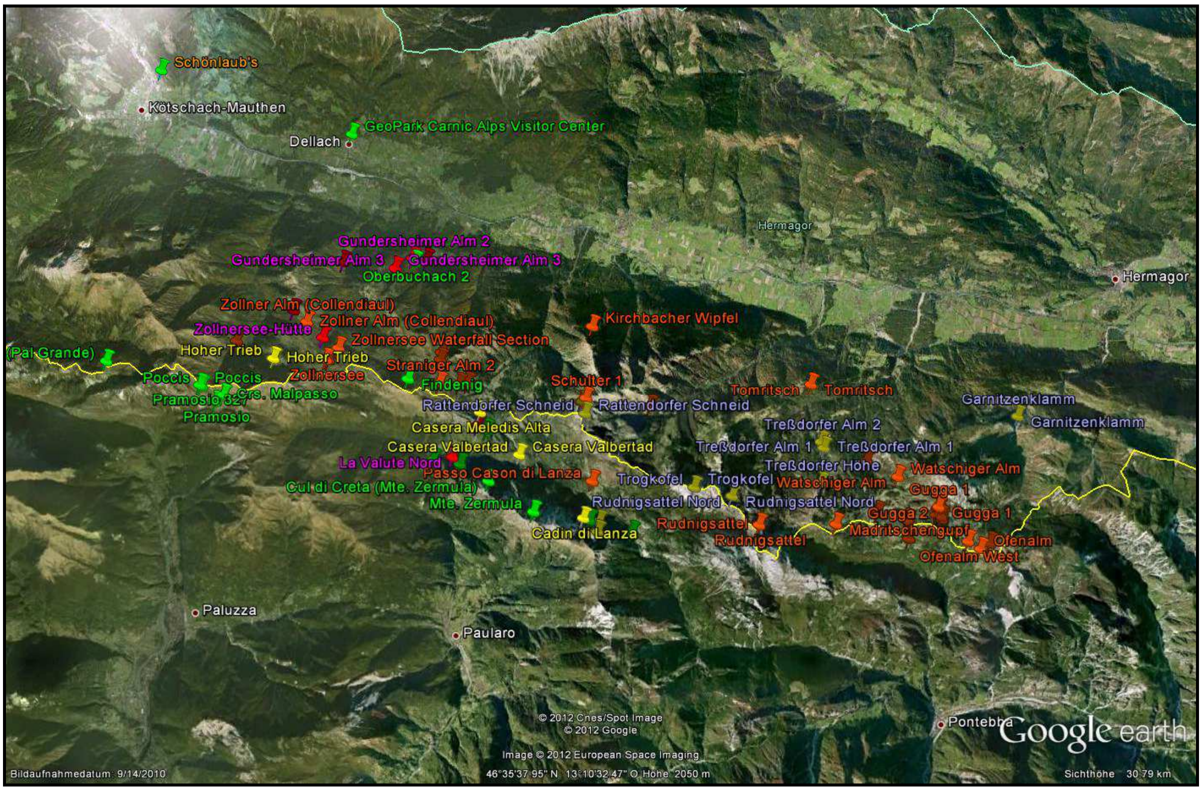


Fig. 1: Example of different fossil localities in the central part of the Carnic Alps (yellow names-Ordovician, pink-Silurian, green-Devonian, brown-Carboniferous, light blue-Permian).

The Carnic Alps are widely regarded as being among the most attractive mountain ranges in Austria and beyond. Their intrinsic beauty originates from the interplay of spectacular limestone mountains with gentle mountain pastures and foothills. A great diversity of colors is derived from the contrasts between the pink to pale-colored limestone massifs and the intervening green forests and flower-covered mountain meadows.

The mountains rise either as isolated peaks or ranges with intersecting ravines, in places forming spectacular arena-like sceneries. Some limestone sections extend vertically over more than 1,500 m and thus rank among the highest limestone cliffs found in the Alps.

Pioneering geologists were among the first who were excited by the beauty of the mountains, and their writing and subsequent publications attracted generations of scholars and visitors alike to become acquainted with the extraordinary aesthetic and scientific appeal of the area.

Soon after the visit of Leopold von Buch, the famous German geologist, paleontologist and geographer in the Carnic Alps in 1824 systematic study of rocks and fossils of the Palaeozoic sequences started in the area of the Geopark. During the first field campaign carried out by the Geological Survey of Austria shortly after the middle of the 19th century the equivalents of the Ordovician, Silurian, Devonian, Carboniferous and Permian were recognized which stimulated the first palaeontological studies. Until today generations of Earth scientists have worked in the Carnic Alps which during these times have become one of the best and most intensively studied mountain range. The current knowledge is based on more than 1500 scientific publications covering geology, structural geology, palaeontology, sedimentology, geochemistry, and Quaternary research.

The Carnic Alps of southern Austria and northern Italy provide an almost continuous sequence of sedimentary rocks from the Ordovician to the Triassic, or almost 250 million years of Earth's history. They are characterized by highly diverse marine fossil assemblages ranging from shallow water lagoonal deposits to coral-stromatoporoid reefal buildups, slope and open and deep sea environments.

The record of life of both faunas and floras in the Carnic Alps has been documented in numerous palaeontological descriptions dealing with almost all fossil groups ranging from eye-catching macroscopic creatures to micro- and nannofossils. The rich faunal spectrum covers planctonic, nectonic and benthonic animal groups.

Following the Variscan Orogeny, the late Upper Carboniferous and Lower Permian shallow-water deposits range from coastal swamps to those of an intertidal shelf embayment of the expanding Tethys Sea. They are characterized by exceptionally rich faunal and floral remains. During the late Lower Permian shelf-edge reefal deposits accumulated which were terminated due to an uplift event resulting in a short gap in sedimentation and subsequent karstification. In the Middle and Upper Permian this episode was succeeded by the red clastics of the Gröden Formation and the locally evaporitic Bellerophon Formation.

Fig. 2: The new generation (right to left): Hans Peter Schönlaub, Maria Cristina Perri, Rosy Piller, Werner E. Piller, Enzo Farabegoli, Luca Simonetto, Carlo Corradini, Maria G. Corriga, Monica Pondrelli, Claudia Spalletta, Dodo Dojen, Damien Pas, Erika Kido, Thomas Suttner.

In a global comparative analysis there is no other property in the world which comprises such a continuous succession of rocks ranging from the late Ordovician to the lower Triassic Periods with evidences of rich fossil occurrences, shifting palaeoclimates, plate drifting, and mountain building processes. They suggest a steady northward drift of one of the Peri-Gondwanide terranes from high southern and cool-tempered latitudes in the Ordovician to the moderate and tropical belt in the Silurian, Devonian and Carboniferous followed by an equatorial position with desert conditions in the Permian; ongoing drifting during the remaining 250 m.y. moved the continental plates to its present position. The fully marine succession spanning some 250 m.y. of Earth's history has opened a window to many groups of organism in a true oceanic setting – where evolution primarily takes place. This case strongly differs from other world famous fossil sites listed in various compilations (e.g., "Evolution" eds. D. Palmer & P. Barrett, 2009) which have almost nothing in common with the Carnic Alps since they mainly comprise freshwater and shallow marine faunas (tetrapods, arthropods, fishes).

To date, more than 100 fossil sites across the state border between southern Austria and northern Italy are shown in a specially designed Google Earth map (Fig. 1). This list is based on more than 160 scientific papers published in renowned journals in different countries. It includes the name of the locality, its coordinates, elevation, lithostratigraphic assignment, main fossil groups and the bibliographic references. In addition, photo images of both the outcrop and fossils can be downloaded. This new service of the GeoPark Carnic Alps is the result of a close cooperation of an international team of young scientists (Fig. 2) who, with the same spirit as the pioneers from the 19th and 20th centuries, continue cross-border research in the area of the EGN Geopark Carnic Alps and beyond.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

A short overview on the Palaeozoic sequence of the Carnic Alps

CORRADINI, C.[1], SCHÖNLAUB, H.P.[2], PONDRELLI, M.[3], SIMONETTO, L.[4], CORRIGA, M.G.[1], SUTTNER, T.J.[5] & KIDO, E.[5]

(1) Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari, Italy; *corradin@unica.it*, *maria.corriga@unica.it*
(2) Austrian Academy of Sciences, Center for Geosciences, Dr. Ignaz Seipel-Platz 2, A-1010 Vienna, Austria; *hp.schoenlaub@aon.at*
(3) International Research School of Planetary Sciences, Università d'Annunzio, viale Pindaro 42, I-65127, Pescara, Italy; *monica@irsps.unich.it*
(4) Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; *luca.simonetto@comune.udine.it*
(5) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; *thomas.suttner@uni-graz.at*, *erika.kido@uni-graz.at*

Abstract: *An overview of the geological evolution of the Carnic Alps during the Palaeozoic is presented: the Variscan sequence, the Permo–Carboniferous sequence and the basal part of the Alpine sequence were deposited between the Late Ordovician and the Middle Triassic.*

Introduction

The Carnic Alps are located across the Italian-Austrian border. One of the better exposed and complete Palaeozoic sequence of the world, ranging from Upper Ordovician to Upper Permian is here exposed.

The "Palaeocarnic Chain" is considered as part of the Hercynian ancient core of the Eastern Alps in the Southalpine domain, and extends as a narrow strip for more than 100 km in a W-E direction, with a N-S width that rarely exceeds 15 km. To the North it is bordered by the Gailtail Line, the eastern segment of the Insubric Lineament, separating the Austroalpine domain from the Southalpine domain; towards the South it is unconformably covered by Upper Palaeozoic and Triassic successions (VENTURINI & SPALLETTA, 1998, SCHÖNLAUB & FORKE, 2007). The Palaeocarnic Chain can be splitted into two parts (Fig. 1), separated by the Val Bordaglia Line, a prominent N50°E trending fault: the western zone is made exclusively of greenschist facies metamorphic rocks, and the eastern zone which consists prevalently by sedimentary not metamorphic successions (VENTURINI & SPALLETTA, 1998) except for the northernmost part where banded limestones occur.

In this paper the sedimentary sequence and the evolution of the depositional basin of the eastern zone is briefly exposed.

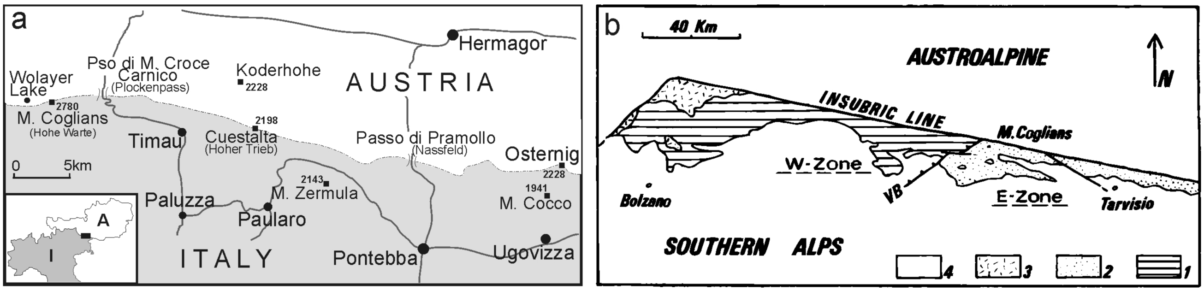


Fig. 1: (a) location map of the Carnic Alps. (b) simplified geological map of the Southern Alps showing the partition of the Palaeocarnic Chain into a West and a East Zone (after VENTURINI & SPALLETTA, 1998). VB: Val Bordaglia line; 1: low to middle grade metamorphic basement; 2: non- to anchi-metamorphic units; 3: Variscan intrusive bodies; 4: post-Palaeozoic units.

Review of the stratigraphic sequence

Rocks deposited between Late Ordovician and the Middle Triassic are exposed in the Carnic Alps. They are organized into three sequences: the Variscan, the Permo–Carboniferous and the Alpine sequences. The Variscan sequence includes rocks of Late Ordovician to early Late Carboniferous age, that were affected by the Variscan orogeny during the Moscovian (SCHÖNLAUB & FORKE, 2007); the Permo–Carboniferous sequence ranges from Late Carboniferous to Early Permian. The youngest Palaeozoic rocks of the Carnic Alps represent the basal terms of the Permo–Triassic succession that is part of the so-called 'Alpine' sequence (VENTURINI, 1990).

The most ancient rocks of the Carnic Alps belong to the Uqua shales (Katian–Hirnantian). They are represented by up to 100 m of pelites, sandstones and rare conglomerates deposed in shallow water at medium-high southern latitudes (Fig. 2). Fossils, mainly bryozoans, brachiopods, echinoderms, trilobites and gastropods, are abundant. In the western part of the basin a coarser grained sandstone unit (Himmelberger Sandstone) and even basic and acid volcanics ("Comelico Porphyroid") are present.

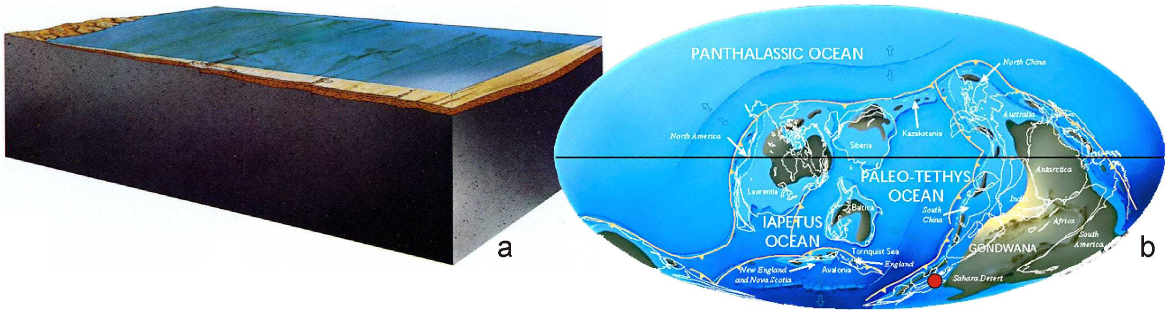


Fig. 2: Upper Ordovician. (a) Block diagram of the of the Carnic Alps depositional environment. (b) Palaeogeographic map (after Scotese.com): the red circle indicates the position of the Carnic Alps.

The basal clastic sequence is capped by an encrinitic parautochthonous limestone (Wolayer Lms) in the western part of the chain and by the deeper water limestones of the Uqua Lms. Both these units are fossilifeorus, with abundant echinoderms, bryozoans and conodonts.

The global glacially-induced regression of the the Hirnantian is documented by the calcareous sandstone of the Plöcken Fm. It resulted in erosion and local non-deposition, testified by the fact that the Silurian strata rest disconformably upon the late Ordovician sequence (SCHÖNLAUB & HISTON, 1999; HAMMARLUND et al., 2012).

Silurian deposits (Fig. 3) are irregularly distributed within the Carnic Chain, and range from shallow water bioclastic limestones to nautiloid-bearing limestones, interbedded shales and limestones to black graptolitic shales and cherts ("lydites"). The overall thickness does not exceed 60m. The Silurian transgression started at the base of the Llandovery, and, due to the disconformity separating the Ordovician and the Silurian, a varying pile of sediments is locally missing, which corresponds to several conodont zones of Llandovery and early Ludlow age (SCHÖNLAUB & HISTON, 1999; ŠTORCH & SCHÖNLAUB, 2012).

The Silurian of the Carnic Alps is subdivided into four lithological facies (Fig. 3c), representing different depths of deposition and hydraulic conditions (WENZEL, 1997). The Wolayer-facies is characterised by proximal sediments, the Bischofalm-facies by deep water euxinic deposits; the Plöcken-facies and the Findenig-facies are intermediate between the ones mentioned above. In rough approximation, the four facies seem to be distributed north-west to south-east in the western-central sectors of the chain. The depositional features suggest an overall transgressional regime from Llandovery to Ludlow. Uniform limestone sedimentation within the Prídoli suggests that more uniform conditions were developed at that time (SCHÖNLAUB, 1997).

In terms of the recently established new lithostratigrapic subdivision, in correspondence of the calcareous proximal parts of the basin, three units follow each other: the Kok Fm (Llandovery–lower Ludlow), the *Cardiola* Fm (Ludlow) and the *Alticola* Lms (upper Ludlow–Pridoli). All these units are mainly represented by "*Orthoceras* limestones", a wackestone-packstone with high bioclastic content. The colour gradually turns from dark red and black in the lower Silurian levels to light grey-ochre in the Pridoli. Nautiloid cephalopds are very abundant, trilobites, bivalves and conodonts are common; crinoids, gastropods and rarer ostracods, brachiopods, chitinozoans are also present (CORRADINI et al., 2010).

In the deeper part of the basin, the Bischofalm Fm deposited: it is a monotonous sequence, up to 60 m thick, of black siliceous shales, with cherts interbedded and clayish alum slates, mainly deposited in an euxinic environment. Graptolites are generally abundant (SCHÖNLAUB, 1997).

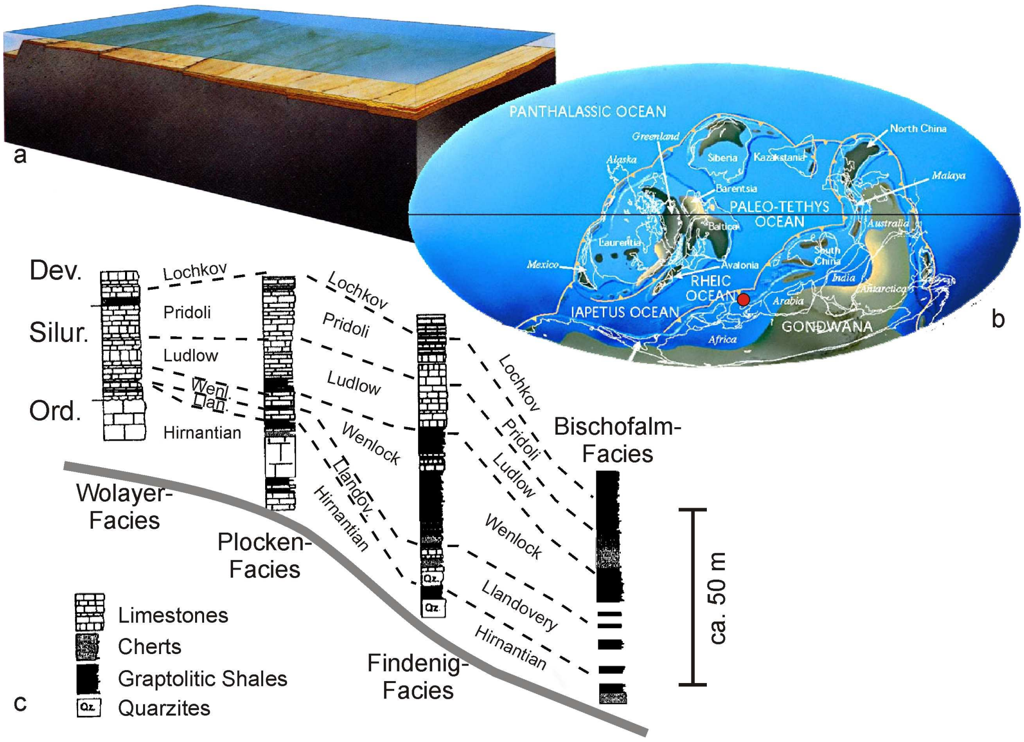


Fig. 3: Silurian. (a) Block diagram of the of the Carnic Alps depositional environment. (b) Palaeogeographic map (after Scotese.com): the red circle indicates the position of the Carnic Alps. (c) Lithology of the Silurian and lowermost Devonian sediments in the four lithofacies of the Carnic Alps (after WENZEL, 1997, modified).

Intermediate sedimentary conditions between calcareous and shaley facies are represented by the Nölbling Fm, constituted by alternating black graptolitic shales, marls and limestone beds (SCHÖNLAUB, 1997).

During the beginning of the Lochkovian the general condition remained similar to the late Silurian, whereas starting within the upper Lochkovian differences within the sedimentary basin increased: "the Devonian Period is characterized by abundant shelly fossils, varying carbonate thicknesses, reef development and interfingering facies ranging from near-shore sediments to carbonate buildups, lagoonal and slope deposits, condensed pelagic cephalopod limestones to deep oceanic off-shore shales" (SCHÖNLAUB & HISTON, 1999: p. 15).

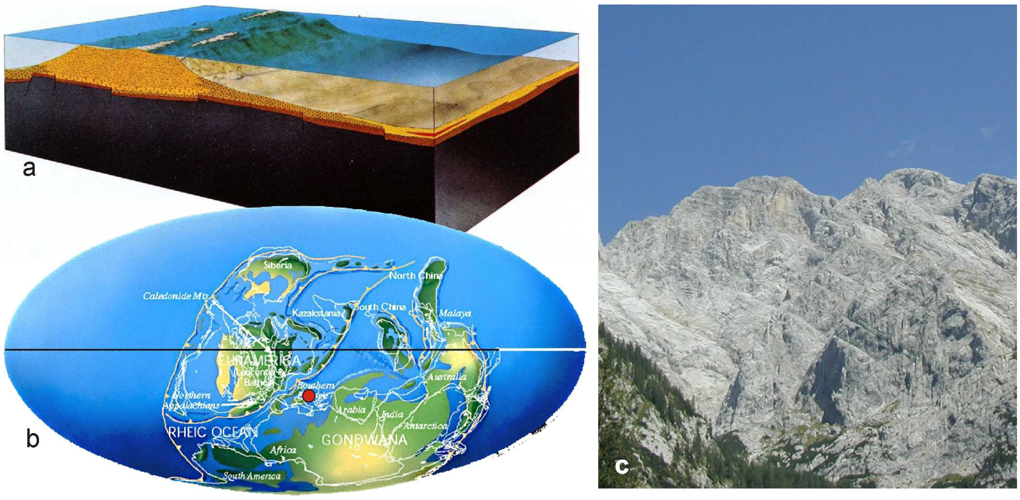


Fig. 4: Middle Devonian. (a) Block diagram of the of the Carnic Alps depositional environment. (b) Palaeogeographic map (after Scotese.com): the red circle indicates the position of the Carnic Alps. (c) the white calcareous cliffs of Mt. Coglians/Hohe Warte are constituted by more than 1000 m of reefal sediments and related facies.

During the Emsian and the Middle Devonian (Fig. 4), within short distances a strongly varying facies pattern developed, indicating a progressive but not uniform deepening of the basin. More than 1000 m of reef and near-reef limestones, and various intertidal lagoonal deposits, are time equivalent to about 100 m of pelagic limestones. Pelites and cherts deposed in the deeper part of the basin. The reefs reached their maximum extension during the Givetian and lower Frasnian, when the present Carnic Alps were about at a latitude of about 30° South (SCHÖNLAUB, 1992). Four major reefs developed, now represented by the cliffs of Mt. Coglians/Hohe Warte (Fig. 4c), Mt. Zermula, Mt. Cavallo/Roßkofel and Mt. Oisternig, beside several minor buildups. The fossil content is always very high: stromatoporoids, tabulate and rugose corals, brachiopods, crinoids, gastropods, ostracods, bivalves, cephalopods, trilobites, algae, calcispheres, and foraminifers.

