# Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics

# ABSTRACT VOLUME

IUGS UNESCO IGCP 668

United Nations
Educational, Scientific and
Cultural Organization

**INAUGURAL MEETING**
**Bangkok, Thailand**
**29-30 November 2018**

# Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics

## Inaugural Meeting
## Asia Hotel, Bangkok, Thailand

## 29 - 30 November 2018

United Nations
Educational, Scientific and
Cultural Organization

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# Preface from IGCP668 Project Leader

A sincere welcome to this inaugural meeting of newly approved IGCP project 668. I am sure that you will all join me in thanking our most gracious hosts, the Department of Mineral Resources of His Majesty's Government of Thailand. What better place to start our project on the ancient margin of Gondwana than here, right at the heart of the Shan-Thai/Sibumasu block? Hence on behalf of us all, may I express my particular thanks to the Director General of the Department of Mineral Resources, to our tireless IGCP co-chair Dr. Apsorn Sardsud, to DMR chief financial officer Mr. Suvapak Imsamut, and to all in the DMR family who have worked so hard to make this meeting happen. Participants will doubtless have noticed that there is no registration fee for this conference – this is solely due to the hospitality extended to all by our Thai hosts. Please do not be shy to thank them personally for this unusual kindness in particular.

IGCP668 draws together persons with a shared interest in learning how the Earth has changed through its long history, and in understanding and expressing the relevance of that history today. Our meeting and excursion focus on a particular region during a particular time in Earth History because of the special geological record of this region, and of its promise for informing us about the timing and cause of important global changes that were happening at that time. We are delighted that our meeting is attended by those with a wide range of geological interests, and also by those skilled in other areas, and particularly those in the art of presenting our findings about the ancient world in exciting ways to a wider audience. This effort assumes particular importance in a time in which our understanding of Earth history is critical for making informed decisions about the planet's future.

This meeting also offers the chance to visit Ko Tarutao, one of the first sites in the Shanthai/Sibumasu block in which Cambrian fossils were collected, and where an on-going tradition of paleontological work has been established. We are again grateful to our kind host for arranging this trip to this beautiful but isolated location, which is a rare privilege.

The main focus of our project is the integrated record of biological, sedimentological, and tectonic/magmatic events that took place as the world transitioned from the "boom and bust" episodes of evolutionary radiation in the Cambrian and earliest Ordovician into the more sustained and enduring radiation with the Ordovician onwards. The Shan-Thai/Sibumasu block is fortunate to have an uniquely well preserved record of these events that will help not only to reveal possible interactions between the ancient physical conditions and the contemporary biota, but also allow us to put precise geochronological dates on these.

This inaugural meeting of IGCP668 has attracted attendees from 11 countries, 9 of which are non-OEGC nations, and 5 of whom are student. One quarter of our foreign participants are female: clearly not yet the appropriate representation. Our backgrounds represent a rich diversity of the globe's traditions, and we gather together to discover and share what the Earth is telling us about her own story, and seek to understand the relevance of this history to our shared future. On behalf of the IGCP668 leadership committee, may I extend our warmest welcome in the manner of our most kind hosts: Sawadikrap!

(Prof.Dr. Nigel C. Hughes)
University of California, Riverside

# Preface from Department of Mineral Resources, Thailand

The first IGCP668 Inaugural Meeting, Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics are hold in Bangkok and Satun province in Thailand where the areas are related as the evolution of Shan Thai block, Gondwana. Cambrian sediment evidence in Thailand is first recorded from Tarutao island, Satun province since sixty years ago by Kobayashi in 1957. Many researchers visited Tarutao Island and published many papers about the stratigraphy, paleontology and others until now. Recently, Prof. Dr. Nigel Hughes, Prof. Dr. Paul Myrow and his team collaborated with the Department of Mineral Resources of Thailand are working on trilobites, stratigraphy and absolute dating of zircon in volcanic ashes from Tarutao island. That all valuable researches are the important as the international geological significance for the first Thailand Geopark and have led the UNESCO to accept it as the Satun Global Geopark in April 2018. Satun Global Geopark is proved that geological knowledge can be a good tool for economic development in this area.

This Abstract Volume of IGCP 668 Inaugural Meeting, Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics, comprises almost 34 abstracts from geologists and researchers around the world, especially in 11 countries. The meeting is divided into 23 oral presentations and 11 posters and participated with about 130 geologists and researchers who working on the transition between Cambrian-Ordovician “boom and bust” episodes of evolution in Shan Thai (Sibumasu) block and all relevant parts of Gondwana including Indochina, North China, South China, Australia, India and Antartica. It aims through a multidisciplinary approach incorporating: geochronology, igneous petrology, stratigraphy, and paleontology.

On behalf of the IGCP668 Inaugural Meeting host, The Royal Thai Government through the Department of Mineral Resources, Ministry of Natural Resources and Environment, IGCP668 project coordinators and our collaboration organizers would like to extend our warmest welcome all the distinguish participants to IGCP 668 Inaugural Meeting, Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics, during 29th to 30th November 2018 at Asia Hotel, Bangkok, and post-excursion during 1st to 5th December 2018 in geoheritage site; Tarutao Island, Satun Global Geopark, Thailand.

(Dr.Sommai Techwan)
Deputy Director-General

**Inaugural Meeting**
**IGCP 668 Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics**
**Schedule**

29 November 2018

| | |
|---|---|
| 8.00 - 9.00 a.m. | Register and Poster attached |
| 9.00 - 10.00 a.m. | Opening ceremony and Break |
| 10.00 – 10.30 a.m. | **Scope and Mission of IGCP668** By Nigel C. Hughes |
| 10.30 – 10.50 a.m. | **Early Ordovician sponge-bearing microbialites from Peninsular Malaysia and their geobiological significance** By Qijian LI |
| 10.50 – 11.10 a.m. | **Proposed GSSP for the base of Cambrian Stage 10 (Furongian Series) at FAD of *Lotagnostus americanus* in the Wa'ergang section, Hunan, South China** By PENG Shanchi |
| 11.10 – 11.30 a.m. | **Revised Cambrian trilobite biostratigraphy of the northern Victoria Land, Antarctica** By Tae-Yoon PARK |
| 11.30 a.m. – 11.50 p.m. | **The evolution of the Palaeoscolecidian worms** By Di-Ying HUANG |
| 12.00 – 1.00 p.m. | Lunch |
| 1.00 – 1.30 p.m. | **Who are hyoliths?** By SUN Haijing |
| 1.30 – 1.50 p.m. | **Earth surface evolution during the Early Paleozoic** By Ryan MCKENZIE |
| 1.50 – 2.10 p.m. | **An Ediacaran-Cambrian age for the Bambui Basin in Brazil and the Gondwana collage** By Gabriel Jube UHLEIN |
| 2.10 – 2.30 p.m. | **Carbonate Petrology and Depositional Environment of the Lower Ordovician Wunbye Formation from Doktoye Area, Northwest of Ywa Ngan, Southern Shan State, Myanmar** By MYO Myint |
| 2.30 – 2.50 p.m. | **Reconstruction of tectonic history of Myanmar Region** By Hla Hla Aung |
| 2.50 – 3.10 p.m. | **Style, type and origin of Kyadwinye iron ore deposits in the western margin of Shan Plateau, Central Myanmar** By Tin Aung MYINT |
| 3.10 – 3.30 p.m. | Break |
| 3.30 – 3.50 p.m. | **Cambrian faunal links along the equatorial Gondwanan margin** By Nigel C. HUGHES |
| 3.50 – 4.10 p.m. | **Upper Cambrian faunae of Langkawi Archipelago, Malaysia** By José Antonio GÁMEZ VINTANED |
| 4.10 – 5.00 p.m. | Poster Session |

**Inaugural Meeting**
**IGCP 668 Equatorial Gondwanan History and Early Paleozoic Evolutionary Dynamics**
**Schedule**

30 November 2018

| | |
|---|---|
| 9.30-9.50 a.m. | **New trilobite fauna from the Tarutao Formation, Thailand and their biostratigraphic and paleogeographic significance** By Shelly WERNETTE |
| 9.50-10.10 a.m. | **Cambrian-Ordovician sediment successions at Tarutao Island, the International Geological Significance evidence of Satun Global Geopark** By Apsorn Ampornmaha-Sardsud |
| 10.10 – 10.30 a.m. | **First discovery of early Paleozoic magmatism in the northern part of Thailand : Evidence from Zircon age determination** By Dr.Somboon Kositanon |
| 10.30 – 10.50 a.m. | **Konservat-Lagerstätten in upper Cambrian and Ordovician shales in South China—a brief review** By ZHANG Yuandong |
| 10.50 – 11.10 a.m. | Break |
| 11.10 – 11.30 a.m | **Lower Palaeozoic strata in southern Myanmar and Ordovician correlations in South East Asia** By Clive BURRETT |
| 11.30-11.50 a.m. | **Preliminary Evolution of the Drainage System in Central Myanmar Basin with Stratigraphic Development of Headwater of the Hukawnng and Myitsone Areas** By Naing Maw THAN |
| 11.50 a.m. – 12.10 p.m | **Sediment continuity along the equatorial margin of Gondwana: Detrital zircon U-Pb insights from the Shan-Thai Terrane** By Cody L. COLLEPS |
| 12.10-1.00 p.m. | Lunch |
| 1.00 – 1.20 p.m | **Early Paleozoic basements of peninsular Thailand: crustal and tectonic evolution** By Punya charusiri |
| 1.20 – 1.40 p.m. | **Comparison of sources of the lower paleozoic strata of southern thailand and southern australia: evidence from sedimentology and u-pb detrital zircons** By Sitthinon Kultaksayos |
| 1.40 – 1.55 p.m. | Meeting for excursion |
| 1.55 – 3.00 p.m. | Break |
| 1.00 – 3.30 p.m. | Coffee Break |
| 3.30 – 4.30 p.m. | Discussion and Conclusion |
| 4.30 p.m. | Closed |

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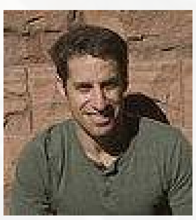
# PROJECT COORDINATORS

**Prof. Nigel Hughes (Project Head)**
Research Interests: Trilobite paleobiology and ontogenetic mechanisms in the early Paleozoic. Lower Paleozoic paleogeography and tectonics (particularly the early Paleozoic history of India and the peri-Gondwanan region).
Dept. of Earth Sciences, University of California Riverside United States
nigel.hughes@ucr.edu

**Dr. Apsorn Sardsud**
Research Interests: Evolution and stratigraphy of Paleozoic to Mesozoic sediments in Shan Thai (Sibumasu)Terrane, peri-Gondwana; Triassic conodonts; Geo-education and Geopark
Department of Mineral Resources, Thailand
apsornsa@yahoo.com

**Prof. Shanchi Peng**
Research Interests: Trilobite morphology, ontogenetic development, and phylogenetics based systematics. Cambrian biostratigraphy, primarily in China but with global correlations, and refining the Cambrian interval of the geologic time scale. State Key Laboratory on Geology and Palaeontology, Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences, China
scpeng@nigpas.ac.cn

**Mr. Kyaing Sein**
Research Interests: Ophiolites. Myanmar's stratigraphy including ophiolites, Precambrian/upper Cambrian boundary, the Bawdwin Volcanic Series, and the Cretaceous through Eocene succession. Myanmar's suture zones.
Myanmar Geosciences Society (President), Myanmar
kyaingsein@gmail.com



**Prof. Paul Myrow**
Research Interests: Process-oriented sedimentary Geology. Paleoenvironmental analyses of lithofacies. Late Precambiran and Cambrian lithostratigraphy, detrital zircon geochronology, carbon isotope chemostratigraphy, and paleogeographic reconstructions.
Dept. of Geology, Colorado College, United States
pmyrow@coloradocollege.edu

**Prof. Sachiko Agematsu-Watanabe**
Research Interests: Conodont taxonomy, biostratigraphy, and paleoenvironments during the Early and Middle Paleozoic.
Faculty of Life and Environmental Sciences, University of Tsukuba, Japan
agematsu@geol.tsukuba.ac.jp

**Dr. Ryan McKenzie**
Research Interests: Evolution of the Earth-life system as recorded in sedimentary successions and understood through detrital sediment geochronology, geochemistry, and biostratigraphy.
Dept. of Earth Sciences, The University of Hong Kong, China
ryan00@hku.hk

# OUTREACH COLLABORATORS

**Ms. Marufa Chowdhury**
Interests: Visual artist and illustrator exploring connections between humans and their physical and social environment
Project role: Illustrator for outreach projects, Bangladesh
ttaayyrraa@gmail.com

# RESEARCH COLLABORATORS

**Prof. Jonathan Aitchison**
Research Interests: Tectonic evolution of Gondwana and its diaspora in Asia, India-Asia collision, Arc-continent collisions in general, paleobiogeography and Paleozoic radiolarian biostratigraphy.
SEES University of Queensland, Australia
jona@uq.edu.au

**Ms. Hla Hla Aung**
Research Interests: Seismotectonics, earthquake geology, petrology, structure
Myanmar Earthquake committee, Myanmar engineering society, Hlaing University, Yangon Myanmar
hhlaaung@gmail.com

**Prof. Aye Ko Aung**
Research Interests: Geology and Palaeontology of Myanmar; corals
Department of Geology, University of Malaya, Retired, Myanmar
ayekoaung.mm@gmail.com

**Dr. Clive Burrett**
Research Interests: Palaeozoic geology, paleontology of Southeast Asia and Greater Gondwana reconstructions
Paleontological Research Center, Mahasarakham University, Thailand
cfburrett@gmail.com

**Prof. Punya Charusiri**
Research Interests: Tectonic evolution of mainland SE Asia; gold metallogenesis, tectonostratigraphy, mineral exploration.
Chulalongkorn University, Thailand
punya.C@chula.ac.th

**Mr. Ravi Chaubey**
Research Interests: Early Paleozoic Integrated Litho-Bio-Chrono-Sequence Stratigarphy of Spiti-Kinnaur Basin, Lesser Himalaya Basin and Bikaner-Nagaur Basin (India and peri-Gondwanan region).
Centre for Advanced Study in Geology, Panjab University, Chandigarh and Geologist at Geological Survey of India, India
ravischaubey@hotmail.com

**Dr. L. Robin M. Cocks**
Research Interests: Ordovician to Devonian brachiopods, stratigraphy, and paleogeography globally and with a focus on south-east Asia Department of Earth Sciences, The Natural History Museum, London, United Kingdom
r.cocks@nhm.ac.uk

# RESEARCH COLLABORATORS

**Mr. Cody Colleps**
Research Interests: The use of geo-/thermochronology and geochemistry to understand the erosional and uplift history of source terranes and their sedimentary products, particularly in Paleozoic Sibumasu.
Graduate Student in McKenzie Lab, Dept. of Earth Sciences, The University of Hong Kong, China
ccolleps@connect.hku.hk

**Ms. Louisa Dent**
Research Interests: Ordovician lithostratigraphy, sequence stratigraphy and chemostratigraphy in the Canning Basin, WA and regional to global applications
Geological Survey of Western Australia, Australia
louisa.dent@dmirs.wa.gov.au

**Dr. Mathew Domeier**
Research Interests: Paleogeography and the history of plate kinematics
Centre for Earth Evolution and Dynamics, University of Oslo, Norway
mathewd@geo.uio.no

**Dr. Stephen Dornbos**
Research Interests: Cambrian paleoecology, paleobiology, and taphonomy
University of Wisconsin-Milwaukee, United States
sdornbos@uwm.edu

**Prof. Olaf Elicki**
Research Interests: Cambrian and Ordovician; palaeoecology, stratigraphy, sedimentology, palaeogeography, marginal marine ecosystem evolution, biotic events in W. Gondwana (Middle East, N. Africa, Central and S. Europe); skeletal microbiota, trace fossils
Freiberg University, Germany
elicki@geo.tu-freiberg.de

**Prof. David Evans**
Research Interests: Paleogeographic Reconstructions
Yale Universeity, United States
david.evans@yale.edu

**Mr. Than Htun**
Research Interests: Tin / Tungsten exploration and research on land and offshore
Economic geologist, Myanmar
uthanhtun@gmail.com

**Prof. Jim Jago**
Research Interests: Cambrian biostratigraphy; Tasmania, Antarctica, South Australia; Emu Bay Shale lagerstatte
University of south Australia, Australia
jim.jago@unisa.edu.au

**Ms. Ramanpreet Kaur**
Research Interests: Cambrian biostratigraphy and sequence stratigraphic analysis of Spiti, India and their subsequent regional and global correlation.
Department of Geology (Centre of advanced study in Geology), Panjab University, Chandigarh, India
toorraman1811@gmail.com

# RESEARCH COLLABORATORS

**Dr. Kyi Khin**
Research Interests: Geological and tectonic history of the Indo-Myanmar Ranges (IMR); Arakan Coastal Ranges in western Myanmar, and provenance of siliciclastic sequences in the Central Myanmar Basin, and Himalaya–Bengal-Andaman System
Senior Geologist, Public Utilities Board, Singapore
kyikyaw2@gmail.com

**Dr. Somboon Khositanont**
Research Interests: Igneous petrology for tectonic evolution and ore deposit research in Thailand and SE Asia
Director of Geological Resources Information Center at Department of Mineral Resources Thailand
khositanont.s@gmail.com

**Mrs. Tin Tin Latt**
Research Interests: Carboniferous and Permian foraminifers and their paleobiogeographic distribution in Cimmerian continent; Paleo-Tethys, Mesozic andCenozoic foraminifers
Graduate Student and Senior lecturer, Department of Geology, University of Yangon, Myanmar
tintinlatt@gmail.com

**Dr. Mirinae Lee**
Research Interests: Paleontology, paleoecology, and paleobiogeography of Paleozoic corals and coral-like organisms (coralomorphs), and calcareous algae
Division of Polar Earth-System Sciences, Korea Research Institute, South Korea
mirinae.lee@kopri.re.kr

**Seung-bae Lee**
Research Interests: Early Paleozoic trilobites and stylophoran echinoderms from Korea, North China, and related regions: biostratigraphy, paleobiogeography, and evolution
Geological Museum, Korea Institute of Geoscience and Mineral Resources (Republic of Korea) South Korea
sblee@kigam.re.kr

**Prof. Guoxiang Li**
Research Interests: Cambrian small shelly fossils (paleobiology, biostratigraphy, and paleogeography) from South China, Tarim, and North China; analyzing the radiation pattern of the Cambrian Explosion.
Nanjing Institute of Geology and Palaeontology, Chinese National Academy of Sciences, China
gxli@nigpas.ac.cn

**Dr. Qijian Li**
Research Interests: Ordovician reefs and hypercalcified sponges from South China and Malaysia
Nanjing Institute of Geology and Palaeontology, Chinese National Academy of Sciences, China
qijianli@hotmail.com

**Ms. Anastasiya Makarova**
Research Interests: Cambrian trilobites, biostratigraphy, regional (Siberian platform) and global correlation
All-Russian Research Geological Oil Institute (Novosibirsk Branch), Russia
trilobite74@mail.ru

**Dr. Charles Makoundi**
Research Interests: Geochronology and geochemistry of the volcaniclastic Semanggol Formation in Peninsular Malaysia and the implications for a mass extinction about 252 million years ago
University of Tasmania, Australia
c.makoundi@utas.edu.au

# RESEARCH COLLABORATORS

**Prof. Ian Metcalfe**
Research Interests: Tectonic history and palaeogeography of eastern Gondwana and the Tethys ocean basins and the amalgamation of modern SE Asia using geochronology, magmatic isotope geochemistry, biostratigraphy, and conodont/radiolarian biogeography
University of New England, Australia
imetcal2@une.edu.au, http://www.metcalfeian.com

**Dr. Andrew Mitchell**
Research Interests: Mineral deposits and their tectonic settings
Mineral exploration and mining consultant, United Kingdom
andrewmitch999@aol.com

**Dr. Myo Myint**
Research Interests: Paleozoic rocks of the western Malaysian Peninsula
Universiti Teknologi PETRONAS, Perak, Malaysia
myo.myint@utp.edu.my

