Evidence of global climatic and sea level cycles in the Cambrian

Babcock, Loren; Peng, Shanchi; Brett, Carlton E.; Zhu, Maoyan; Ahlberg, Per; Bevis, Michael

Published in:
IGCP 591 Field Workshop 2014, Kunming, China, 12-21 August 2014, Extended Summary

2014

Link to publication

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Evidence of global climatic and sea level cycles in the Cambrian

Loren E. BABCOCK1,2, PENG Shanchi1, Carlton E. BRETT4, ZHU Maoyan1, Per AHLBERG2 and Michael BEVIS3

1School of Earth Sciences, The Ohio State University, Columbus, Ohio, 43210, USA < babcock.5@osu.edu>
2Department of Geology, Lund University, SE-223 62, Lund, Sweden
3State Key Laboratory of Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210006, China
4Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221, USA

New, well resolved chronostratigraphy of the Cambrian provides an intercontinental framework for age interpretation of myriad geologic and biotic phenomena. The precision of correlation on a global scale now available (Peng et al., 2012) greatly exceeds that available prior to one decade ago, when the first internal subdivisions of the Cambrian System were ratified. Using a combination of well-constrained biostratigraphic, chronostratigraphic, and other techniques, a number of correlation issues have been resolved over the past decade. The newly available chronostratigraphic record shows broad time-specific patterns of lithofacies and biofacies that appear to be consistent across all Cambrian paleocontinents. The best intercontinental record of evolutionary events key to correlating globally has come from outer shelf facies, commonly dark, organic-rich shales and limestones. Some taxa preserved in these strata, including some agnostoid, pelagic polymerid, micromollusk, conodont, acritarch, and other species, have widespread or cosmopolitan distributions, particularly around continental margins. Important evolutionary events including radiations, migrations, and extinctions, tend to coincide with perturbations in the global carbon cycle (Zhu et al., 2006), so the secular pattern of δ13C provides a good baseline for constraining correlations even in situations where traditional biostratigraphic criteria are absent or ambiguous. Even in low latitude paleocontinents where there is commonly great disparity between faunas of the outer shelf and the more restricted inner shelf, carbon isotope chronostratigraphy has proven valuable for correlation.

In this preliminary report we call attention to lithofacies and biofacies attributes of Cambrian and genetically related lowermost Ordovician strata that reveal evidence of synchronous or near-synchronous global cyclicity in sedimentary patterns. We infer that these patterns are linked to oceanographic and climatic cycles characteristic of glacial expansion and deglaciation.

One striking aspect of Cambrian stratigraphy is the coincidence of biotic events with shifts in the δ13C cycle (Zhu et al., 2006; Peng et al., 2012). Evolutionary events, such as the radiation of archaeocyaths and various arthropod clades, as well as significant extinction events such as the extinction of archaeocyaths and the extinction of trilobite and other taxa at biomere boundaries, line up closely with shifts in δ13C. Understanding the interplay of biotic factors and δ13C history provides a semi-independent means of assessing time relationships in the Cambrian, and providing a check on biostratigraphic interpretations.

Another striking aspect of Cambrian stratigraphy, particularly in the upper two series, is in the zonation of agnostoids (reflecting the evolution of new species and rapid global migration; Peng and Robison, 2000; Peng et al., 2012; Fig. 1), and repeated extinctions of polymerid trilobites followed by recovery and radiation, or biomeres (Palmer, 1965; Stitt, 1975; Fig. 1). One of the most readily recognizable sedimentary horizons in the Cambrian is the position marking the base of the Ptychagnostus gibbus Zone. Generally this horizon is a disconformity, and in low paleolatitudes it is commonly marked by shales containing P. gibbus overlying a carbonate platform succession. It is interpreted as a major marine flooding surface, one of the most substantial in the Paleozoic. Above this position, there is a good record of outer-shelf facies, and a commensurate record of cosmopolitan agnostoid taxa. The agnostoids provide one of the best tools for precise intercontinental correlation
from the *P. gibbus* Zone through the Lower Ordovician (Tremadocian). There is a regular, repeating pattern of species appearances in open-shelf facies, where agnostoid zones seem to have a time duration of about one to two million years each. The appearances of agnostoid species is closely linked to lithofacies patterns (Babcock et al., 2007; Peng et al., 2012), resulting in zonal boundaries slightly above the bases of transgressive systems tracts.