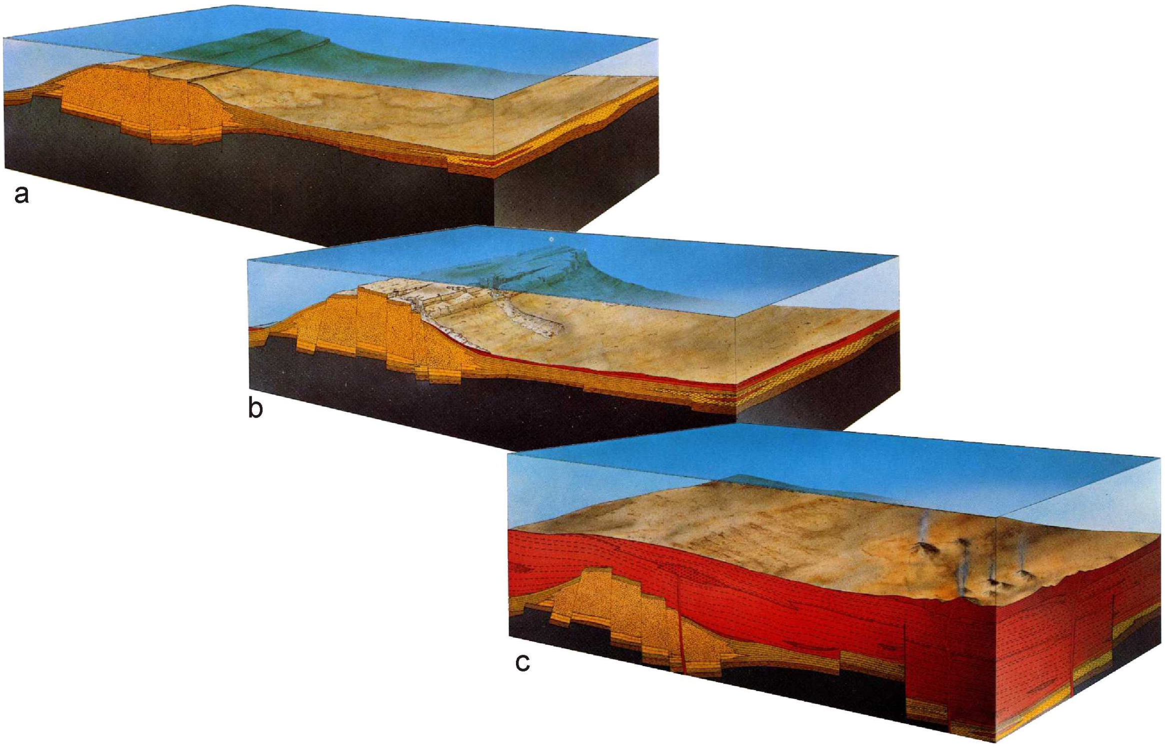


Fig. 5: Evolution of the Carnic basin from Late Devonian to early Late Carboniferous. (a) Late Devonian. (b) Early Carboniferous: beginning of the deposition of the turbidites of the Hochwipfel Fm. (c) early Late Carboniferous: deposition of the Dimon Fm volcanites.

During the early Frasnian, extensional tectonic caused collapse of the basin and consequently reefs rapidly drowned and reefal organisms died out. Starting from the upper Frasnian (Late *rhenana* Zone) a uniform pelagic environment developed (Fig. 5a), which lasted up to the lowermost Visean (SCHÖNLAUB, 1992; SCHÖNLAUB & KREUTZER, 1993; PERRI & SPALLETTA, 1998). The "Clymeniae limestone" is represented by a reddish, pinkish, greyish wackestone with cephalopods.

In the Lower Carboniferous up to 1000 m of arenaceous pelitic turbidites of the Hochwipfel Fm deposited. It is interpreted as a Variscan “flysch” sequence (VENTURINI & SPALLETTA, 1998 and references therein). This Kulm deposits indicate a Variscan active plate margin in a collisional regime following the extensional tectonics during the Devonian and the Early Carboniferous (SCHÖNLAUB & HISTON, 1999). The Hochwipfel Fm consists of quartz-sandstones and greyish shales turbidites, with intercalations of mudstones, chaotic debris flows and chert and limestone breccias. In place plant remains are common, and rare trace fossils are present. In the upper part of Early Carboniferous, the basic volcanites and volcanoclastic deposits of the Dimon Fm occur (Fig. 5c), related to crustal thinning associated to a rifting episode. These conditions continued up to the Moscovian (Upper Carboniferous), when the Hercynian orogeny in the Carnic area marked the end of the deposition of the Hercynian Sequence (SCHÖNLAUB & FORKE, 2007).

The Variscan orogeny had its climax during the Moscovian and affected the Variscan sequence, producing different systems of asymmetric folds, faults and thrusts distributed along a N 120°-140°E direction (VENTURINI, 1990).

The uplift of the Paleocarnic Chain generated an erosional-depositional sedimentary hiatus. In places (Forni Avoltri, Pramollo and Tarvisio sectors) this gap lasted until the latest Moscovian, where, because of subsidence related to a strike-slip tectonic system, the Permo–Carboniferous Sequence deposited in disconformity on top of the Hercynian Sequence. It consists of alternating cycles of fluvio-deltaic and marine deposits, caused by frequent eustatic sea level changes due to the Permo-Carboniferous glaciation. The sequence starts with basal breccias and conglomerates, resulting from the erosion of the Paleocarnic Chain.

The basal conglomerates (attributed by VENTURINI, 1990 to the Bombaso Fm) are overlaid by sediments subjected to frequent transgressive-regressive cycles, with alternating fluvio-deltaic clastic sediments and calcareous shallow water deposits (Fig. 6a). Different authors discriminate five formations belonging to the Auernig Group (VENTURINI, 1990), or several members within the Auernig Fm (FORKE et al., 2006; SCHÖNLAUB & FORKE, 2007).

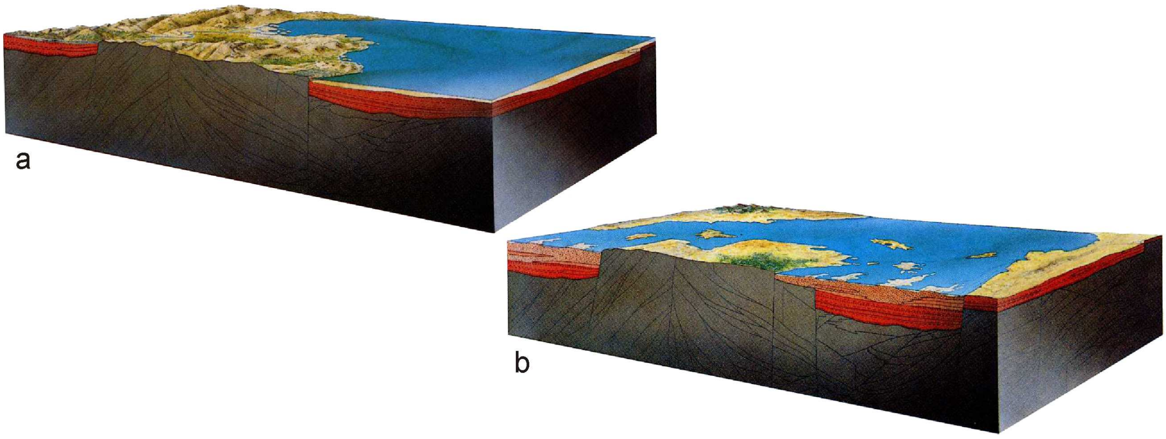


Fig. 6: Evolution of the Carnic basin from Late Carboniferous to Early Permian.

Across the Carboniferous–Permian boundary and in the Lower Permian (Fig. 6b), calcareous facies are dominant; the three formations (Schulterkofel Fm, Val Dolce Fm and Zweikofel Fm), grouped in the Rattendorf Group (VENTURINI, 1990) indicate a general transgression with more stable marine conditions. The transgressive trend continues throughout the Lower Permian, and ends with the Trogkofel Group (VENTURINI, 1990) (Trogkofel Fm, FORKE et al., 2006), characterized by reefs up to 400 metres thick.

Within the Middle Permian, a transpressional tectonic phase causes extensive emersion and karstification. In the Upper Permian an extensional phase starts, controlling the deposition of a sequence of continental ruditic deposits (Tarvisio Breccia and Sesto Conglomerates) followed by marine to terrigenous (Val Gardena Sandstones), and finally evaporitic, lagoonal and shallow marine water (*Bellerophon* Fm). This sequence was deposited in an environment characterised by alluvial fans (Tarvisio Breccia and Sesto Conglomerates), alternating with alluvial plains with irregular braided rivers deposited a thick sequence of pelites and sandstones (Val Gardena Sandstones). The *Bellerophon* Fm, marking the end of the Carnic Palaeozoic, indicates a slow rise in sea level, and is characterized by gypsum, rauhwackes and evaporitic dolostone in the lower part of the succession and by dolostone and black limestone in the upper part.

Acknowledgements: This paper is a contribution to IGCP projects 591 (*The Early to Middle Paleozoic Revolution*) and 596 (*Climate change and biodiversity patterns in the Mid-Paleozoic*).

References

CORRADINI, C., CORRIGA, M.G., PONDRELLI, M., SERVENTI, P. & SIMONETTO, L. (2010): Il Siluriano di Monte Cocco (Alpi Carniche). Gortania Geologia, Paleontologia, Paletnologia, 31: 23-30.

FORKE, H.C., SCHÖNLAUB, H.P. & SAMANKASSOU, E. (2006): Late Palaeozoic of the Carnic Alps (Austria/Italy), Field Trip of the SCCS Task Group to establish GSSP's close to the Moscovian/Kasimovian and Kasimovian/Gzhelian boundaries, 31 July-1 August 2006. Berichte der Geologischen Bundesanstalt, 70: 57 pp.

HAMMARLUND, E.U., DAHL, T.W., HARPER, D.A.T., BOND, D.P.G., NIELSEN, A.T., BJERRUM, C.J., SCHOVSBO, N.H., SCHÖNLAUB, H.P., ZALASIEWICZ, J.A. & CANFIELD, D.E. (2012): A sulfidic driver for the end-Ordovician mass extinction. Earth and Planetary Science Letters, 331-332: 128-139.

PERRI, M.C. & SPALLETTA, C. (1998): Updating of the conodont biostratigraphy in the Carnic Alps (Italy). 116-119. In: PERRI, M.C. & SPALLETTA, C. (Eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, s. 3, 60, Spec. Issue.

SCHÖNLAUB, H.P. (1992): Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its implications for Plate movements. Jahrbuch der Geologischen Bundesanstalt, 135: 381-418.

SCHÖNLAUB, H.P. (1997): The Silurian of Austria. 20-41. In: SCHÖNLAUB, H.P. (ed.), IGCP-421 North Gondwanan Mid-Paleozoic Biodynamics, Guidebook. Berichte der Geologischen Bundesanstalt, 40, Wien.

SCHÖNLAUB, H.P. & FORKE, H.C. (2007): Die post-variszische Schichtfolge del Karnischen Alpen - Erläuterungen der Geologische Karte des Jungpaläozoikum der Karnischen Alpen 1:12500. Abhandlungen der Geologisches Bundesanstalt, 61: 3-157.

SCHÖNLAUB, H.P. & HISTON, K. (1999): The Palaeozoic of the Southern Alps. 6-30. In: HISTON, K. (ed.): V International Symposium, Cephalopods - Present and Past, Carnic Alps Excursion Guidebook. Berichte der Geologischen Bundesanstalt, 47, Wien.

SCHÖNLAUB, H.P. & KREUTZER, L.H. (1993): Lower Carboniferous Conodonts from the Cima di Plotta Section (Carnic Alps, Italy). Jahrbuch der Geologischen Bundesanstalt, 136 (1): 247-269.

ŠTORCH, P. & SCHÖNLAUB, H.P. (2012): Ordovician-Silurian boundary graptolites of the Southern Alps, Austria. Bulletin of Geosciences, 3 (3): 12 pp. DOI 10.3141/bull.geosci.1350

VENTURINI, C. (1990): Geologia delle Alpi Carniche centro orientali. Pubblicazioni del Museo friulano di storia naturale, 36: 222 pp.

VENTURINI, C. & SPALLETTA, C. (1998): Remarks on the Palaeozoic stratigraphy and the Hercynian tectonics of the Palaeocarnic Chain (Southern Alps). 69-88. In: PERRI, M.C. & SPALLETTA, C. (Eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, s. 3, 60, Spec. Issue.

WENZEL, B. (1997): Isotopenstratigraphische Untersuchnungen an silurischen Abfolgen und deren paläozeanographische Interpretazion. Erlanger geologischen Abhandlungen, 129: 1-117.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Carboniferous–Permian sequence of the Nassfeld area (Carnic Alps, Austria-Italy)

KIDO, E.[1], SUTTNER, T.J.[1], SIMONETTO, L.[2], CORRIGA, M.G.[3], CORRADINI, C.[3], PONDRELLI, M.[4] & MUSCIO, G.[2]

(1) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; *erika.kido@uni-graz.at*, *thomas.suttner@uni-graz*.at
(2) Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; *luca.simonetto@comune.udine.it*, *giuseppe.muscio@comune.udine.it*
(3) Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari (Italy); *corradin@unica.it*, *maria.corriga@unica.it*
(4) International Research School of Planetary Sciences, Dipartimento di Scienze, Università d'Annunzio, viale Pindaro 42, I-65127 Pescara, Italy; *monica@irsps.unich.it*

Abstract: *In the Nassfeld area the post-Variscan sequences of the Carnic Alps is well preserved and consists of Late Palaeozoic to Early Mesozoic units which were deposited in equatorial realms. Of them the lithological and stratigraphical characteristics of the Carboniferous to Permian sediments are briefly described.*

Introduction

The Nassfeld area (= *ital.* Pramollo area) is located close to the border between Austria and Italy in the Carnic Alps (Fig. 1). It represents one of the most important localities in the Carnic Alps where the post-Variscan sedimentary sequence crops out (VENTURINI, 1990; KRAINER, 1990, 1995; SCHÖNLAUB & FORKE, 2007). According to VENTURINI (1983, 1990), the Carboniferous to Permian post-Variscan sequence at Nassfeld developed inside a narrow N120°E elongated tectonic basin (Pramollo Basin) which is separated from other basins in that region (Forni Avoltri and Tarvisio basins) by tectonically uplifted low elevations of the Hercynian basement. Since the tectonic evolution of the Nassfeld area is very complex, several hypotheses are published on the basinal development of that area (for different interpretations compare e.g., LÄUFER et al., 1993; VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007).

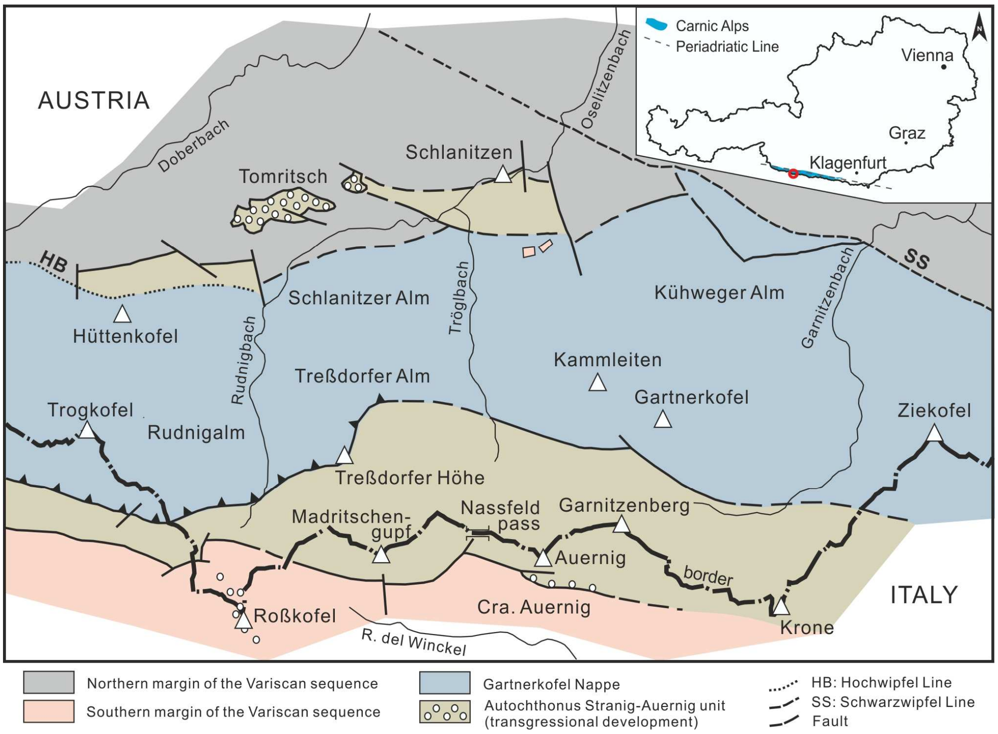


Fig. 1: Map of the Nassfeld area (Carnic Alps); modified after SCHÖNLAUB & FORKE (2007).

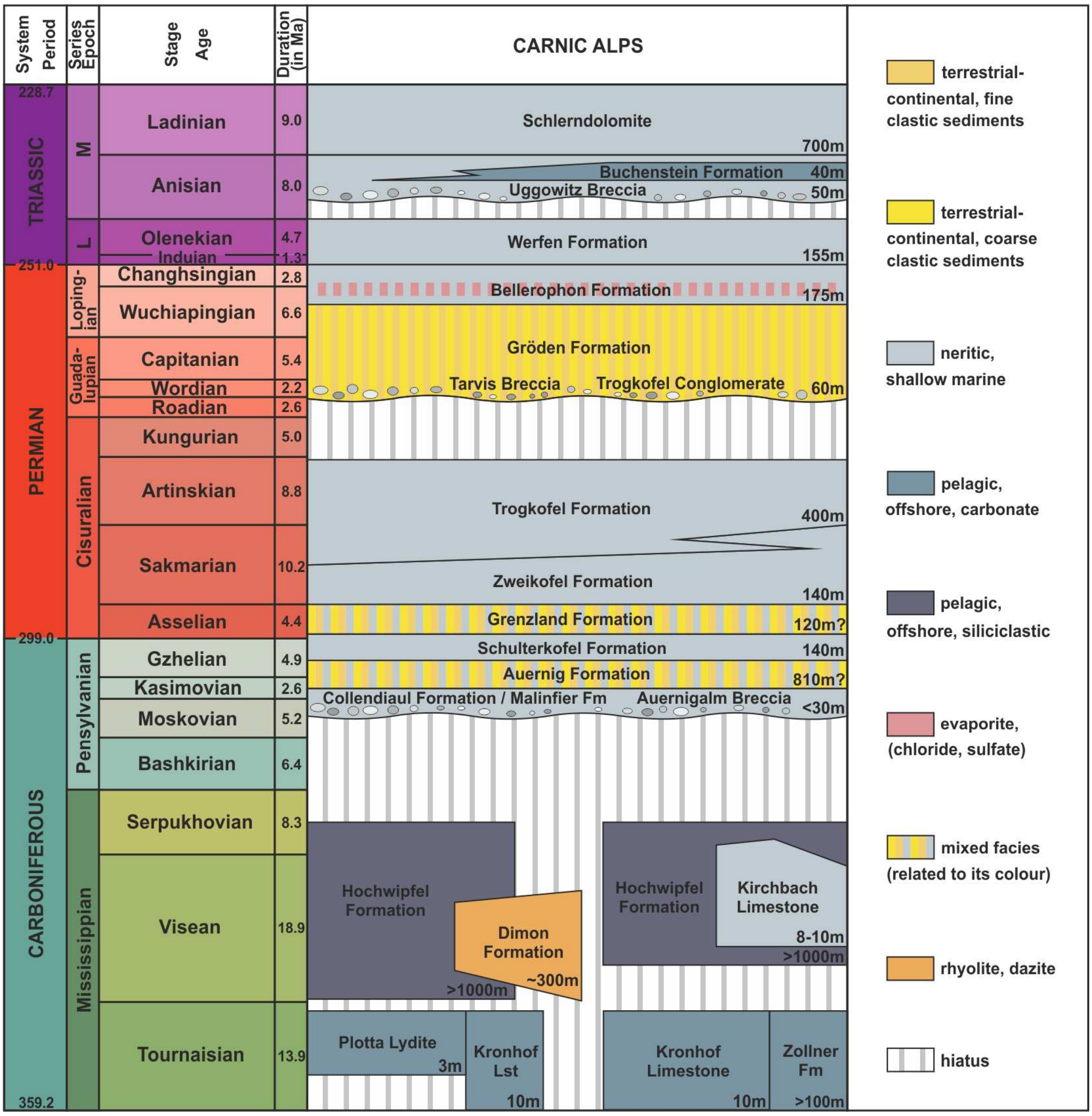


Fig. 2: Stratigraphic chart of Early Carboniferous (pre-Variscan sequence; after PILLER et al., 2004) and Late Carboniferous–Middle Triassic (post-Variscan sequence; after SCHÖNLAUB & FORKE, 2007) units in the Carnic Alps. The hiatus between the Serpukhovian–Moskovian stages demarcates the Variscan orogeny.

In general, the entire succession can be discriminated into three transgressive phases which rest unconformably upon each other and start with breccia-levels or conglomerates at the base (Fig. 2). The first transgressive phase covers the Late Carboniferous to Early Permian interval (Collendiaul Formation, Auernig Formation, Schulterkofel Formation, Grenzland Formation, Zweikofel Formation and Trogkofel Limestone) and reaches a thickness of about 1600 m. The second phase lasted from Middle Permian into Early Triassic (Tarvis Breccia, Gröden Formation, *Bellerophon* Formation and Werfen Formation) with a thickness of ca. 400 m. And the third transgressive phase covers the Middle Triassic time interval (Uggowitz Breccia, Buchenstein Formation and Schlerndolomite) with a thickness of approx. 800 m.

The sediments of this sequence are characterized by both, terrigenous and carbonatic deposits, which correspond to continental, deltaic, marginal marine, shelf and, but seldom, slope environments (VENTURINI, 1990). Here we briefly summarize the lithological character and fossil content of Upper Carboniferous to Permian deposits of Mount Krone (Carboniferous), Auernig (Carboniferous), Trogkofel (Permian) and Gartnerkofel (P/T boundary).

Post-Variscan sequence in the Nassfeld area

Upper Carboniferous

At Nassfeld, the basal units of the post-Variscan sequence are represented by the Collendiaul Formation (SCHÖNLAUB & FORKE, 2005), Malinfier Formation (VENTURINI, 1982) and the Auernig Breccia (SCHÖNLAUB & FORKE, 2005) resting unconformably upon the Hochwipfel Formation (Tournaisian–Visean). These deposits are composed of breccia and conglomerate horizons (max. 30 m in thickness). The upper part is marked by coarse clastic layers which are intercalated by silty and sandy shale. Based on conodonts (*Idiognathodus* sp. cf. *I. expansus* and *Swadelina*? sp. cf. *S. makhlinae*) and foraminiferans like *Fusulina* (*Quasifusulinoides)* sp., obtained from the uppermost part of the Auernig Breccia, an early Kasimovian age is proposed (SCHÖNLAUB & FORKE, 2007).

The overlying Auernig Formation (FRECH, 1894; KRAINER, 1992) is characterized by quartz conglomerates, cross-bedded sandstones, bioturbated siltstones, and bedded, massive or nodular limestones comprising a total thickness of about 600 to 800 m. A summary on further subdivision into six distinctive members (“Meledis” Mb, “Pizzul” Mb, Watschig Mb, Corona Mb, Gugga Mb and Carnizza Mb) is provided by FORKE et al. (2006) and SCHÖNLAUB & FORKE (2007). The fossil content of this unit is highly diverse and includes calcareous algae, foraminiferans (e.g., fusulinids), coralline sponges, gastropods, ostracods, brachiopods, bryozoans, echinoderms, conodonts and plants (e.g., DAVYDOV & KRAINER, 1999; FOHRER, 1991; FORKE & SAMANKASSOU, 2000). The age of the formation is based on different fossils groups and refers to the Kasimovian–Gzhelian (KRAINER & DAVYDOV, 1998; DAVYDOV & KRAINER, 1999; FORKE, 2007; FORKE & SAMANKASSOU, 2000; GAURI, 1965; KAHLER, 1983a, b, 1986, 1992; for summary see SCHÖNLAUB & FORKE, 2007).

Fig. 3: Panoramic view of Mount Krone (= *ital.* Mt. Corona); upper right corner: outcrop of plant-rich deposits.