**Dr. Tin Aung Myint**
Research Interests: Gold, silver, copper, and base metal mineralization; Petrology; Tectonic and metallogenic evolution of Myanmar, U-Pb geochronology; Pyrite geochemistry; Gondwana reconstructions in Myanmar region
University of Mandalay, Myanmar
tinaungmyint02@gmail.com

**Mr. Leon Normore**
Research Interests: Geochronology, biostratigraphy, provenance, petroleum potential and regional correlation studies of the Lower to Middle Ordovician of the Canning Basin, Western Australia
Geological Survey of Western Australia
leon.normore@dmirs.wa.gov.au

**Dr. Tae-Yoon Park**
Research Interests: Cambrian explosion, trilobite ontogeny, Cambrian trilobite biostratigraphy in Korea, Antarctica, and related regions.
Korea Polar Research Institute, South Korea
typark@kopri.re.kr

**Prof. John R. Paterson**
Research Interests: Cambrian faunas of East Gondwana, particularly the Emu Bay Shale Konservat-Lagerstätte of South Australia; palaeobiology and early evolution of arthropods (especially trilobites); Cambrian chronostratigraphy and correlation
Palaeoscience Research Centre, University of New England, Australia
jpater20@une.edu.au

**Dr. Ian Percival**
Research Interests: Orovician and Cambrian brachiopods; Ordovician and latest Cambrian conodonts; biostratigraphy, palaeogeography, palaeobiogeography
Geological Survey of New South Wales, Australia
ian.percival@planning.nsw.gov.au

**Mr. Subhay Kumar Prasad**
Research Interests: Cambrian of Lesser and Tethyan Himalayan zones, Himalaya, India
Panjab University, India
subhay.lovely@gmail.com

# RESEARCH COLLABORATORS

**Prof. Brian Pratt**
Research Interests: Stratigraphy, sedimentology, paleontology, paleoecology
University of Saskatchewan, Canada
brian.pratt@usask.ca

**Mr. Manop Raksaskuwong**
Research Interests: geologic mapping and geophysical exploration
Department of Mineral Resources, Thailand
manopraksa@gmail.com

**Prof. Mega Fatimah Rosana**
Research Interests: Ore Deposits, Petrology-Mineralogy, Gemstone, Geothermal, Geoparks
Faculty of Geology, Universitas Padjadjaran, Bandung, Indoenesia
mega.fatimah.rosana@unpad.ac.id

**Dr. Thomas Servais**
Research Interests: organic-walled microphytoplankton (acritarch), Lower Palaeozoic ecosystems and palaeo(bio)geography
University of Lille, France
Thomas.Servais@univ-lille1.fr

**Dr. Yuefeng Shen**
Research Interests: Biosedimentology; Carbonate sedimentology and diagenesis; Fossil calcimicrobes, calcareous algae and calcified sponges; Biomineralization and organomineralization; Cathodoluminescence and fluorescence microscopes
Hefei University of Technology China
yuefengshen@hfut.edu.cn

**Dr. Birendra Singh**
Research Interests: Cambrian biostratigraphy (trilobite) and paleogeography (particularly India and peri-Gondwanan region) and lower Paleozoic paleontology of India's northern margin (biostatigraphy and paleogeography)
Department of Geology (Centre for Advanced Study in Geology), Panjab University, Chandigarh, India
v_ruh@rediffmail.com

**Ms. Garry Singla**
Research Interests: Cambrian trilobite biostratigraphy and geochemical studies in Spiti, India and their subsequent regional and global correlation.
Department of Geology (Centre of advanced study in Geology), Panjab University, Chandigarh, India
garry.singla@gmail.com

**Dr. Weerapan Srichan**
Research Interests: Tectonic evolution in mainland SE Asia; Igneous petrology, age dating and ore deposits
Department of Geological Sciences, Chiang Mai University, Thailand
weerapan.s@cmu.ac.th

**Dr. Haijing Sun**
Research Interests: Paleontology, paleobiology, taphonomy, and phylogeny of hyoliths.
State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeongology, China
hjsun@nigpas.ac.cn

# RESEARCH COLLABORATORS

**Mr. Naing Maw Than**
Research Interests: Data evaluation on geotechnical instruments, Tectonic framework of SE ASia, Tectono-magmatic development of Myanmar, basin and reservoir characterization, and mineral exploration
Myanmar Geologists Society of Singapore (MGSS), Singapore
naingmawthan@gmail.com

**Dr. Hathaithip Thassanapak (Udchachon)**
Research Interests: Radiolarian biostratigraphy of the Palaeozoic and Triassic successions in SE Asia
Applied Paleontology and Biostratigraphy Research Unit, Department of Biology, Faculty of Science, Mahasarakham University, Thailand
bthaithip@yahoo.com

**Dr. Halay Tsegab**
Research Interests: Carbonate sedimentology and stratigraphy
Department of Geosciences, Universiti Teknologi PETRONAS, Malaysia
haylay.tsegab@utp.edu.my

**Dr. Dhiti Tulyatid**
Research Interests: Regional tectonics of Southeast Asia and the application of airborne geophysics to mineral exploration and tectonic studies
CCOP: Coordinating Committee for Geoscience Programme in East and Southeast Asia. Thailand
dr.dhiti@ccop.or.th

**Dr. Mongkol Udchachon**
Research Interests: Biostratigraphy and palaeoenvironment of Palaeozoic sequences in SE Asia using conodonts, radiolaria, fusuline, and sedimentology
Applied Palaeontology and Biostratigraphy Research Unit, Department of Biology, Mahasarakham University, Thailand
mongkol.c@msu.ac.th

**Dr. Tanot Unjah**
Research Interests: Conservation Geology, Tourism, Nature Conservation and management, Geomorphology and Natural Hazard and climate change adaptation
Langkawi Research Centre and Institute for Environment and Development (LESTARI), National University of Malaysia, Malaysia
tanot-u@ukm.edu.my

**Ms. Shelly Wernette**
Research Interests: Systematics, biogeography, and biostratigraphy of Upper Cambrian trilobites from the marginal Gondwanan terrane, Sibumasu.
Graduate Student in Hughes Lab, Dept. of Earth Sciences, University of California Riverside United States
swern001@ucr.edu

**Dr. Thanis Wongwanich**
Research Interests: Thai Ordovician carbonate sedimentology and diagenesis
Department of Mineral Resources, Thailand
thaniswongwanich@gmail.com

# RESEARCH COLLABORATORS

**Prof. Shuhai Xiao**
Research Interests: Ediacaran and Cambrian Earth history, with a focus on the evolutionary history of multicellular eukaryotes and its environmental context
Virginia Tech Department of Geosciences, United States
xiao@vt.edu

**Dr. Xianfeng Yang**
Research Interests: Stratigraphic divisions and paleontology for the Cambrian system
Associate Professor, Key Laboratory for Paleobiology, Yunnan Province, China
yangxf@ynu.edu.cn

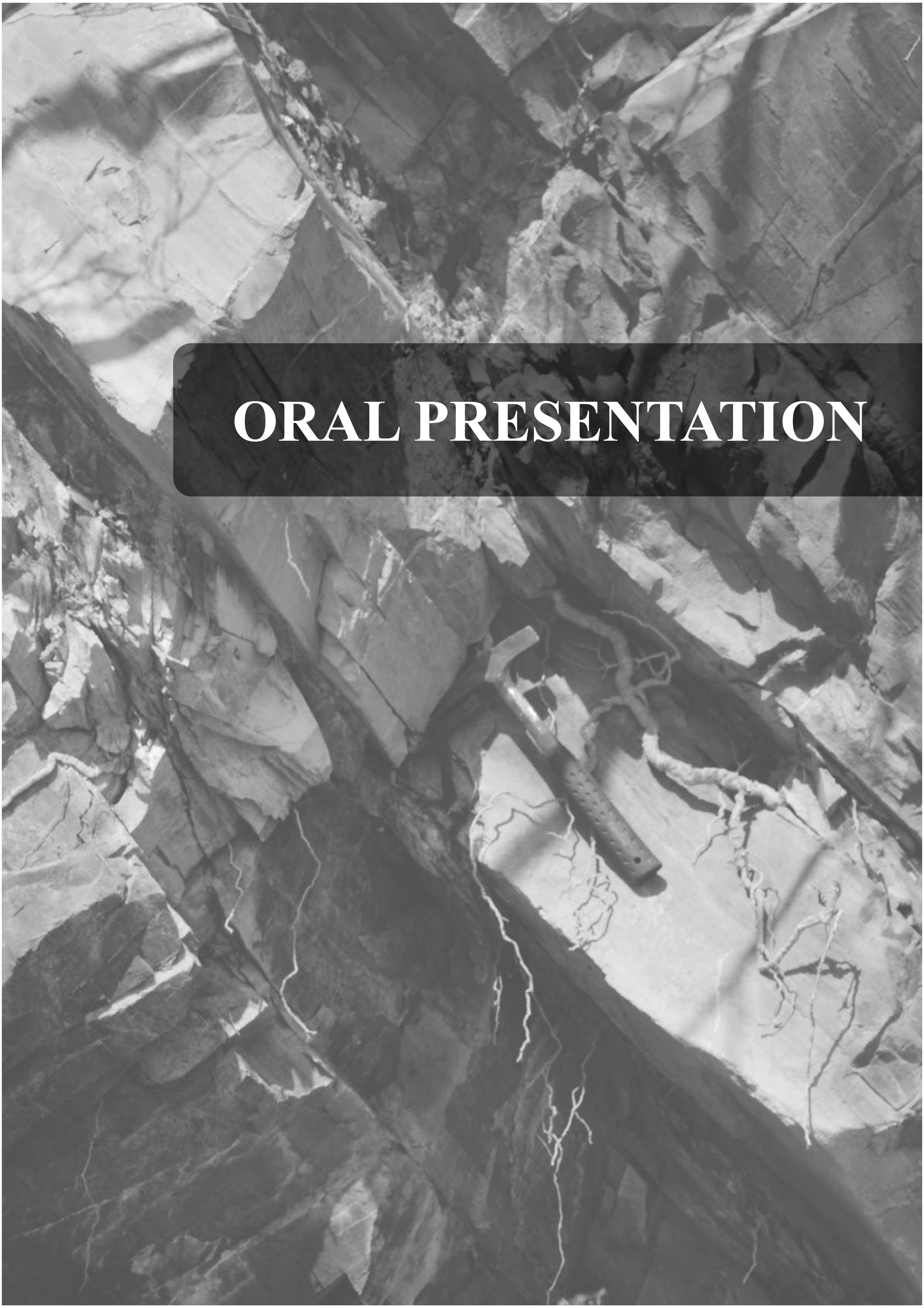
**Prof. Khin Zaw**
Research Interests: Tectonic and metallogenic evolution of SE Asia and U-Pb Geochronology, Stable and Radiogenic isotopes, Geofluids, Pyrite, Geochemistry, Mass Extinction, Ocean Anoxia, and Gplate Gondwana reconstructions in Myanmar region
CODES Centre of Excellence in Ore Deposits, University of Tasmania, Australia
khin.zaw@utas.edu.au

**Prof. Xingliang Zhang**
Research Interests: Cambrian paleontology and stratigraphy
Department of Geology, Northwest University, China
xzhang69@nwu.edu.cn

**Dr. Yong Yi Zhen**
Research Interests: Palaeontology, palaeogeography, palaeoecology and biostratigraphy of the Early to Middle Palaeozoic conodonts, corals and stromatoporoids from Australia and Asia
Geological Survey of New South Wales, Australia
yong-yi.zhen@planning.nsw.gov.au

**Dr. Xuejian Zhu**
Research Interests: Trilobite paleontology, including ontogeny, phylogenetics, biostratigraphy, and paleogeography
Chinese National Academy of Sciences, Nanjing Institute of Geology and Palaeontology, China
xjzhu@nigpas.ac.cn

**Prof. Andrey Zhuravlev**
Research Interests: Early metazoan evolution, palaeoclimatioly, biomineralization, preservation, carbonate sedimentology; Ecology & functional morphology of Neoproterozoic/Cambrian fauna and flora; Interplay of Neoproterozoic-phanerozoic biotic and abiotic events
Division of Biological evolution, Moscow State University, Russia
ayzhur@gmail.ru



# ORAL PRESENTATION

# An Ediacaran-Cambrian age for the Bambui Basin in Brazil and the Gondwana collage

**Gabriel Jube UHLEIN[1]**, Alexandre UHLEIN[1], Lucas V. WARREN[2], Juliana OKUBO[2], Fabricio A. CAXITO[1]
[1]Federal University of Minas Gerais; guhlein@gmail.com
[2]São Paulo State University

**Keywords:** Bambui Basin, São Fransisco craton, Cambrian, Deformation, West Gonwana

The Bambuí Basin in east central Brazil records a mixed carbonate-siliciclastic succession deposited on the São Francisco craton mainly during the Ediacaran Period. The lowermost Sete Lagoas Formation bears a typical post-Marinoan (early Ediacaran) cap carbonate interval deposited above glaciogenic units or Paleoproterozoic basement rocks. In the middle Sete Lagoas Formation (about 50 m above basement) and after a depositional hiatus between cap carbonate rocks, *Cloudina*-bearing levels and detrital zircons as young as 550 Ma attest a late Ediacaran age (< 549 Ma) for the rest of the Bambuí Basin. Thus, considering the lower and upper boundaries of the *Cloudina* biozone (549-541 Ma), the remaining 1,000 m of sedimentary succession subdivided, from base to top, into the Serra de Santa Helena, Lagoa do Jacaré, Serra da Saudade and Três Marias formations must span beyond this age interval. From this perspective, is perfectly plausible that much of the sedimentary pile or, at least, the upper part of the basin is Cambrian in age. In the last years, a considerable research effort brought new evidences of younger ages for the Bambuí Basin and recent new geochronological data from a volcaniclastic layer shed new light to this hypothesis. However, a Cambrian minimum sedimentation age for the Bambuí Basin causes serious geodynamic problems involving the time interval between sedimentation and tectonic deformation. The Bambuí Basin is clearly deformed on its margins, where in contact to two main Brasiliano/Pan-African fold belts: the Brasília fold belt, to the west, and the Araçuaí fold belt, to the east. The final amalgamation ages from both orogens are well constrained by U-Pb geochronological data on zircon, monazite and titanite at ~600 and ~540 Ma, respectively, and this is obviously inconsistent with an Ediacaran-Cambrian sedimentation age for the Bambuí Basin. Thus, one must carefully look for the real age and nature of the deformation event that affected the Bambuí succession, if direct related to low-temperature, late compressional event from the neighbor fold and thrust belts evolution, or perhaps to long distance, intraplate deformation resulted from the final stages of Gondwana supercontinent collage in the late Cambrian. These new age constraints for the Bambuí Basin have still much to reveal about tectonic, basin and life evolution of the Cambrian Period in west Gondwana.

# Cambrian faunal links along the equatorial Gondwanan margin

**Nigel C. HUGHES**[1]
[1]University of California, Riverside; nigel.hughes@ucr.edu

Notable similarities occur between the late Neoproterozoic and earlier Cambrian successions of the Lesser Himalaya and those of the shelf region of South China, but towards the end of Series 2 the south Chinese shelf became carbonate dominated, while the Lesser Himalayan region continued to accumulate a thick clastic succession. In the somewhat more distal Tethyan Himalaya such sedimentation continued into Series 3 where, although trilobites such as *Oryctocephalus indicus* occur in rare mudstone facies, most of the thick succession likely reflects nearshore or even fluvial sedimentation. Thus there is a notable contrast between Series 3 relatively thick and coarse clastic deposits on the Indian margin and the South Chinese shelf carbonates and South Chinese slope mudstones and siltstones with very little sandstone. considerable faunal similarity exists among late Series 2 and Miaolingian faunas of the subcontinent and south eastern Yunnan. The same may also apply in the Furongian deposits of the Himalaya (Bhutan) and South China including northern Veitnam, and also Baoshan and Sibumasu. Much taxonomic work needs to be done to revise faunas from all these areas, but particular similarities do occur between certain areas: the Tethyan Himalaya and southeastern Yunnan for example. Such work, in coordination with sedimentological characterization of fossil bearing sections, will ultimately lead to better understanding of Cambrian biofacies and paleogeography in the region.

# Cambrian-Ordovician sediment successions at Tarutao Island, the International Geological Significance evidence of Satun Global Geopark

**Apsorn Ampornmaha-Sardsud** [a,*], Thanis Wongwanich [a], Sachiko Agematsu-Watanabe[b]
Katsuo Sashida [b], Nigel C. Hughes [c], and Paul M. Myrow [d]

[a] Department of Mineral Resources, Bangkok 10400, Thailand ;apsornmini4@gmail.com
[b] Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaragi, 305-8572 Japan
[c] Department of Earth Sciences, University of California, Riverside, CA 92521, USA
[d] Department of Geology, Colorado College, Colorado Springs, CO 80903, USA

**Keywords:** Tarutao, trilobite, Cambrian, Satun, Geopark, significance

Satun Geopark is the newest UNESCO Global Geopark having been accepted and announced in April 2018. It was accepted for its international geological value with regard to an abundant and highly diverse early Paleozoic fossils in Southeast Asia, along with the interbedded, datable volcanic ashes that can provide absolute age estimates. The designation of this UNESCO Global Geopark required a geological heritage of international value based on the international peer-reviewed, published research conducted on the geological sites within the area. Satun Global Geopark is includes 28 specific geological attractions. Tarutao Island is located in the Satun Global Geopark area, and includes at least three geological heritage sites. This island is also well-known as a former jail for politic prisoners in Thailand many decades ago, according to its rugged topography and harsh environment. It is not only important for Thailand political history but also important for geological research among the geologists more than a half of century ago. In 1957 Teiichi Kobayashi reported the evidence of Cambrian trilobites as the oldest fossil in Thailand from the Ao Mo Lae geological heritage site. Many international researchers have since come and studied on the Cambrian and Ordovician fossils and sediment successions at Tarutao Island. The late Cambrian trilobite fauna are abundant and deposited in the red sandstone and siltstone of Tarutao Group, such as *Pagodia thaiensis*, *"Eosaukia" buravasi*, and *Coreanocephalus phanulatus*, etc. The volcanic ash layers are interbeded with the trilobite beds and indicate the absolute age of the sediments. The latest Cambrian sediments were identified by trilobites; *Parakoldinioidia thaiensis*, as the age closely to the Cambro-Ordovician boundary (Shergold *et al*., 1988). It is also known as the oldest succession in Shan-Thai terrane. At least one new genus and five species of Cambrian trilobite were reported from Taruato Island (Kobayashi, 1957). Tarutao Island is the only location presently known in Thailand in which late Cambrian by trilobite beds are interbedded with volcanic ash beds. These volcanic ashes have international importance for absolute age dating of the late Cambrian. The lowest unit of the Malaka Formation, Thung Song Group (Wongwanich, 1990) at Laem Chorakhe in the north of Tarutao Island is clearly exposed and conformably overlies the Tarutao Group. The argillaceous and dolomite limestone displaying cyanobacterial laminations and also contains a thick tuff bed (Teraoka et al., 1982). This evidence of the Cambrian - Ordovician sedimentary successions with the datable ash layers on Tarutao Island are one reason of international geological significance that lead UNESCO to accept the Satun Geopark as Satun *Global* Geopark. Improved geological knowledge at Tarutao Island can hopefully be transfererd to understand the broader geological evolution of Satun Global Geopark. This is important not only for researchers, but for the people, economy and sustainable development of the Satun Global Geopark.

* Corresponding author at: Mineral Resources Research and Development Center, Department of Mineral Resources, Bangkok 10400, Thailand. (A. Ampornmaha-Sardsud).

# Carbonate Petrology and Depositional Environment of the Lower Ordovician Wunbye Formation from Doktoye Area, Northwest of Ywa Ngan, Southern Shan State, Myanmar

**MYO Myint**[1], MYITTA[2]
[1]Universiti Teknologi PETRONAS; myo.myint@utp.edu.my
[2]Department of Geology, University of Yangon, Myanmar, Ret.