<table>
<thead>
<tr>
<th>GLOBAL SERIES</th>
<th>GLOBAL STAGES</th>
<th>EUSTATIC RECORD</th>
<th>AGNOSTOID FIRST APPEARANCES</th>
<th>BIOMERES IN LAURENTIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOWER</td>
<td>Tremadocian</td>
<td>Stage 10</td>
<td>FAD Lotagnostus americanus</td>
<td>Plychaspid Biomere</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jiangshanian</td>
<td>FAD Agnostotes orientalis</td>
<td>Pterocephalid Biomere</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paibian</td>
<td>FAD Glyptagnostus reticuatus</td>
<td></td>
</tr>
<tr>
<td>FURONGIAN</td>
<td></td>
<td>Guzhangian</td>
<td>FAD Lejopyge laevigata</td>
<td>Marjuman Biomere</td>
</tr>
<tr>
<td>SERIES 3</td>
<td></td>
<td>Drumian</td>
<td>FAD Plyagnostus atavus</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stage 5</td>
<td>FAD Plyagnostus gibbus</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Inferred eustatic record in the upper two series of the Cambrian System (Series 3 and Furongian Series) compared with the first appearance datum (FADs) of cosmopolitan agnostoids, and biomere intervals recorded in Laurentia.

Multiple lines of evidence suggest that water temperature was a controlling factor on marine biota of the latter part of the Cambrian. In low latitude regions, disjunct shelf (warm water) and deeper slope-basinal (cool water) trilobite faunas have been documented from Series 3 (Babcock, 1994) and the Furongian Series (Taylor and Cook, 1976). By way of analogy with the Quaternary, such a distribution of marine arthropods implies a stratified water column, with warm water near the surface in the tropics and cooler water of polar origin below (Taylor and Cook, 1976). In the Quaternary, a temperature-stratified water column in which warm and cool water masses have different circulation patterns, is a function of the presence of continental glaciers in polar regions. A similar forcing mechanism has been hypothesized for the Cambrian (Babcock, 1994), and this is supported in part by the interpretation that large portions of southern Gondwana lay astride the south polar region (Peng et al., 2012).

Biomere extinctions have commonly been attributed to the transgressive rise of deep, cool waters onto shallow shelf platforms, followed by extinction or displacement of most shelf trilobites, and their replacement by taxa whose ancestors were cool-water adapted (e.g. Stitt, 1975). Two biomere boundaries mark the bases of Cambrian stages (Drumian and Paibian), and reflect significant turnovers in shelf-dwelling polyomorphs coincident with the arrival of agnostoid taxa used for global correlation (Fig. 1). The first appearances of these agnostoids are just above the bases of major
transgressive surfaces, suggesting that deglaciation associated with icehouse-to-greenhouse transitioning supplied quantities of cool water to polar shelf areas of Gondwana sufficient to induce eustatic rise. The cool water likely circulated northward toward the equator below warmer surface waters. Accompanying the transgressions, agnostoids and cool-water-adapted polymerids arrived onto outer shelf areas of low latitude continents.