At Mount Krone (type locality of the Corona Member; Fig. 3) and Mount Garnitzen (type locality of the Carnizza Member), less well bedded to massive limestone horizons consisting mainly of dasycladacean-boundstones reach a thickness of up to 22 m (*Anthracoporella* mounds; KRAINER, 1992 and SAMANKASSOU, 1998). These are alternating with realtively thick siliciclastic deposits of which especially the silt to fine grained sandstones near the middle part of the Mount Krone section (approx. 1730 m altitude) are rich in plants (Fig. 4). Since the first plant fossils were collected by HÖFER from and around Mount Krone in 1869 (FRITZ & BOERSMA, 1982), about 93 different taxa are described from more than 40 localities of this area (FRITZ et al., 1990; FRITZ & KRAINER, 2006, 2007). Taxa of following groups occur: Equisetophyta, Lycophyta, Filicophyta, Pteridospermae, Pteridophylla and Cordaitospermae.

Fig. 4: (a)-(g) Plant fossils of the section at Mt. Krone. (a) *Annularia* sp. (b) *Aphlebia* sp. (c) ?*Pecopteris* sp. (d) ?*Callipteridium* sp. (e) ?*Odontopteris* sp. (f) right: *Annularia* sp. (g) undetermined plant remains, and (h) casts of crinoid stem plates and brachiopods.

Fig. 5: Panoramic view of Mount Garnitzen (= *ital.* Carnizza).

At the western and southern slopes of Mount Auernig (Fig. 5) conglomerate levels alternating with sandstones, shales and limestones can be found. A more prominent interval of limestone beds occur in the uppermost part of the section (Carnizza Mb) which is well-known as "bed s" (SCHELLWIEN, 1892). This limestone produced abundant and exceptionally well-preserved silicified fossils (Figs. 6-8). Comprehensive palaeontological studies on bed g (= bed 15 of GEYER, 1896, and bed 116 of SCHÖNLAUB & FORKE, 2007) and bed s (= bed 30 of GEYER, 1896, and bed 148 of SCHÖNLAUB & FORKE, 2007) of the Auernig Formation at the Garnitzen and Auernig sections have been done for the i.e., fusulinids, ostracods, algae and bryozoans (SCHELLWIEN, 1898; FOHRER, 1991; LEPPIG et al., 2005). Additional fossil material of contemporaneous beds has been collected from the area around Lake Zollner and limestone hills in southeastern direction (DAVYDOV & KRAINER, 1999; FORKE & SAMANKASSOU, 2000) including foraminiferans (e.g., *Staffella*, *Schubertella*, *Fusiella*, *Protriticites*, *Quasifusulinoides*, *Beedeina*, *Fusulinilla*, *Montiparus* and *Praeobsoletes*), algae (e.g., *Herakella* sp., *Archaeolithophyllum* sp., *Euflugelia* sp.), coralline sponge (*Peronidella*), *Tubiphytes* and conodonts (e.g., *Hindeodus minutus*, *Idiognathodus* sp. cf. *I. expansus* and *Streptognathodus neverovensis*).

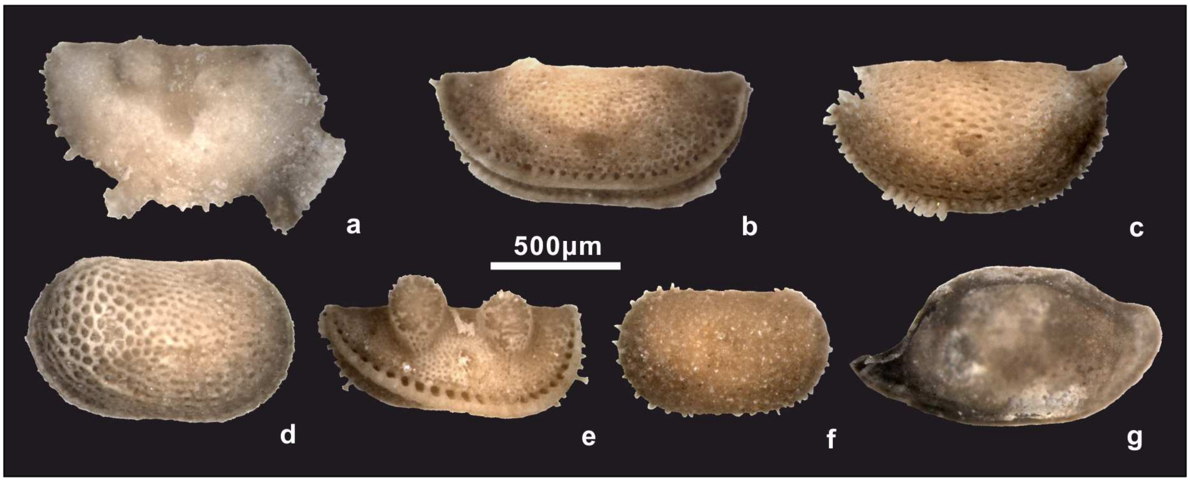


Fig. 6: Silicified ostracods of "bed s". (a) *Gortanella* sp. (b) *Aurikirkbya* sp. (c) *Coronakirkbya* sp. (d) *Shleesha* sp. (e) *Kellettina* sp. (f) *Roundyella* sp. (g) *Bairdia* sp.

Fig. 7: Silicified foraminiferans of “bed s”. (a) *Palaeotextularia* sp. (b) *Climacammina* sp. (c) *Cribrogeneria* sp. (d)-(e) *Deckerella* sp. (f) encrusting specimen of *Calcitornella*, right specimen 250 µm. (g)-(i) *Tetrataxis* sp. (j) *Bradyina* sp. (k) cross-section of a fusulinid specimen.

The overlying Schulterkofel Formation (type locality: Mount Schulterkofel) is ca. 140 m in thickness and consists of bedded and massive limestones with subordinate siliciclastic rocks such as siltstone and fine-grained sandstone (KRAINER, 1995; SCHÖNLAUB & FORKE, 2007). Fossils occur in calcareous sandstones to sandy limestone horizons. The fauna consists mainly of foraminiferans, echinoderms, brachiopods and gastropods. Massive limestones are represented by *Anthracoporella* mounds (thickness: 2 - 3 m; max. 20 m), of which a mound and intermound facies can be discriminated (SAMANKASSOU, 1998, 1999). Based on the biostratigraphical study of fusulinids (*communis* to *versabilis* zones) the formation is Gzhelian in age (e.g. FORKE et al., 1998; KRAINER & DAVYDOV, 1998).

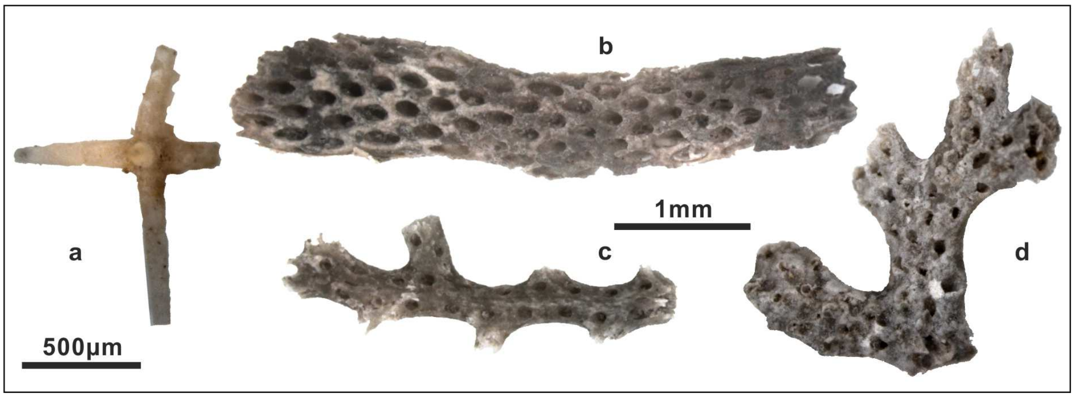


Fig. 8: Silicified fossils of “bed s”. (a) sponge spiculae. (b)-(d) bryozoans.

Depositional environments and cyclic patterns of the Auernig and Schulterkofel formations

The sedimentation of the post-Variscan sequence of the Pramollo Basin is related to marine transgressive and regressive cycles which conform to single cyclothems of about 10 to 40 m in thickness (VENTURINI, 1990; KRAINER, 1992; SCHÖNLAUB & FORKE, 2007). That cyclicity is recognized in field by repetitive alternations of marine carbonates (Fig. 9; fossil content: fusulinids, algae, ostracodes, bryozoans, and brachiopods) and siliciclastic deposits bearing fossil mega-plants. The specific depositional pattern of the Auernig Formation has been intensively studied by e.g., FRECH (1894), GEYER (1896), HERITSCH et al. (1934), KAHLER (1955), BUTTERSACK & BOECKELMANN (1984), MASSARI & VENTURINI (1990), MASSARI et al. (1991), VENTURINI (1990), KRAINER (1991, 1992), SAMANKASSOU (1997a, b, 2002) and SCHÖNLAUB & FORKE (2007).

VENTURINI (1990) proposed that the close cyclicity developed in the Auernig deposits, which reflects sudden sea level fluctuations, is due to glacio-eustatic control with tectonic interferences. Accordingly he suggested that the Upper Carboniferous of “Auernig Group” (redefined as Auernig Formation by SCHÖNLAUB & FORKE, 2007) could be subdivided into two sets based on the sedimentation rate: A_1 - A_{2pp} (Kasimovian to lower Gzhelian) and A_{2pp} – A_3 – A_4 – A_5 (upper Gzhelian). Whereas the former set, indicates evidence of partial or generalized uplifts inside the Pramollo Basin, the latter one, conforms to lowering of large areas in the basin.

A similar cyclic pattern is documented from the overlying Schulterkofel Formation (HOMANN, 1969; SAMANKASSOU, 1997a, 1999). Here, four cyclothems which are related to sea level rise and fall are recognized within the *bosbytauensis-robusta* fusulinid zones. According to HOMANN (1969) and SAMANKASSOU (1997a), each of the cycles starts with siliciclastic deposition that grades into bedded and massive algal limestones.

Based on the palaeoenvironmental preferences of the distinctive association of heterozoan and photozoan communities within the Auernig cyclothems, temporary coastal upwelling is suggested for the Nassfeld area which was located in humid, tropical realms of the low latitudes during the Late Carboniferous (SAMANKASSOU, 2002).

Fig. 9: (a) Limestone interval within the Auernig Fm cropping out at the top of Mount Garnitzen. (b) in situ calcareous algae. (c) silicified fusulinids.

Permian

The Carboniferous Schulterkofel Formation is succeeded by the Grenzland Formation which is considered to be Permian in age, but due to uncertain correlation with the fusulinids biostratigraphy the position of the Carboniferous/Permian boundary remains unclear (e.g., KAHLER, 1983a, b: KAHLER & KRAINER, 1993; FORKE, 1995; FORKE et al., 1998; KRAINER & DAVYDOV, 1998; SCHÖNLAUB & FORKE, 2007). Although the contact with underlying and/or overlying strata is observed in the section of the Schulterkofel (FORKE et al., 1998; FORKE, 2000), at the Rudnigalm (FORKE, 2002), the Trogkar (FORKE, 2002) and at the Zweikofel (KRAINER, unpublished; SCHÖNLAUB & FORKE, 2007), the entire thickness of the formation is not known (estimated thickness is ca. 120 m; SCHÖNLAUB & FORKE, 2007). The formation is mainly composed of beds of clastic rocks such as conglomerate, sandstone and siltstone. Limestone beds are intercalated within the above mentioned beds, which consist of oncoidal limestones that yield foraminiferans (fusulinids), bioclastic limestones with a diversified fossil fauna and red limestone. The calcareous sandstone beds are observed in the transition to the limestone beds, and are characterized by brecciation on the top of the beds in which red matrix fills the space between brecciated components. Siltstone beds are commonly bioturbated. Sediments that indicate subaerial exposure of the deposits (recognized by the formation of palaeosols, fracture fillings, and collapse breccias) are outcropping in the section at the Zweikofel (Fig. 10). Within the sequence slumping, convolute bedding and load casts as well as ichnofossils are observed (SCHÖNLAUB & FORKE, 2007). The Grenzland Formation yields fusulinids like *Sphaeroschwagerina carniolica* and *Pseudoschwagerina extense* which are indicating a lower? to middle Asselian age. Additionally other fusulinids such as *Zellia*, *Robustoschwagerina* and species that belong to the *Paraschwagerina nitida* group are observed (FORKE, 2002).

The late Sakmarian to early Artinskian of the Zweikofel Formation is characterized by oncoidal and foraminiferal – algal limestones and siliciclastic deposits (conglomerate and sandstone). The thickness of the formation at the Zweikofel (type section) is 135 m (SCHÖNLAUB & FORKE, 2007). The fossil content of the Zweikofel Formation includes fusulinids such as *Zellia heritschi*, *Robustoschwagerina geyeri*, *Paraschwagerina nitida*, *Pseudofusulina* sp., *Pseudofusulinoides* sp. and conodonts like *Sweetognathus* sp. aff. *S. whitei*, *Mesogondolella bisselli* and species of *Diplognathodus* (FORKE, 2000; SCHÖNLAUB & FORKE, 2007).

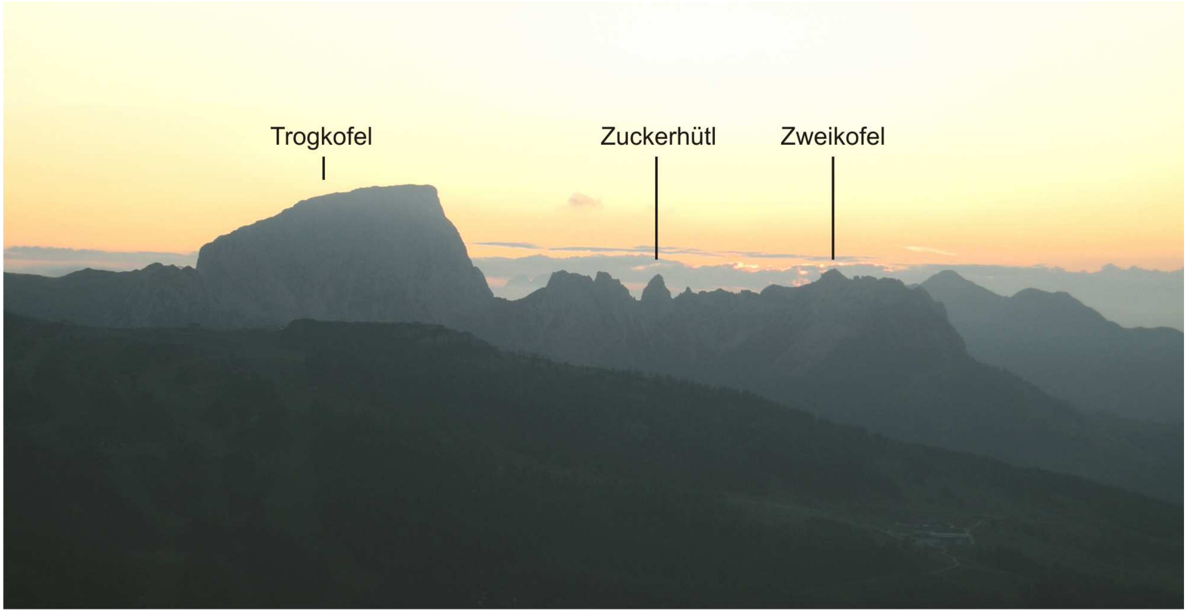


Fig. 10: Panoramic view of Mount Trogkofel and Zweikofel.

The Trogkofel Limestone is composed of mainly massive limestone which is partly reddish in color. In the section also shale beds and limestone breccia layers occur (SCHÖNLAUB & FORKE, 2007). The limestones are often dolomitized. According to VENTURINI (1990) the thickness is at maximum 400 m and decreases towards southeast. The formation is cropping out at the Trogkofel (Fig. 10) and the Reppwand. Within the massive limestone, *Archaeolithoporella* (encrusting algae) and *Tubiphytes* (microploblematica) which play role for cementation constructing boundstone, as well as bryozoans and echinoderms are observed (VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007). Additionally, wacke- and grainstones are observed in the unit (FORKE, 2000). Foraminiferans are low in diversity and occur in dasycladacean wack- and grainstones. The age of the Trogkofel Limestone is the late Artinskian which is based on the co-occurrence of the conodont *Neostreptognathodus* sp. cf. *N. pequopensis* and the fusulinid taxon *Robustoschwagerina spatopsa* (FORKE, 2000).

The Gröden Formation is unconformably overlain by metamorphic rocks and Late Palaeozoic marine deposits which are exposed north and south of the Periadriatic Lineament (SCHÖNLAUB & FORKE, 2007). The formation consists of breccia levels and conglomerates at the base, followed by the pelites which are red and partly greenish-grey in color. The deposits at the base of the Gröden Formation are assigned to the Tarvis Breccia when these cover the Auernig Formation and to the Trogkofel Conglomerate when deposits are accumulated on the Trogkofel Limestone (revised assignment follows SCHÖNLAUB & FORKE, 2007). The lithological features between the Tarvis Breccia and the Trogkofel Conglomerate differ. In the Straniger area, the Tarvis Breccia (thickness ca. 10 m) is composed of massive dolomite, rauwacke and red siltstones, whereas the Trogkofel Conglomerate consists of limestone pebbles which derived from the Trogkofel Limestone and from siliciclastic deposits. The beds composed of the pelites within the remaining part of the formation include alternating series of dolomitic shales and siltstones which are intercalated by nodular dolomitic marls or dolomites. The thickness of the Gröden Formation is approximately 60 m. The unit contents plant debris, stromatolithic algae, foraminiferans, ostracods, and gastropods (KAHLER & PREY, 1963; BUGGISCH, 1978).

As a high resolution biostratigraphy could not be established yet, the age of this unit is constrained to the interval from Guadalupian to Lopingian by the underlying Trogkofel Formation and the overlying *Bellerophon* Formation (SCHÖNLAUB & FORKE, 2007).

The Late Permian *Bellerophon* Formation is composed of dolomite, dolomitic marl and rauwacke in the lower part and platy to coarse bedded dolomitic limestones in upper part (SCHÖNLAUB & FORKE, 2007). The thickness is about 175 m. Within deposits of this unit small sized foraminiferans, dasycladacean, algae, ostracods, and radiolarians are found. The age of the formation is dated by foraminiferans belonging to the genus of *Paraglobivalvulina* and *Paradagmarita* (BOECKELMANN, 1988).

Depositional environments and cyclic patterns of Permian units

It is assumed that the Grenzland Formation (= *ital. syn.* Val Dolce Formation) was deposited at high-energy nearshore settings (FLÜGEL, 1975). Continued from the underlying Schulterkofel Formation, the unit remains a cyclic sedimentation. The individual cycles which are up to 10 m in thickness are characterized by siliciclastic deposits (conglomerates and sandstone at the base), covered by calcareous clastic beds which finally are overlain by oncoidal limestones.

Compared to the Grenzland Formation, the Zweikofel Formation comprises well developed limestones whereas siliciclastic input is reduced. In the Zweikofel, Zottachkopf and Trogkar areas, ooid barriers, oncoid limestone, and small mounds have been observed respectively. Based on facies analysis of the formation, these sediments are interpreted as deposits that accumulated on a carbonate platform under high energy to subtidal environments (SCHÖNLAUB & FORKE, 2007). In the formation, cyclic patterns show lateral variations. It is considered that they reflect morphological feature in the deposition at the shelf and sea-bottom as well as high-frequent sea-level fluctuations during the Sakmarian to Artinskian (SAMANKASSOU, 1997a).

The Trogkofel Limestone is characterized by massive limestone yielding algae and fusulinids and limestone breccia levels. Based on the lithological character of the unit a depositional environment on the shelf margin, platform and slope is assumed (VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007). The stratigraphically younger Gröden Formation shows a disconformable contact with the Trogkofel Limestone and the Auernig Formation. It is not clear yet whether the Gröden Formation was deposited under marine or continental conditions. Following BUGGISCH (1978), it is considered that the formation represents marine deposits based on fossils and the geochemical signal. The sediments of the *Bellerophon* Formation are interpreted as shelf environment with shallow water conditions that mostly referred to the open sea (VENTURINI, 1990).

Permian–Triassic boundary

In the Carnic Alps, the Permian/Triassic boundary can be observed in the surroundings of Nassfeld area. It is well documented from the drilling core in the Gartnerkofel region (Fig. 11) and the sequence exposed at the western Reppwand cliff. The scientific drilling was performed within an international project in 1986 at the Kammleiten peak (see publications in HOLSER & SCHÖNLAUB, 1991).

Fig. 11: Panoramic view of Mount Gartnerkofel.

At Kammleiten (summit height: 1998 m), a core of 331 m length was drilled with the position of the P/T boundary at the depth of 225 m. According to SCHÖNLAUB & FORKE (2007: p. 137) no sedimentary gap between the Permian and Triassic beds is found. The sediments across the boundary consist of dolomites which belong to the Permian *Bellerophon* Formation and also to the Triassic Werfen Formation. Although the dolomites show similar lithological character on both side of the boundary, the Permian and Triassic beds are distinguished by its fossil content and the distribution of quartz. In the outcrop section at the western Reppwand cliff, the P/T boundary is located between the *Bellerophon* and Werfen formations and is documented by the first occurrence of *Hindeodus parvus* in the Tesero Horizon of the Werfen Formation (SCHÖNLAUB, 1991).

Acknowledgements: This paper is a contribution to IGCP projects no. 580 (*Application of Magnetic Susceptibility on Palaeozoic sedimentary rocks*) and 596 (*Climate change and biodiversity patterns in the Mid–Palaeozoic*).

References

BOECKELMANN, K. (1988): Die Werfener Schichten in den Karnischen Alpen und westlichen Karawanken (Osterreich und Italien). Unveröff. Diss.: 213 pp., Rheinisch-Westfälische Technische Hochschule Aachen.

BUGGISCH, W. (1978): Die Grödener Schichten (Perm, Südalpen). Sedimentologische und geochemische Untersuchungen zur Unterscheidung mariner und kontinentaler Sedimente. Geologische Rundschau, 67: 149-180.

BUTTERSACK, E. & BOECKELMANN, K. (1984): Palaeoenvironmental evolution during the Upper Carboniferous and the Permian in the Schulter-Trogkofel area (Carnic Alps, Northern Italy). Jahrbuch der Geologischen Bundesanstalt, 126/3: 349-358.

DAVYDOV, V.I. & KRAINER, K. (1999): Fusulinid assemblages and facies of the Bombaso-Formation and basal Meledis-Formation (Moscovian–Kasimovian) in the Central Carnic Alps (Austria/Italy). Facies, 40: 157-196.

FLÜGEL, E. (1975): Fazies-Interpretation der unterpermischen Sedimente in den Karnischen Alpen. Carinthia II, 84: 43-62.

FOHRER, B. (1991): Verkieselte Flachwasserostracoden und ihre Begleitfauna und -flora aus dem Oberkarbon der Karnischen Alpen (Nassfeld-Region). Abhandlungen der Geologischen Bundesanstalt, 46: 1-107.

FORKE, H.C. (1995): The Carboniferous/Permian boundary in the Carnic Alps (Austria): Additional observations on correlating fusulinid zones in the Southern Urals and the Darvaz region with the Schulterkofel section. Permophiles, 26: 13-16.

FORKE, H.C. (2000): Late Paleozoic fusulinaceans from the Carnic Alps. 199-204. In: PILLER, W. et al. (eds), Palaeontological Highlights of Austria. *Mitteilungen* der *Österreichischen Geologischen Gesellschaft*, 92 (1999).

FORKE, H.C. (2002): Biostratigraphic subdivision and correlation of Uppermost Carboniferous/Lower Permian sediments in the Southern Alps: Fusulinoidean and conodont faunas from the Carnic Alps (Austria/Italy), Karavanke Mountains (Slovenia), and Southern Urals (Russia). Facies, 47: 201-276.

FORKE, H.C. (2007): Taxonomy, systematics, and stratigraphic significance of fusulinoidean holotypes from Upper Carboniferous sediments (Auernig Group) of the Carnic Alps (Austria, Italy). 259-268. In: WONG, Th.E. (ed.), Proceedings of the XVth International Congress on Carboniferous and Permian Stratigraphy, Utrecht, 10-16th August 2003. Royal Dutch Academy of Arts and Sciences (Amsterdam), Utrecht.