**Keywords:** Wunbye Formation, Ordovician, Ywa Ngan, Myanmar

The present revised paper is a part of the master thesis submitted to Department of Geology, Universty of Yangon, Myanmar in 1990, which was based on 800 meters stratigraphic section of moderate dip amount with southwest dipping of bedded carbonate sequences of Limestone subunit of the Lower Ordovician Wunbye Formation of the Pindaya Group, exposed at Doktoye village, northwest of the Ywa-Ngan, Southern Shan State, Myanmar (Fig. 1). The present study area covers the southwestern part of the broad and south-plunging Pindaya Anticline located at the Pindaya ranges, Yarksauk, Southern Shan State, Myanmar (Myint Lwin Thein, 1973).

In the study area, the Wumbye Formation can be subdivided into three subunits including Limestone subunit, Siltstone intercalated with limestone subunit and Mottled dolomitic limestone intercalated with shale, in ascending order, which was assigned to be Early to Middle Ordovician age (Myo Myint, 1990). The carbonate petrographic study based on 60 numbers of thin section collected form one section of Limestone subunit of the preset study area reveals that twelves lithofacies have been identified. They are Faecal pelsperite facies, Oosperite facies, Oointrasperite facies, Dismicrite facies, Pemicrite facies, Mottled dolomitic micrite facies, Intrapel dolomite facies, Dolomitized pelloidal oobiosparite facies, Intrabiopelmicrite facies, Oointrabiospertie facies, Intraoobiosparite facies and algal biolithite facies (PL. I to IV). Those facies indicate four main types of carbonate depositional environments behaving Inner-shelf (back shoal) platform, Oolitic grainstone shoal or barrier, Outer-shelf platform and lime mud mound on shelf-edge platform. Inner-shelf platform contains faecal pelsperite facies and dismicrite facies (PL. I, Fig.1; PL. III, Figs. 6, 7 & 8). Oolitic grainstone shoal or barrier represents Oosparite facies (PL. I, Figs. 2 & 3). Outer-shelf platform has cyclic nature of nine facies, which contains fore-barrier flat, supratidal, intertidal, intertidal and subtidals subenvironments (PL. I to IV). Lime mud mound on shelf-edge platform employs Epiphyton and Girvanella shelf-edge reef complex of Algal biolithite facies (PL. II, Figs. 6, 7 & 8).

Moreover, it is concluded that dolomitization appears as a strongly fabric selectivity, however dolomitization mechanisms were unknown in this study. Five types of dolomitization descriptively characterizes as initial matrix-selective replacement of micritic matrix, initial replacement of peloids and oolites, replacement dolomite in burrow infilled sediment and zone dolomite in pore spaces (PL. I, Figs. 3, 4 & 8; PL. II, Figs. 1 & 2; PL. III, Figs. 1, 2 & 5; PL. IV, Fig. 4). Moreover, mechanical compaction significantly preserves as rearrangement of grains including close-packed rock fabrics, alignment of grains and compaction of oolite indicating spalled-off laminae (PL. II, Fig. 5; PL. III, Figs. 3 & 4; PL. IV, Fig. 2). Chemical compaction appears as pressure solution features at grain contacts and along stylolite surfaces, a part in a removal of portions of oolitic cortices and apophyses of distorted oolites (PL. II, Fig. 5; PL. III, Figs. 3 & 4; PL. IV, Fig. 2).

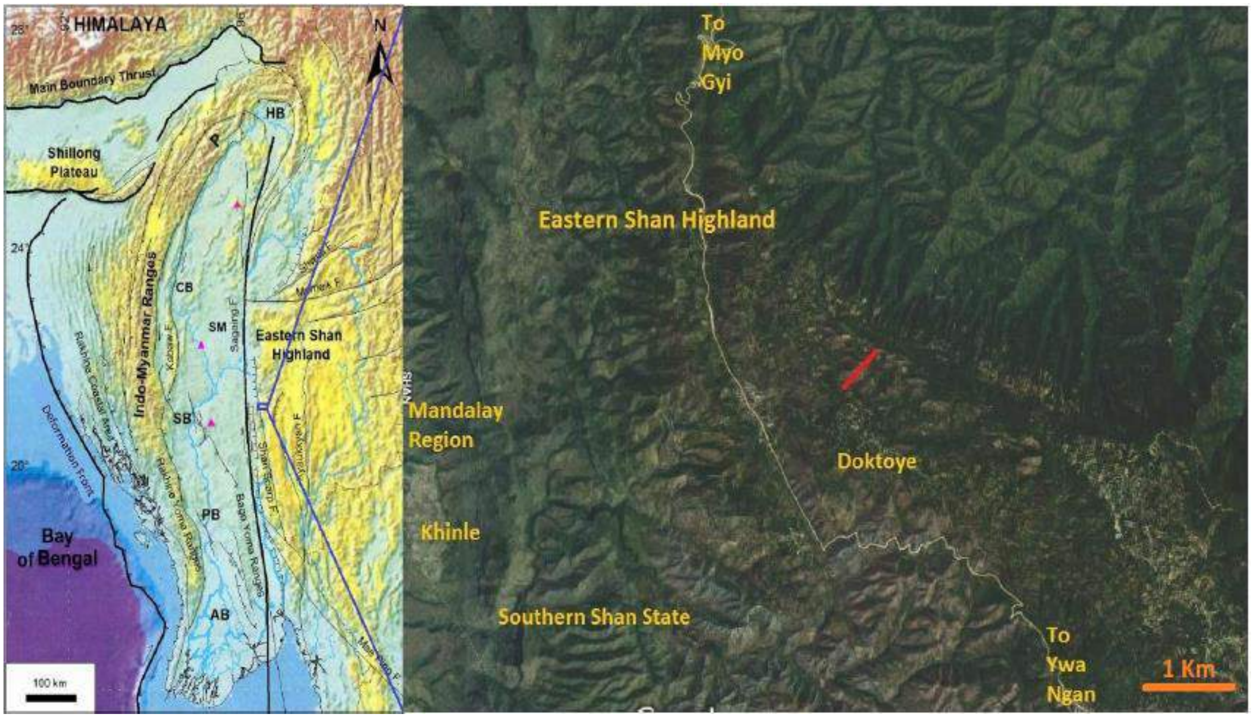



Fig. 1. Maps showing location of study area, Sagaing Fault and Eastern Shan Highland (Sibumasu). P, Patkoi Ranges; HB,Hukaung Basin; CB, Chindwin Basin; SM, Shwebo–Monywa Basin; SB, Salin (Central) Basin; PB, Pyay (Prome) Basin; AB, Ayeyarwady Embayment Basin. Pink triangles are Quaternary volcanoes, Purple square is a study area and Red line is location of carbonate section of Lower Ordovician Wumbye Formation (after Lin Thu Aung et al. 2015).

PLATE I

Figure 1. Photomicrograph of faecal pelsparite facies; moderate to good sorting of pellets in size with diffuse margins indicating faecal origin and scattered quartz grains are cemented by neospar and incipient micrite. PPL, Bar scale is 0.13mm.

Figure 2. Photomicrograph of Oointrasparite facies; poorly sorted oolite and intraclast are cemented by sparry calcite, some oolite are completely obliterated by micritization. PPL, Bar scale is 0.35mm.

Figure 3. Photomicrograph of Oosparite facies; invisible internal structure due to almost entirely dolomitization on well sorting in size and shape of oolites. PPL, Bar scale is 0.35mm.

Figure 4. Photomicrograph of Oosparite facies; internal structure is indistinctively visible, XN, Bar scale is 0.35mm

Figure 5. Photomicrograph of Pelmicrite facies; lithic origin of pellets are closely packed. PPL. Bar scale is 0.35mm.

Figure 6. Photomicrograph of Mottled dolomitic micrite facies; iron-coated dolomite patches representing burrow infilled dolomite, length-slow chalcedony replaced pre-existing micrite along the course of contact between the dolomite patches area and pre-existing matrix. PPL. Bar scale is 0.35mm.

Figure 7. Photomicrograph of Mottled dolomitic micrite facies; a sharp boundary between burrow wall and unaltered host sediment and burrow-end point of individual vertical burrow. PPL. Bar scale is 0.35mm.

Figure 8. Photomicrograph of Intrapeldolomite facies; incipient micritic matrix in the interparticle pore has been replaced by dolomite in which allochems escapes dolomitization. PPL. Bar scale is 0.35mm.

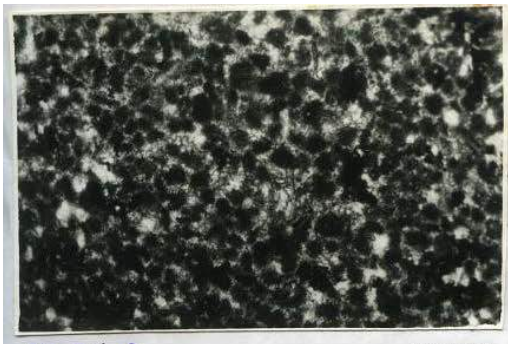


Fig. (1)

Fig. (2)

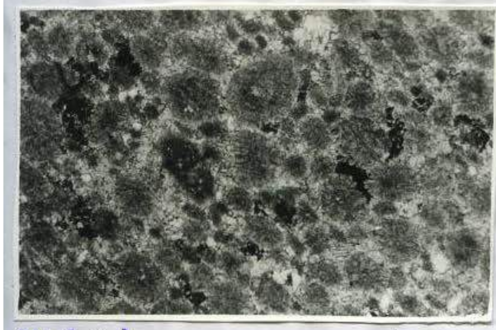


Fig. (3)

Fig. (4)

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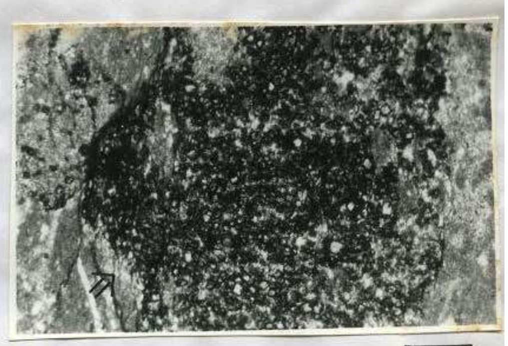

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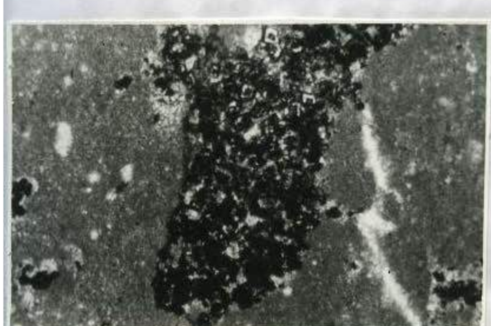

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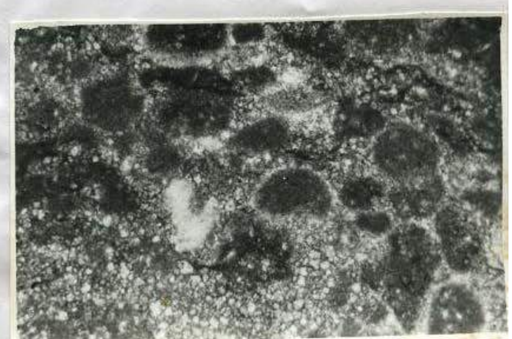

Fig. (8)

PLATE II

Figure 1. Photomicrograph of Dolomitized peloidal oobiosparite facies; almost all allochems have been dolomitized in varying degree where cement escapes dolomitization. Oolite is completely dolomitized (arrow), micritic matrix altered to neospar. PPL, Bar scale is 0.35mm.

Figure 2. Photomicrograph of Dolomitized peloidal oobiosparite facies; partly dolomitized peloid and ellipsoidal oolite are cemented by orthospar. PPL, Bar scale is 0.35mm.

Figure 3. Photomicrograph of Intrabiopelmicrite facies; echinoderm fragment has algal boring and micritive envelopes, micritic matrix initially alters to microspar. PPL, Bar scale is 0.35mm.

Figure 4. Photomicrograph of Oointrabiosparite facies; pellet nucleus of oolite encrusted by micrite. PPL, Bar scale is 0.35mm

Figure 5. Photomicrograph of Intraoobiosparite facies; tightly packed, distorted allochems, faintly alignments and compaction are well preserved; oolite grain retained their original shape but spall-off laminae and displaced nucleus due to effect of mechanical compaction (lower center) and some oolite grains do not retain their original shape and pressure solution at grain contact due to their chemical compaction. PPL. Bar scale is 0.35mm.

Figure 6. Photomicrograph of Algal biolithite facies; consisting of numerous Girvanella sheets (upper left), arborescent Epiphyton cluster (lower) and scattered quartz grains encrusted by micrite and neospar. PPL. Bar scale is 0.13mm.

Figure 7. Photomicrograph of Girvanella sp. of Algal biolithite facies; view of Girvanella sheet and very loosely intertwined preserved. PPL. Bar scale is 0.13mm.

Figure 8. Photomicrograph of Epiphyton sp. of Algal biolithite facies; view of Epiphyton clusters with more or less common level in diameter of branches and commonly dichotomously and rarely sympodial of stems are present, in association of grumeleuse structure. PPL. Bar scale is 0.13mm.

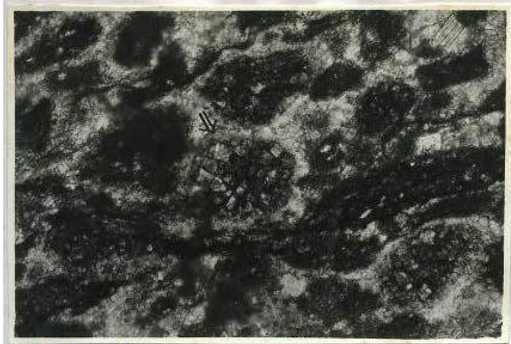

Fig. ( 1 )

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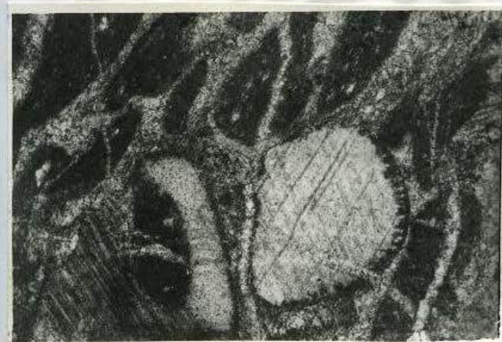

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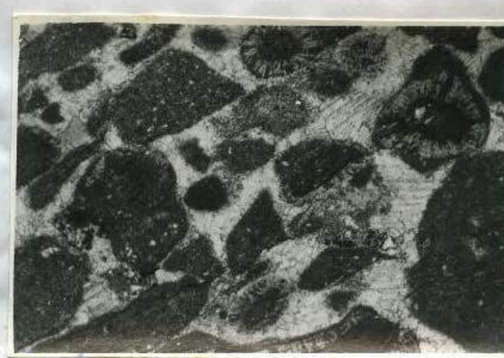

Fig. ( 4 )

Fig. ( 5 )

Fig. ( 6 )

Fig. ( 7 )

Fig. ( 8 )

PLATE III

Figure 1. Photomicrograph of cluster of zone dolomite with compromise boundaries, incipient relic micrite and complete euhedral shape have been preserved and it assumed to be fracture pore; PPL, Bar scale is 0.13mm.

Figure 2. Photomicrograph of zone dolomite cement taking place within interparticle pores spaces, it is encrusting allochems and has planar free-growth boundaries, Oointrasparite facies. PPL, Bar scale is 0.13mm.

Figure 3. Photomicrograph of distorted oolite of Intraoobiosparite facies, this type is notched, streatched and linked by narrow apophyses, no effect of distortion of the interparticle calcite cement and pressure solution at grain contacts are observed. PPL, Bar scale is 0.13mm.

Figure 4. Photomicrograph ofdistorted oolite of Intraoobiosparite facies, the external shape of oolite is modified and laminallae of cortex is undistorted, the nucleus of oolite is merely distorted, pressure solution of grains contact is affected by chemical compaction. PPL, Bar scale is 0.13mm

Figure 5. Photomicrograph of fascicular optic axis (pseudounixial cross) of oolite due to the effect of inversion eomorphosim, Oointrasparite facies. PPL. Bar scale is 0.13mm.

Figure 6. Photomicrograph of irregular isolated fenestral structure, Dismicrite facies. PPL. Bar scale is 0.13mm.

Figure 7. Photomicrograph of laminated planar fenestral structure, Dismicrite facies. PPL. Bar scale is 0.13mm.

Figure 8. Photomicrograph of grumeleuse structure (porphyroid aggrading neomorphism), Dismicrite facies. PPL. Bar scale is 0.13mm.

Fig. ( 1 )

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Fig. ( 5 )

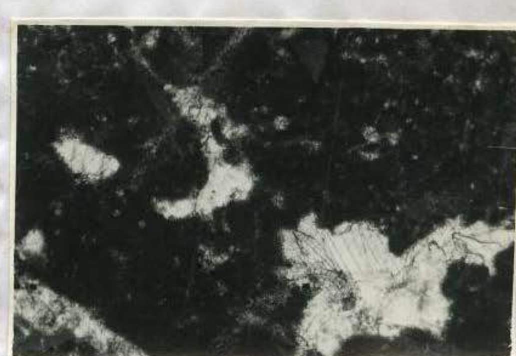


Fig. ( 6 )

Fig. ( 7 )

Fig. ( 8 )

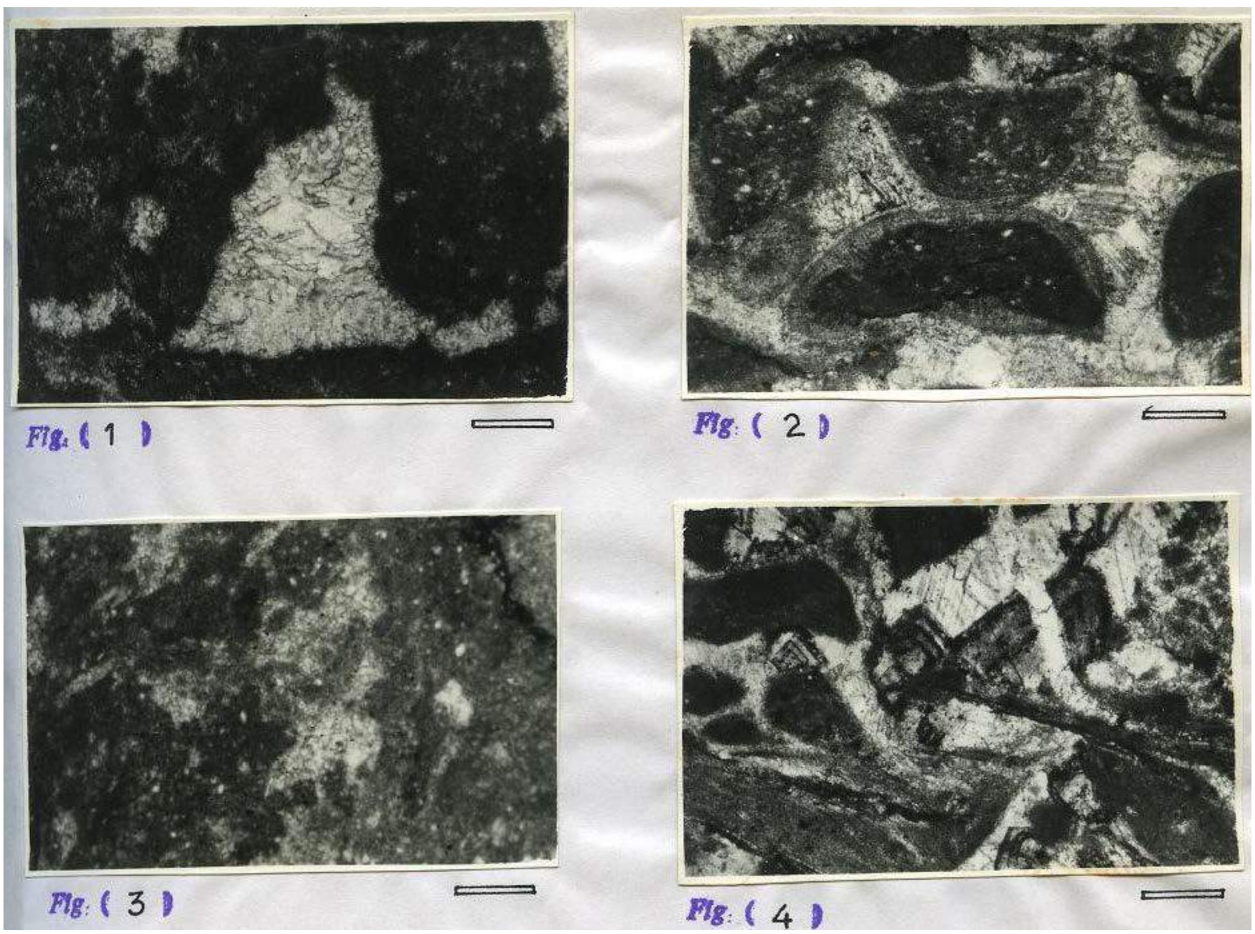
PLATE IV

Figure 1. Photomicrograph of a vug porosity is filled by drusy calcite, Algal biolithite facies; PPL, Bar scale is 0.13mm.