A variety of sedimentologic signals, recognizable on a global scale in the same stratigraphic positions, tend to reinforce the inferred eustatic pattern, or alternatively, to suggest pulses of water mass movement of global consequence. Among these, hash beds of agnostoids, notably in the dysoxic facies of the Furongian Stage, suggest temporary pulses of oxygenation of the sea floor. Pulses of oxygenation are likely the result of oxygen-rich cool water arriving from polar deglaciation. Coquinas of agnostoids, notably in the lower Drumian Stage and in various positions within the Furongian Series, suggest lag deposition related to sediment starvation during late transgressive phases or highstands. In the Furongian, slide deposits along continental slopes, comprising carbonate material of shelf-edge origin, imply lowstand intervals. Carbonate concretion horizons, known best from the Alum Shale Formation (e.g. Calner et al., 2013), seem to correlate near-globally, although the concretions are not always of the same large size as the famous ‘órsten’ concretions of Scandinavia. Dissolution of the upper surfaces of some concretions in Scandinavia suggests sediment starvation and removal through corrosion. In dysoxic or anaerobic facies, some concretionary horizons feature cone-in-cone calcite, and the positions of these horizons correlate near-globally.

Selected references


IGCP Project 591 Field Workshop 2014

in conjunction with

International Subcommission on Silurian Stratigraphy (ISSS)
International Subcommission on Ordovician Stratigraphy (ISOS)
and
International Subcommission on Cambrian Stratigraphy (ISCS)

Extended Summary

Edited by
ZHAN Renbin and HUANG Bing
"Geologic and biotic events and their relationships during the Early to Middle Paleozoic"
Kunming, China; 13 – 21 August 2014

Organizing and Scientific Committee:
ZHAN Renbin (chair), Nanjing Institute of Geology & Palaeontology
HOU Xiangguang (vice-chair), Yunnan University, Kunming
ZHANG Yuandong (vice-chair), Nanjing Institute of Geology & Palaeontology
WANG Yi (secretary), Nanjing Institute of Geology & Palaeontology
HUANG Bing (secretary), Nanjing Institute of Geology & Palaeontology
FENG Zuo (secretary), Yunnan University, Kunming
MIKE MELCHIN (ISSS), St. Francis Xavier University, Canada
DAVID HARPER (ISOS), Department of Earth Sciences, Durham University, UK
ZHANG Xingliang (ISCS), Northwest University, Xi'an
CONG Peiyun, Yunnan University, Kunming
WU Rongchang, Nanjing Institute of Geology & Palaeontology
YANG Qun, Nanjing Institute of Geology & Palaeontology
LIU Yu, National Natural Science Foundation of China
Brad CRAMER, University of Iowa, USA
Jinsuo JIN, Western University, Canada

Suggested reference format:


Explanations of cover photos:
Cover: upper—a ventral internal mould of brachiopod Sauvania sp. (~x15) from the Shihtien Fm (Darriwilian, Middle Ordovician) of Laqianshan, Baoshan; down—graptolite Lithostrotia glomerata Ni (~x5) from the lower Jenhawkian Fm (upper Aeronian, middle Llandovery) of the same section as above.
Rock cover: a complete specimen of Anomalocaris sarus (~17cm) from the lower Yu’anshan Mpb of the Heilinpu Fm (Cambrian Stage 3) of Maotianshan, Chengjiang, eastern Yunnan.

ISBN 978-7–305–13559–0
Preface

IGCP Project 591 is dedicated to investigating the "Early to Middle Paleozoic Revolution". Indeed, the geological interval from Cambrian to Devonian was full of revolutionary events, both in the organic and inorganic realms, and their interactions triggering the macroevolution of Earth ecosystems as well as the solid Earth itself. The well known Cambrian Explosion, the first macroevolutionary radiation of ecosystem, comprises several episodes from its prologue (represented by the Ediacara Biota), through the first (the Small Shelly Fauna) and the main stages (the Chengjiang Biota) to the epilogue (the Burgess Shale Fauna, the Kaili Fauna etc.). The great Ordovician biodiversification event (GOBE), i.e. the Ordovician radiation, spanned tens of million years, highlighted by several diversity acmes, and established the basic framework of the Paleozoic Evolutionary Fauna that dominated the marine ecosystems for more than 290 Ma. The end-Ordovician mass extinction was the first catastrophic event in life history. It is now known not to be ranked as one of the Big Five, and the marine ecosystem did not collapse at all during this mass extinction. None of these major biotic events are regional in scale, not to say local, although all of them were closely related with local, regional and global tectonic movements, paleogeographic and paleoclimatic changes and apparently some sedimentary innovations (e.g. the Substrate Revolution in Cambrian and Ordovician), as well as some other geological activities such as volcanic eruptions, comets collision, Milankovich cycles, etc. To investigate these Early to Middle Paleozoic revolutionary events and their dynamics, geoscientists in the world need a common language, i.e. the GSSPs and the establishment of regional and global chronostratigraphic frameworks, which have been some of the major tasks of each Subcommission of ICS for several decades.