FORKE, H.C., KAHLER, F. & KRAINER, K. (1998): Sedimentology, Microfacies and Stratigraphic Distribution of Foraminifers of the Lower *Pseudoschwagerina* Limestone (Rattendorf Group, Late Carboniferous), Carnic Alps (Austria/Italy). Senckenbergiana lethaea, 78 (1/2): 1-39.

FORKE, H.C. & SAMANKASSOU, E. (2000): Biostratigraphical correlation of Late Carboniferous (Kasimovian) sections in the Carnic Alps (Austria/Italy): Integrated paleontological data, facies, and discussion. Facies, 42: 177-210.

FORKE, H.C., SCHÖNLAUB, H.P. & SAMANKASSOU, E. (2006): Late Paleozoic of the Carnic Alps (Austria/Italy), Field Trip of the SCCS Task Group to establish GSSP's close to the Moscovian/Kasimovian and Kasimovian/Gzhelian boundaries, 31st July - 1st August 2006. Berichte der Geologischen Bundesanstalt, 70: 57 pp.

FRECH, F. (1894): Die Karnischen Alpen. Ein Beitrag zur vergleichenden Gebirgstektonik. *Der Abhandlungen* der Naturforschenden *Gesellschaft zu Halle,* 18: 1-514.

FRITZ, A. & BOERSMA, M. (1982): Revision pflanzlicher Großreste aus dem Oberkarbon der Karnischen Alpen: Sammlung HÖFER 1869. Carinthia II, 172/92: 109-152.

FRITZ, A., BOERSMA, M. & KRAINER, K. (1990): Steinkohlenzeitliche Pflanzenfossilien aus Kärnten. Sonderheft der Carinthia II 49: 108 pp.

FRITZ, A. & KRAINER, K. (2006): Vegetationsgeschichtliche und florenstratigraphische Untersuchungen im Oberkarbon und Unterperm der Ost- und Südalpen (Teil 1). Carinthia II, 196/116: 93-120.

FRITZ, A. & KRAINER, K. (2007): Vegetationsgeschichtliche und florenstratigraphische Untersuchungen im Oberkarbon und Unterperm der Ost- und Südalpen (Teil 2). Carinthia II, 197/117: 91-148.

GAURI, K.L. (1965): Uralian stratigraphy, Trilobites and Brachiopods of the Western Carnic Alps (Austria). Jahrbuch der Geologische Bundesanstalt, Sonderband 11: 1-94.

GEYER, G. (1896): Über die geologischen Verhältnisse im Pontafeler Abschnitt der Karnischen Alpen. *Jahrbuch* der kaiserlich-königlichen Geologischen Reichsanstalt, 46: 127-233.

HERITSCH, F. (1934): Die Stratigraphie von Oberkarbon und Perm in den Karnischen Alpen. Mitteilungen der Geologischen Gesellschaft in Wien, 26 (1933): 162-189.

HOLSER, W.T. & SCHÖNLAUB, H.P. (eds) (1991): The Permian–Triassic boundary in the Carnic Alps of Austria (Gartnerkofel region). Abhandlungen der Geologischen Bundesanstalt, 45: 1-232.

HOMANN, W. (1969): Fazielle Gliederung der Unteren Pseudoschwagerinenkalke (Unter-Perm) der Karnischen Alpen. Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, 1969 (5): 265-280.

KAHLER, F. (1955): Entwicklungsraume und Wanderwege der Fusulinen im Eurasiatischen Kontinent. Geologie, 4: 179-188.

KAHLER, F. (1983a): Fusuliniden aus Karbon und Perm der Karnischen Alpen und der Karawanken. Carinthia II, Sonderheft 41, 107 pp., Klagenfurt.

KAHLER, F. (1983b): Ein denkbares Standardprofil für die Grenze Oberkarbon/Unterperm im marinen Bereich. Anzeiger der Österreichischen Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Klasse, 1983: 45-46.

KAHLER, F. (1986): Eine neue Fusuliniden-Gemeinschaft in tiefen Oberkarbon-Schichten der Karnischen Alpen. Carinthia II, 96: 425-441.

KAHLER, F. (1992): Beziehungen der Karnischen Alpen zur Paläotethys. *Mitteilungen* der *Österreichischen Geologischen Gesellschaft*, 84: 309-326.

KAHLER, F. & PREY, S. (1963): Erläuterungen zur geologischen Karte des Gartnerkofel Gebietes in den Karnischen Alpen. Geologische Bundesanstalt, 116 pp., Wien.

KAHLER, F. & KRAINER, K. (1993): The Schulterkofel Section in the Carnic Alps, Austria: Implications for the Carboniferous–Permian Boundary. Facies, 28: 257-276.

KRAINER, K. (1990): 3rd excursion day: The limestone facies of the A_4 and A_5 Formation (Auernig Group). 76-80. In: Field Workshop on Carboniferous to Permian Sequence of the Pramollo-Nassfeld Basin (Carnic Alps), 2-8th September 1990. Guidebook, Uni. Bologna, Bologna.

KRAINER, K. (1991): The limestone facies of the Auernig and Carnizza Formations (Auernig Group, Pontebba Supergroup, Carnic Alps). Giornale di Geologia, 3a, 53: 161-169.

KRAINER, K. (1992): Fazies, Sedimentationsprozesse und Paläogeographie im Karbon der Ost- und Südalpen. Jahrbuch der Geologischen Bundesanstalt, 135/1: 99-193.

KRAINER, K. (1995): Anthracoporella Mounds in the Late Carboniferous Auernig Group, Carnic Alps (Austria). Facies, 33: 195-214.

KRAINER, K. & DAVYDOV, V.I. (1998): Facies and biostratigraphy of the Late Carboniferous/Early Permian sedimentary sequence in the Carnic Alps (Austria/Italy). 643-662. In: CRASQUIN-SOLEAU, S., IZART, D., & DE WEVER, P. (eds), Peri-Tethys: stratigraphic correlation 2, Geodiversitas, 20 (4).

LÄUFER, A., LOESCHKE, J. & VIANDEN, B. (1993): Die Dimon-Serie der Karnischen Alpen (Italien) - Stratigraphie, Petrographie und geodynamische Interpretation. Jahrbuch der Geologischen Bundesanstalt, 136: 137-162.

LEPPIG, U., FORKE, H.C., MONTENARI, M. & FOHRER, B. (2005): A three- and two dimensional documentation of structural elements in schwagerinids (superfamily Fusulinoidea) exemplified by silicified material from the Upper Carboniferous of the Carnic Alps (Austria/Italy): a comparison with verbeekinoideans and alveolinids. Facies, 51: 541-553.

MASSARI, F., PESAVENTO, M. & VENTURINI, C. (1991): The Permian- Carboniferous cyclothems of the Pramollo Basin sequence (Carnic Alps). Giornale di Geologia, 3a, 53/1: 171-185.

MASSARI, F. & VENTURINI, C. (1990): The significance of the Auernig Group cyclicity. 81-86. In: VENTURINI, C. (ed.), Field Workshop on Carboniferous to Permian sequence of the Pramollo-Nasfeld Basin (Carnic Alps), Bologna.

PILLER, W.E., EGGER, H., ERHART, C.W., GROSS, M., HARZHAUSER, M., HUBMANN, B., VAN HUSEN, D., KRENMAYR, H.-G., KRYSTYN, L., LEIN, R., LUKENEDER, A., MANDL, G.W., RÖGL, F., ROETZEL, R., RUPP, C., SCHNABEL, W., SCHÖNLAUB, H. P., SUMMESBERGER, H., WAGREICH, M. & WESSELY, G. (2004): Die stratigraphische Tabelle von Österreich 2004 (sedimentäre Schichtfolgen). Österreichische Stratigraphische Kommission.

SAMANKASSOU, E. (1997a): Muster und Kontrollfaktoren der zyklischen Sedimentation im Jungpaläozoikum (Oberkarbon–Unterperm) der Karnischen Alpen, Österreich: Eine integrierte Untersuchung. Dissertation der *Naturwissenschaftlichen Fakultäten* der *Friedrich-Alexander-Universität* Erlangen: 397 pp.

SAMANKASSOU, E. (1997b): Paleontological response to sea-level change: Distribution of fauna and flora in cyclothems from the Lower Pseudoschwagerina Limestone (Latest Carboniferous, Carnic Alps, Austria. Geobios, 30 (6): 785-796.

SAMANKASSOU, E. (1998): Skeletal framework mounds of dasycladalean alga *Anthracoporella*, Upper Paleozoic, Carnic Alps, Austria. Palaios, 13: 297-300.

SAMANKASSOU, E. (1999): Drowning of algal mounds: records from the Upper Carboniferous Lower Pseudoschwagerina Limestone, Carnic Alps, Austria. Sedimentary Geology, 127: 209-220.

SAMANKASSOU, E. (2002): Cool-water carbonates in a paleoequatorial shallow-water environment: The paradox of the Auernig cyclic sediments (Upper Pennsylvanian, Carnic Alps, Austria - Italy) and its implications. Geology, 30 (7): 655-658.

SCHELLWIEN, E. (1892): Die Fauna des karnischen Fusulinidenkalks. Teil I. Palaeontographica, 39, 56, Stuttgart.

SCHELLWIEN, E. (1898): Die Fauna des karnischen Fusulinidenkalks. Teil II. Palaeontographica, 44, 237-282, Stuttgart.

SCHÖNLAUB, H.P. (1991): The Permian-Triassic of the Gartnerkofel - 1 Core (Carnic Alps, Austria): Conodont Biostratigraphy. 79-98. In: HOLSER, W.T. & SCHÖNLAUB, H.P. (eds), The Permian-Triassic Boundary in the Carnic Alps of Austria (Gartnerkofel Region). Abhandlungen der Geologischen Bundesanstalt, 45, Wien.

SCHÖNLAUB, H.P. & FORKE, H. (eds) (2005): Das Jungpaläozoikum der Karnischen Alpen und das Karbon von Nötsch. 75 *Jahrestagung* der Österreichischen Paläontologischen Gesellschaft, Graz, 27 August – 02 September 2005: 48 pp.

SCHÖNLAUB, H.P. & FORKE, H.C. (2007), Die post-variszische Schichtfolge der Karnischen Alpen – Erläuterungen zur Geologischen Karte des Jungpaläozoikums der Karnischen Alpen 1:12500. 3-157. In: SCHÖNLAUB, H.P., FORKE, H.C., LOTTER, M. & MOSER, M. (eds), Geologische Karte 1:12500 Des Jungpaläozoikums der Karnischen Alpen Erläuternde Texte. Abhandlungen der geologischen Bundesanstalt, Band 61, Wien.

VENTURINI, C. (1982): Il bacino tardoercinico di Pramollo (Alpi Carniche): un evoluzione regolata dalla tettonica sinsedimentaria. Memorie della Societa Geologica Italiana, 24: 23-42.

VENTURINI, C. (1983): Il bacino tardo-ercinico di Pramollo (Alpi Carniche): una evoluzione regolata dalla tettonica sinsedeimentaria. *Memorie della Società Geologica Italiana*, 24: 23-42.

VENTURINI, C. ed. (1990): Field Workshop on Carboniferous to Permian Sequence of the Pramollo-Nassfeld Basin (Carnic Alps). 2-8th September 1990, Guidebook, Uni. Bologna, Bologna: 159 pp.

Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 17	Graz 2012
IGCP 580, 4th Annual Meeting	Graz, 24-30th June 2012		

Geology and stratigraphy of the Cason di Lanza area (Mount Zermula, Carnic Alps, Italy)

CORRADINI, C.[1], PONDRELLI, M.[2], CORRIGA, M.G.[1], SIMONETTO, L.[3], KIDO, E.[4], SUTTNER, T.J.[4], SPALLETTA, C.[5] & CARTA, N.[6]

(1) Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari, Italy; *corradin@unica.it*, *maria.corriga@unica.it*
(2) International Research School of Planetary Sciences, Dipartimento di Scienze, Università d'Annunzio, viale Pindaro 42, I-65127 Pescara, Italy; *monica@irsps.unich.it*
(3) Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; *luca.simonetto@comune.udine.it*
(4) Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; *erika.kido@uni-graz.at*, *thomas.suttner@uni-graz*
(5) Dipartimento di Scienze della Terra e Geologico Ambientali, Alma Mater Studiorum Università di Bologna, via Zamboni 67, I-40126 Bologna, Italy; *claudia.spalletta@unibo.it*
(6) via Emilio Lussu 21, I-09040 Settimo S. Pietro (CA); *nicola.carta1@virgilio.it*

Abstract: *In the Cason di Lanza-Mt. Zermula area rocks from Ordovician to Permian are exposed. They belong to the "Variscan sequence" and to the "Permo–Carboniferous sequence" of the Carnic Alps. The structural settings and the stratigraphic sequence of neritic and pelagic deposits are described.*

Introduction

Cason di Lanza Pass is located in the heart of the Carnic Alps, along the mountain road connecting Paularo and Pontebba (Fig. 1). The Carnic Alps are one of the classic areas for the study of the Palaeozoic in Europe (BANDEL, 1972; SCHÖNLAUB, 1979, 1985; SELLI, 1963; VAI, 1976). This area represents the external non- to low-metamorphic portion of the Variscan substratum within the Southern Alps (VAI, 1976; SPALLETTA et al., 1982; BRIME et al., 1998).

Fig. 1: Location map and panoramic view of the Cason di Lanza Pass, taken from the top of Mt. Pizzul. In front right the white cliffs of the Zuc della Guardia, constituted by Devonian reefal carbonates. In the northern side of the valley, behind the hut, mainly Permo–Carboniferous rocks are exposed.

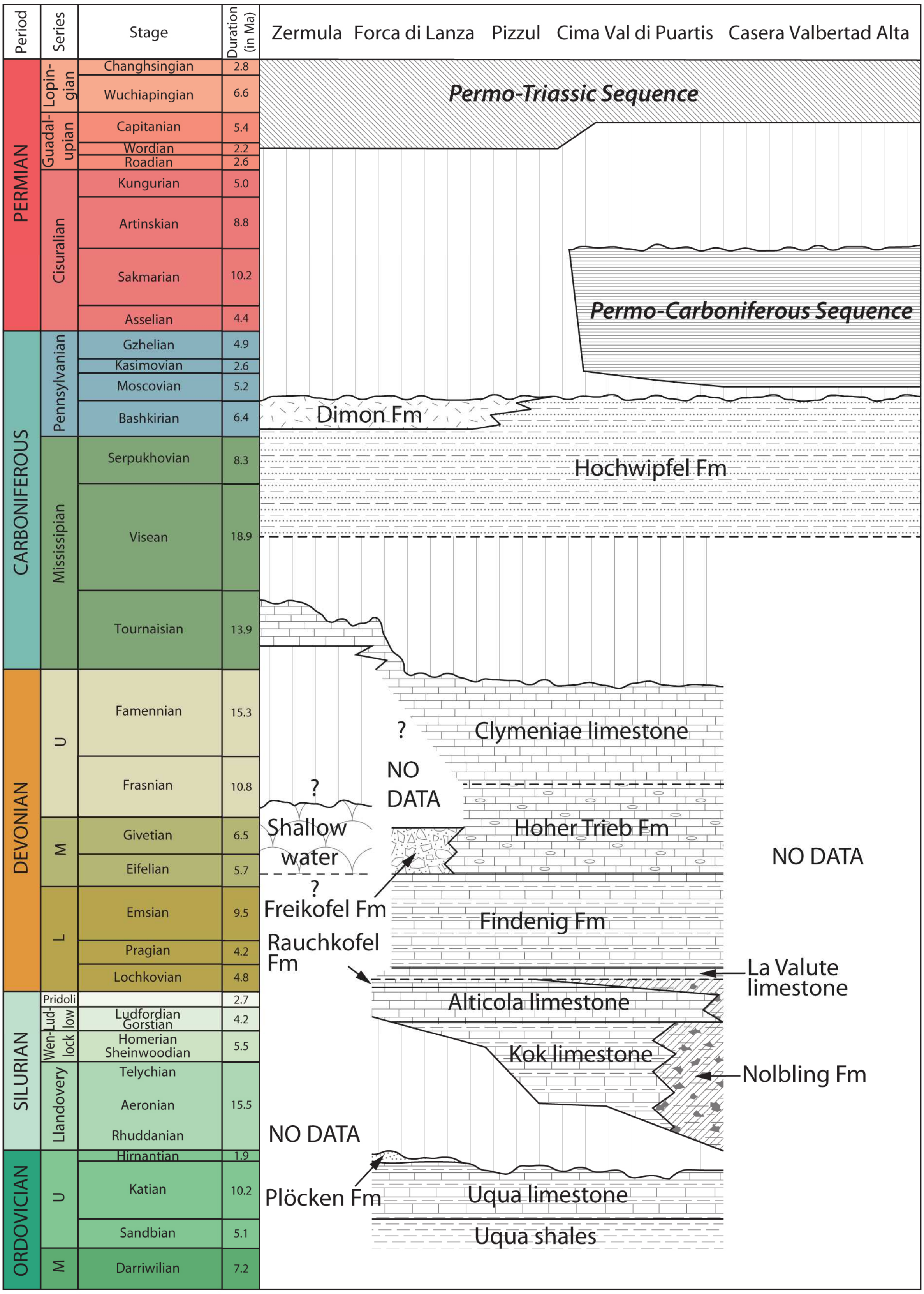


Fig. 2: Simplified stratigraphic sketch of the Cason di Lanza Pass area.

The succession of the Cason di Lanza Pass area ranges from Ordovician to Lower Permian: the Variscan and the Permo–Carboniferous sequences of the Carnic Palaeozoic are widely exposed in an area of a few square kilometers, with the lowermost part of the Permo–Triassic succession being locally exposed. The Variscan sequence includes rocks of Late Ordovician to Early Carboniferous age that were affected by the Variscan orogeny during the Westphalian (VENTURINI, 1990). The Permo–Carboniferous sequence is also known as 'late Hercynian' sequence (VENTURINI, 1990) and ranges from Early Carboniferous to Early Permian. The Permo–Triassic succession is part of the so-called 'Alpine' sequence (VENTURINI, 1990). In the study area only Upper Permian rocks are exposed. The present complex geological setting is due to the Alpine tectonics, both extensional and compresional phases, that involved the whole Carnic area, starting from the Cenozoic.

The morphology of the area conforms to a typical high mountain morphology, controlled by lithology (massive Middle Devonian limestone constituting the highest and sharpest edifices), tectonic, mass wasting and with a glacial imprint.

History of researches

The geology of Mt. Zermula and the Cason di Lanza area was studied since the second half of 19th century. For long time the main goal of scientist was the reconstruction of the stratigraphic sequence of the Carnic Alps, and the age of the calcareous mountain groups was debated on the basis of lithological similitude with the other mountains of the area and recovery of fossil remains from the underlying sediments. In this respect, the calcareous cliffs of Mt Zermula were considered either Carboniferous (i.e.: STUR, 1856; PIRONA, 1861; TARAMELLI, 1878, 1881, 1882; PANTANELLI, 1882), or Triassic (FRECH, 1894). Finally, TARAMELLI (1895), on the basis of the stratigraphy of the area, recognized the Devonian age of Mt. Zermula.

At the beginning of the 20th century the Palaeozoic sequence in the Cason di Lanza area was widely investigated by Michele Gortani and Paolo Vinassa de Regny, who considered the area as part of the "central core of the Carnic Alps", and published tens of papers on various geological and palaeontological topics. Among them, they described the stratigraphic sequence of the area (VINASSA DE REGNY & GORTANI, 1905a, 1908; GORTANI, 1913, 1915, 1920), discriminating for the first time the Silurian shales from the Carboniferous sediments, and published a geological map of the area (VINASSA DE REGNY & GORTANI, 1905a). Furthermore, they described several fossils from the area: various Ordovician groups (VINASSA DE REGNY, 1910) Silurian graptolites (VINASSA DE REGNY, 1907; GORTANI, 1920), Carboniferous plant remains (VINASSA DE REGNY & GORTANI, 1905b) and Permian invertebrates (VINASSA DE REGNY & GORTANI, 1905b).

After a gap of several years, the Cason di Lanza/Zermula area was investigated in the sixties within mapping projects (SELLI, 1963a), with special regards on the Permo–Carboniferous sequence (SELLI, 1963b). At the same time biostratigraphic researches on conodonts were carried out on different intervals of the Variscan sequence: Ordovician (MANZONI, 1965; SERPAGLI & GRECO, 1965; SERPAGLI, 1967) and Upper Devonian/Lower Carboniferous (MANZONI, 1965, 1966; FERRARI & VAI, 1966). Devonian corals were studied by FERRARI (1968).

More recently, the Permo–Carboniferous sequence cropping out north of Cason di Lanza was studied in detail by VENTURINI (1990a, 1990b). The age of the various calcareous units from Ordovician to Lower Carboniferous was studied by means of conodonts in several stratigraphic sections (i.e.: BAGNOLI et al., 1998; PERRI & SPALLETTA, 2001; KAISER, 2005; CORRIGA, 2011; CORRIGA et al., 2011). Finally, fossils belonging to different groups and ages were described: vertebrates (DALLA VECCHIA, 2000), loboliths (CORRADINI et al., 2005), graptolites (PIRAS & SIMONETTO, 2011), corals (KIDO et al., 2011b), and trace fossils (MIETTO et al., 1986).

Geological and structural settings

The Variscan sequence is largely laterally uniform across the Cason di Lanza Pass area with the exception of the Eifelian–Frasnian interval, when the basin was differentiated in a shallow water part, with the deposition of back reef and reef deposits, and a distal part, with pelagic deposits interlayered by gravity driven redeposited material coming from the shallow water units (Fig. 2). During the Westphalian, this sequence was affected by the Variscan orogeny, which in the Carnic Alps resulted in a non to low grade metamorphic thin-skinned fold-and-thrust belt with structures mainly N120°E trending (VENTURINI, 1990a; BRIME et al., 2008). In the Cason di Lanza Pass area a top to the south detachment led to the formation of a pluri-kilometric asymmetric NW-SE trending fold with an

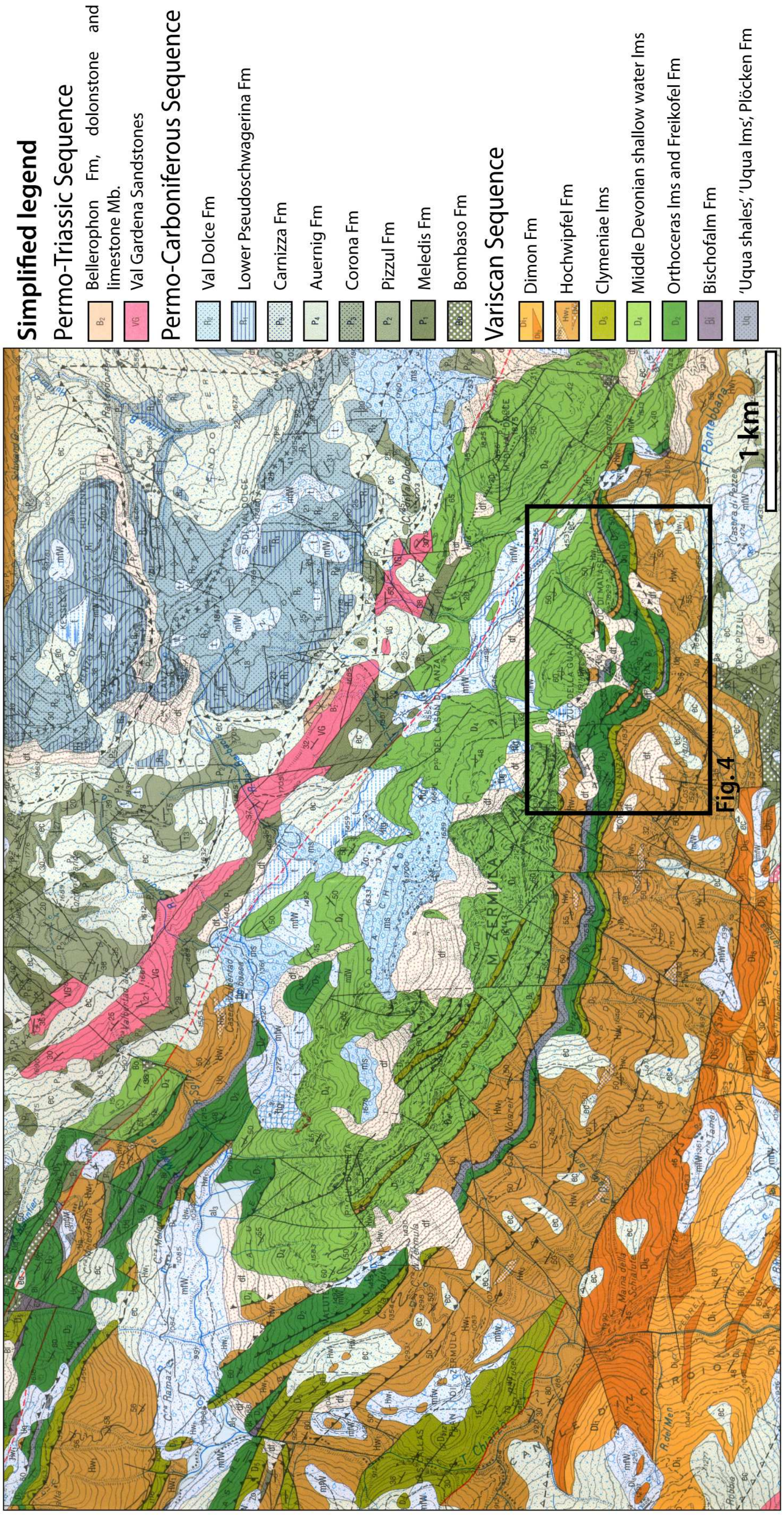


Fig. 3: Simplified geological map of the Cason di Lanza Pass area (after Venturini et al., 2001). See text for the description of the units. Light patterned yellow, blue and red represents Quaternary deposits. The box represents the location of the detailed geological map of Fig. 4.