Figure 2. Photomicrograph of distorted superficial oolite of the Intraoobiosparite facies; the original shape and size of oolite are invisible due to the effect of mechanical compaction. PPL, Bar scale is 0.35mm.

Figure 3. Photomicrograph of grumeleuse structure of Algal biolithite facies. PPL, Bar scale is 0.35mm.

Figure 4. Photomicrograph of zone dolomite in association with orthospar and precursor mineral of micritic matrix is filling at the interparticle pore. PPL, Bar scale is 0.35mm



# Comparison of Sources of the Lower Palaeozoic Strata of Southern Thailand and Southern Australia: Evidence from Sedimentology and U-Pb Detrital Zircons

***Sitthinon Kultaksayos*[1]**, *Sebastien Meffre*[2], *Punya Charusiri*[3], *San Assavapatchara1*
1 Department of Mineral Resources, Bangkok, Thailand; 2 CODES, University of Tasmania, Hobart, Australia; 3 Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

**Keywords:** Detrital Zircon, Gondwana, Tectonics, Provenance, Sibumasu, Australia

The Transgondwana Supermountain is one of the largest collision event in Earth's history, this was a result of collision event between East and West Gondwana during ~650 – 515 Ma. That produced the huge amount of erosion and developed the Gondwana super-fan system which was driven the erosion of over 8,000 km-long and over 1,000 to five different continents such as India, Africa, Australia, South America and Antarctica (Squire et al., 2006). The Cambrian rocks dominated detrital zircon age peak ~650 – 550 and ~1200 – 900 Ma represent feature of Gondwana source.

This study uses detrital-zircon age spectra determined using LA-ICP-MS to understand the provenance of siliciclastic rocks in Western Tasmania during Cambrian - Ordovician. The detrital zircons were extracted from Late Cambrian – Early Ordovician quartz-rich sandstone (Owen Group) in Rosebery and Queenstown. The Owen Sandstone dominates the youngest concordant grain is 489±8 Ma and have major peaks around 500 and 1800 Ma and lesser peak at 1100, 1500, 1600 and 1700 Ma. The 1800 Ma detrital zircon component is most likely the quartzarenite to pelite of Rocky Cape Group (Halpin et al., 2014, Black et al., 2004). This peak is widespread in ancient sediments deposited in the Nuna supercontinent (Mulder et al. 2015) and is thought to be derived from granitoids in Laurentia (North America) and Baltica (Condie et al., 2009). While, the 500 Ma detrital zircon age peak could be derived from the Mt Read Volcanics and/or from the Gondwana Super-fan system which transported to sediments to Australia from the Trans African Orogen in the Early Paleozoic. While, the Middle – Late Ordovician Pioneer Sandstone samples contain mostly 500 Ma detrital zircons with very small 600 1200 and 1800 Ma populations. Although the pattern is similar to that in Ordovician sandstone from mainland Australia (Squire et al., 2006) the proportion of 500 Ma zircon is much greater in the Pioneer. This suggests that a significant part of the provenance may be from the Mt. Read Volcanics and or Cambrian magmatic arcs in Victoria or Antartica.

Comparing to the Late Cambrian Tarutao Sandstone Formation (Thailand, Sibumasu) have a major peak at 1110 Ma (Grenville Orogeny) and lesser peaks in ancient age. The data assumes that Sibumasu was close to western or northwestern Australia in the latest Cambrian–earliest Ordovician and received zircons from Australia and Antarctica due to the similarity of detrital zircon age spectra of Ordovician Tumblagooda Sandstone in Perth Basin, Western Australia (Burrett et al. 2014). In conclusion, detrital zircon spectra between Southern Thailand and Southern Australia have similarity of major peak of detrital zircon age of 500 Ma in Cambrian rocks. However, it may be an evidence that both detrital sources are from the Gondwana Super-fan system.

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# Early Ordovician sponge-bearing microbialites from Peninsular Malaysia and their geobiological significance

**Qijian LI**[1], Masatoshi SONE[2], Oliver LENHERT[3], LIN Na[1]
[1]Nanjing Institute of Geology and Paleontology; qijianli@hotmail.com
[2]University of Malaya
[3]University of Erlangen-Nürnberg

**Keywords:** *Calathium*, maze-like thrombolite, conodont biostratigraphy, stromatolite, anthaspidellid

Early Ordovician (Floian) lithistid sponge-Calathium-microbial reefs were discovered in the lower part of the Lower Setul Limestone in Perlis, northwestern Malaysia Peninsula. With a thickness of more than 30 m, massive microbial boundstone is surrounded by thick-bedded oncoid-intraclast rudstone/grainstone. The reefs were constructed of cylindrical stromatolites and maze-like thrombolites, accompanying a small proportion of lithistid sponges (anthaspidellids) and hypercalcified sponges (Calathium). The earliest Floian age is based on a conodont fauna including the zonal index species Serratognathus bilobatus. The microbialites might have grown in shallow subtidal environments, indicated by the high aspect ratio of the stromatolites and the associated coarse-grained sediments. The initial growth of stromatolites was sufficient to inhibit hydrodynamic removal of sediment and to create microhabitats in which environmental conditions were favourable for later accretion of thrombolites and colonization by anthaspidellids and calathids. These sponge-bearing microbialites represent the initial rise of metazoans in reefs at the dawn of the Ordovician Radiation, providing crucial information for understanding the transition from microbial- to metazoan-dominant reefs during this unique interval.

# Early Paleozoic basements of peninsular Thailand: Crustal and tectonic evolution

**Punya Charusiri**[1, 2] San Assavapatchara[1] Sitthinon Kultaksayos[1]
[1] Department of Mineral Resources, King Rama VI, Bangkok 10400 Thailand.
[2] Department of Geology, Chulalongkorn University, Bangkok 10330 Thailand

**Keywords:** Early Paleozoic, Basement, Thailand, Arc, Tectonic setting

We review the U-Pb age data obtained from zircons in Shan-Thai (or Sibumasu) granitoids of peninsular Thailand. The new U-Pb dating of Khao Tao orthogneiss in southern Thailand yields the reliable concordant zircon ages of 501.5 + 7.5 Ma. The I-type granite of Khao Pret area in southern Thailand gave a U-Pb zircon age of 477 + 7 Ma. The U-Pb dating of Muang Pan gneiss in northern Thailand gave the zircon age of 445.2 + 3.8 Ma. The $^{40}Ar/^{39}Ar$ dating of hornblende concentrates from Langsan orthogneissic rock yields the age of 446 Ma. All these age dating data point to the fact that the Shan-Thai (or Sibumasu) terrane is composed mainly of the covering Phanerozoic rocks with Late Paleozoic crystalline basement. Additionally, in southern Thailand the Hf model age (av. 1540 Ma) and the wide range of ∑Hf (t) values (from +4.1 to -6.5) of granitoid zircons suggest the protolith of late Proterozoic crust and mantle. We also consider that the coeval ages of Shan Thai crystalline basement and the other basement complexes to the north indicate their close spatial association with magmatic arc – related tectonic setting. Such the Early Paleozoic magmatism is situated along the India - Australia margin and can generate granite intrusions from a mixture source of mantle and mid(?) Proterozoic continental crust. These magmatic/metamorphic rocks form the basement complex as part of Pan – African orogenic belt of Gondwana.

# Earth surface evolution during the Early Paleozoic

**Ryan MCKENZIE**[1]
[1]University of Hong Kong; ryan00@hku.hk

The Neoproterozoic-early Paleozoic encapsulates dramatic shifts in Earth's surface environment, which had proud effects on biosphere evolution. These changes included a swing from icehouse conditions of the Cryogenian 'snowball Earth' events into the extensive greenhouse of the Cambrian, stepwise oxygenation of the atmosphere+ocean system, and secular changes in tectonic processes. The Cambrian is a notable interval of environmental stress with low biodiversity and rapid faunal turnover rates.  Here I will discuss aspects these environmental changes in relationship to global tectonics as associated with supercontinent breakup and amalgamation, particularly Rodina and Gondwana, with the long-term carbon cycle. Ultimately, variation in tectonic regimes can be linked to changes in volcanic outgassing, mountain building, and weathering processes that may have driven the observed changes in Earth's surface environment.

# First discovery of early Paleozoic magmatism in northern part of Thailand: Evidences from U-Pb zircon age determination

**Somboon Khositanont[1]** Khin Zaw[2] Sebastien Meffre[2]
1 Department of Mineral Resources
2 CODES Center of Excellent in Ore Deposit Research, University of Tasmania, Australia

**Keywords:** Loei Fold Belt, LA ICP-MS, U-Pb Zircon age determination, Plate boundary, Subduction

Intermediate extrusive rocks occurring along the Loei-Petchabun volcanic belt, northern part of Thailand, provide a great opportunity to understand the tectonic evolution of the Loei Fold Belt, the richest metallogenic province in Thailand. Dacitic to rhyolitic composition extrusive rocks occurring along the Thai-Laos border, northern part of Loei Province, contain numbers of zircon grains. U-Pb zircon age determination was applied to determine the age of volcanic emplacement using LA ICP-MS analytical technique. 12 zircon grains found in Ban Na Ko dacite yields the age of 434 ± 7 Ma whereas 12 zircon grains found in Ban Na Ngiew rhyolite yields the age of 425 ± 5 Ma respectively. This first discovery of absolute age of the extrusive rocks is an important evidence to supports the plate boundary and early subduction history occurred along the Loei Fold Belt in northern part of Thailand.

# First record of Lower – Middle Ordovician (Tremadocian-Dapingian) carbon isotope ($\delta^{13}C_{carb}$) chemostratigraphy in the Canning Basin, Western Australia; calibrated with geochronology/biostratigraphy and implications for global correlations

**Louisa DENT[1]**, Leon NORMORE[1], Anne FORBES[2]
[1]Geological survey of Western Australia; louisa.dent@dmirs.wa.gov.au
[2]Chemostrat Australia Pty. Ltd.

**Keywords:** Ordovician, chemostratigraphy, carbon isotope, geochronology, biostratigraphy

Significant and isochronous δ13C excursions and trends have been identified throughout the geological record and correlated across paleo-continents (Bergstrom et al., 2009) (Figure 1). New stable carbon isotope data (δ13Ccarb) from the Lower-Middle Ordovician is presented from 319.53 m of continuously cored strata from petroleum exploration well Olympic 1 in the Canning Basin, Western Australia (Figure 2). This cored section comprises a combination of marine carbonate and siliciclastic deposits that constitute the initial depositional sequence of the Canning Basin. Previous work on a series of ash beds recovered from the Olympic 1 core has provided seven high-precision CA-IDTIMS dates between 479.37 ± 0.16 Ma and 470.18 ± 0.13 Ma throughout the Nambeet Formation and lower Willara Formation. Conodont biostratigraphy also previously undertaken on the Olympic 1 core section has identified four conodont biozones ranging from the Paroistodus proteus Zone (Tremadocian) to the Jumudontus gananda Zone (Floian – Dapingian). The new isotope data from the Olympic 1 core is superimposed on this robust geochronological and biostratigraphic framework to provide a new δ13Ccarb¬ curve throughout the Tremadocian to Dapingian over a section currently unrepresented by δ13Ccarb data in Australia.

The δ13C isotope curve in Olympic 1 shows three distinct positive excursions that correlate to the global generalised δ13C curve (Figure 3);

1) A positive δ13Ccarb isotopic excursion at the top of the Floian, immediately above a CA-IDTIMS radioisotopic date of 470.18 +/- 0.13 Ma, within the J. ganada conodont biozone, lower Willara Formation;

2) A positive δ13Ccarb isotopic excursion in the middle Floian, immediately above a CA-IDTIMS radioisotopic date of 472.82 +/- 0.13 Ma, within the O. communis conodont biozone, upper Nambeet Formation; and

3) A positive δ13Ccarb isotopic excursion in the upper Tremadocian, immediately above a CA-IDTIMS radioisotopic date of 479.37 +/- 0.16 Ma, within the P. proteus conodont biozone, lower Nambeet Formation.

The majority of Ordovician δ13C studies have been undertaken in the Laurentian (e.g. Saltzman and Young 2005; Bergström et al., 2010) and Baltican (e.g. Kaljo et al., 2007; Ainsaar et al., 2010) paleo-regions. These correlations have expanded across the globe to the Argentine Precordillera (Buggisch et al 2003; Thompson and Kah 2012), Siberia (Kouchinsky et al., 2008), Northern China (Jing et al., 2008; Ripperdan et al., 1993) and Southern China (Young et al., 2008; Munnecke et al., 2011). In Australia the only major study on δ13Ccarb in the Ordovician was conducted by Ripperdan et al. (1992) on the Black Mountain section in Queensland. This section is limited to Cambrian and earliest Ordovician strata, leaving a gap in the δ13Ccarb data in

Australia over the majority of the Ordovician. The new Olympic 1 δ13Ccarb isotopic curve fills part of this missing interval, recording two existing and one new positive δ13Ccarb excursions that can be correlated globally. The CA-IDTIMS dates and well-defined conodont biostratigraphy that correspond to these three excursions provide a strong means for tying excursions to the global time scale.

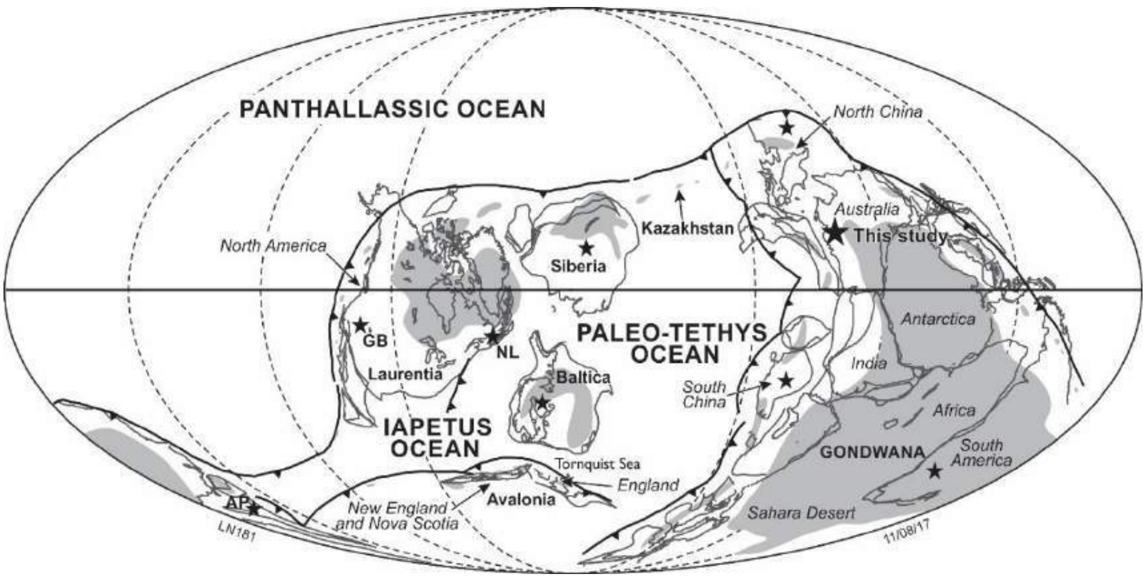


Figure 1: Paleogeography of the Middle Ordovician (~470 Ma) world showing the position of Australia and other studied sections worldwide; Great Basin (GB), the Argentine Precordillera (AP) and western Newfoundland (NL). Modified from Cooper and Sadler, 2012.

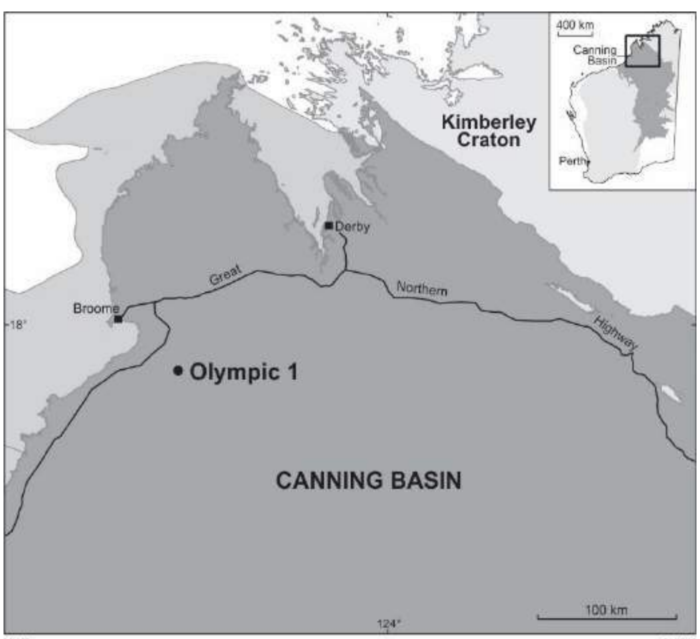


Figure 2: Location map of the Canning Basin, Western Australia, showing petroleum well Olympic 1.

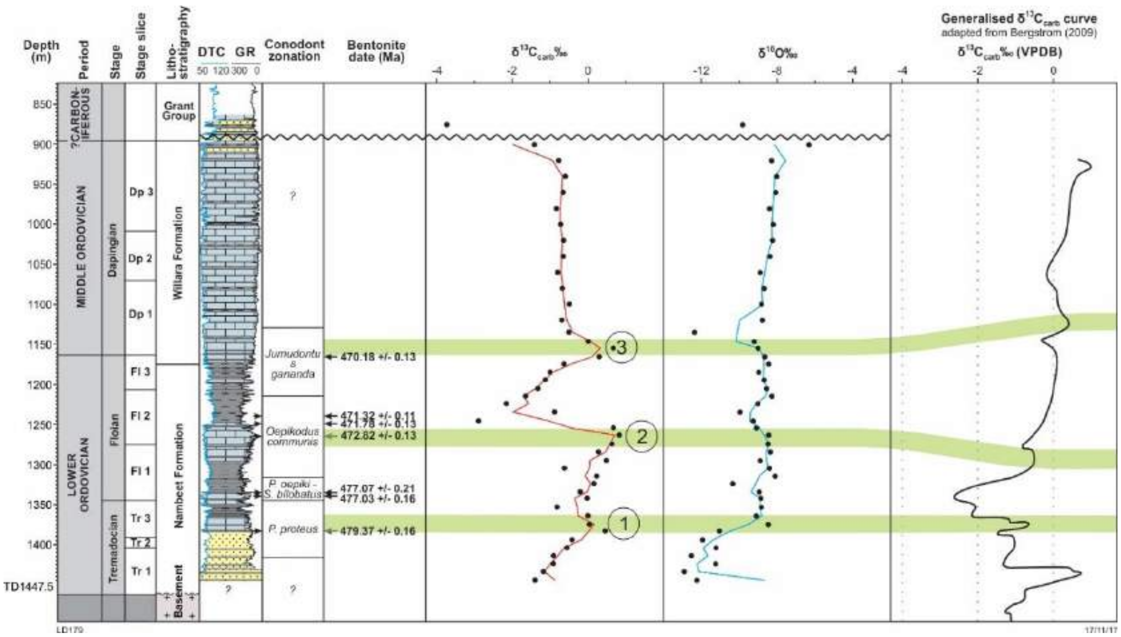


Figure 3: Generalized correlation of the δ13C and δ18O data from the Olympic 1 section (current study) with the global δ13C curve adapted from Bergstrom et al. (2009), original data from Buggisch et al. (2003). Isotope lines represent a three-point moving average of the δ13C and δ18O data. Lithology, biostratigraphic zones, conodont zonation and CA-IDTIMS geochronology from Normore et al. (2018).