On behalf of the Organizing Committee, we would like to take this opportunity to thank all 151 experts who have co-authored the 66 abstracts, summaries and extended summaries in this Extended Summary volume for this meeting. The scope of these papers covers all the above-mentioned topics dealing with the Early to Middle Paleozoic revolutionary events and their triggering factors. Among the 151 contributors, nearly half of them are graduate students or young researchers who brought great vitality to this meeting as well as the IGCP Project. We also want to thank the three keynote speakers, Michael Melchin (ISSS), David Harper (ISOS) and Loren Babcock (ISCs), who prepared both extended summaries and reviewed presentations for this meeting.

Many thanks to the following institutions for their financial support; the National Natural Science Foundation of China (NNSFC; 41221001, 41290260 and another special project); the Nanjing Institute of Geology and Palaeontology (NIGP) of CAS; the State Key Laboratory of Palaeobiology and Stratigraphy (LPS); and the Yunnan Key Laboratory of Paleobiology (YLP) attached to the Yunnan University.

Zhan Renbin and Huang Bing
On behalf of the Organizing Committee
Contents

Leho AINSAAR, Peep MÄNNIK, Andrei V. DRONOV, Olga P. IZOKH, Tõnu MEIDLA and Oive TINN: Carbon isotope chemostratigraphy and conodonts of the Middle–Upper Ordovician succession in Tungus Basin, Siberian Craton ................................................. 1

Anna ANTOSHKINA: Oolite-stromatolite association: A possible sedimentological marker of Silurian bioevents, Timan-northern Ural region ......................................................... 5

Loren E. BABCOCK, PEN G Shanchi, Carlton E. BRETT, ZHU Maoyan, Per AHLBERG and Michael BEVIS: Evidence of global climatic and sea level cycles in the Cambrian ...................................................... 9

Carlton E. BRETT, Thomas J. MALGIERI, James R. THOMKA, Christopher D. AUCOIN, Ben DATTILO and Cameron E. SCHWALBACH: Calibrating water depths of a Late Ordovician ramp, southern Ohio and north-central Kentucky, USA .............................................................. 12

Carlton E. BRETT, James R. THOMKA, Thomas J. MALGIERI, Cameron E. SCHWALBACH and Christopher D. AUCOIN: Faunal epiboles in the Upper Ordovician of north-central Kentucky: Implications for high-resolution sequence and event stratigraphy and recognition of a major unconformity ............................................................. 15

CHEN Qing and FAN Junxuan: Changes in the sedimentary facies during the Ordovician-Silurian transition in South China ........................................................................................................ 18

CHEN Zhongyang, WANG Chengyuan and FAN Junxuan: Problems on the correlation of the Llandovery (Silurian) strata on the Upper Yangtze Platform, South China ................................................. 21

Bradley D. CRAMER, Thijs R. A. VANDENBROUCKE and Gregory A. LUDVIGSON: Asking old rocks new questions: High-resolution event stratigraphy (HiRES) and the quantification of stratigraphic uncertainty .......................................................................................................................... 24

Yulia E. DEMIDENKO and Pavel Yu. PARKHAEV: On the problem of recognition of the lower Tommotian boundary using the SSF .................................................................................................. 26

DUAN Ye: Middle and Upper Cambrian strata, depositional environments and trilobite faunas of the Fenghuang-Chenxi area, western Hunan, China .................................................................................. 32