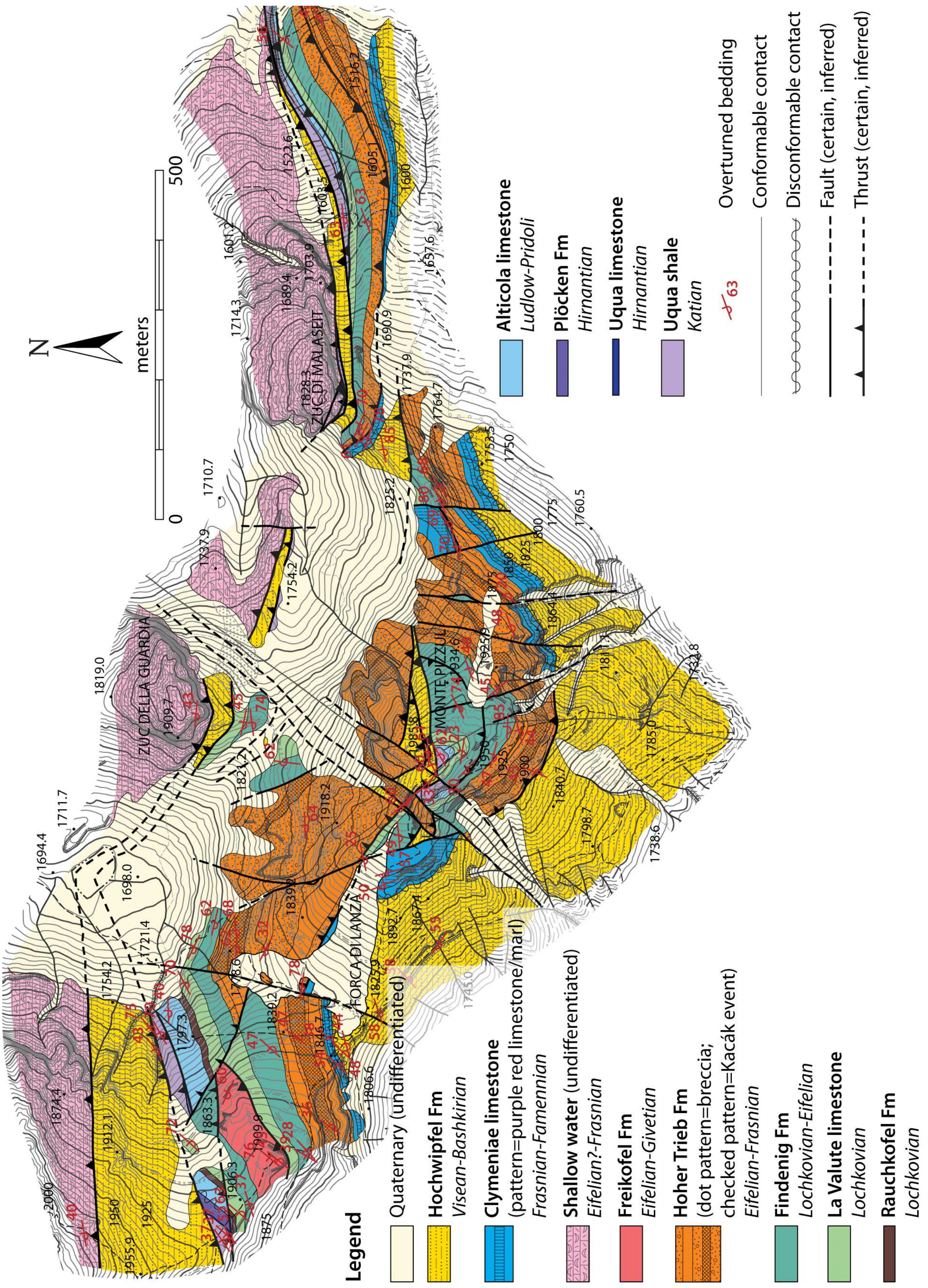


Fig. 4: Detailed geological map of the mount Pizzul area.

overturned flank which includes the Zermula and Pizzul mountains as well as the Malinfier gorge (VENTURINI, 1990a) (Fig. 3). Centrimetric to decametric large parasitic asymmetric folds are superimposed to the pluri-kilometric fold where lithological characters allow such ductile deformation.

The Variscan belt was then subjected to trastensional syn-sedimentary tectonic (VENTURINI, 1990a) which lead to the formation of the Forni Avoltri, Pramollo and Tarvisio basins. The Cason di Lanza area represents the westernmost portion of the Pramollo basin, the largest and better preserved one among these basins. The glacio-eustatic sea level fluctuations superimposed on the higher order tectonically driven subsidence controlled a succession characterized by intercalation of fluvio-deltaic and shallow sea deposition (VENTURINI, 1990a).

The Permo–Carboniferous sequence rests in angular unconformity on top of the Variscan substratum (Punta Cul di Creta, Fig. 3) but in general the contact with the Variscan substratum is of tectonic origin (Fig. 3). The basal part of the Permo–Triassic sequence is also exposed in the study area, resting in disconformity on top of the Permo–Carboniferous sequence in the Casera Valbertad alta area (Fig. 3).

The Carnic area were disrupted by at least three Alpine compressional phases (VENTURINI, 1990a; LÄUFER, 1996), which have been characterized using the stress tensor inversion method from fault striations (PONDRELLI, 1998). The oldest phase of Chattian–Burdigalian age, show a maximum compressional stress roughly coaxial with the Variscan compression in a compressive stress regime. This resulted in enhancing the shortening associated with the structures inherited from the Variscan orogeny (VENTURINI, 1990a; LÄUFER, 1996).

The second alpine phase, of Tortonian–Serravallian age, is characterized by a N-S trending maximum compressional stress, in a compressive stress regime (PONDRELLI, 1998), which resulted in E-W trending south-verging thrusts, NW-SE trending dextral strike-slip faults and NE-SW trending sinistral strike-slip faults. In the study area, E-W trending south verging thrusts lead the shallow water Middle Devonian units of the Mount Zermula, Zuc della Guardia and Zuc di Malaseit to overthrust on top of the Forca di Lanza - Mount Pizzul Upper Ordovician to Lower Carboniferous succession (Figs 3, 4, 5). This thrust tectonically obliterated most of the most proximal slope deposits (Freikofel Fm) which are preserved only in a single outcrop close to the Forca di Lanza (Fig. 4).

The third alpine phase, of Plio–Pleistocene age, is characterized by a NE-SW trending maximum compressional stress, in a strike-slip stress regime (PONDRELLI, 1998), which resulted in a dextral strike-slip reactivation of many E-W and N120°E trending Variscan and Alpine structures. In the study area, this phase is expressed by the N120°E trending dextral strike-slip Cason di Lanza line (Fig. 3), inherited from a syn-sedimentary Permo–Carboniferous fault (VENTURINI, 1990a), which offset the Variscan pluri-kilometric anticline, placing in contact the Variscan and the Permo–Carboniferous sequences (VENTURINI, 1990a). The overturned part of the Variscan anticline rests to the south of the fault, while the part with the ‘normal’ way up is located to the north.

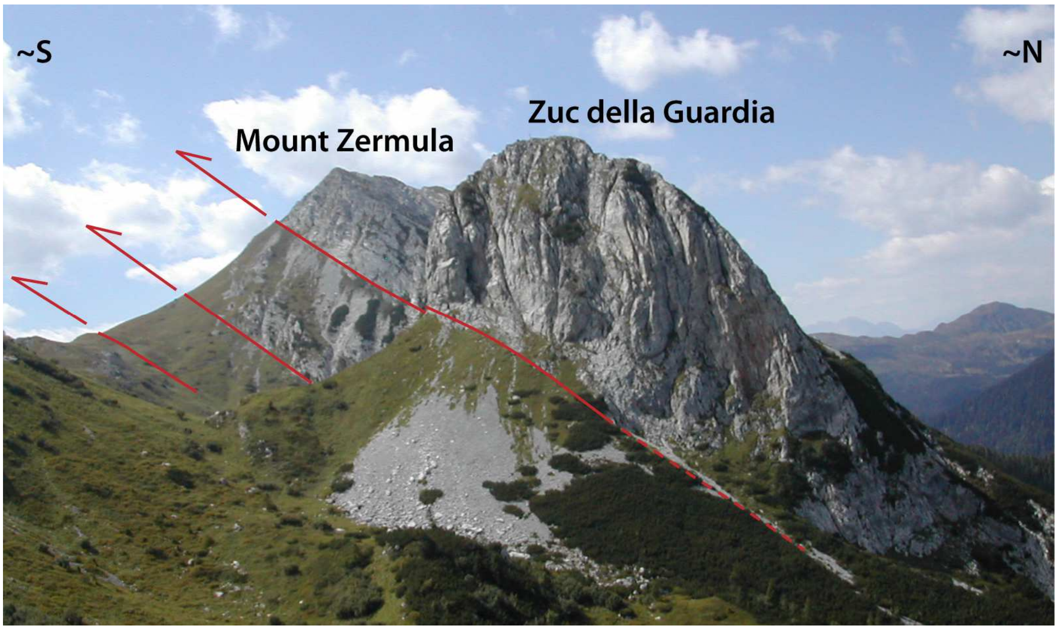


Fig. 5: Roughly east-west trending north dipping Alpine thrust of Tortonian–Serravallian age affecting the Variscan sequence.

Stratigraphy

As already stated before, in the Cason di Lanza area rocks from Ordovician to Permian are exposed. It is remarkable that in a small area the whole Carnic Palaeozoic sequence is observable. However, some units crop out widely, whereas others are limited to a few small localities. In a rough approximation, Devonian rocks are by long the most abundant and differentiated, including facies deposits from very shallow waters to the basin. Carboniferous rocks are abundant, too, mainly North of Cason di Lanza pass. Palaeozoic rocks oif different ages are less widespread, but good outcrops or sections are present.

Ordovician

The oldest rocks in the area are of Ordovician age and belong to the "Uqua shales", which consists of shales, siltstones, sandstones and rare conglomerates. Fossil content is generally high and usually distributed in distinct layers. The unit can be observed in a few small outcrops in the Cadin di Lanza and at Mt. Pizzul (Figs 3, 4), where one of the most fossiliferous Ordovician localities of the Carnic Alps is exposed (Fig. 6). Here brachiopods, trilobites and bryozoans are abundant; cystoids, crinoids and gastropods are rare.
The sequence continues with a few meters of nodular limestones ("Uqua limestones"), and calcareous sandstones (Ploecken Fm). Both these units are poorly exposed at Forca di Lanza.

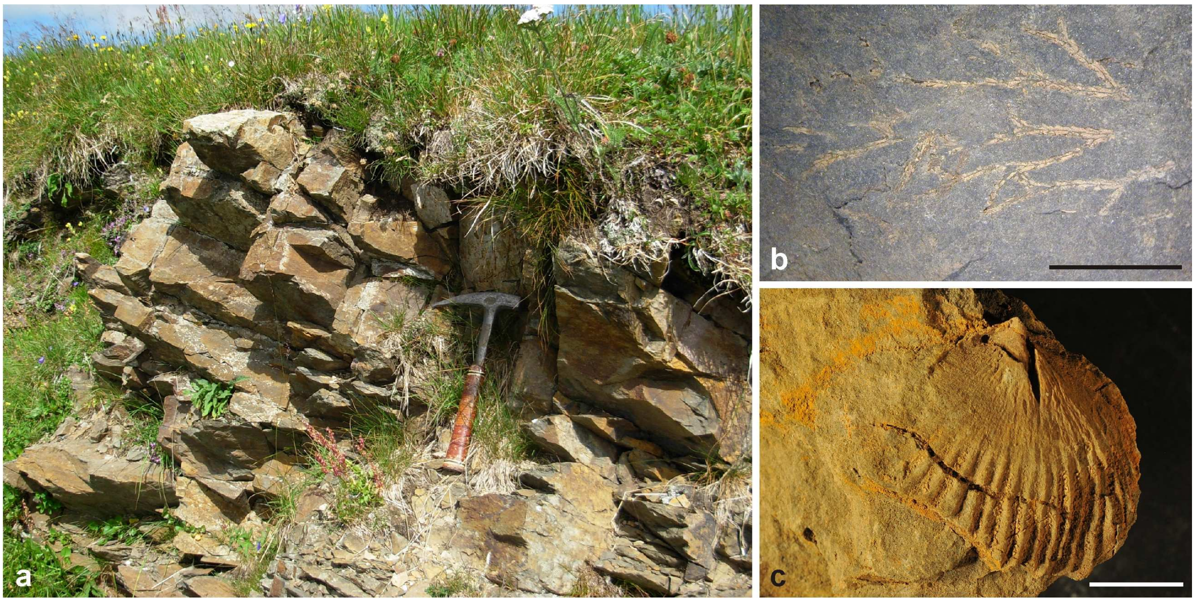


Fig. 6: The "Uqua shales" outcrop at the top of Mt. Pizzul. (a) Detail of the outcrop. (b) undetermined bryozoans. (c) brachiopod. Scale bar = 1 cm.

A good locality to observe the Ordovician sequence is the Valbertad section (BAGNOLI et al., 1998), about 3 Km west of Cason di Lanza (Fig. 7). It exposes both the "Uqua shales" (36 m) and the "Uqua limestones" (2 m). The former is more shaley and less sandy than in the type Uqua locality and outcrops of Cadin di Lanza and Mt. Pizzul. It contains a diverse shelly fauna of Sandbian–Katian age. Disarticulated brachiopod valves (especially large *Porambonites*) and bryozoans are concentrated in lenticular layers through the entire section. Trilobites are rarely present only in the lower part; cystoids are more abundant in the middle part of the section. In addition, the Valbertad section provided the first evidence of Edrioasteroidea in the Ordovician of the Carnic Alps (BAGNOLI et al., 1998). Figured bioturbations and fossil traces are also present.
At about 25 m from the base of the investigated part of the section, centimetric nodular micrite lenses appear in concentrated intervals alternating with sandstones. The uppermost 2 m of the section are represented by the nodular micritic calcareous member of the Uqua Fm ("Uqua limestones"). The rich conodont fauna allowed to refer these beds to the upper Katian–Hirnantian (*A. ordovicicus* Zone; BAGNOLI *et al*., 1998). Well-preserved brachiopods, phosphatic sclerites of the problematic palaeoscolecid *Milaculum*, ostracodes and sponge spiculae were also recovered from the conodont fraction.

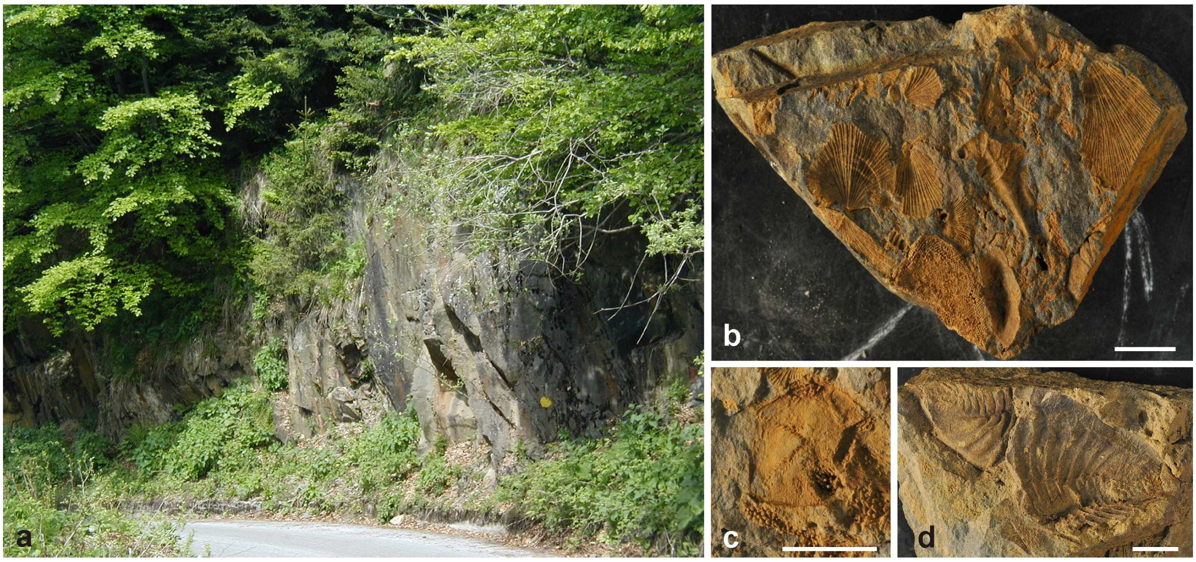


Fig. 7: The Upper Ordovician Valbertad section. (a) Panoramic view of the section. (b) slab with brachiopods and bryozoans. (c) cystoid plate. d: trilobite fragments. Scale bar = 1 cm.

Silurian

Silurian rocks in the Cason di Lanza area are poorly exposed and only a few small outcrops are known. Both, shaley and calcareous facies are observable.

Silurian black shales with graptolites are mainly present in the northern flank of the Rio di Lanza valley in the area of Casera Meledis, about 4 Km west of Lanza pass (Fig. 3). Graptolites from a few outcrops, currently almost hidden by soil and vegetation, were described by VINASSA DE REGNY & GORTANI (1905a), VINASSA DE REGNY (1906) and GORTANI (1923); recently PIRAS & SIMONETTO (2011) revised the classical "Casera Meledis" section (Fig. 8): "it is a very small outcrop, almost hidden in the wood, where abundant shale debris occur on the path and a few beds are exposed after digging a short trench" (PIRAS & SIMONETTO, 2011: p. 14), along the path CAI 449a between Casera Meledis bassa and Casera Meledis alta. The authors reported seven graptolite taxa from the lower Llandovery *triangulatus* Zone.

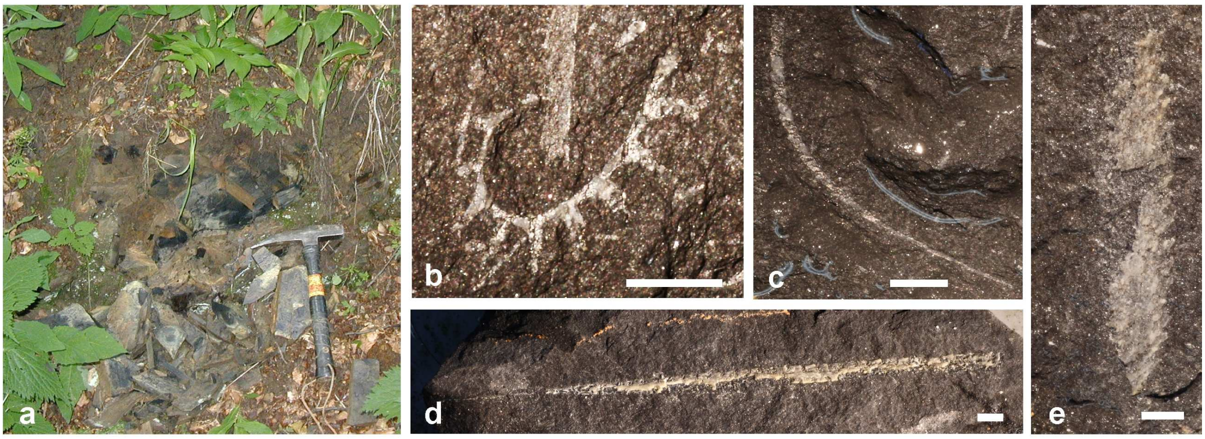


Fig. 8: View of the outcrop and graptolites from the Casera Meledis section. (a) close view of the outcrop. (b) *Demirastrites triangulatus* (HARKNESS, 1851). (c) *Monograptus revolutus* KURCK, 1882. (d) *Rhaphidograptus thoernquisti* (ELLES & WOOD, 1906). (e) *Parapetalolithus palmeus* (BARRANDE, 1850). Scale bar = 2 mm.

Extended outcrops of Silurian black shales and interbedded limestones (Nölbling Fm) in the La Valute area, the northwestern part of Mt. Zermula massif have been dated by conodonts to the Wenlock (*rhenana* and *sagitta* zones) (Fig. 3).

The "*Orthoceras* limestones" are exposed only in a few minor outcrops in the Mt. Pizzul area (Fig. 4). The best section is located at Cadin di Lanza (Cadin II section), where a few meters of *Alticola* limestone crop out (Fig. 9). It is a light grey-brownish, well bedded, micritic limestones, with orthoceratids. The section has been dated by means of conodonts to the Pridoli (CARTA, 2011).

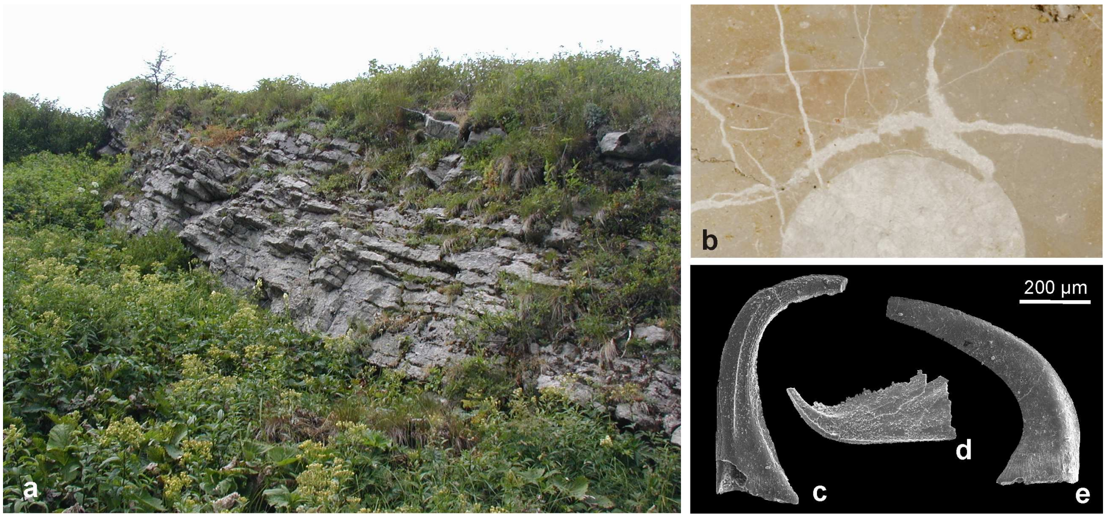


Fig. 9: The Cadin II section. (a) Panoramic view of the section. (b) microfacies with orthoceratid nautiloids. (c)-(e) conodonts; (c) *Panderodus unicostatus* (BRANSON & MEHL, 1933); (d) *Belodella resima* (PHILIP, 1965); (e) *Panderodus recurvatus* (RHODES, 1953).