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# Konservat-Lagerstätten in upper Cambrian and Ordovician shales in South China—a brief review

**ZHANG Yuandong**[1], Lucy A. MUIR[2], Joseph BOTTING[3], MA Xuan[4], SONG Yanyan[5]
[1]Nanjing Instutute of Geology and Palaeontology; ydzhang@nigpas.ac.cn
[2]Department of Natural Sciences, Amguddfa Cymru – National Museum Wales
[3]Nanjing Institute of Geology and Palaeontology [4]University of Chinese Academy of Sciences
[5]Institute of Geology, Chinese Academy of Geological Sciences

**Keywords:** Konservat-Lagerstätte, Shale, biodiversity, facies, Ordovician

The later Cambrian to Ordovician rocks of South China contain many shales that yield diverse faunas and Konservat-Lagerstätten. These shales are developed intermittently and contain exceptionally-preserved faunas in the Furongian, Tremadocian–Floian transition, Darriwilian–Sandbian transition, and late Katian to Hirnantian deposits, combining to reveal a rich record of community development. The Sandu Formation of Jiangshanian (Furongian, Cambrian) age yields the Guole Lagerstätte, a Burgess Shale-type fauna containing arthropods, echinoderms, brachiopods, cnidarians, graptolites, hyolithids, palaeoscolecids and algae, and representing a marginal platform to slope facies. The upper Tremadocian Fenghsiang Formation, typified by intercalated shale and limestone, contains exceptionally-preserved linguloid brachiopods (with pedicles), black corals, conodonts, bryozoans, the cnidarian *Sphenothallus*, conulariids, graptolites and a putative scalidophoran embryo, which together comprise the Fenxiang Biota. The formation represents a marginal platform facies. The Floian Tonggao Formation yields conulariids, palaeoscolecid worms, a possible nematode worm, pelmatozoans, graptolites, brachiopods, gastropods, bryozoans, non-biomineralized arthropods and algae, which comprise the Tonggao Biota. The Sandbian Miaopo Formation, lithologically typified by black shale intercalated with a few layers of limestone, represent deposits of an intra-platform depression in the Yangtze Region, South China. The shale of the formation contains abundant, sometimes exceptionally preserved, graptolites, brachiopods, trilobites, nautiloids, chitinozoans, echinoderms and algae. Some largely contemporaneous shale (upper Darriwilian to Sandbian) also occurs in the North China and Tarim blocks, indicative of a likely global transgression event at the Darriwilian–Sandbian transition. The upper Hirnantian Wenchang Formation is characterized by a thick succession of sandstones and siltstones with a few layers of shale, and represents deep-water, dysaerobic deposits of a basin adjacent to the Cathaysian Land. In a 9-m-thick, deeper-water black shale interval of the formation, the Anji Biota (Konservat-Lagerstätte) occurs, which is dominated by extremely diverse sponges, with abundant soft-tissue preservation, and graptolites, and less common non-biomineralized arthropods, cephalopods and echinoderms. These exceptionally-preserved faunas from upper Cambrian and Ordovician shales in South China are related to various facies, including marginal platform-slope facies, intra-platform depression or foreland basin with anoxic–dysoxic sea water, but all appear to be associated with global or regional transgression events, suggesting a general causative phenomenon. In the Anji Biota in particular, exceptional preservation by rapid sedimentation was generated by post-glacial transgression over weathered land masses, and similar processes may have operated at other times. The combined record of these (and potential further faunas in the region) provides a key window for understanding the development of Ordovician ecology, beyond the normal shelly assemblages.

# Looking for a volcanic source for Lower – Middle Ordovician (Tremadocian – Floian) ash beds from the Canning Basin, Western Australia

**Leon NORMORE[1]**, Louisa DENT[1]
[1]Geological survey of Western Australia; leon.normore@dmirs.wa.gov.au

**Keywords:** Ordovician, geochemistry, paleogeography, geochronology, biostratigraphy

Eleven ash beds have been identified in Tremadocian to Floian strata in core from petroleum well Olympic 1 in the Canning Basin, northwestern Australia (Figure 1). The ash beds are distributed throughout 218 m of continuous core in the Nambeet Formation and lower Willara Formation, the initial depositional fill of the Canning Basin. Previous work on these ash beds has provided seven high-precision Chemical Abrasion-Isotope Dilution Thermal Ionization Mass Spectrometry (CA-IDTIMS) dates between 479.37 ± 0.16 Ma and 470.18 ± 0.13 Ma (Normore et al, 2018). No Ordovician eruptive centres are known in Western Australia. The nearest similar aged volcanic activity in Australia can be found in the Macquarie Arc in central-western New South Wales which could be a potential source area. Geochemical analysis has been carried out on these ash beds to assess potential sources of Tremadocian and Floian volcanic events in adjacent paleo-terranes. Analysis of major and trace elements by ICP-MS following four-acid digestion produce four distinct rare earth element (REE) patterns (Figure 2).

Four samples (221964, 221963, 221962, 221959) have broadly similar and rather unusual chondrite-normalised REE patterns (Fig. 2a) characterised by concave Light REE (LREE) patterns, negative Eu anomalies and broadly flat Heavy REE (HREE) patterns ($(Gd/Yb)_{CN}$ of 0.6 – 1.2). Apart from 221964, these samples have high LREE concentrations (e.g. La of 53-65 ppm). Two samples (221961 and 221960) have REE patterns with weak depletion of LREE, weak negative Eu anomalies and flat to weakly depleted HREE (Fig. 2b). Samples 221957, 221956 and 221955 have sub-parallel REE patterns with flat LREE, a weak positive Sm anomaly, negative Eu anomaly and are HREE enriched (depleted in MREE with respect to HREE) with $(Gd/Yb)_{CN}$ of 0.46 – 0.56 (Fig. 2c). The two remaining samples (Fig. 2d) have flat to HREE depleted REE patterns (221958, 221954). Rare earth element plots from Ordovician ash beds in the United States (Fig. 2e) exhibit comparable signatures to some Canning Basin samples (Fig. 2c), with both LREE and HREE enrichment and negative Eu anomalies. Late Ordovician/Early Silurian ash beds from South China, (Fig. 2f) exhibit REE plots with enriched, concave LREE patterns shown by Canning Basin samples in Figure 2a, but are not HREE enriched.

Geochemical correlations of ash beds based on REE chemistry need to take into account the effects of sorting and dilution during transport in a marine environment, as well as alteration. Diagenesis can cause redistribution of elements, including the REE, and the accumulation of detrital minerals such as garnet and zircon can result in HREE enrichment. Thus far, the Olympic 1 ash bed geochemistry identifies multiple discrete REE profiles suggesting volcanic provenance from a number of sources. The successful geochemical correlation of coeval ash beds from adjacent Lower Ordovician terranes and/or determining the original source of these Canning Basin ash beds will aid in the reconstruction of Australia's location in equatorial Gondwana during the early Paleozoic.

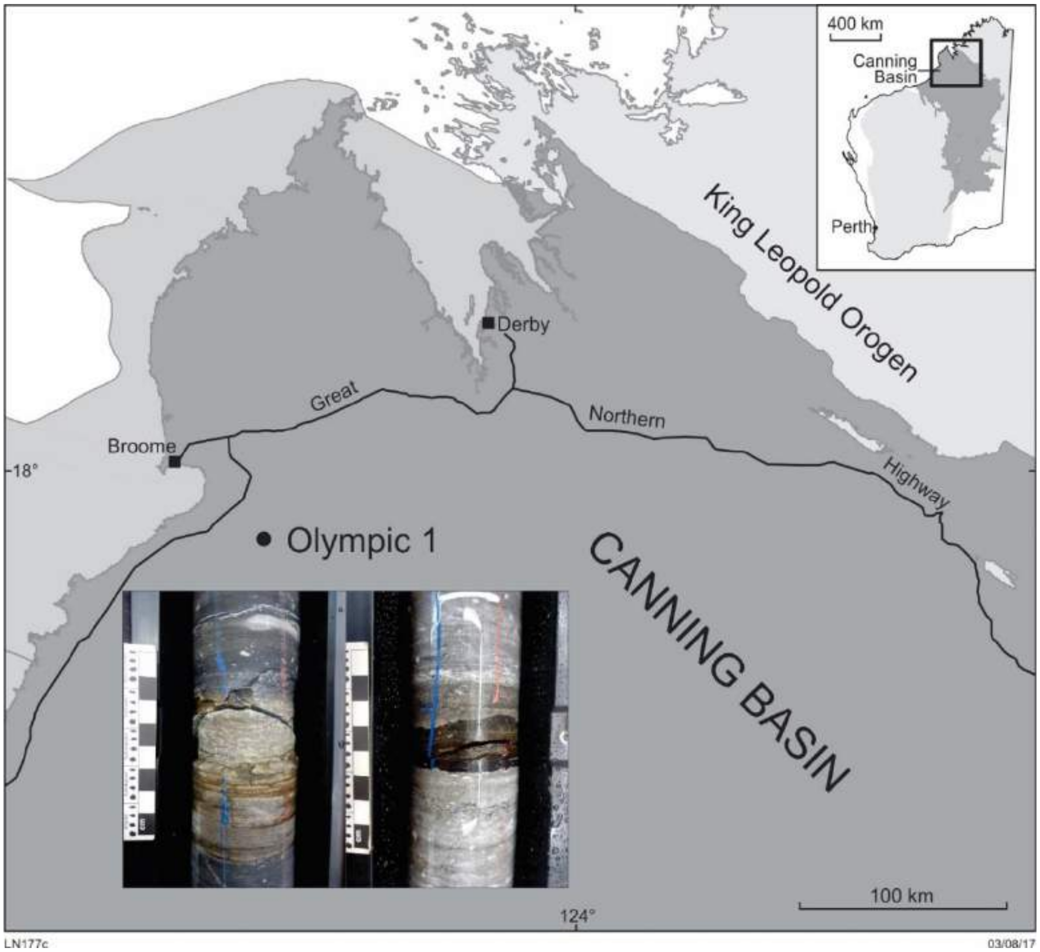


Figure 1: Location map of the Canning Basin, Western Australia, showing petroleum well Olympic 1 and two examples of ash beds identified in core.

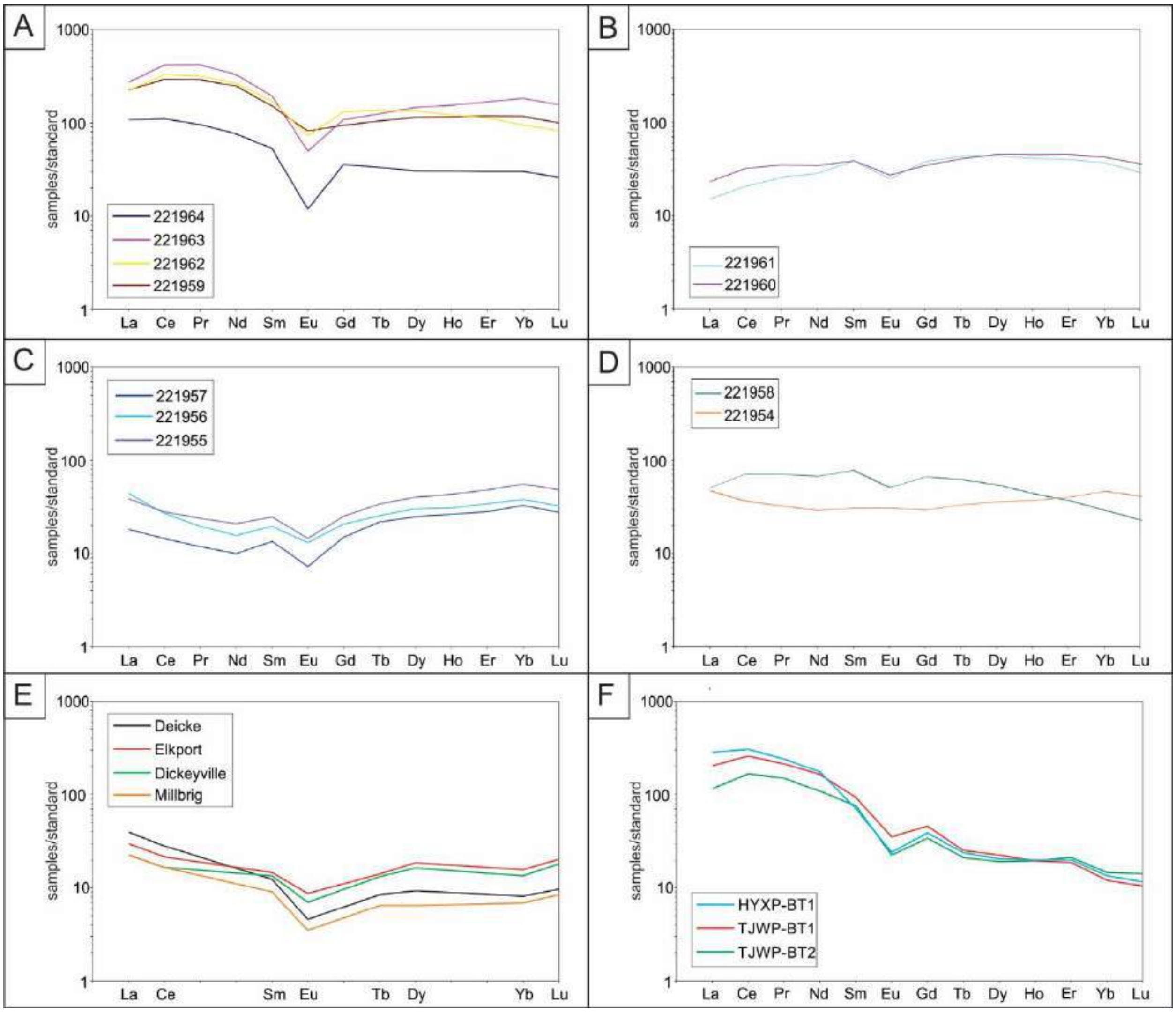

Figure 2: A-D. Four distinct volcanic geochemical assemblages from the Lower Ordovician ash beds of Western Australia based on the plot of Rare Earth Elements normalized to Cl chondrite (McDonough and Sun, 1995); E. Limited REE data from a reference suite of Ordovician ash beds from mid-continental United States (Kolata *et al*., 1987) and F. Selected REE data from Late Ordovician/Early Silurian ash beds from South China (Ge *et al*., 2018).

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# Lower Palaeozoic strata in southern Myanmar and Ordovician correlations in South East Asia

**Clive BURRETT**[1], M. UDCHACHON[1], H. THASSANAPAK[1], P. CHRARUSARI[2]
[1]Mahasarakham University; cfburrett@gmail.com
[2]Chulalongkorn University

**Keywords:** Ordovician, Thailand, Myanmar, Malaysia, Carboniferous orogeny

Lower Palaeozoic rocks have been mapped in Kayin State in an area previously shown on published maps as either metamorphic or possibly Lower or Upper Palaeozoic rocks. Three new formations, with a total thickness of over 900 m, apparently overlain by an, at least, 100 m thick Upper Palaeozoic formation are mapped along the Salween River and along the road from Yinbaing, in Myanmar, to Tha Song Yang, in Thailand. The Lower Palaeozoic succession consists of the predominantly siliciclastic Kyaukpulu and Kushwe–e–we formations and an overlying, predominantly carbonate Meseik Ashe Formation which contains Middle Ordovician (Darriwilian) conodonts. The older two formations are probable correlates of the Ngwetaung and Lokeypin formations of the southern Shan State of Myanmar and the Lower Ordovician siliciclastics of western Thailand. The overlying, peritidal to shallow subtidal carbonates of the Meseik–Ashe Formation are correlates of the Wunbye and Sitha formations of Shan State, Myanmar. The thick–bedded, quartz arenites of the Nyaungwiang Formation are faulted against the Ordovician carbonates and are probable lithological correlates of the Carboniferous Taungnyo Formation. Cambro-Ordovician correlations between Myanmar, Thailand and Langkawi are suggested based on mapping in Langkawi, Satun and southern Myanmar.The folds in the Lower Palaeozoic rocks are overturned to the northeast and deformation was in one major phase between the Tournaisian and the Early Permian. The Lower Palaeozoic strata may probably be followed as a ridge for at least 100 km towards the NNW, close to the western border of the Sibuma Block which is separated by a postulated cryptic suture from the Irrawaddy Block to the west. This newly mapped sequence in peninsular Myanmar is similar to that in parts of western Thailand and following Brunschweiller (1970) we emphasise the poorly known Late Carboniferous folding which does not appear on present models to have a collisional cause.

# New trilobite fauna from the Tarutao Formation, Thailand and their biostratigraphic and paleogeographic significance

**Shelly WERNETTE**[1], Nigel C. HUGHES[1], Paul MYROW[2], Apsorn Sardsud[3]
[1]University of California, Riverside; swern001@ucr.edu
[2]Colorado College, Colorado Springs
[3]Department of Mineral Resources, Thailand

The Tarutao Formation of Thailand is geologically significant for its interbedded volcanic ashes and fossiliferous sandstones spanning the Cambrian-Ordovician boundary. A recent expedition to Tarutao in 2016 recovered two taxa previously unknown in the Tarutao Formation. *Mansuyarcus satunensis* (nomina nuda) is a new Kaolishaniidae trilobite genus and species, subfamily Mansuyiinae, from the Furongian. *M. satunensis* co-occurs with other endemic taxa, including *Thailandium solum,* a genus and species described by Kobayashi in the first report on Tarutao's Cambrian fauna. The other taxon previously unknown on Tarutao is *Apatokephalus* sp., an Ordovician trilobite co-occurring with trilobites previously identified by Stait et al., including *Akoldinioida* sp., *Asaphellus* sp., and *Rossaspis bunopasi*. *M. satunensis* is a biostratigraphically important taxon for Furongian rocks, because it is more stratigraphically restricted than the other taxa with which it occurs. Its known occurrences on Tarutao include a single horizon within the Ao Talo Topo section and across a .03m interval near the top of the 2.5m measured at the Ao Molae locality. The restrictiveness of the former range is likely the result of having only sampled one horizon at Ao Talo Topo, but the latter range is restricted despite sampling eight horizons with a great deal of material from each horizon. Because *M. satunensis* occurs only near the top of the Ao Molae, allowing confident correlation with the Ao Talo Topo section. *Apatokephalus* sp. is an abundant taxon that is easy to recognize in the Ordovician section of the Tarutao fauna. Both *Mansuyarcus* and *Apatokephalus* help strengthen paleogeographic ties between Sibumasu and Australia. *Mansuyarcus* is endemic to Thailand, but the most similar Mansuyiniid is found in the Pacoota Sandstone and Chatsworth Limestone of Australia. *Apatokephalus* is also found in the Pacoota sandstone as well as on the Korean peninsula and throughout China.  Combined with the other fauna and stratigraphy of the Tarutao formation, these two trilobites enhance understanding of biostratigraphy and paleogeography.

# Preliminary Evolution of the Drainage System in Central Myanmar Basin with Stratigraphic Development of Headwater of the Hukawnng and Myitsone Areas

**Naing Maw THAN**[1]
[1]Myanmar Geologists Society, Sigapore; naingmawthan@gmail.com

**Keywords:** Myanmar, Irrawaddy, Chindwin, Yarlung Tsangpo, Hukawng, Myitsone

The eastern syntaxis of the Himalayas and the Tibetan Plateau contains the most tectonically complex geology in Asia. This region is drained by the Red, Mekong, Salween, Ayeyarwaddy (Irrawaddy), Ganges, and Brahmaputra Rivers debouch into the Indian Ocean (Robinson et al., 2007).