Jorge ESTEVE: Morphological variation in paradoxid trilobites from Cambrian Series 3 of Spain ........... 37

Jorge ESTEVE and YUAN Jinliang: Enrolment of Guzhangian trilobites from Shandong Province, North China ................................................................................................................................. 40

FANG Xiang, ZHANG Yunbai, CHEN Ting’en and ZHANG Yuandong: Taxonomy of Ordovician cephalopods Sinoceras chinense (Foord): A quantitative approach .............................................. 42

Oldrich FATKA, Petr BUDIL, Martin DAVID, Vladislav KÖZÁK, Václav MICKA and Michal SZABAD: Digestive structures in Cambrian and Ordovician trilobites from the Barrandian area (Czech Republic) .......................................................... 49

David A. T. HARPER: The Great Ordovician Biodiversification Event: Reviewing two decades of research on diversity’s big bang ........................................................................................................... 52

HUANG Bing, ZHAN Renbin and WANG Guangxi: Brachiopod associations from late Rhuddanian in South China and their bathymetric significance ........................................................................ 57
Extended Summary

HOU Xudong and FAN Junxuan: CONOP—A quantitative stratigraphic software and an approach to its parallelization ................................................................. 61

JING Xiuchun, ZHOU Hongrui and WANG Xunlian: Conodont biostratigraphy of the Darriwilian and the Sandbian from Wuhai area, Inner Mongolia, China .............................................................. 64

Igor V. KOROVNIKOV: New data on the paleobiogeography of Cambrian trilobites from western and northern margins of the Siberian Platform .................................................................................. 67

Lukáš LAIBL, Oldřich FATKA, Jorge ESTEVE and Petr BUDIL: Ontogeny and larval ecology of paradoxid trilobites (Eccaparadoxides and Hydrocephalus) from the Skryje-Týrovice Basin (Czech Republic) ........................................................................................................... 71

LI Yujing, ZHANG Jun, CONG Peiyun and HOU Xianguang: New morphological specificity of vetulicolians and its implications ................................................................. 74

LIANG Yan, TANG Peng and ZHAN Renbin: Preliminary report on the chitinozoans from the Lower Ordovician Tungtzu and Henghuayuan formations of Tongzi, northern Guizhou, southwest China ........................................................................................................... 75

LUAN Xiaonong, LIU Jianbo and ZHAN Renbin: Microfacies of the Lower to Middle Ordovician Zitai Formation of southern Anhui and its implications ......................................................... 80

MA Xiaoya, CONG Peiyun, HOU Xianguang, Gregory EDGECOMBE and Nicholas STRAUSFELD: Deep thoughts from deep time—central nervous systems of Cambrian panarthropods ............................................. 85

Michael J. MELCHIN and Kevin-Dane MACRAE: Insights into the Rhuddanian-Aeronian and Aeronian-Telychian boundary intervals from eastern and Arctic Canada ..................................................... 86

Michael J. MELCHIN, H. David SHEETS, Charles E. MITCHELL and FAN Junxuan: Global stratotype sections and points and quantitative stratigraphic correlation: A way forward for defining and correlating the Silurian System ........................................................................................................... 89

Lucy A. MUIR and Joseph P. BOTTING: Environmental distribution and diversity of Ordovician Porifera in the Bwlch Inlier, Wales ......................................................................................................................... 92

Martina NOHEJLOVÁ and Oldřich FATKA: Ontogenetic development of the genus Akadocrinus (Eocrinoida, Echinodermata) from the Barrandian area, Czech Republic ................................................................. 97

Natalya V. NOVOZHILOVA: Morphological and microstructural features of Early Cambrian Archasterellida (Chancelloriida) of the Siberian Platform ......................................................................................... 99

Pavel Yu. PARKHAEV: On the stratigraphy of Aldarella attleborensis—potential index-species for defining the base of Cambrian Stage 2 ................................................................................................................. 102