Lower Devonian

Lower Devonian deposits are abundant and widespread in the Cason di Lanza area, where four lithostratigraphic units are discriminated: Rauchkofel Fm, Nölbling Fm, La Valute limestone and Findenig Fm. All these units are well exposed in Cadin di Lanza- Mt. Pizzul area, just south of the pass, and/or in the Rio Malinfier-La Valute area, a few Km on the west (Figs 3-4).

Fig. 10: Loboliths from the Rauchkofel Fm in the Cadin di Lanza area. (a) slab with four loboliths and a few stem fragments (Museo Friulano di Storia Naturale). (b) slab in Cadin di Lanza area with several small loboliths (arrows) and crinoidal and cephalopod remains. (c) level with loboliths in the Rio Malinfier West section. (d) detail of photo (c).

The Rauchkofel Fm is represented by few meters of dark wackestones to packstones with black shales interbedded. The fossil fauna is dominated by orthocerathid cephalopods, crinoids and conodonts; graptolites, brachiopods, bivalves are also present; loboliths (Fig. 10) mark a level just above the Silurian/Devonian boundary (CORRADINI et al., 2005; CORRIGA, 2011).

The Nölbling Fm ranges from lower Silurian to Lochkovian and consists of black shales, with mudstone and wackestone lenses interbedded. Pyritized fossils (Fig. 11) and rare conodonts are present in the carbonatic levels, and in some places graptolites can be obtained from the shales. This unit reaches its maximum thickness (about 40 meters) in the Valute area; however, likely tectonic duplication may have occurred. The upper part of the unit and the boundary with the overlying La Valute limestone is exposed in the Rio Malinfier section (Fig. 11).

Fig. 11: (a) The Nölbling Fm-La Valute limestone transition in the Rio Malinfier section. (b)-(c) pyritized fossils from the Nölbling Fm, Rio Malinfier area; (b) gastropod; (c) pygidium of an encrinurid trilobite. Scale bar = 5 mm.

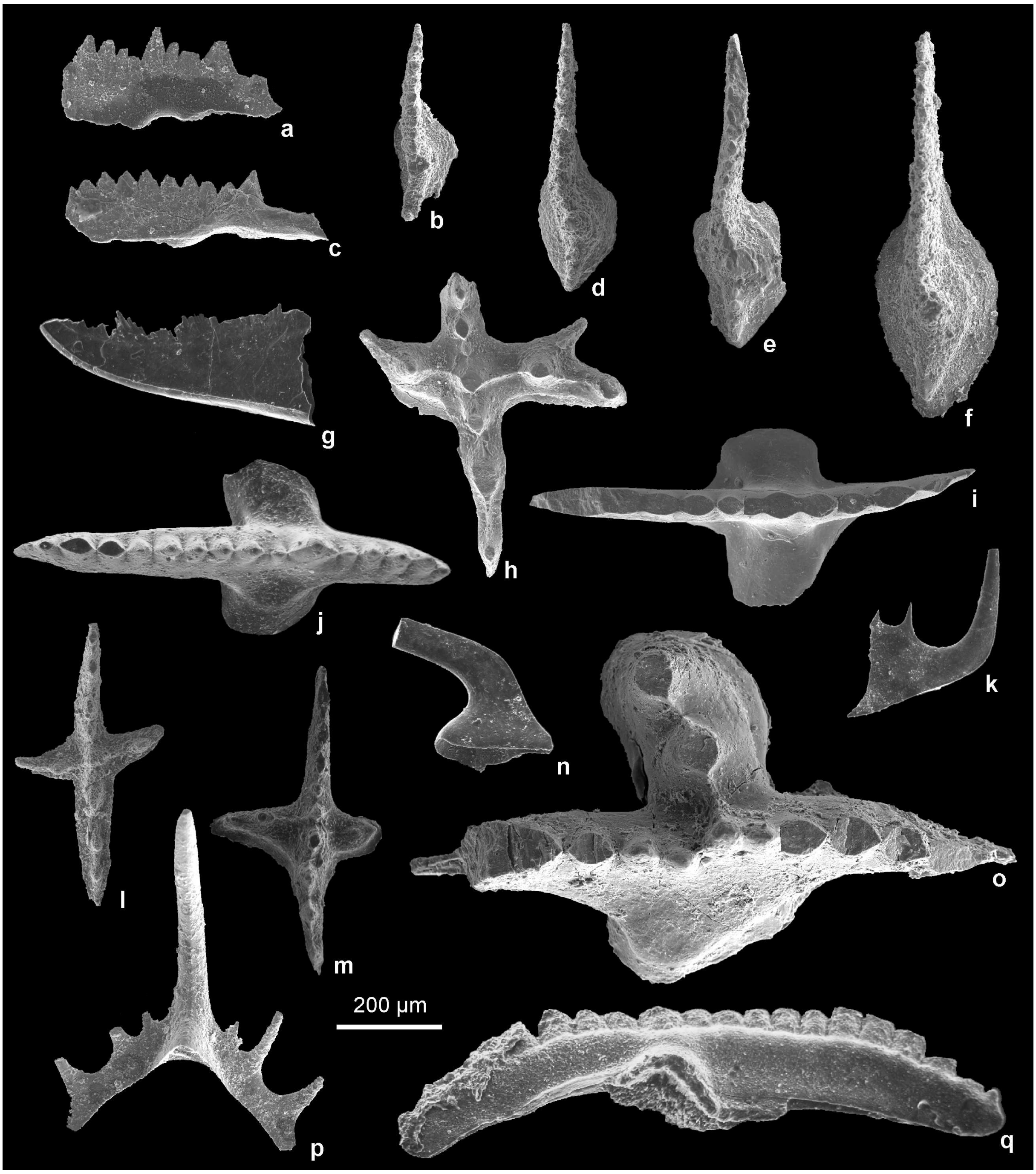
The La Valute limestone is represented by about twenty meters of centimetric thick light grey-ochre nodular mudstones and wackestones with orthoceratids and conodonts. The upper part of the unit grades into the overlying Findenig Fm. This latter unit is about 25 meters thick and consists of centimetric thick layers of nodular purple red mudstones and wackestones with marl millimetric thick intercalations. Locally, for example in the Malinfier gorge, centimetric thick levels of gray packstones occur suggesting gravity driven redeposition from the shallower part of the basin (BANDEL, 1972, 1974; VAI, 1980).

A detailed stratigraphy of the Lower Devonian of the area has been obtained by means of conodonts (Fig. 12) in several sections of the area (CORRIGA, 2011; CORRIGA et al., 2011, and unpubl. data).

All these units are well exposed in the Rio Malinfier area. The Rio Malinfier West section (CORRIGA, 2011) is about 100 m thick and, besides being overturned and affected by a few folds and faults, expose rocks from the *Alticola* lms to the Findenig Fm (Fig. 13).

Fig. 12: Selected Lower Devonian conodonts from Cason di Lanza area. Section abbreviations: CAD III= Cadin di Lanza III; RM = Rio Malinfier; RMW = Rio Malinfier West. (a) *Ozarkodina malladai* VALENZUELA-RIOS, 1994, P1 element, lateral view, sample RMW 4A (*transitans* Zone). (b) *Flajsella streptostygia* VALENZUELA-RIOS & MURPHY, 1997, P1 element, upper view, sample RMW 5 (*trigonicus* Zone). (c) *Flajsella schulzei* (BARDASHEV, 1989), P1 element, lateral view, sample RMW 4X (*eleanorae* Zone). (d) *Flajsella schulzei* (BARDASHEV, 1989), P1 element, upper view, sample RMW 4C (*trigonicus* Zone).

continued next page



(e) *Flajsella sigmostygia* VALENZUELA-RIOS, 1997, P1 element, upper view, sample RMW 4C (*trigonicus* Zone). (f) *Flajsella stygia* (FLAJS, 1967), P1 element, upper view, sample RMW 4C (*trigonicus* Zone). (g) *Belodella resima* (PHILIP, 1965), S0 element, lateral view, sample RMW 8 (*hesperius* Zone). (h) *Ancyrodelloides murphyi* VALENZUELA-RIOS, 1994, P1 element, upper view sample CAD III (*trigonicus* Zone). (i) *Lanea omoalpha* MURPHY & VALENZUELA-RIOS, 1999, P1 element, upper view, sample RMW 1X (*carlsi* Zone); (j) *Ozarkodina planilingua* MURPHY & VALENZUELA-RIOS, 1999, P1 element, upper view, sample RMW 4 (*carlsi* Zone). (k) *Icriodus hesperius* (KLAPPER & MURPHY, 1975), Sc element, lateral view, sample RMW 8 (*hesperius* Zone). (l) *Ancyrodelloides transitans* (BISCHOFF & SANNEMANN, 1958), P1 element, upper view, sample RMW 5 (*trigonicus* Zone). (m) *Lanea telleri* (SCHULZE, 1968), P1 element, upper view, sample RMW 5 (*trigonicus* Zone). (n) *Dvorakia amsdeni* BARRICK & KLAPPER, 1983, S1 element, lateral view, sample RMW 8 (*hesperius* Zone). (o) *Ancyrodelloides carlsi* (BOERSMA, 1973), P1 element, upper view, sample RM 1 (*transitans* Zone). (p) *Oulodus spicula* MAWSON, 1986, S0 element, lateral view, sample RMW 5 (*trigonicus* Zone). (q) *Wurmiella wurmi* (BISCHOFF & SANNEMANN, 1958), P1 element, lateral view, sample RMW 4 (*carlsi* Zone).

Fig. 13: Sketched stratigraphic log and selected views of the Rio Malinfier West section (modified after CORRIGA, 2011). Red numbers indicate conodont samples. The section is overturned. (a) panoramic view of the upper half of the section. (b) detail of the base of the section. (c) the slightly tectonized boundary between the *Alticola* lms and the Rauchkofel Fm in the central part of the section. (d) the La Valute limestone. (e) the gradual transition between the La Valute limestone and the Findenig Fm in the upper part of the section.

Middle Devonian: the reef and related facies

Starting from the Emsian this part of the Carnic basin begins to differentiate into a proximal part with extensive carbonatic build ups and related depositional environments and a deeper part characterized by deposition in calm waters. In the fore-reef area, thick bodies of gravitative driven material grade in the deeper parts of the basin. The main diffusion of bioherms and reefs is recorded during the Middle Devonian and the reefal facies persisted to be the most prominent carbonatic deposit up to the first part of the Late Devonian (Frasnian).

The white calcareous cliffs of Mt. Zermula and Zuc della Guardia (Fig. 14), that dominate Cason di Lanza Pass on the south, and Mt. Cavallo di Pontebba a few Km eastward consist of shallow water deposits (Fig. 3). Other major Devonian reefs are located at Mt. Coglians and Mt. Osternig, but small outcrops are scattered all along the whole chain: as a results, in the Carnic Alps the most extended Devonian reefs of Europe are preserved. The reefal facies constitute the majority of carbonatic rocks deposited in the Carnic domain during the Middle Devonian, and are about 1000 m thick at Mt. Coglians.

Fig. 14: The white rocks forming the cliffs of northern flank of Mt. Zermula (right), Zuc della Guardia (centre) and Zuc di Malaseit (left) and are constituted by Middle Devonian reefal carbonates.

Reefs are mainly represented by massive, poorly bedded limestone with a facies being characterized by high diversity. In the Carnic Alps the reefal facies yields stromatoporoids, tabulates, rugose corals, brachiopods, crinoids, gastropods, ostracods, bivalves, cephalopods, trilobites, algae, calcispheres, and foraminifers.

Additionally, all types of facies connected to the reef environment are preserved in the Devonian of the Carnic Alps. Fore-reef and slope deposits consist of prevailing carbonatic rudites and calcarenites with abundant reefal bioclastic content. A variety of back-reef, lagoon and tidal-flat facies characterized by their sedimentological features and fossils are also well represented (Fig. 15).

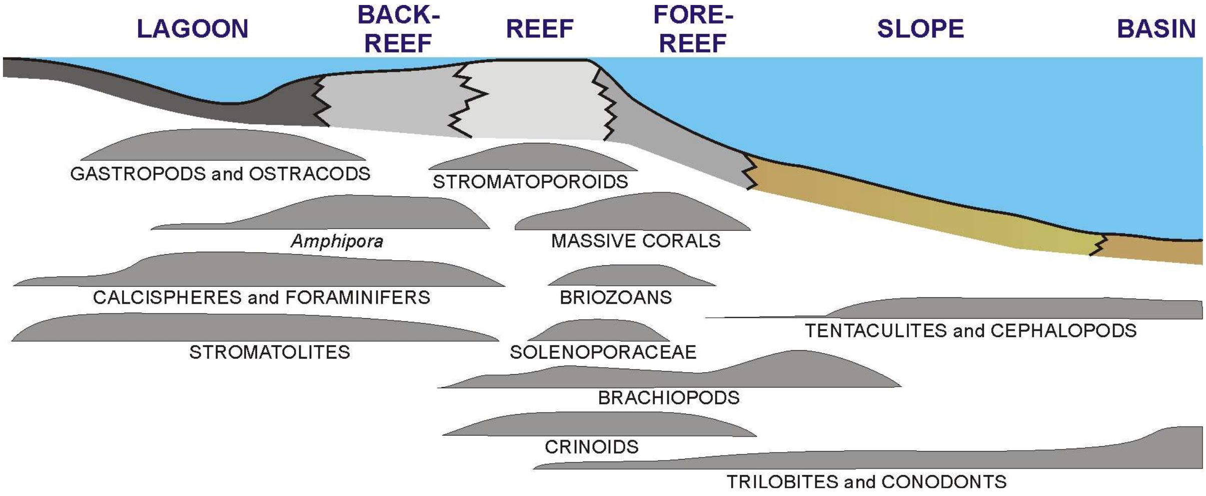


Fig. 15: The distribution of main fossil groups in the Middle Devonian of the Carnic Alps (modified after VAI et al., 2002).

The back reef (Amphipora lms)

On the southern side of the Cason di Lanza pass, right below the reefal cliffs of Mt. Zermula and Mt. Zuc della Guardia, sediments from the calm lagoonal back-reef environment crop out. They are better exposed around the old military house at the Cason di Lanza pass (Fig. 16).

These rocks of Givetian (Middle Devonian) age are known as "Amphipora limestones" and are constituted of "prairies" of *Amphipora ramosa*, trapping carbonatic mud. Additionally it yields rugose corals predominately of the genus *Dendrostella*. Within the unit darker levels with the brachiopod *Stringocephalus burtinii* are present here and there. This taxon confirms the Givetian age of the outcrop. In other areas of the Carnic Chain this unit spans a wider time interval (Eifelian–Frasnian, Middle–Upper Devonian) and its thickness reaches 200-400 meters.

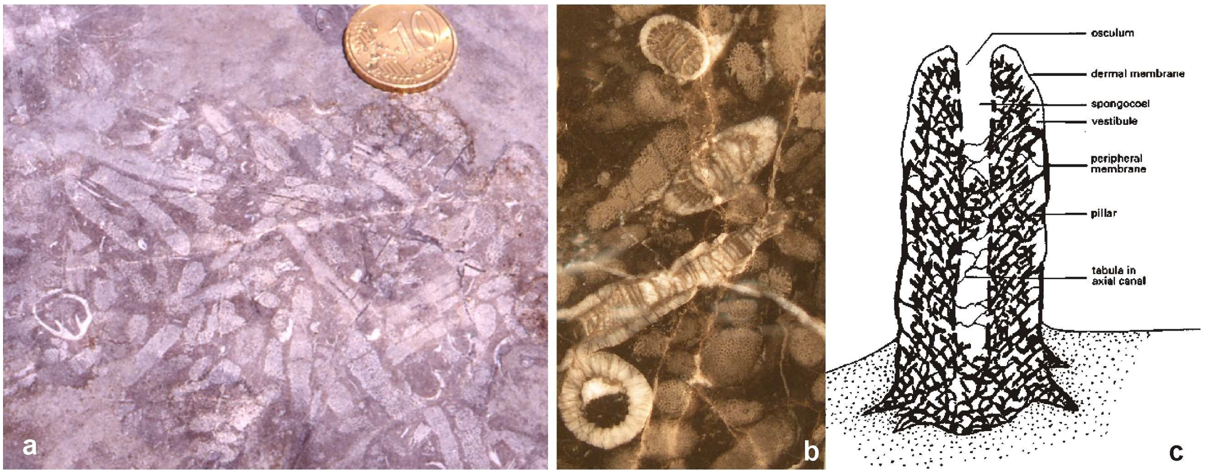


Fig. 16: (a) The *Amphipora* lms at Cason di Lanza Pass. (b) polished slab. (c) reconstruction of *Amphipora ramosa* as a small sponge rooted in the substrate (after STEARN, 1997).

The Genus *Amphipora* is known from Emsian to early Famennian, with the most widespread distribution in Middle Devonian time. The amphiporoid animal was a small, cylindrical, branching, calcified sponge (STEARN, 1997). The stems are rods of a few millimeters in diameter and are composed of skeletal elements of fibrous calcite defining an irregular network of hard tissue in which concentric elements are obscure, and radial elements are hard to distinguish. The labyrintine canals between the elements open on the periphery in apertures of irregular shape or are covered there by a thin hard tissue membrane. The peripheral membrane may be present on only some of the stems or only on some parts of individual stems. A prominent axial canal crossed by dissepiments may or may not be present. Some specimens are branched, other remain as single tubes. Taxonomically, Amphiporidae (Silurian–Permian) are considered a family of the Class Stromatoporoidea, but their phylogenetic relationships with others representatives of the group are still unclear (STEARN, 1997).

Amphipora lived in shallow, calm waters. The stem was anchored inefficiently by irregular outgrowths at the base or cemented into the substrate; the latter hypothesis seems to be more probable (STEARN, 1997).

The fore reef (Hoher Trieb Fm and Freikofel Fm)

Fore reef units consist of slope deposits distally interlayered with pelagic deposits. In the Cason di Lanza Pass area a proximal (Freikofel Fm) and a distal (Hoher Trieb Fm) unit can be distinguished (Figs 2, 4) (PONDRELLI et al., 2011).

In the study area the Freikofel Fm crops out only at one single locality west of Forca di Lanza (Fig. 17) and is about 20 meters thick, resting with an erosional base on top of the Findening limestone, while the upper limit is tectonically erased (Figs 4, 5). It is made of meter thick floatstone and rudstone layers interlayered with decimetric thick grainstones to packstones often showing parting lineations, suggesting deposition in an upper flow regime. The layers base is either erosional or sharp. Erosional surfaces are common within the breccia levels. Locally both facies show normal grading, which suggest deposition from waning flows. Freikofel Fm has been interpreted as result of gravity driven deposition. It has been dated by conodonts to the Eifelian, possibly heteropic with the Cellon Fm found in the western part of the Carnic Alps (KREUTZER, 1990).

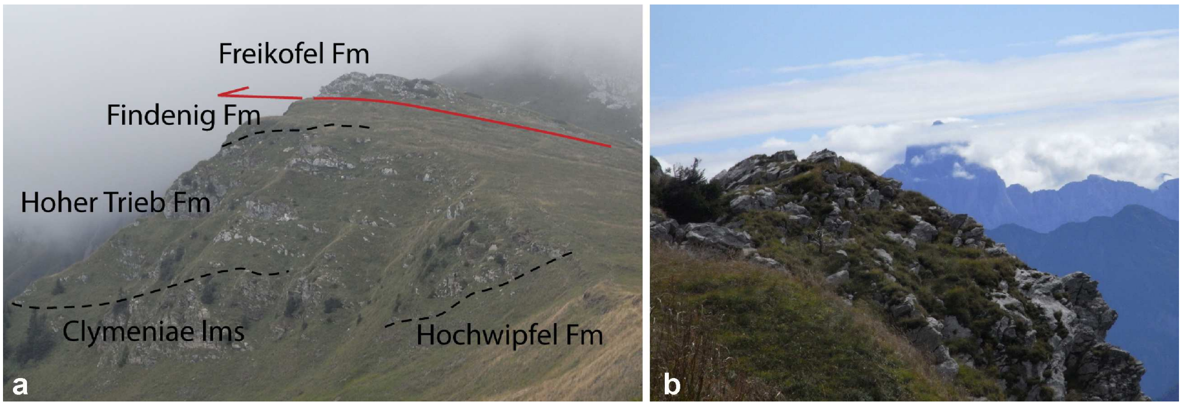


Fig. 17: (a) Panoramic view of the Forca di Lanza section. (b) the Freikofel Fm in the Forca di Lanza section.

The Hoher Trieb Fm crops our extensively along the study area, from the Cima Val di Puartis in the north to La Valute, Forca di Lanza, Mt. Pizzul and Zuc di Malaseit in the south (Fig. 4). The overall thickness can be estimated around 45 meters. It rests on top of the Findening limestone and it is covered by the deposits of the Clymeniae limestone (Figs 2, 4). This unit consists of interlayered meter thick floatstone, centimetric and decimetric thick grainstone and packstone, centimetric thick black radiolarite and shales and rare sandstones. Breccia layers are characterized by the presence of silicified remains of corals (e.g. *Dendrostella* sp., *Grypophyllum* sp. and *Cyathophyllum* sp.) resedimented from the shallow water (Fig. 18). Grainstone and packstone are often laminated and normally graded, suggesting deposition from a waning flow. A black shales episode have been hypothesize to mark the Kačák Event (KIDO et al., 2011a, 2011c; PONDRELLI et al., 2011). This unit is interpreted as transitional from slope to pelagic deposits. According to conodont data, the Hoher Trieb Fm spans an interval from Eifelian through Frasnian, and is partly heteropic with the Freikofel Fm.

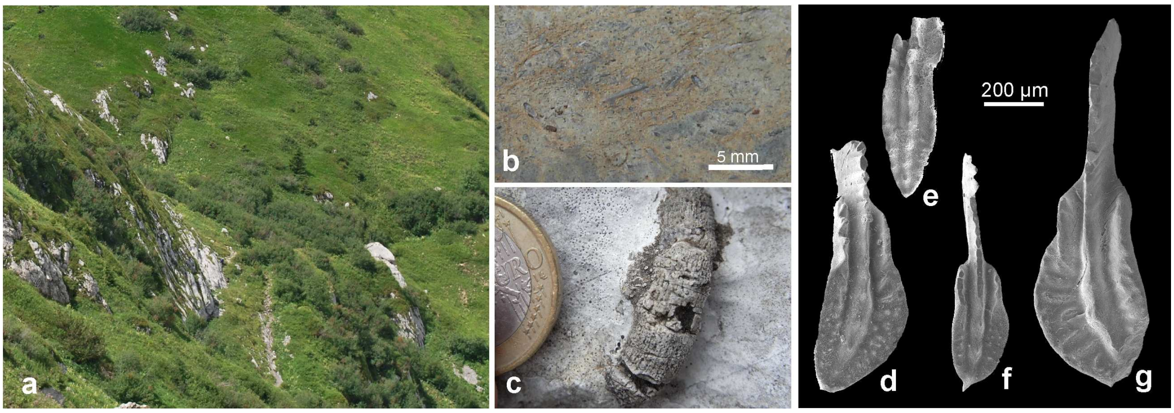


Fig. 18: The Hoher Trieb Fm in the Cadin di Lanza Parete (CAD P) section. (a) panoramic view of the section. (b) tentaculitic limestone. (c) a silicified coral in the outcrop. (d)-(g) conodonts. (d) *Polygnathus eiflius* BISCHOFF & ZIEGLER, 1957. (e) *Polygnathus timorensis* KLAPPER, PHILIP & JACKSON, 1970. (f) *Polygnathus xylus ensensis* ZIEGLER & KLAPPER, 1976. (g) *Polygnathus pseudofoliatus* WITTEKINDT, 1966.