The Yarlung Tsangpo River (YTS) drains southern Tibet and the deep Siang River gorge through the eastern Himalayan syntaxis before joining the Brahmaputra in northeastern India. U-Pb age dating and Hf isotope analyses of detrital zircons, Robinson et al. (2013) proposed that the (YTS) formerly drained into the Ayeyarwaddy River (ADY) in Myanmar through the eastern syntaxis, and that this ancient river system was established by (at least) the Middle–Late Eocene. The YTS–ADY were disconnected in the Early Miocene driven by increased deformation in the eastern syntaxis and headward erosion by tributaries of the Brahmaputra.

Conversely, based on the study of the Minbu (Salin) basin Licht et al. (2014) remarked that (CMB) drainage system remained closed and did not experience any major capture recognition since the beginning of the Indian-Asia collision. Since 1940 Stamp remarkably noted that Proto-Ayeyarwaddy, flowed into the gulf roughly along the line of the present Chindwin and later extended southwards, as the gulf became infilled, along the present course of the Lower Ayeyarwaddy. There was probably a parallel river along the line of the Upper Ayeyarwaddy and Sittaung, which may be called the Proto-Sittaung.

Now, according to the comparative study on basin development of headwater areas (Hukawng and Myitsone) envisage to define the Chindwin was major antecedent river in Myanmar. Hukawng Basin is closely lied to the Western ophiolite belt of Early Cretaceous (ca. 127 m.a) coeval with Neo-Tethyan ophiolites along the YTS suture. In contrast, Myitsone area immediately exist on the Eastern ophiolite belt occupying Mid. Jurassic (ca.173 m.a) and the southern continuation of the Meso-Tethyan Bangong-Nujiang suture in the Tibetan Plateau (Liu et al. 2016).

The headwater area of Chindwin River in Hukawng basin consist of Cretaceous ophiolites with marginal marine environment of tide dominant Eocene shales, siltstones and Oligo-Miocene pebbly sandstones (Tin Tun Aung et al. 2005). To the East, Mytitsone area where two major tributaries (Maykha and Malikha) drain and merge to build up the ADY. There are cropped out a typical ophiolites suits in Middle Jurassic age associated with metamorphics, greywacke, limestone and metasedimentary rocks (Hla Htay et. al 2017). In which the Tonbun conglomerates (Mio - Pliocene) of fluviatile deposits are well developed along the Maykha and ADY bank.

According to the studying of stratigraphic and sedimentological approaches, since at least of Eocene tide dominant marginal sea environs was well developed in Hukawng area as a result of downstream deposits by YTS whereas less fluvial evidences in Myitsone area and only built up of terrestrial deposit as appeared as newly born river in Mio-Pliocene. By this indications the Yarlung

Tsangpo initially connected to Chindwin and captured into Ayeyarwaddy after the deformation of eastern syntaxis.

An extensive study of insight on detrial zircons age dating accompanied with CMB basin analysis are required to complete configuration of drainage system in Myanmar.

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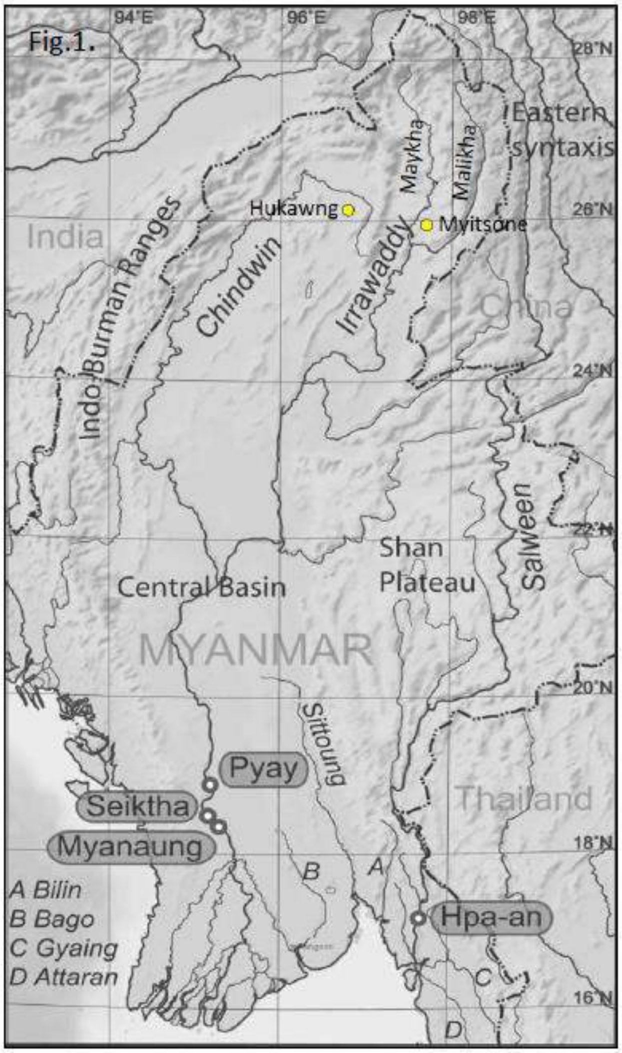


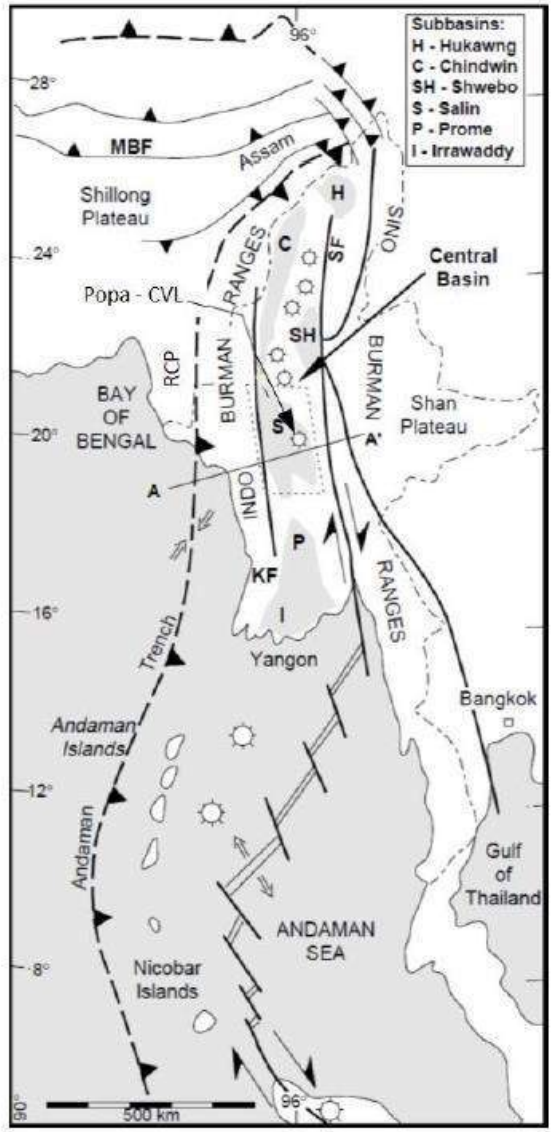




Fig.1. Map showing physiography and major rivers of Myanmar (After Robinson et al. 2007)
Fig.2. Tectonic framework and sub-basins of the Central Basin in Myanmar (after Pivnik et al. 1998). Index: MBF (Main Boundary Fault), KF (Kabaw Fault), SF (Sagaing Fault), CVL (Central Volcanic Line), RCP (Rakhine Coastal Plane), Not shown Section AA in here.

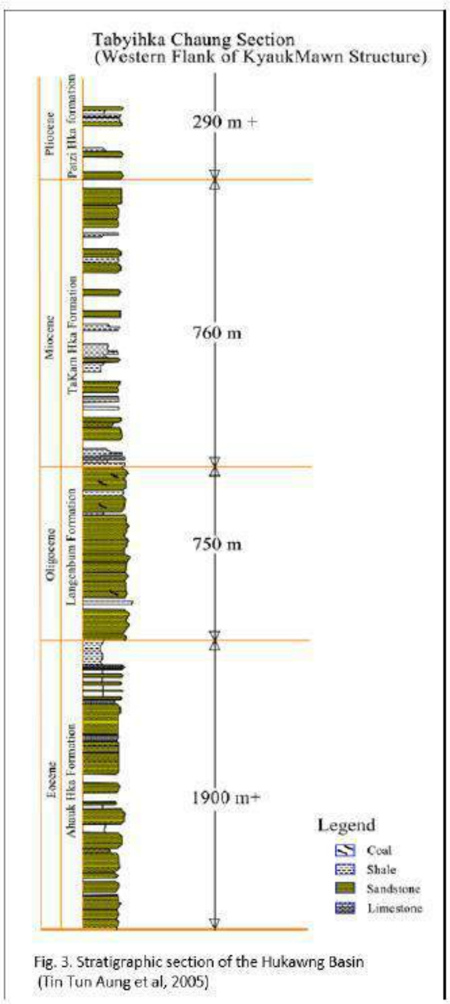


Fig. 3. Stratigraphic section of the Hukawng Basin
(Tin Tun Aung et al, 2005)

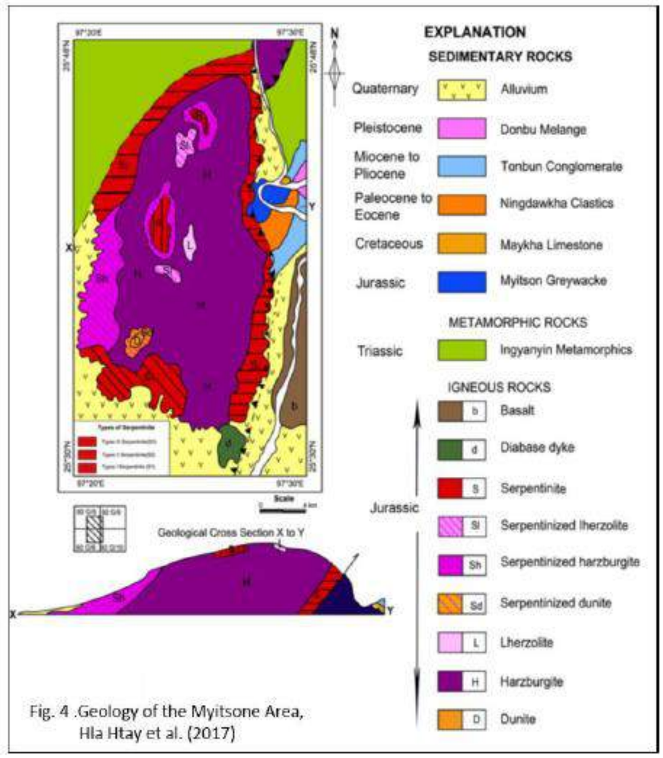


Fig. 4 .Geology of the Myitsone Area,
Hla Htay et al. (2017)

Fig.3. Stratigraphic Section of the Hukawng Basin (Tin Tun Aung et al. 2005).

Fig.4. Geology of the Myitsone Area (Hla Htay et al. 2017).

# Proposed GSSP for the base of Cambrian Stage 10 (Furongian Series) at FAD of *Lotagnostus americanus* in the Wa'ergang section, Hunan, South China

**PENG Shanchi**[1], Loren E. BABCOCK[2], Gabriella BAGNOLI[3], SHEN Yanan[4], MEI Mingxiang[5], ZHU Xuejian[1], LI Dandan[4], WANG Long[5]
[1]Nanjing Instutute of Geology and Palaeontology; scpeng@nigpas.ac.cn
[2]Ohio State University [3]University of Pisa [4]University of Science and Technology of China
[5]China University of Geosciences (Beijing)

The FAD of cosmopolitan agnostoid arthropod Lotagnostus americanus has been decided as primary tool to define the base of provisional Cambrian Stage 10 as voted by ISCS in 2005. The horizon has been well constrained in the Wa'ergang section, Hunan, China and the Khose-Nelege section, Siberia, Russia, and both sections have been proposed as GSSP for Stage 10, the uppermost stage of the Cambrian System.

Wa'ergang section is located in NW Taoyuan County, Hunan Province, South China, and exposes a thick Cambrian-Ordovician carbonate succession in slope facies. Detailed field study on the trilobite biostratigraphy of the L. americanus-bearing interval allows recognition of three agnostoid zones and reveals that the FAD of L. americanus lies at 29.65 m above the base of the Shenjiawan Formation and this horizon is more or less coincident with the lowest known occurrences of two important polymerid trilobites, Hedinaspis regalis and Charchaqia norini, both of which have an intercontinental distribution.

Four conodont zones with several species having intercontinental correlation value are recognized by detailed sampling in the Waergang section. Cosmopolitan species include Proconodontus tenuiserratus, P. muelleri, P. serratus, and Eoconodontus notchpeakensis. The base of the P. posterocostatus Zone, marked by the lowest occurrence of Dasytodus trasmutatus, nearly coincides with the first appearance of L. americanus, the proposed GSSP horizon. The presence of E. notchpeakensis is critical as its FAD was proposed as an alternative horizon for the base of Stage 10. The Wa'ergang section is probably the only section known to yield both L. americanus and E. notchpeakensis, providing direct difference of the lowest occurrences of these two species and confirming they do not occur at a comparable stratigraphical level but are separated in a considerable interval of strata. The FAD of E. notchpeakensis lies at about half way between the FAD of L. americanus and the base of Ordovician and this horizon may be useful to subdivide the Stage 10 into two substages.

Recent δ13C isotopic studies from elsewhere in the world show multiple negative excursions occurred in Stage 10. High-resolution δ13C analyses in the Wa'ergang section reveal three negative excursions (N1, N2, N3) within this stage, among which the N1 and N2 excursions are older than the HERB/TOCE (N3) excursion, and the N1 excursion begins just above the proposed GSSP horizon. The N1 excursion represents the first significant carbon isotope excursion event following the SPICE excursion, and correlates into Australian,

Argentine, and probably Laurentian sections. The near-coincidence of this isotope excursion with the first occurrences of widely distributed agnostoid, polymerid, and conodont species, allows confident recognition of the base of Cambrian Stage 10 on a global scale.

The study on the sequences stratigraphy of Wa'ergang section reveals that the nearly whole Shenjianwan Formation consists of a single third-order sequence that embraces 44 carbonate meter-scale cycles of the L-M type. The third order sequence can be subdivided into 2 fourth order sequences, each of which is further subdivided into 6 fifth order sequences.

The proposed GSSP lies within the first fifth order sequence at the basal part of the Shenjianwan Formation, about 8 m above the conterminous base of the third order, the lowermost fourth and fifth order sequences.

# Reconstruction of tectonic history of Myanmar Region

**Hla Hla Aung**
Myanmar Earthquake Committee; hhlaaung@gmail.com

**Keywords:** movement, accretion, correlation, deformation, spreading, reconstruction, subduction

The relative movement and interaction of the Indian, the Burma-platelet and the Indochina plate (Eurasian plate) through time are responsible for the tectonics, structures, morphotectonic features, sedimentation patterns of basin formation that define tectonic history of Myanmar region. Separation of the India from its former Gondwana neighbors in Early Cretaceous, detachment of the Burma platelet from the India plate and accretion to the Indochina plate have formed an accreted belt at the western edge of Indochina plate in Late Cretaceous-Early Eocene. Myanmar represents an evolving continent of two crustal formation histories consisting of the Burma plate and the Indochina plate. The Burma plate consists of three distinct lithotectonic entities of: 1) a continental fragment; 2) a subduction-related accreted complex and 3) a coastal area. Eastern Myanmar that is western continuation of Indochina plate is composed of three tectonostratigraphic entities:1).An accreted belt, 2).Shan Massif (SIBUMASU), and 3). Paleo-Tethys suture zone. Biostratigraphic correlation between the known distribution of dominant Mesozoic representatives of Monotis, Halobia, and Daonella fauna and Tethyan fusulinid assemblages of Triassic age from Myanmar are made with those from neighboring countries of SE Asia to get estimated palaeogeographic position and reconstruction of tectonic history for Myanmar. These plates may have originated in Gondwana in Paleozoic. Each tectonic units have been separated by three suture zones of the Paleo-, Meso- and Neo-Tethys. They are: 1) the Than Lwin Belt in the easternmost part of Myanmar, which is a tectonic linkage between Inthanon Zone of West Thailand and Changning-Menglian belt (West Yunnan); 2) Shan Boundary Belt of Meso-Tethys suture in the western edge of Indochina plate; 3) Rakhine Western Ranges (Rakhine-Andaman-Nicobar belt) of Neo-Tethys suture at the westernmost part of Myanmar. Biostratigraphic correlation of micro-and macro-foraminiferas with biostratigraphic provinces of neighboring countries are made for reconstruction of tectonic history of Myanmar. The accretionary episodes which ended in Early Tertiary, have been followed by post-accretionary deformation of strike-slip faulting of the Sagaing Fault in Myanmar; West Andaman Fault and Sumatra Fault System in Sumatra; spreading in Andaman back-arc basin.

# Revised Cambrian trilobite biostratigraphy of the northern Victoria Land, Antarctica

**Tae-Yoon PARK**[1], Ji-Hoon KIHM[1], Jusun WOO[1], Young-Hwan KIM[1], Jong-Ik LEE[1]
[1]Korea Polar Research Institute; typark@kopri.re.kr

**Keywords:** Trilobite, Cambrian, biostratigraphy, Antarctica, northern Victoria Land

Antarctica was located in East Gondwana during the Early Paleozoic. The Cambrian rocks in Antarctica are most exposed along the Transantarctic Mountains which runs along the eastern margin of the continent, and ends in the northern Victoria Land (NVL). The Cambrian sedimentary successions in NVL were formed in association with subduction of the paleo-Pacific plate under the Antarctic continent, and represented by an accretionary complex of sedimentary rocks in three tectonic terranes: the Wilson, Bowers and Robertson Bay terranes, from inboard to outboard. The Bowers Supergroup of the Bowers Terrane is well-known for containing Cambrian trilobites which can be used for biostratigraphic correlation. The original Cambrian stratigraphy of the Bowers Terrane was established on the basis of the trilobites collected from five localities (Fig. 1) during 1974/75 and 1981/82 expeditions by the New Zealand Antarctic Research Programme (NZARP). Of the five localities, Edlin Neve and Mariner Glacier represent the northwest and the southeast end points, and are only about 200 km apart (Fig. 1). Nevertheless, the Cambrian stratigraphy of the area were interpreted to show a remarkable lateral facies variation (Fig. 2). Korea Polar Research Institute carried out four expedition to the northern Victorian Land from 2012/2013 season to 2015/2016 season, with setting up field camps at Mariner Glacier and Reilly Ridge. A detailed biostratigraphic researches in the area has revealed that the thick Spurs Formation at Mariner Glacier is due to stratigraphic repetitions by tectonic folds, and the Paibian aspect of the Spurs Formation at Reilly Ridge was due to misidentifications of some taxa. As a result, the revised Cambrian stratigraphy of the Bowers Terrance has become to show less lateral facies variation than the original version (Fig. 3). The remaining issues of the area include 1) the unusually thicker Molar Formation at Houliston Glacier; 2) the unreliable age of the Eureka Formation which occurs only at Marine Glacier, and; 3) the lower boundary of the Spurs Formation at Mariner Glacier which was covered by snow (Fig. 3).