PENG Jin, ZHANG Yuanlong, SUN Haijing, YAN Qiaojie, WEN Rongqin, SHEN Zhen and LIU Shuai: Biostratigraphic study on the Balang Formation (Series 2, Cambrian) of Guizhou, China ........................................................................................................ 106

Ian G. PERCIVAL and Peter D. KRUSE: Biostratigraphy and biogeographic affinities of middle to late Cambrian lingsulforme brachiopods from Australasia ........................................................................... 109

Kairi PÖLDSAAR and Leho AINSAR: Recognizing triggers for extensive liquefaction structures in two Early Paleozoic shallow-marine sandstones, NW Estonia: Earthquake shock vs. cyclic storm loading ........................................................................................................................................ 117

RONG Jiayu, ZHAN Renbin and HUANG Bing: The pre-Hirnantian Late Ordovician shallow water brachiopod biogeography of Tarim, Qaidam, North and South China: A preliminary report ........................................................................................................ 120

Jacky ROUSSELLE: A look at certainties and uncertainties relating to the Early Paleozoic climate (earliest Cambrian-end of Silurian) .................................................................................................................. 126
Sergey ROZHNOV: The history of tiering in Ordovician and Silurian crinoid communities and myelodactyloid occurrences in Russia and China ......................................................... 130
N. V. SENNIKOV, O. A. RODINA, N. G. IZOKH and O. T. OBUT: New data on Silurian vertebrates from Siberia and their stratigraphic ranges ......................................................... 134
SONG Yanyan, ZHANG Yuandong, Daniel GOLDMAN, WANG Zhihao, FANG Xiang and MA Xuan: Latest Darriwillian to early Sandbian graptolite biostratigraphy in Chengkou, northern Chongqing, South China ........................................................................................................ 138
Colin SPROAT, Jisuo JIN, ZHAN Renbin and David RUDKIN: Morphological variability in the Late Ordovician Pareastraphina from eastern Canada and the Tarim Basin, northwestern China and its paleoecological implications ...................................................................... 144
Petr ŠTORCH, Štěpán MANDA and Zuzana TASÁRYOVÁ: Rhuddanian-Aeronian boundary strata in graptolite-bearing black shale succession of the Barrandian area (Czech Republic) ......................................................... 148
Svend STOUGE, Gabriella BAGNOLI, QI Yuping, WU Rongchang and LI Zhihong: Darriwillian-Sandbian (Ordovician) conodonts from the top Kunituan, Datianba and Miaopo formations, central and south China ........................................................................................................... 152
SUN Haijing, Loren E. BACCOCK, PENG Jin and ZHAO Yuanlong: New systematic and anatomical information about Cambrian hyoliths from Guizhou, China and Nevada, USA ....................................................................................... 153
TANG Peng, WANG Jian, WANG Chengyuan, LIANG Yan and WANG Xin: Microfossils from the Llandover-Wenlock boundary sections in Ziyang-Lango region, southern Shaanxi, central China ......................................................... 155
Zuzana TASÁRYOVÁ, Petr SCHNABL, Vojtěch JANOUŠEK, Petr PRUNER. Petr ŠTORCH.
Kristýna ČÍÝŽKOVIÁ, Štěpán MANDA and Jiří FRÝDA: Paleomagnetism and geochemistry of middle Silurian volcanic rocks of the Prague Basin ....................................................................................... 158
Oive TINN, Viirika MASTIK, Leho AINSAAR and TõnU MEIDLA: Exceptionally well-preserved noncalcified algal fossils from the lower Silurian (Llandover, Aeronian) of Estonia .............................................................................................................................. 160
Tatiana Yu, TOLMACHEVA and K. E. DEGTYAREV: Conodonts of the Open-Sea Realm and their diversity in the Early and Middle Ordovician ........................................................................................................... 163
Petra TONAROVÁ and Olle HINTS: Silurian scolecodonts and extinction events ................................................................................................................................. 168
Valeria VAŠKANINOVÁ: Preliminary report on the occurrence of vertebrate remains in the Silurian of the Prague Basin .............................................................................................................................. 170
WANG Chuanshang, CHEN Xiaohong, WANG Xiaofeng and LI Xubing: The Sedimentary Evolution of the late Caledonian foreland basin in the Upper Yangtze Region ........................................................................ 173
WANG Guangxu and ZHAN Renbin: A new species of Paramplexoides (rugosans) from the Hirnantian Kuanyinchiao Formation of northern Guizhou, South China ....................................................................................... 178
WANG Jian, WANG Xin, Petr ŠTORCH, ZHANG Ju. MENG Yong, FU Lipu and LI Rongshe: Graptolite fauna from the Llandover-Wenlock boundary section, southern Shaanxi Province, central China ........................................................................................................... 182
WANG Pingli, SUN Zhixin and YUAN Jiliang: Preliminary study on an exceptionally well-preserved preserved fauna from the Mantou Formation, Cambrian Series 3, Weifang City, Shandong ....................................................................................... 185
WANG Yi, ZHANG Xiaole and JIANG Qing: The Pridoli palynological assemblage of the Sibumasu Block from Baoshan, western Yunnan, SW China ....................................................................................... 189
WEN Rongqin, PENG Jin and ZHAO Yuanlong: The morphology and ontogeny of Tuzoa bispinosa from the Cambrian in eastern Guizhou, South China ........................................................................................................... 193
Anthony J. WRIGHT: *Evolution and biogeography of Silurian and Devonian operculate corals* .............................................. 197