Upper Devonian and lowermost Carboniferous: the "Clymeniae limestones"

During the Frasnian the Carnic basin underwent extensional tectonic pulses and the reefal facies collapsed and drowned (VENTURINI et al., 2009 and reference herein). The Upper Devonian is almost exclusively represented by “Clymeniae limestones” (Fig. 2): pelagic massive and/or nodular limestones with ammonoid remains and conodonts, and rare small trilobites, bivalves, vertebrate microremains (fish teeth and scales) and brachiopods.

In the Cason di Lanza area this unit is poorly exposed, being present only in a few strongly tectonized outcrops at Forca di Lanza and on the western slope of Mt. Pizzul (Fig. 4). Here several metres of nodular grey-pinkish limestone with some more massive levels interbedded have been dated to the upper Frasnian–lower Famennian (Lower *rhenana*-Upper *marginifera* Zone); the colour turns to dark red in the upper part of the sections (Fig. 19).

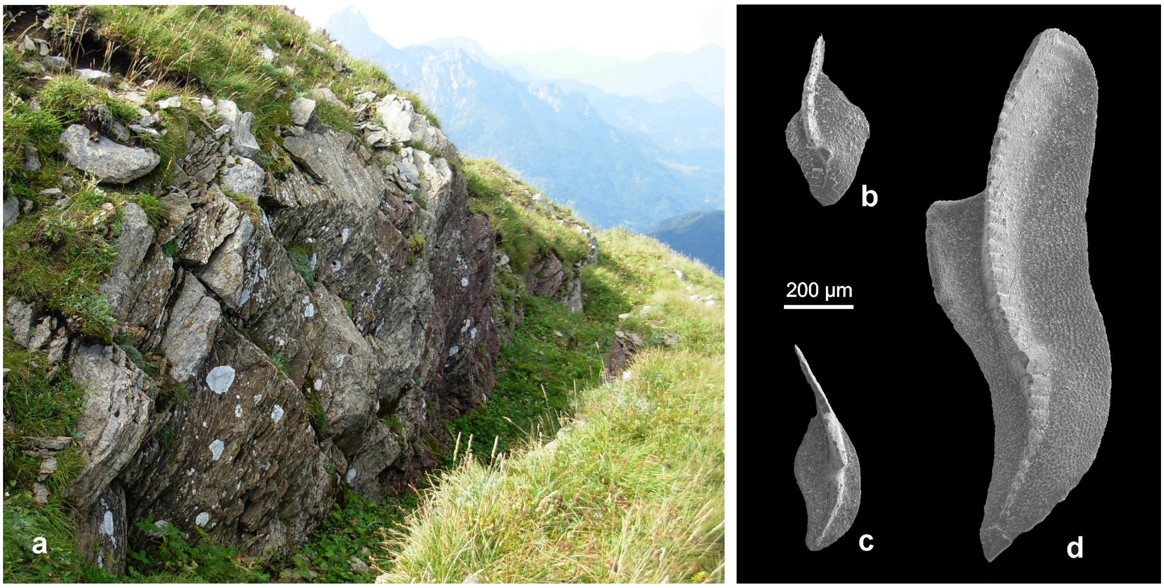


Fig. 19: The Clymeniae limestone in the Pizzul West section. (a) panoramic view of the section. (b)-(d) conodonts from sample PZW 5. (b) *Palmatolepis rhomboidea* SANNEMANN, 1955. (c) *Palmatolepis minuta minuta* BRANSON & MEHL, 1934. (d) *Palmatolepis glabra glabra* ULRICH & BASSLER, 1926.

Massive grey micritic limestones are exposed on the western slope of Mt. Zermula massif, a few km west of Cason di Lanza Pass. These limestones are part of the overturned flank of the Mt. Zermula kilometric antiform (Figs 3, 4). The tectonic style is complicated by the presence of many Variscan and Alpine faults, mainly paralleling the bedding planes, producing elisions and/or tectonic duplications

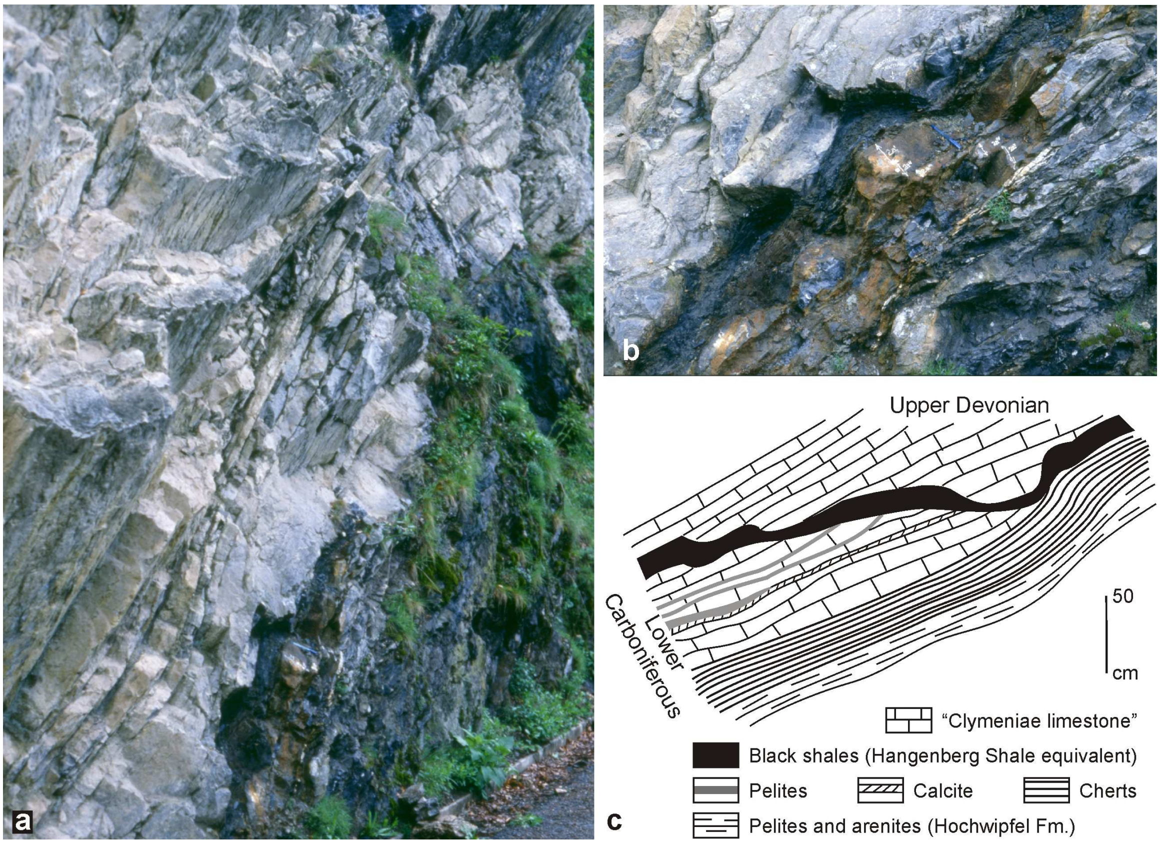


Fig. 20: The Plan di Zermula A section. (a) panoramic view. (b) close view of the Hangenberg Shale equivalent, between the Devonian and Carboniferous beds. (c) sketched drawing of the Plan di Zermula A section (after PERRI & SPALLETTA, 2001, modified).

of a part of the sequence. Here, near the top of the limestone beds, a stratigraphic section across the Devonian/Carboniferous boundary was measured and sampled (PERRI & SPALLETTA, 2001; KAISER, 2005; KAISER et al., 2009). In this section the boundary beds are represented by a level of black shales about 15 cm thick, likely corresponding to the globally known Hangenberg Shale (Fig. 20). According to conodont data, the last limestone level, just below the black shales, belongs to the Lower *praesulcata* Zone, and the first carbonatic level above the shales to the *sulcata* Zone (PERRI & SPALLETTA, 2001; KAISER et al., 2009).

Lower Carboniferous: the "Hercynian flysch"

In the Lower Carboniferous the Carnic basin was affected by strike-slip tectonics releted to the dextral offset of the Insubric Palaeoline. The action of this transtensional to transpressional tectonics lead to the drowinig of some sector of the basin, while other areas were uplifted in some case to emersion. Gravitative driven accumulation of breccias, conglomerates, sandstones and pelites occurred in the depocenters, forming a thick turbiditic sequence (Hochwipfel Fm). Later, where the intensification of transtensional movements lead to break up of the crust and opening of a narrow oceanic basin, these sediments were in place overlaid, and laterally interlayered, by basic volcanic and volcanoclastic deposits (Dimon Fm) (Fig. 2).

In the Cason di Lanza Pass area the Hochwipfel Fm is exposed mainly at Cadin di Lanza, along one of the major Variscan overthrusts (Figs 3, 4). It is represented by thin bedded sandstones and pelites showing normal grading and ripple cross lamination at some places, which suggest a deposition as distal turbidites.

Permo–Carboniferous sequence

North of Cason di Lanza, deposits of the Permo–Carboniferous sequence are extensively exposed. They belong to the western part of the Pramollo Basin. The Carboniferous terms are represented by alternations of fluvio-deltaic and marine deposits, whereas in the Lower Permian units the marine calcareous facies are dominant. For a complete discussion of the Permo–Carboniferous sequence, refer to VENTURINI (1990a) and SCHÖNLAUB et al. (2007).

In the Cason di Lanza area the better exposed Permo–Carboniferous sediments belongs to the Meledis Fm (Upper Carboniferous) and to the Val Dolce Fm (Lower Permian), but other units are also exposed here and there.

The Upper Carboniferous Meledis Fm

The Meledis Fm is widely exposed north of the Cason di Lanza Line, and is mainly represented by fluvio-deltaic quartzitic conglomerates and transitional and shallow marine pelites and sandstones. A fossil flora is abundant in pelitic levels, where also rare insect remains can be found; abundant ichnofossils (mainly *Zoophycus* and *Cosmoraphae*) occur in some sandstone levels (Fig. 21).

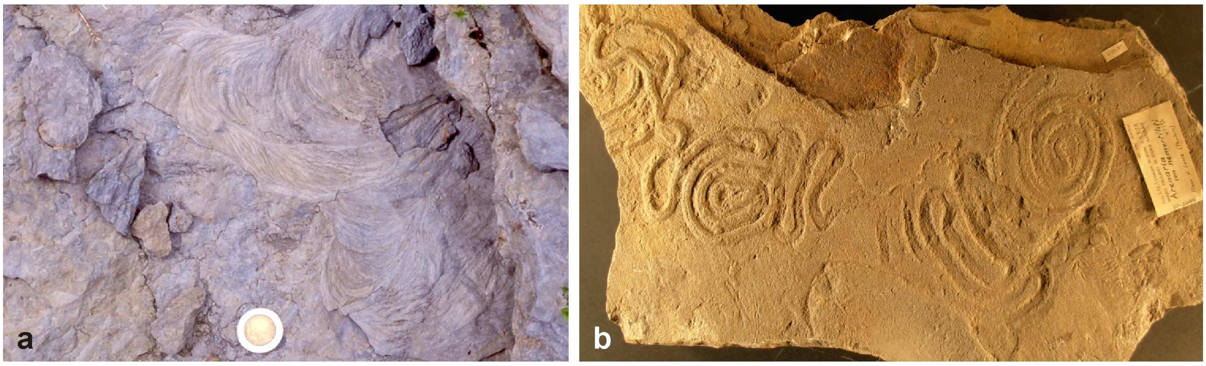


Fig. 21: Trace fossils from the Meledis Fm in Cason di Lanza area. (a) *Zoophycus*. (b) ?*Cosmoraphae.*

One of the most classical localities for Carboniferous flora is located a few hundred meters from Cason di Lanza hut. In the Rio del Museo section (Fig. 22) the main terrigenous lithotypes of the Meledis Fm can be observed; the section is tectonically cut at the base, near the confluence with Lanza Creek, by the Cason di Lanza Line, and is interrupted at the top by a tectonic contact with the red sandstones of the Val Gardena Formation (Upper Permian). The rich fossil flora is preserved in a politic interval just above a thick quartzitic conglomerate bed, interpreted as a channel deposits

(VENTURINI, 1990a). The association is mainly represented by "ferns" (e.g. *Alethopteris*, *Callipteridium*, *Linopteris* and *Pecopteris*) and equisetaleans (e.g. *Annularia*, *Sphenophyllum* and *Calamites*).

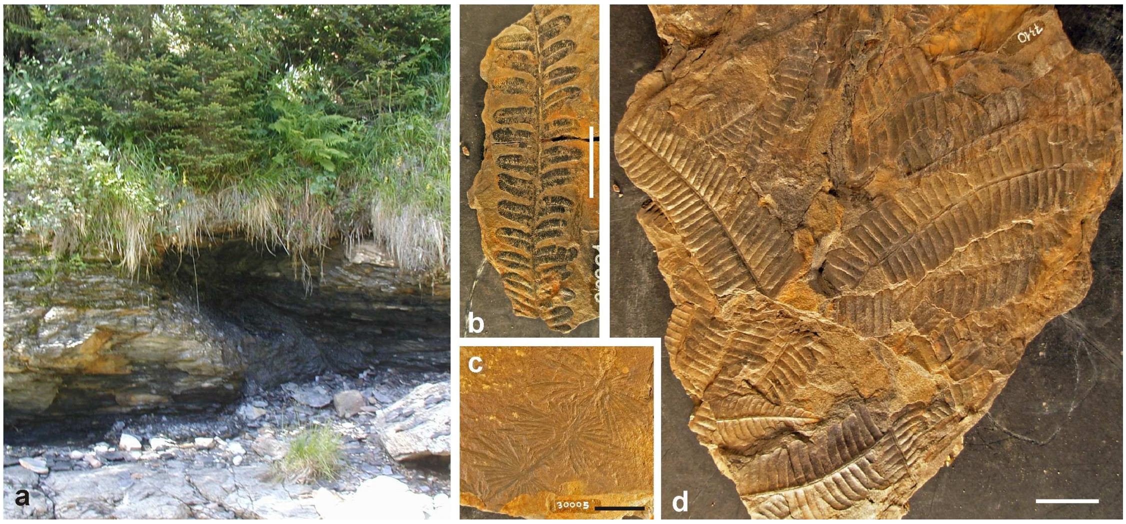


Fig. 22: The Carboniferous plants locality in Rio del Museo. (a) view of the outcrop. (b) *Alethopteris* sp. (c) *Annularia stellata*. (d) large slab with several *Callipteridium* sp. leaves. Scale bar = 2 cm.

The Lower Permian Val Dolce Fm

The Val Dolce Fm crops out extensively more to the North, close to the Italy/Austria border. It is mainly constituted by grey and red shales with sandstones, quartz-conglomerates and calcarenites. In the pelitic levels of Piani di Lanza area a rich invertebrate fauna, dominated by brachiopods is present (Fig. 23); ammonoids (*Imitoceras*), orthocerid nautiloids, bivalves, gastropods, solitary corals, bryozoans and rare trilobites are also present.

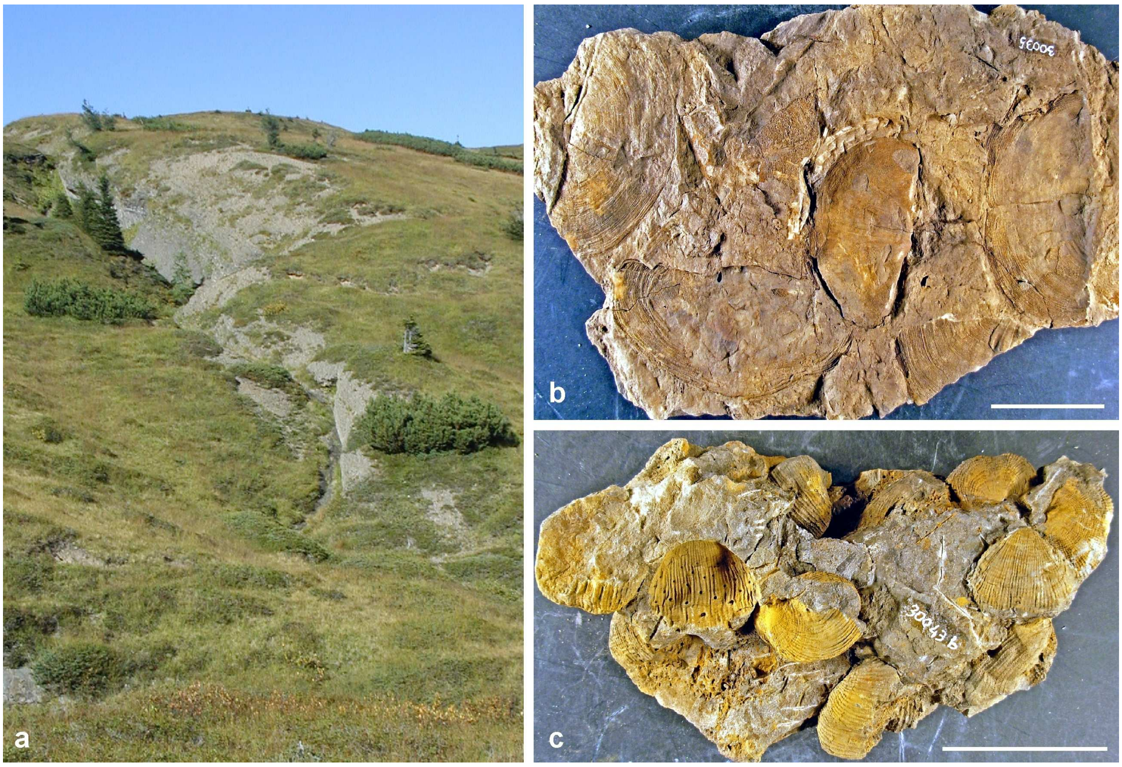


Fig. 23: (a) The brachiopod locality in the Val Dolce Fm at Piani di Lanza. (b) *Isogramma* sp. (c) slab with several *Linoproductus* and other brachiopods. Scale bar = 5 cm.

Other Carboniferous and Lower Permian units

The other units of the Permo–Carboniferous sequence are less widespread in the area, and are exposed mainly in the Piani di Lanza and Val Dolce areas, and at Mt. Creta d'Aip/Trogkofel.

From these units a few vertebrate remains (Fig. 24) have been found: a late Carboniferous footprint, tentatively attributed to ichnogenus ?*Limnopus* by MIETTO et al. (1986), and two teeth of petalodontiform condrychtians (DALLA VECCHIA, 2000).

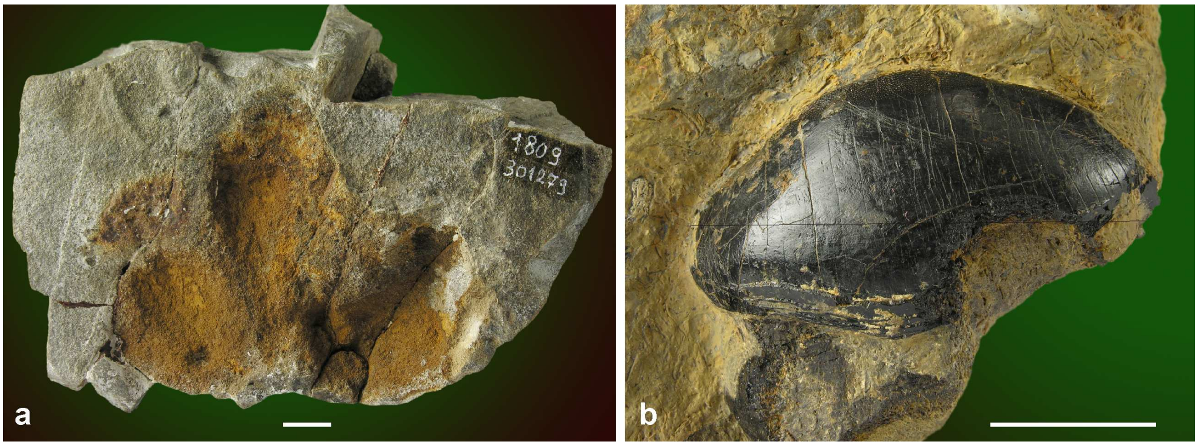


Fig. 24: Evidence of vertebrates from the Lower Permian of Cason di Lanza area. Scale bar = 1 cm. (a) tetrapod footprint belonging to ichnogenus ?*Limnopus*. (b) tooth of the condrychtian *Petalodus ohioensis*.

The Permo–Triassic sequence

The older units of the Permo–Triassic sequence are exposed in the Cason di Lanza area: the Val Gardena Sandstone and the Bellerophon Fm.

The better exposed unit is the Val Gardena Sandstones, which mark the beginning of the Alpine stratigraphic-structural cycle, and is constituted by reddish sandstones unconformably lying on top of the Permo–Carboniferous deposits (Fig. 2). A small outcrop of the dark dolostones and limestones of the Bellerophon Fm is also present within a small anticline in Piani di Lanza locality.

Acknowledgements: Dr. C. Cleal (National Museum Wales) is acknowledged for determinations of fossil plants on Fig. 22. This paper is a contribution to IGCP projects no. 580 (*Application of Magnetic Susceptibility on Palaeozoic sedimentary rocks*), 591 (*The Early to Middle Paleozoic Revolution*) and 596 (*Climate change and biodiversity patterns in the Mid–Paleozoic*).

References

BAGNOLI, G., FERRETTI, A., SERPAGLI, E. & VAI, G.B. (1998): Late Ordovician conodonts from the Valbertad Section (Carnic Alps). 138-149. In: PERRI M.C. & C: SPALLETTA (eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, s. 3, 60, Spec. Issue.

BANDEL, K. (1972): Palökologie und Paläogeographie im Devon und Unterkarbon der zentralen Karnischen Alpen. Palaeontographica A, 141 (1-4): 1-117.

BANDEL, K. (1974): Deep-water limestones from the Devonian–Carboniferous of the Carnic Alps, Austria. 93-115. In: HSÜ, K.J. & JENKYNS, H.C. (eds), Special Publication of the International Association of Sedimentologists, 1.

BRIME, C., PERRI, M.C., PONDRELLI, M., SPALLETTA, C. & VENTURINI, C. (2008): Polyphase metamorphism in the eastern Carnic Alps (N Italy'S Austria): Clay minerals and conodont Colour Alteration Index evidence. International Journal of Earth Sciences, 97 (6): 1213-1229.

CARTA, N. (2011): Caratterizzazione Biostratigrafica delle Unità Litologiche affioranti nell'area di Monte Pizzul, Passo del Cason di Lanza (Alpi Carniche). Master Thesis, University of Cagliari: 130 pp.

CORRADINI, C., SIMONETTO, L., SERVENTI, P., CALLIGARIS, C. & RIGO, R. (2005): Loboliti (Crinoidea) del Devoniano basale di Monte Zermula (Alpi Carniche, Italia). Rendiconti della Società Paleontologica Italiana, 2: 27-34.

CORRIGA, M.G. (2011): Biostratigrafia a conodonti attorno al limite Siluriano–Devoniano in alcune aree del Nord Gondwana. PhD Thesis, University of Cagliari: 152 pp.

CORRIGA, M.G., SUTTNER, T.J., KIDO, E., CORRADINI, C., PONDRELLI, M. & SIMONETTO, L. (2011): The age of the La Valute limestone-Findenig limestone transition in the La Valute Section (Lower Devonian, Carnic Alps, Italy). Gortania Geologia, Paleontologia, Paletnologia, 32: 5-12.