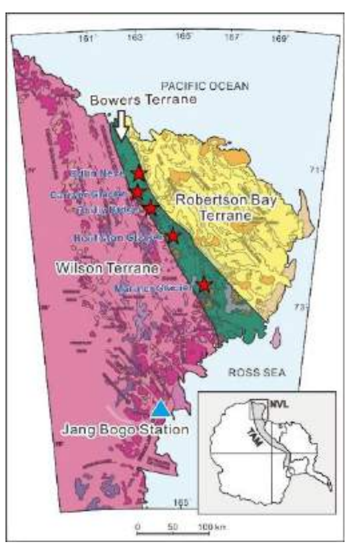
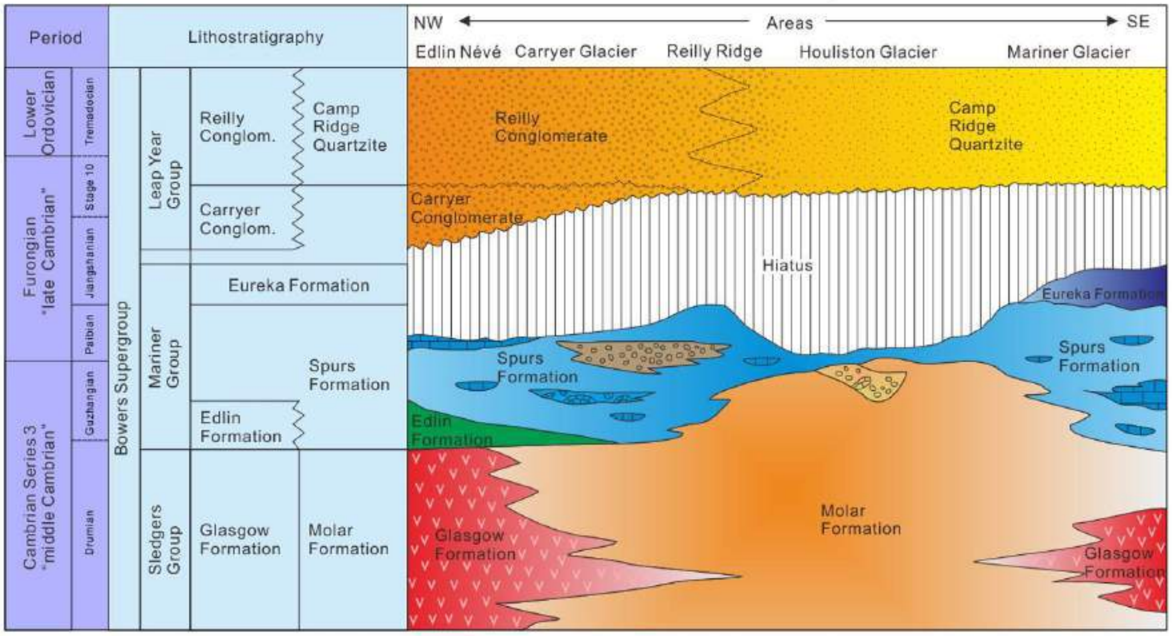



Fig. 1

## Stratigraphy of Bowers Supergroup

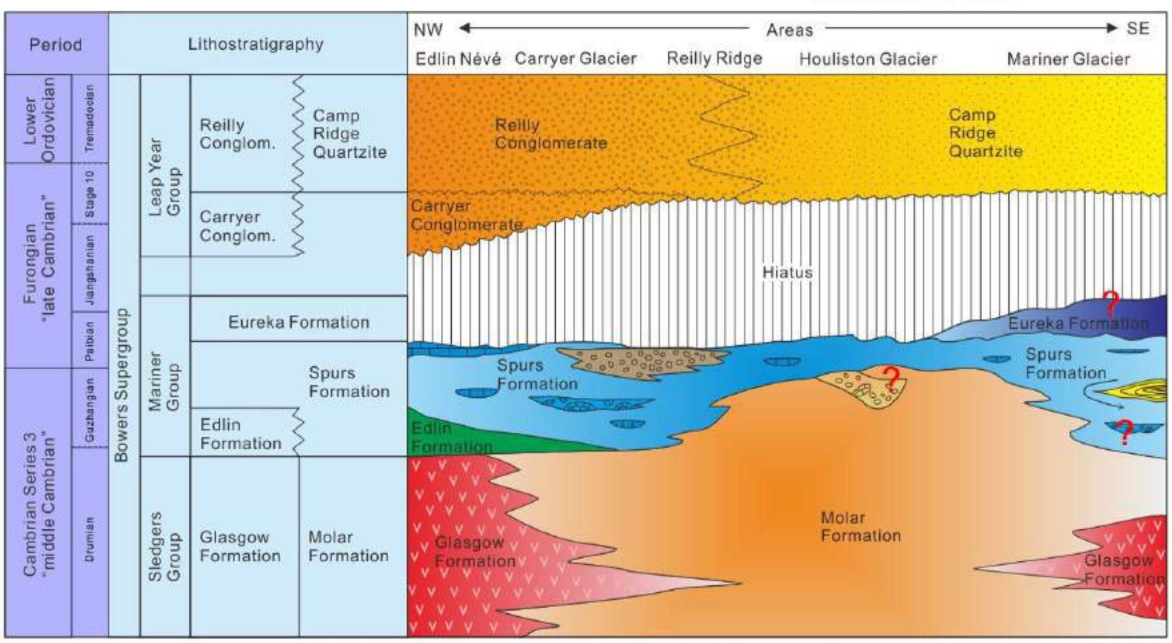
Original version




Modified from Cooper et al. (1983), Laird and Bradshaw (1983), and Cooper et al. (1996). Fig. 2

## Stratigraphy of Bowers Supergroup

Revised version




Modified from Cooper et al. (1983), Laird and Bradshaw (1983), and Cooper et al. (1996). Fig. 3

# Sediment continuity along the equatorial margin of Gondwana: Detrital zircon U-Pb insights from the Shan-Thai Terrane

**Cody L. COLLEPS[1]**, Nigel C. HUGHES[2], Paul M. MYROW[3], Tristan WHITE[3], Shelly WERNETTE[2], Aye Ko AUNG, Apsorn SARDSUD[4], N. Ryan MCKENZIE[1]
[1]University of Hong Kong; ccolleps@connect.hku.hk
[2]University of California, Riverside
[3]Colorado College, Colorado Springs
[4]Department of Mineral Resources, Thailand

The relative positions of various outboard terranes of equatorial Gondwana remains a highly speculative topic. Integration of geochronologic, geochemical, and biostratigraphic constraints on Cambrian–Ordovician strata provide valuable comparable insight into discerning spatially correlative deposits along the eastern Gondwanan margins. This study presents new detrital zircon age data from the Shan-Thai (Sibumasu) terrane in Myanmar and Thailand to test the potential for sediment continuity from drainage systems that fed Cambrian deposits along the north Indian and Australian margins. This scenario requires the Shan-Thai terrane to be in close proximity northeast of the north Indian margin during the Cambrian. Detrital zircon ages from all samples yielded similar results with minimal spatial and stratigraphic variation. Similarity tests indicate that zircon age populations from the Shan-Thai terrane are statistically indistinguishable when compared to detrital zircon age data from Cambrian deposits of the north Indian margin, suggesting that the Shan-Thai terrane most likely shared a common source with Himalayan Cambrian strata. At a first order, these data agree with a hypothesized connection between the north Indian margin and the Shan-Thai terrane during the Cambrian as an extensive belt along the equatorial margin of Gondwana, though additional biostratigraphic and geochemical constraints are necessary for further corroboration.

# Style, type and origin of Kyadwinye iron ore deposits in the western margin of Shan Plateau, Central Myanmar

**Tin Aung MYINT**[1], Mi Mi Ko[2]
[1]Department of Geology, University of Mandalay; tinaungmyint02@gmail.com
[2]Department of Geology, Monywa University

**Keywords:** Sedimentary iron ores, Maymyo Formation, Sibumasu Terrane

Kyadwinye iron mine is located at Latitude 21° 53' N and Longitude 96° 32' 20" E, Mandalay region, Myanmar. It lies in the western margin of the Shan Plateau within Sibumasu Terrane. Rock units exposed in the area are Paleozoic rocks including Nyaungbaw Formation (Silurian age), Zebingyi Formation (early to middle Devonian age) and Maymyo Formation (middle Devonian to Permian age). Iron ores are mainly limonite and hematite with minor amounts of pyrite and magnetite. The deposit mainly forms in Maymyo Formation. Jordan et al., (2017) dated the zircon U-Pb ages of 399 Ma, for a limestone near Pyinoolwin which suggests that the age is consistent with fossil ages of the Middle Devonian Maymyo Formation. The relativity plots of the zircons suggest the provenance has a Gondwana affinity, as the peaks of the zircons confirm the affinity with the Sibumasu Terrane. At mine site, ore deposit entirely overlies on dolomite and sandstone of Maymyo Formation. Large ore boulders may reach about 15 cubic meters in size. Small nodular, concretionary iron ore and float ore also occur. In some places, these iron ores are embedded in reddish brown ferruginous sandy soil and sandy loam layers. Based on the result of borehole data, ore boulders decrease in size from south to north. This is because the fault that separates the two blocks, impounds oxidizing water and enriches iron in the hanging wall block (south), causing more concentration and thickening of the iron deposits. The occurrences of micro fossils (forams?) and ooids which are entirely or partially replaced by interlayered hematite indicate that the iron deposit is primarily of sedimentary origin probably formed at the end of Paleozoic time (Tin Aung Myint, 2002). The porous and soluble nature of Maymyo Formation is the favorable place for the formation of iron deposits on Shan Plateau. Besides, chemical weathering processes leached dolomite and calcite minerals from earlier formed iron deposit, causing the increasing of iron grade in the ore as well as removing of gangue minerals from the ore in order to form the ferric iron oxides as secondary residules. The estimated iron ore reserve is 2 million tons with average iron content of 58.5% (Tin Aung Myint & Mi Mi Ko, 2004).

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# The evolution of the Palaeoscolecidian worms

**Di-Ying HUANG[1]**,
[1]Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences; dyhuang@nigpas.ac.cn

**Keywords:** Cambrian, Ordovician, Priapulida, evolution

Palaeoscolecidians are the most common worms in endobenthic ecosystem of some Cambrian exceptional fauna such as Chengjiang fauna, Guanshan fauna, Balang fauna, Kaili fauna, and Guole fauna in SW China. The fossil records of palaeoscolecidian worms range from the Cambrian to Silurian. They are abundant and diverse in the Cambrian and Ordovician.

Most author believed palaeoscolecidians belong to a small recent phylum Priapulida, which has a remote evolutionary history even could traced back to the Precambrian-Cambrian boundary. The has ageneral morphology of palaeoscolecidian worms display a slender tube-like shape and divided into two section as the introvert and the trunk. Its introvert normally no wider than the trunk and armed with scalid rows anteriorly. The trunk covered with well-marked annulations. Its cuticle armed with fine and regularly arranged ornaments. Posterior of the trunk bear paired hooks. Mouth cone is short. The pharynx relatively elongate and armed basal circlet pentagonal teeth or interleaving teeth.

Their small cuticular plates always formed button-shape microfossils in the Early Paleozoic. Such plates of palaeoscolecidians display a rounded shape with circlet margin and short conic center represented by the early forms such as *Mafangscolex* from the Chengjiang fauna, Cambrian Stage 3. *Wronascolex* (with body structure) or *Hadimopanella* (only isolated plates) are common and world widely distributed in mid-Cambrian with cuticle ornaments display rounded shape with circlet margin and short conic center surround by small cones or formed by only small cones. The cuticle ornaments of late Cambrian and Ordovician palaeoscolecidians formed by complex pattern instead plates. Thus, the detailed morphology of palaeoscolecidian cuticle ornament would have potential significant to understanding the biostratigraphy since they are in fact not rare by both print fossil and micro-plates.

# Upper Cambrian faunae of Langkawi Archipelago, Malaysia

**José Antonio GÁMEZ VINTANED[1]**, Andrey Yu ZHURAVELEV[2], Anna A. MADISON[3], Yana E. MALAKHOVSKAYA[3], Mergen B. MEREDOV[1]

[1]Department of Geosciences – Institute of Hydrocarbon Recovery, Universiti Teknologi PETRONAS;
[2]Department of Biological Evolution, Lomonosov Moscow State University
[3]Morisyak Palaeontological Institute, Russian Academy of Sciences

**Keywords:** Upper Cambrian, Langkawi Archipelago, Malaysia, trilobites, brachiopods

Cambrian rocks in Malaysia are located in the northwestern domain of the Western Belt, namely, on the northwestern Langkawi Archipelago and nearby the states of Kedah and Perlis mainland, where the siliciclastic Machinchang and Jerai formations crop out. The Machinchang Formation has a close lithological similarity to the Tarutao Formation of the Tarutao Island, Thailand; both units are dominated by quartzose sandstone, with some siltstone and subordinate conglomerate and ash beds, but the latter yields late Cambrian (Furongian) and earliest Ordovician trilobite faunas. During new detailed paleontological and sedimentological investigations, the mostly saukiid trilobite fragments as well as multiple disarticulated rhynchonelliform brachiopod shells are found in the upper Chinchin Member of the Machinchang Formation. This dominantly saukiid trilobite nearshore fauna mirrors the Furongian fauna of the Tarutao Formation, broadly indicates the uppermost Cambrian age of the Chinchin Member and confirms the affinities of the both formations to a single sedimentary basin. Among the brachiopods, despite a poor shell preservation (imprints and moulds), several individuals show a discernible external ornamentation and details of shell interior. These brachiopods according to the shell growth type, ornamentation and inner peripheral rim are ascribed to billingsellids and to strophomenids. The most interesting component of the assemblage are strophomenids with external ornamentation characterizing by regular alternation of ribs of two orders; long posterior margin, stretched ears and peripheral rim on the inner valve interior surfaces; and a diminutive apical foramen on a single ventral valve. Probably, these brachiopods are the oldest representatives of the order. Although the late Cambrian trilobite fauna points to a broad affinity of the Sibumasu terrane to Greater Gondwana abutting its Australian and Chinese blocks, strophomenids of this time inhabited higher latitude environments of Baltica and Laurentia.The research was supported by the grant URIF 2014-00735 / URIF 0153AA-B61 [Paleontology, sequence stratigraphy, and regional and international correlation of the Cambrian rocks of Kedah (Langkawi Island and peninsular Malaysia)].

# Who hyoliths are?

**SUN Haijinga[1]**, Martin R. SMITH[2], Han ZENG[1], Fangchen ZHAO[1],
Guogiang LI[1], Maoyan ZHU[1]
[1]Nanjing Instutute of Geology and Palaeontology; hjsun@nigpas.ac.cn
[2]Department of Earth Sciences, Mountjoy Site, Durham University

**Keywords:** Pedicle, orthothecide hyoliths, stem brachiopod, Chengjiang Lagerstätte, Cambrian

Hyoliths are a taxonomically problematic group of Palaeozoic lophotrochozoans that are among the first shelly fossils to appear in the Cambrian period. They are known principally from their originally aragonitic helly elements, which comprise an elongate conical shell ('conch') capped with a lid-like operculum and, in the hyolithide subgroup, a pair of elongate helens. On account of this unfamiliar morphology, the ecology and relationships of this group have long attracted debate. A recurrent suggestion treats hyoliths as an extinct phylum in taxonomic limbo between molluscs (Malinky and Yochelson, 2007) and sipunculans (Runnegar et al., 1975), but recent reports of soft tissue anatomy (Moysiuk et al., 2017) have led to the disputed suggestion that hyoliths belong to the brachiozoan group, which contains the brachiopod and phoronid phyla. However, their precise phylogenetic position remains uncertain.

Here we describe a new orthothecide hyolith from the Chengjiang Lagerstätte (Cambrian Series 2 Stage 3), which exhibits a non-mineralized attachment structure that strikingly resembles the brachiopod pedicle – the first report of a peduncular organ in hyoliths. This organ establishes a sessile, suspension feeding ecology for these orthothecides, and – together with other characteristics (e.g., bilaterally symmetrical bivalve shell enclosing a filtration chamber and the differentiation of cardinal areas) – identifies hyoliths as stem-group brachiopods. Our phylogenetic analysis indicates that both hyoliths and crown brachiopods derived from a tommotiid grade, and that the pedicle has a single origin within the brachiopod total group.

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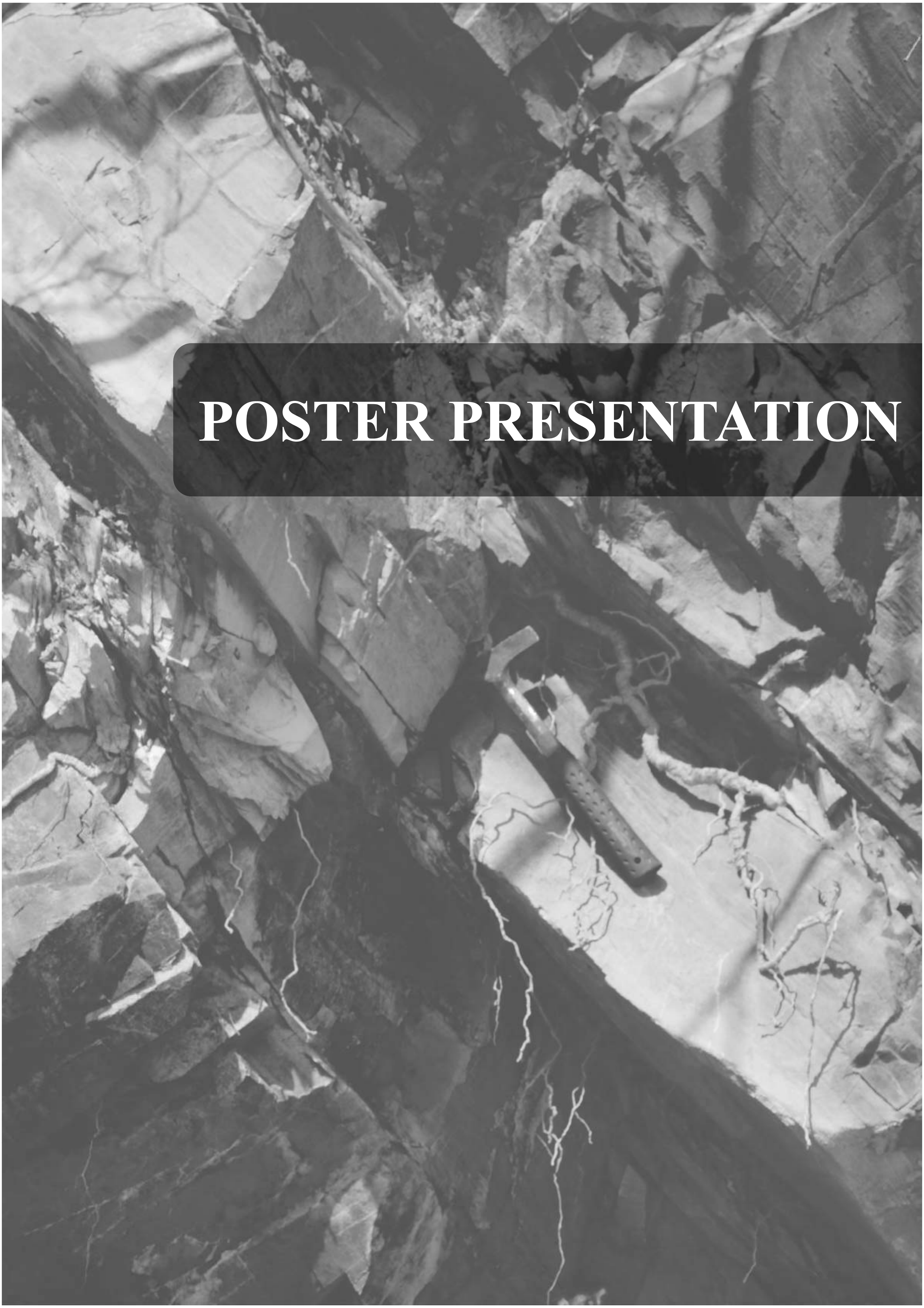
# POSTER PRESENTATION



# Ancient arc magmatism in Wang Nam Khiao area, Nakhon Ratchasima, Central Thailand

**Alongkot Fanka**[1,*] and Chakkaphan Sutthirat[1, 2]
[1] Department of Geology, Faculty of Science, Chulalongkorn University, Pathumwan, Bangkok 10330, Thailand
[2] Research Program of Toxic Substance Management in the Mining Industry, Center of Excellence on Hazardous Substance Management (HSM) and Research Unit of Site Remediation on Metals Management from Industry and Mining (Site Rem), Environmental Research Institute, Chulalongkorn University, Pathumwan, Bangkok 10330, Thailand
*email: alongkotf@gmail.com; alongkotf@yahoo.com

**Keywords**: Arc magmatism, Plutonic rock, Volcanic rock, Thailand

Varieties of plutonic and volcanic rocks have been found in Wang Nam Khiao area, Nakhon Ratchasima Province, northeastern Thailand. The plutonic rocks are composed of mafic-ultramafic rocks (i.e., hornblendite, hornblende gabbro) and granitic rocks (i.e., biotite granite, hornblende granite, and biotite-hornblende granite). The volcanic rocks are characterized widely by rhyolite to dacite and andesite; moreover, their associated dikes mostly contain basaltic-andesitic compositions. Whole-rock geochemistry of the plutonic rocks identically shows LILE enrichment (e.g. Ba, K, Sr) and HFSE depletion (e.g. Nb, Ta, Zr). The volcanic rocks and associated dikes also present similar compositions that enrich in LILF (e.g. Sr) with depletion of HFSE (e.g. Nb); moreover, they also show similar REE patterns. Mineral chemical data of particular minerals (e.g., clinopyroxene, hornblende and biotite) are also reported herein. These data indicate that these rocks have been formed by crystallization of hydrous calc-alkaline magma. U-Pb zircon geochronology clearly supports the model of multiple-arc magmatism within the Loei Fold Belt related to the subduction of Palaeo-Tethys beneath Indochina Terrane.