WU Rongchang, ZHAN Renbin, LIU Jianbo, Michael JOACHIMSKI, CHEN Jun and Axel MUNNECKE: *Carbon and conodont apatite oxygen isotope records from the Floian to lower Darrwilian (upper Lower and Middle Ordovician) in South China, and their paleoenvironmental implications* ......................................................... 201

YAN Kui and LI Jun: *Acrinarch and prasinophyte assemblage from the Qiaoqia Formation in Luquan, Yunnan Province, South China* ........................................................................................................ 206

ZHANG Linna, FAN Junxuan and ZHANG Yuandong: *Insights into the lithofacies paleogeography and paleobiogeography in South China during the Darrwilian (Middle Ordovician)* .......................................................... 210

ZHANG Xiaole and LIU Jianbo: *Red beds of the Laojiashan Formation in western Yunnan: Sedimentary evolution of tidal dominated deposits* ........................................................................................................ 213

ZHANG Yuanyuan, LI Yue and WANG Jianpo: *Lithofacies of the Yijiantang Formation (Darrwilian, Middle Ordovician) in the Lunnan Oil Field, Tarim, northwest China* ................................................................. 216

ZHENG Wenjin and ZHU Min: *Silurian fishes from Yunnan, China and related biostratigraphy* .................................................. 221

ZHENG Xiuli, LI Shoujun, REN Xiangbin, WANG Lili, CHEN Yuhui, MA Wenzhao and WANG Xiujing: *Sporopollen assemblage characteristics and significance of the Forth Member of Shahejie Formation in Qingdong Sag* ........................................................................................................ 226

ZHENG Yuanlong, CHENG Xin, ZHU Maoyan, YANG Xinglian, PENG Jin, WANG Pingli and WANG Mingkun: *Preliminary study on the Medusiform fossils Pararotodiscus (Zhao and Zhu, 1994) coexistence with other fossils from the Kali Biota* ................................................................................................................. 231

ZHENG Yongyi and Ian G. PERCIVAL: *Floian (Early Ordovician) conodont biogeography, biofacies, and biostratigraphic correlation between Australia and South China* .................................................................................. 234

ZHENG Yongyi and ZHANG Yuandong: *Early Ordovician conodont biostratigraphy of the Jiangnan Slope, South China* .............................................................................................................................. 238

ZHU Xuejian and PENG Shanchi: *A new Burgess Shale-type biota from the later Cambrian rocks of China.* ......................................................................................................................................................... 242

Index for Authors ................................................................................................................................................................................. 245