DALLA VECCHIA, F.M. (2000): A new petalodont tooth (Chondrichthyes, Petalodontiforms) from the Lower Permian of the Carnic Alps. Bollettino della Società Paleontologica Italiana, 39 (2): 225-228.

FERRARI, A. (1968): Tetracoralli delle Alpi Carniche. La fauna di Monte Zermula. Giornale di Geologia, 34 (2): 531-592.

FERRARI, A. & VAI, G.B. (1966): Ricerche stratigrafiche e paleoecologiche al Monte Zermula (Alpi Carniche). Giornale di Geologia, 33 (2): 389-416.

FRECH, F. (1894): Die Karnischen Alpen. Ein Beitrag zur vergleichenden Gebirgstektonik: Abhandlungen der Naturforschenden Gesellschaft zu Halle, 18: I-XIV+ 1-515.

GORTANI, M. (1913): Rilevamento nel nucleo centrale carnico. Bollettino del Regio Comitato Geologico d'Italia, 43: 71-75.

GORTANI, M. (1915): Revisione del rilevamento nel nucleo centrale carnico. Bollettino del Regio Comitato Geologico d'Italia, 44: 309-314.

GORTANI, M. (1920): I bacini della But, del Chiarsò e della Vinadia in Carnia. Geologia, morfologia, idrografia. Carta della permeabilità delle rocce. Ufficio Idrografico del Reale Magistrato delle Acque, pubbl. 104: 1-71.

GORTANI, M. (1923): Contributo allo studio del Paleozoico. VI. Faune a Graptoliti. Palaeontographia Italica, 26: 1-56.

GORTANI, M. & VINASSA DE REGNY, P. (1908): Nuove ricerche geologiche sul nucleo centrale delle Alpi Carniche. Rendiconti della Reale Accademia dei Lincei, s. 5, 17: 603-612.

KAISER, S.I. (2005): Mass extinction, climatic and oceanographic changes at the Devonian/Carboniferous boundary. PhD Thesis, University of Bochum: 156 pp.

KAISER, S.I., BECKER, R.T., SPALLETTA, C. & STEUBER, T. (2009): High-resolution conodont stratigraphy, biofacies, and extinctions around the Hangenberg Event in pelagic successions from Austria, Italy, and France. Palaeontographica Americana, 63: 97-139.

KIDO, E., SUTTNER, T.J., KOPTIKOVA, L., PONDRELLI, M., CORRADINI, C., CORRIGA, M.G., SIMONETTO, L., BERKYOVÁ, S. & VODRÁŽKA, R. (2011a): Magnetic susceptibility as tool for high-resolution correlation of pelagic and distal slope facies of the Middle Devonian in the Carnic Alps: preliminary results. 31-32. In: KOPTIKOVA, L., HLADIL, J. & ADAMOVIC, J. (eds), Miroslav Krs Conference: Time, Magnetism, Records, Systems and Solutions. The 2011 Annual IGCP 580 Meeting, Prague, Czech Republic, October 12-18 Prague.

KIDO, E., SUTTNER, T.J., PONDRELLI, M., CORRADINI, C., CORRIGA, M.G., SIMONETTO, L. & BERKYOVÁ, S. (2011b). Correlation of Mid-Devonian coral deposits of the Carnic Alps across the Austro-Italian border. Kölner Forum für Geologie und Paläontologie, 19: 77-81.

KIDO, E., SUTTNER, T.J., PONDRELLI, M., CORRADINI, C., CORRIGA, M.G., SIMONETTO, L. & BERKYOVÁ, S. (2011c): Middle Devonian rugose corals of the Carnic Alps and their relation to the Late Eifelian Kačák Event. 54-56. In: SUTTNER, T.J., KIDO, E., PILLER, W.E. & KÖNISGHOF, P. (eds), IGCP 596 - Opening Meeting, Graz, 19-24th September 2011. Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität, 16, Graz.

KREUTZER, L.H. (1990): Mikrofazies, Stratigraphie und Paläogeographie des Zentralkarnischen Hauptkammes. Jahrbuch der Geologischen Bundesanstalt, 133: 275-343.

LÄUFER, A.L. (1996): Variscan and Alpine tectonometamorphic evolution of the Carnic Alps (Southern Alps)- structural analysis, illite cristallinity, K-Ar and Ar-Ar geochronology. Tübinger Geowisseschaften Arbeiten, A26: 40 pp.

MANZONI, M. (1965): Faune a conodonti del Siluriano e Devoniano delle Alpi Carniche (Nota 1: M. Cocco, M. Lodin, M. Zermula, Val Bombaso, alta valle del Degano). Giornale di Geologia, s. 2, 33: 179-206.

MANZONI, M. (1966): Conodonti neodevonici ed eocarboniferi al Monte Zermula (Alpi Carniche). Giornale di Geologia, s. 2, 33: 461-491.

MIETTO, P., MUSCIO, G. & VENTURINI, C. (1986): Impronte di tetrapodi nei terreni carboniferi delle Alpi Carniche. Gortania, 7 (1985): 59-74.

PANTANELLI, D. (1882): Note microlitologiche sopra i calcari. Memorie della Reale Accademia dei Lincei, s. 3, 12: 387-396.

PERRI, M.C. & SPALLETTA, C. (2001): Hangenberg Event al limite Devoniano/Carbonifero al Monte Zermula, Alpi Carniche, Italia. Giornale di Geologia, s. 3, 62 (Suppl.): 31-40.

PIRAS, S. & SIMONETTO, L. (2011): The *triangulatus* Biozone in the Casera Meledis outcrop (Silurian, Lower Graptolitic Shales, Carnic Alps). Gortania Geologia, Paleontologia, Paletnologia, 32: 13-24.

PIRONA, G.A. (1861): Cenni geognostici sul Friuli. Annuario dell'Associazione Agraria del Friuli, 4: 259-299.

PONDRELLI, M. (1998): Evoluzione deformativa del Nucleo Ercinico Carnico Centro-Orientale. PhD Thesis, University of Bologna: 178 pp.

PONDRELLI, M., CORRADINI, C., CORRIGA, M.G., KIDO, E., SIMONETTO, L., SPALLETTA, C., SUTTNER, T.J. & CARTA, N. (2011): Pragian to Famennian depositional evolution of the M. Pizzul area (Carnic Alps, Italy): preliminary results. 78-79. In: SUTTNER, T.J., KIDO, E., PILLER, W.E. & KÖNISGHOF, P. (eds), IGCP 596 - Opening Meeting, Graz, 19-24th September 2011. Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität, 16, Graz.

SCHÖNLAUB, H.P. (1979): Das Paläozoikum in Österreich: Verbreitung, Stratigraphie, Korrelation, Entwicklung und Paläogeographie nicht-metamorpher und metamorpher Abfolgen. Abhandlungen der Geologischen Bundesanstalt, 33: 1-109.

SCHÖNLAUB, H.P. (1985): Das Paläozoikum der Karnischen Alpen. Arbeitstagung der Geologischen Bundesanstalt, 1985: 34-52.

SELLI, R. (1963a): Schema geologico delle Alpi Carniche e Giulie occidentali. Giornale di Geologia, s. 2, 30: 1-121.

SELLI, R. (1963b): Carta geologica del Permo-Carbonifero Pontebbano. Scala 1:20.000. Litografia Artistica Cartografica, Firenze.

SERPAGLI, E. (1967): I conodonti dell'Ordoviciano Superiore (Ashgilliano) delle Alpi Carniche. Bollettino della Società Paleontologica Italiana, 6 (1): 30-111.

SERPAGLI, E. & GRECO, A. (1965): Osservazioni preliminari su alcuni conodonti ordoviciani e siluriani delle Alpi Carniche italiane. Bollettino della Società Paleontologica Italiana, 3 (2): 192-211.

SPALLETTA, C., VAI, G.B. & VENTURINI, C. (1982): La Catena Paleocarnica. 281-292. In: CASTELLARIN, A. & VAI G.B. (eds) Guida alia geologia del Sudalpino centro-orientale. Guide Geologiche Regionali Società Geologica Italiana, Bologna.

STEARN, C.W. (1997): Intraspecific variation, diversity, revised systematics and type of the Devonian stromatoporoid, *Amphipora*. Palaeontology, 40 (3): 833-854.

STUR, D. (1856): Die geologischen Verhältnisse der Thäler der Drau, Isel, Möll und Gail in der Umgebung von Lienz, ferner der Carnia im Venetianischen Gebiete. Jahrbuch der kaiserlich-königlichen Geologischen Reichsanstalt, 7: 405-459.

TARAMELLI, T. (1878): Catalogo ragionato delle rocce del Friuli. Memorie della Reale Accademia dei Lincei, s. 3, 1: 511-609.

TARAMELLI, T. (1881): Carta Geologica del Friuli rilevata negli anni 1867-74. Scala 1:200.000. Lit. E. Passero, Udine.

TARAMELLI, T. (1882): Geologia delle Provincie Venete con carte geologiche e profili. Memorie della Reale Accademia dei Lincei, s. 3, 13: 303-536.

TARAMELLI, T. (1895): Osservazioni stratigrafiche sul terreni paleozoici nel versante italiano delle Alpi Carniche. Rendiconti della Reale Accademia dei Lincei, s. 5, 4: 185-193.

VAI, G.B. (1976): Stratigrafia e paleogeografia ercinica delle Alpi. Memorie Società Geologica Italiana, 13 (1): 7-37.

VAI, G.B. (1980): Sedimentary environment of Devonian pelagic limestones in the Southern Alps. Lethaia, 13 (1): 79-91.

VAI, G.B., VENTURINI, C., CARULLI, G.B. & ZANFERRARI, A. (2002): Alpi e Prealpi Carniche e Giulie (Friuli Venezia Giulia). Guide Geologiche Regionali S.G.I. BE-MA Editrice, 9: 390 pp., Milano.

VENTURINI, C. (1990a): Geologia delle Alpi Carniche centro orientali. Pubblicazioni del Museo friulano di storia naturale, 36: 222 pp.

VENTURINI, C., (ed.) (1990b): Field Workshop on Carboniferous to Permian sequence of the Pramollo-Nassfeld Basin (Carnic Alps).Guidebook Arti Grafiche Friulane: 160 pp., Udine.

VENTURINI, C., SPALLETTA, C., VAI, G.B., PONDRELLI, M., DEL ZOTTO, S., FONTANA, C., LONGO SALVADOR, G. & CARULLI, G.B. (2009): Note Illustrative al Foglio 031 Ampezzo, Carta geologica d'Italia alla scala 1:50.000. ISPRA, Servizio Geologico Italiano: 232 pp.

VINASSA DE REGNY, P. (1907): Graptoliti carnici. Atti del congresso dei Naturalisti Italiani, Milano, settembre 1906: 161-186.

VINASSA DE REGNY, P. (1910): Fossili ordoviciani del nucleo centrale carnico. Memorie dell'Accademia Gioenia di Scienze Naturali di Catania, s. 5, 3: 48 pp.

VINASSA DE REGNY, P. & GORTANI, M. (1905a): Osservazioni geologiche sui dintorni di Paularo (Alpi Carniche). Bollettino della Società Geologica Italiana, 24 (1): 1-15.

VINASSA DE REGNY, P. & GORTANI, M. (1905b): Fossili carboniferi del M. Pizzul e del Piano di Lanza nelle Alpi Carniche. Bollettino della Società Geologica Italiana, 24 (2): 461-520.

VINASSA DE REGNY, P. & GORTANI, M. (1908): Nuove ricerche sul Nucleo centrale delle Alpi Carniche. Rendiconti della R. Accademia dei Lincei. Classe di scienze fisiche, matematiche e naturali, s. 5, 17, (10): 603-612.

Addresses of authors

AMINI, A. – University of Tehran, Department of Geology, Tehran, Iran

AN, Z.-S. – State Key Laboratory of Loess and Quaternary Geology, Institute of Earth and Environment, CAS, Xi'an, Shaanxi, 710075, China; qiangxk@loess.llqg.ac.cn

BELGHITHI, H. – Sfax engineering school, sedimentary dynamic and environment, 3038 Sfax, Tunisia / Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; belghithihanene@gmail.com

BERTOLA, C. – Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium

BOULVAIN, F. – Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; fboulvain@ulg.ac.be

BRANDANO, M. – Department of Earth Sciences, University of Rome "La Sapienza", 00185-Rome, Italy; marco.brandano@uniroma1.it

BULTYNCK, P. – Department of Paleontology, Royal Belgian Institute of Natural Sciences, rue Vautier 29, BE-1000 Brussels, Belgium; pierre.bultynck@naturalsciences.be

CATIANIS, I. – GeoEcoMar, 23-25 Dimitrie Onciul St., RO-024053 Bucharest, Romania; catianis_irina@yahoo.com

ČÁP, P. – Czech Geological Survey, P.O.B. 85, 118 21 Praha 1, Czech Republic

CARTA, N. – via Emilio Lussu 21, I-09040 Settimo S. Pietro (CA); nicola.carta1@virgilio.it

CHEN, D. – Institute of Geology and Geophysics, Chinese Academy of Science, #19 Beitucheng Xilu, Chaoyang District, Beijing 100029, China; dzh-chen@mail.igcas.ac.cn

CHEN, X.-Q. – State Key Laboratory of Palaeobiology & Stratigraphy, Nanjing Institute of Geology and Palaeontology, Nanjing, China, 39 East Beijing Road, Nanjing 210008, China; xqchen@nigpas.ac.cn

CLAEYS, P. – Earth System Sciences and Department of Geology, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium; phclaeys@vub.ac.be

CORNET, P. – Sedimentary Petrology, B20, Université de Liège, Sart-Tilman 4000, Liège, Belgium

CORRADINI, C. – Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari, Italy; corradin@unica.it

CORRIGA, M.G. – Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, I-09127 Cagliari, Italy; maria.corriga@unica.it

DA SILVA, A.C. – Liège University, Sedimentary Petrology Laboratory, B20, Sart Tilman, 4000 Liège, Belgium; ac.dasilva@ulg.ac.be

DAI, S. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China; daisher@lzu.edu.cn

DEKKERS, M.J. – Faculty of Earth Sciences, Department of Earth Science, Paleomagnetic Laboratory Fort Hoofddijk, Utrecht University, Utrecht, The Netherlands

DE VLEESCHOUWER, D. – Earth System Sciences and Department of Geology, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium; dadevlee@vub.ac.be

DEVLEESCHOUWER, X. – Institut royal des Sciences naturelles de Belgique, rue Vautier, 29, B-1000 Bruxelles, Belgium; Xavier.Devleeschouwer@naturalsciences.be

ESSEFI, E. – Sedimentary Dynamics and Environment (DSE) (Code 03/UR/10-03), National Engineering School of Sfax, University of Sfax, Road of Soukra, km 4. Sfax, 3038 Sfax, Tunisia; hocinsefi@yahoo.fr

FRÝDA, J. – Czech Geological Survey, P.O.B. 85, 118 21 Prague 1 / Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6 – Suchdol, 165 21, Czech Republic; bellerophon@seznam.cz

FU, C.-F. – Key Laboratory of Western Mineral Resources and Geological Engineering, Ministry of Education of China & Chang'an university, Xi'an, Shaanxi, 710054, China; fuchaofeng@gmail.com / State Key Laboratory of Loess and Quaternary Geology, Institute of Earth and Environment, CAS, Xi'an, Shaanxi, 710075, China; qiangxk@loess.llqg.ac.cn

GRABOWSKI, J. – Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warszawa, Poland; jacek.grabowski@pgi.gov.pl

HARZHAUSER, M. – Geological-Paleontological Department, Natural History Museum Vienna, 1010 Vienna, Austria; mathias.harzhauser@nhm-wien.ac.at

HLADIL, J. – Institute of Geology ASCR, v.v.i., Rozvojova 269, Prague 6, 16500, Czech Republic; hladil@gli.cas.cz

HUANG, Y.-B. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China

JAN, B. – Geomagnetism Lab, School of Environment Science, University of Liverpool, Oliver Lodge Building, Liverpool L69 7ZE, UK; janbloemendal@gmail.com

JAROCHOWSKA, E. – GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany; e.jarochowska@student.uw.edu.pl

KIDO, E. – Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; erika.kido@uni-graz.at

KÖNIGSHOF, P. – Senkenberg, Forschunginstitut und Naturmuseum Frankfurt, Senkenbergganlage 25, 60325 Frankfurt, Germany; peter.koenigshof@senckenberg.de

KONG, L. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China

KOPTÍKOVÁ, L. – Institute of Geology ASCR, v.v.i., Rozvojova 269, Prague 6, 16500, Czech Republic; koptikova@gli.cas.cz

KOZŁOWSKI, W. – Faculty of Geology, University of Warsaw, 93 Żwirki i Wigury Str., 02-089 Warsaw, Poland; woko@uw.edu.pl

LI, C.-X. – State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, No 10 Fenghui Nan Road, Xi'an, Shaanxi 710075,China

LIU, H.-J. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China

LIU, J.-W. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China

LIU, X. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China

ŁUCZYŃSKI, P. – University of Warsaw, Faculty of Geology, Żwirki I Wigury 93, 02 089 Warsaw, Poland

LUKENEDER, A. – Geological and Palaeontological Department, Natural History Museum Vienna, Burgring 7, A-1010 Vienna, Austria; alexander.lukeneder@nhm-wien.ac.at

LUKENEDER, S. – Geological and Palaeontological Department, Natural History Museum Vienna, Burgring 7, A-1010 Vienna, Austria; susanne.lukeneder@nhm-wien.ac.at

MANDA, Š. – Czech Geological Survey, P.O.B. 85, 118 21 Praha 1, Czech Republic

MARSHALL, C. – Geosystems Research Group, School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, B15 2TT, UK; Present address: VNG Norge AS. Postboks 720 Sentrum, NO-4003 Stavanger, Norway; Carly.Marshall@vng.no

MAWSON, R. – Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW, 2109, Australia; rmawson37@gmail.com

MUNNECKE, A. – GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany; axel.munnecke@gzn.uni-erlangen.de

MUSCIO, G. – Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; giuseppe.muscio@comune.udine.it

NARKIEWICZ, M. – Polish Geological Institute, National Research Institute, Rakowiecka 4, 00-975 Warszawa, Poland; marek.narkiewicz@pgi.gov.pl

PAS, D. – Sedimentary Petrology, B20, Université de Liège, Sart-Tilman 4000, Liège, Belgium; dpas@ulg.ac.be

PETICLERC, E. – Royal Belgian Institute f Natural Sciences, Geological Survey of Belgium, Rue Jenner 13, B-100 Brussels, Belgium; estelle.petitclerc@naturalsciences.be

PILLER, W.E. – Institute of Earth Sciences, University of Graz, 8010 Graz, Austria; werner.piller@uni-graz.at

PONDRELLI, M. – International Research School of Planetary Sciences, Dipartimento di Scienze, Università d'Annunzio, viale Pindaro 42, I-65127 Pescara, Italy; monica@irsps.unich.it

PRASANNAKUMAR, V. – Department of Geology, University of Kerala, Trivandrum, Kerala, India-695 581; prasannan@cgist.ac.in

PRATHEESH, P. – Department of Geology, University of Kerala, Trivandrum, Kerala, India-695 581

PRUNER, P. – Institute of Geology AS CR v.v.i., Rozvojova 269, 165 00 Praha 6, Czech Republic; pruner@gli.cas.cz

QIANG, X.-K. – State Key Laboratory of Loess and Quaternary Geology, Institute of Earth and Environment, CAS, Xi’an, Shaanxi, 710075, China; qiangxk@loess.llqg.ac.cn

RĂDAN, S. – GeoEcoMar, 23-25 Dimitrie Onciul St., RO-024053 Bucharest, Romania; radan@geoecomar.ro

RĂDAN, S.-C. – Geological Institute of Romania, 1 Caransebes St., RO-012271 Bucharest, Romania; sc.radan@yahoo.com

RAJESH, R. – Department of Geology, University of Kerala, Trivandrum, Kerala, India-695 581

RAJESH, S. – Department of Geology, University of Kerala, Trivandrum, Kerala, India-695 581

RAKOCINSKI, M. – University of Silesia, Faculty of Earth Sciences, Bedzińska Str. 60, 41–200 Sosnowiec, Poland; mrakocin@us.edu.pl

REUTER, M. – Institute of Earth Sciences, University of Graz, 8010 Graz, Austria; markus.reuter@uni-graz.at

SARDAR ABADI, M. – University of Liege, Pétrologie Sédimentaire, B20, Boulevard du Rectorat 15, 4000 Liege, Belgium; Mehrdad.SardarAbadi@student.ulg.ac.be

SCHNABL, P. – Institute of Geology AS CR v.v.i., Rozvojova 269, 165 00 Praha 6, Czech Republic; schnabl@gli.cas.cz

SCHNYDER, J. – University Paris VI, case 117, 4, pl. Jussieu, 75252 Paris Cedex 05, France; johann.schnyder@upmc.fr

SCHÖNLAUB, H.P. – Geopark Carnic Alps, A-9636 Dellach/Gail, Austria & Austrian Academy of Sciences, Center for Geosciences, Dr. Ignaz Seipel-Platz 2, A-1010 Vienna, Austria; hp.schoenlaub@aon.at

SIMONETTO, L. – Museo Friulano di Storia Naturale, via Marangoni 39-41, I-33100 Udine, Italy; luca.simonetto@comune.udine.it

SKOMPSKI, S. – University of Warsaw, Faculty of Geology, Żwirki I Wigury 93, 02 089 Warsaw, Poland

SLAVÍK, L. – Institute of Geology ASCR, v.v.i., Rozvojova 269, Prague 6, 16500, Czech Republic; slavik@gli.cas.cz

SLIWINSKI, M. – Department of Geology and Geophysics, University of Alaska Fairbanks, Faribanks, AK 99775, U.S.A.; mgsliwinski@alaska.edu

SOBIEŃ, K. – Polish Geological Institute - National Research Institute, 4 Rakowiecka Street, 00-975 Warsaw, Poland; Katarzyna.Sobien@pgi.gov.pl

SONG, Y. – State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, No 10 Fenghui Nan Road, Xi'an, Shaanxi 710075,China; syg@ieecas.cn

SPALLETTA, C. – Dipartimento di Scienze della Terra e Geologico Ambientali, Alma Mater Studiorum Università di Bologna, via Zamboni 67, I-40126 Bologna, Italy; claudia.spalletta@unibo.it

SUTTNER, T.J. – Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Heinrichstrasse 26, A-8010 Graz, Austria; thomas.suttner@uni-graz.at

VODRÁŽKOVÁ, S. – Czech Geological Survey, P.O.B. 85, 118 21 Praha 1, Czech Republic and GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Universität Erlangen, Loewenichstrasse 28, Erlangen, D-91054, Germany; stana.vodrazkova@seznam.cz

WANG, J. – Institute of Geology and Geophysics, Chinese Academy of Science, #19 Beitucheng Xilu, Chaoyang District, Beijing 100029, China; wangjg04@gmail.com

WATERS, J.A. – Department of Geology, Appalachian State University, Boone, NC 28608, USA; watersja@appstate.edu

WHALEN, M. – Department of Geology and Geophysics, University of Alaska Fairbanks, Faribanks, AK 99775, U.S.A.; mtwhalen@gi.alaska.edu

WÓJCIK, K. – University of Warsaw, Faculty of Geology, Żwirki i Wigury 93, 02-089 Warsaw, Poland; krystian.karol.wojcik@student.uw.edu.pl

YAICH, C. – Sfax engineering school, sedimentary dynamic and environment, 3038 Sfax, Tunisia; chokriyaich@gmail.com

ZENGHUI, G. – Institute of Geology and Geophysics, Chinese Academy of Science, #19 Beitucheng Xilu, Chaoyang District, Beijing 100029, China; guozenghui19890525@126.com

ZHAO, J. – Key Laboratory of Western China's Environmental Systems, Ministry of Education of China & College of Resources and Environment, Lanzhou University, Gansu 730000, China

ZHU, Q. – Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

Index