# Cambrian Stage 10 Trilobites of Korea

**Paul HONG**[1]
[1]Korea Institute of Geoscience and Mineral Resources; hongps@kigam.re.kr

**Keywords:** Cambrian, Stage 10, trilobites, Korea

Cambrian-Ordovician strata located at the northeastern part of Korea are subdivided into three regions with distinct lithological sequences: Taebaek, Yeongwol, and Mungyeong areas. In the Taebaek area, *Asioptychaspis subglobosa*, *Quadraticephalus*, *Mictosaukia*, *Pseudokoldinoidia*, and *Richardsonella* zones identified from the Hwajeol and Dongjeom formations are related to the Cambrian Stage 10 range. In the Yeongwol area, the Cambrian Stage 10 interval is positioned at the upper part of the Machari Formation, and a newly discovered trilobite fauna containing saukiid trilobites from the Formation might represent Cambrian Stage 10 interval of region. In the Mungyeong area, fauna containing *Hedinaspis regularis* has been reported from the Hanaeri Formation, but the location of the site has not been rediscovered since the original collection. Trilobite fauna of the Taebaek region are known to be similar to that of North China, whereas Yeongwol and Mungyeong trilobites include cosmopolitan species not reported from North China. Taxonomic works on trilobites from the three regions are expected to offer paleogeographic information of the eastern Asian region.

# Checklist of Ordovician Nautiloid Fossils (Cephalopoda) from Thailand

**Kittichai Tongtherm[1]**, Katsuo Sashida[1], Yasunari Shigeta[2], Apsorn Ampornmaha Sardsud[3], Sachiko Agematsu[1*]

[1] Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
[2] National Museum of Nature and Science, Tsukuba, Ibaraki, Japan.
[3] Mineral Resources Research and Development Center, Department of Mineral Resources, Bangkok, Thailand.
*Corresponding author: agematsu@geol.tsukuba.ac.jp

**Keyword:** checklist, nautiloid cephalopod, fossil, Thailand.

We have many records on the occurrence of Ordovician Nautiloid fossils from Thailand. However, there are no checklist and sufficient information concerning the fossil deposition and others. We present herein a detailed and up-dated checklist on Ordovician Nautiloid from Thailand including their geologic age, geographic distribution, deposition of fossil specimens and related literatures. We recognized the occurrence of Ordovician Nautiloid from Thailand at least 4 subclass, 6 orders, 12 families, 15 genera, 19 species and 12 indeterminate taxa. The checklist includes the record on their occurrence from three main geographic regions: 1) Western region (Tak, Kanchanaburi and Uthai Thani Province), 2) Upper Peninsula (Nakhon Si Thammarat) and 3) Lower Peninsula (Satun Province). Previously reported Ordovician Nautiloid have been discriminated from the Chao Nen Group (Western region) and the Thung Song Group (Peninsular Thailand).

# Devonian siliceous successions recorded Paleo-Tethys opening in Thailand

**Hidetoshi HARA[1]**, Toshiyuki KURIHARA[2]
[1]Geological Survey of Japan; hara-hide@aist.go.jp
[2]Niigata University

**Keywords:** Paleo-Tethys, Opening, Devonian, Chert, Geochemistry, Thailand

The opening process of the Paleo-Tethys is reconstructed, based on an analysis of radiolarian fossils and the geochemistry of a Devonian siliceous succession in the Chiang Dao area of northern Thailand, and the Klaeng area of southeastern Thailand. The succession in the Chiang Dao area is subdivided into the following five rock types (in ascending stratigraphic order): black shale (Lower Devonian), siliceous shale (Middle Devonian), tuffaceous chert and tuff (Middle/Upper Devonian), and chert (Upper Devonian), described by Hara et al. (2010). The succession in the Klaeng area is composed of black shale (lower Upper Devonian), chert, tuffaceous chert, tuff, and sandstone (Upper Devonian), and siliceous shale (Upper Devonian). The concentrations of terrestrial-derived elements (Al2O3, TiO2, Rb, and Zr) suggest that the succession (except for the chert) was supplied with terrigenous material and volcanic ash from the adjacent continent. Geochemical indicators of redox conditions (total organic carbon and the Th/U ratio) reveal a gradual change from anoxic to oxic oceanic conditions between the black shale and chert. Taking into account the interpreted depositional setting and redox conditions, the initial Paleo-Tethys developed as a small, closed anoxic–suboxic oceanic basin, located close to the continental margin. Opening of the Paleo-Tethys started around the Middle and Upper Devonian boundary, marked by volcanic activity. The tuffaceous chert was deposited under oxic conditions, suggesting that ash and pumice within the chert were derived from a continental source. After the Late Devonian, the Paleo-Tethys developed as a deep, broad ocean in which pelagic chert was deposited. The successions in the Chiang Dao and Klaeng areas were deposited in continental margin and pelagic environments between the Sibumasu Block and the Indochina Block. However, successions between both areas are slightly different stratigraphy caused by depositional setting and the geographical position. In addition, the succession in the Klaeng area has a lithological variation including sandstone, meaning more contribution of a continental source.

# Formation of Sinkholes in some parts of Cuddapah Basin, Andhra Pradesh, India: Implications to Limestone Dissolution

**Jayaraju NADIMIKERI**[1]
[1]Yogi Vemana University; nadimikeri@gmail.com

**Keywords:** Sinkholes, Groundwater Exploitation, Dissolution, Formation, Cuddapah Basin

In the end of November, 2015 and July, 2016, the mysterious formation of huge sinkholes with deafening voice in three villages in Chinthakommadinne Mandal of Kadapa District, Andhra Pradesh has caused fear and sleepless nights to its residents. The formation of sinkholes of a diameter of 25 ft is formed in Nayanori palli, Kadapa district. Land suck, forming 15 ft wide and 7 ft deep circular sinkholes at four places of Chinthakommadinne area. The farmers were baffled finding three large sinkholes of about 20 ft each diameter filled with water and sand. Sinkholes have caused damaged to drip irrigation equipment engulfing Banana Plantation. As sinkholes were forming with deafening sounds, the officials called upon residents and evacuated the villagers, as continuing to live there could endanger lives. The large sinkhole formations coupled with deafening sounds has spread fear and panic among the villagers. It is observed that the limestone deposits are found to occur at a depth of 30 ft which belong to Vempalli Lime stone formation of Papagni Series in deep South-East of crescent shaped Cuddapah Basin. A week-long torrential rains during the late November in 2015, resulted in dissolving the underneath limestone which might have caused soil sink to a depths of about 30 ft. creating sinkholes. Greater variability in the precipitation has a close nexus to the climate change resulting unexpected and unpredicted down pours in a specified area. This is the first of its kind in this key Basin.

# Geochronology of Cambrian rocks of Thailand and Myanmar

**Tristan WHITE[1]**, Paul MYROW[1], Ryan MCKENZIE[2], Blaire SCHOENE[3]
[1]Colorado College; tristan.white@yale.edu
[2]University of Hong Kong
[3]Princeton University

**Keywords:** Cambrian-Ordovician, Sibumasu, detrital zircon, U-Pb ID-TIMS, U-PB LA-MC-ICP-MS

Undeformed, fossiliferous Cambrian and Ordovician strata with interbedded volcanic ash beds are present in the rocks of the lithotectonic terrane Sibumasu on Tarutao Island, Thailand and in central Myanmar. The trilobites are present within fine-grained siliciclastic strata, and primary exist in very thin (< 3 cm) storm-generated coquinas. Eleven single zircons from ash beds were analyzed using U–Pb ID-TIMS, of which two yielded concordant dates of ~486.0 Ma and ~484.2 Ma (precise dates withheld) that bookend the 485.4 ± 1.9 Ma Cambrian–Ordovician boundary and provide age constraint on specific trilobite fossils in the Cambrian–Ordovician boundary interval. These data represent the first high-precision U–Pb dates on rocks of this age in Thailand and Myanmar. Detrital zircon spectra, derived by U–Pb LA-MC-ICP-MS analyses, of Thailand samples were similar to the spectra of Myanmar samples and all are statistically identical to the detrital zircon spectra of Cambrian–Ordovician units across the Himalaya Mountains, suggesting a proximal paleogeographic location on the northern Gondwana margin and shared orogenic history across an area far more extensive than previously postulated.

# The Cambrian Low-grade Regional Metamorphic rocks, Meta-arkosic to Meta-argillaceous Arkosic Sandstones in Kanchanaburi Province, Thailand

**Sirot Salyapongse**, Sittiporn Kongsuchko, Janejira Sratongyung and Prinya Putthapiban*
Geoscience Program, School of Interdisciplinary Studies, Mahidol University, Kanchanaburi Campus, 199 Moo 9, Sai Yok, Kanchanaburi, Thailand, 71150
*Corresponding author

**Keywords** : Chao Nen meta-sandstones, Thamanao meta-argillaceous limestones, transitional contacts, Thabsila, paragneiss, Lower Paleozoic passive continental margin

The Cambrain Chao Nen meta-sandstone and the Ordovician Thamanao meta-argillaceous limestone rock units of Kanchanaburi, western Thailand, show evidences that they are attributed to those classified earlier and commonly found in southern Thailand peninsular, the Tarutao group and the Thungsong group respectively. Field and petrographic observations strongly suggest transitional contacts both between the Chao Nen and the Thamanao and between the Chao Nen and the older rock unit. The siliciclastic nature of the Cambrian rock in Thailand was gradually altered to the carbonate sequence of the Ordovician. The sericite feature, either foliated or non-foliated is only found in the Cambrain meta-arkosic/subarkosic sandstones.

The Chao Nen meta-sandstones was apparantly underlain by the inferred-Precambrain Thabsila unit which is distinguished by the alternating sequence of argillaceous-siliciclastic-carbonate more or less similar lithofacies to those of the previously mentioned Cambrian-Ordovician transitional sequence. However, the Thabsila unit suffered from a higher grade metamorphism. By examining it's aluminium silicate contents, we found that the transition from kyanite, andalusite, cordierite to sillimanite in the upper part of the sequence was apparent. In contrast, in the lower part, foliated biotite and hornblende bearing calc-silicate and paragneiss are frequently observed before reaching the migmatite transition.

The protoliths of both the Chao Nen siliciclastics and those of the inferred Precambrian Thabsila especially in the upper part were so similar and may close to argillaceous feldspathic sandstone in composition.

The modal compositions of the Cambrain meta-arkosic/subarkosic sandstones plotted on craton interior to transitional continental provenances. Their chemical discrimination plots have suggested that they would have been deposited on the Lower Paleozoic passive continental margin environment.

# Mineralogy and chemical characteristics of waste rocks from mining area in northeastern Thailand: implication for a source of toxic elements

**Thitiphan Assawincharoenkij[1]**, Christoph Hauzenberger[2] and Chakkaphan Sutthirat[1,3]
[1] Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
[2] NAWI Graz Geocenter, Petrology and Geochemistry, University of Graz, Universitätsplatz 2, 8010, Graz, Austria
[3] Environmental Research Institute, Chulalongkorn University, Bangkok 10330, Thailand
E-mail: t.assawincharoenkij@gmail.com

**Keywords**: Waste rock, Gold mine, Toxic element, Gossan

Acid Mine Drainage (AMD) is a serious environmental impact which often occurs in metal sulfide mines including gold mine. It may cause of toxic element releasing. Waste rocks from the study gold deposit located in the northeastern Thailand are investigated. Mineralogical and chemical characteristics of waste rocks were carried out using microscope, EPMA, XRF and ICP-MS to identify potential of AMD generation and releasing of toxic elements such as arsenic, lead, zinc and cadmium. Waste rocks (precious metal-barren rocks) have been dumped at dump sites during mine operation. These waste rocks consist of sandstone, siltstone, gossan, skarn, skarn-sulfide, massive sulfide, diorite and limestone/marble. Subsequently, we found that the massive sulfide and skarn-sulfide rocks mainly consist of pyrrhotite, pyrite, arsenopyrite and chalcopyrite that can generate AMD. Moreover, the gossan rocks appear to be main sources of As (<800 ppm), Cu (<7500 ppm) and Zn (<350ppm). Consequently, the massive sulfide/skarn-sulfide rocks have potential of AMD generation whereas gossan contain high contents of toxic elements. These toxic elements are unstable under acid drainage and may release into the environment. Therefore, the waste rock dumping sites that contained the massive sulfide and skarn-sulfide rocks should be cover by layers of compacted clay and soil after the mine closure.

# Ordovician warm water dasycladaceae algae from the Pin Formation, Parahio Valley, Spiti, India

**Subhay Kumar PRASAD[1]**, Ravi S. CHAUBEY[1], Olev VINN, Birendra P. SINGH[1], Naval KISHORE[1]
[1]Panjab University; subhay.lovely@gmail.com

**Keywords:** Ordovician-Silurian, Pin Formation, Spiti Himalaya, India

The Ordovician-Silurian Pin Formation of the Spiti region (Himalaya) is a highly fossiliferous lithounit and it yielded bryozoa, corals-reefs, conodont, algae, ostracods and trilobites (Hayden, 1904; Reed, 1912; Bhargava and Bassi, 1986; 1998; Suttner, 2007, 2008, 2009, 2011; Myrow et al., in press). One of the fossil originally described from Pin Formation as Pasceolus Billings (Reed, 1912) later on subjected to various other nomenclature. Reed (1912) described Pasceolus Billings (Pasceolus melliformis) and P. shianensis from the collection made by Hayden (1904) on Ordovician-Silurian successions exposed in the Pin River section in the Pin valley. Sahni (1953) and Maithy (1974) considered it as psilophytes remains and lower group of plants respectively. Similar structures from the Pin and Parahio valleys sections of the Pin Formation were later described as Paleodictyon meneghini (Kumar and Kashkari, 1987) indicating algal nature. Subsequently, Kato et al. (1987) considered Pasceolus? shianenesis (Reed, 1912) to be dasycladaceae algae Coelosphaeridium shianenese (Reed). The fresh collections of specimens from the Pin Formation exposed at Gechang village in the Parahio valley display that these structures are cyclocrinitids dasycladaceae algae Mastopora sp., and Cyclocrinites sp. Along the Gechang locality where they occur in abundant in the lower part of the Pin Formation and particularly in the calcareous siltstone and sandstone units of the Farakh Muth Member of Suttner et al. (2007). Cyclocrinitids was named by Pia (1920) and emended by Bassoullet et al., (1979). It includes the Ordovician and Silurian genera Cyclocirinites Eichwald, Mastopora Eichward, Coelosphaeridium Roemer, and Apidium Stolley. Mastopora is now commonly regarded as junior synonyms of Cyclocirinites as were Nidulites Salter, Pasceolus Billings, Cerionites Meek and Wortten, and Lunulites Owen (Nitecki, 1970).The Cyclocrinitids are now widely accepted as an extinct dasycladaceaen tribe (Beadle, 1988), however, Nitecki (1986) suggested that they are problematic algae related to receptaculitids. Cyclocrinitids preserved in the Pin Formation are having flattened thallus and show high degree of compaction. Cyclocrinitids in Ordovician are known from several localities in central and southern Asia including Kazakhstan (Grilovskaya, 1972), northern India (Reed, 1912; Kato et al., 1987) and western China (Mu 1982a, 1982b).The oldest cyclocrinitids have been reported from the lower middle Ordovician of California (Nitecki, 1970) as Cyclocirinites weller Niteck, They were most abundant and diverse during the Caradoc, and became less common in Ashgill and declined throughout the Llandovery (Beadle and Johnson, 1986) and went extinct by the end of Llandovery (Silurian).The decline and end of these warm-water algae in Ordovician may correlate with the end Ordovician cooling and glaciations (Beadle, 1988).

# Possible late middle Cambrian radiolarians from the Tethyan Himalaya, Himachal Pradesh region, India

**Jonathan AITCHISON[1]**, Qiangfen MA[2], Nighel HUGHES[3], Jiani SHENG[1]
[1]University of Queensland; jona@uq.edu.au
[2]China University of Geosciences, Wuhan
[3]University of California, Riverside

**Keywords:** Cambrian, Radiolaria, India

The Zanskar Valley provides the best characterized succession of Cambrian strata on the Indian subcontinent having been studied since the 1860s (Stoliczka 1865; Hayden, 1904; Myrow et al. 2006; Hughes et al. 2018). Excellent sections are located within Tethyan Himalaya strata in the upper tributaries of the Zanskar River in Ladakh and are well known for their fossil content. In the hope of extracting radiolarian microfossils, we processed numerous fine-grained limestone samples from a section where the Teta Member of the Karsha Formation (Nanda and Singh (1976) is well exposed on the north side of the Tsarap Lingti Chu. One sample KU07 from the Kuru 1 section produced useful albeit not well-preserved material. Although completely recrystallized, the microfossils are of a composition and size that is consistent with their identification as radiolarians. The age of strata at this level is well constrained to the late middle Cambrian Lejopyge acantha Biozone, Series 3, Guzhangian Stage. This level is correlative to the middle Cambrian Ptychagnostus gibbus Biozone, Series 3, Stage 5 (= Australian Templetonian Stage), Beetle Creek Formation (Jones and McKenzie, 1980), Queensland, Australia from which Won and Below (1999) reported radiolarians. We are presently studying those radiolarians using micro CT methods (Sheng et al. 2018).

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# The oldest radiolarian evidence of Thailand and depositional environment

**Doungrutai Saesaengseerung**
Fossil Protection Division, Department of Mineral Resources, Thailand; sdoungrutai@yahoo.com

**Keywords:** Radiolarian, Thailand, Devonian, Palaeo-Tethys, Gondwanaland

Micro-paleontological investigations indicate that the Paleozoic chert and other fine grained-siliceous sedimentary rocks, which are thought to have been deposited in the deep sea in a pelagic or hemipelagic environment, are widely distributed in Thailand (e.g. Caridroit et al., 1990; Sashida et al., 1993, 1998, 2002; Wonganan and Caridroit, 2005; Saesaengseerung et al., 2007, 2009; Kamata et al., 2015). In the modern understanding of the geotectonics of Southeast Asia, it is widely accepted that Southeast Asia is composed of several terranes or continental blocks. The origin of most of the continental blocks was drifted away from Gondwanaland at different times (e.g., Metcalfe, 1999, 2011). Furthermore, the detailed biostratigraphic data of siliceous sedimentary rocks that yield radiolarians are necessary to elucidate the tectonic development and paleogeography of Southeast Asia. However, the timing of these events is still debatable. The oldest radiolarian of Thailand is in the Middle Devonian interval. The Devonian-Carboniferous radiolarian assemblage is composed of *Ceratoikiscum, Circulaforma, Popofskyellum, Tlecerina, Entactinia, Trilonche, Stigmoshaerostylus, Palaeoscenidium, Archocyrtium, Polyentactinia*, and others. The occurrence of radiolarians from Thailand indicates the close faunal similarity among South China, Eastern Australia, Texas and Germany. Most of the discovered radiolarian faunas from the localities mentioned exhibit low latitude of Tethyan affinities. The Middle Devonian to Early Carboniferous radiolarian fauna was reported from several areas in Thailand. This radiolarian was reported from ribbon-bedded chert of the "Fang Chert" in the north of Chiang Dao city, Chiang Mai Province, northern Thailand and the "Pak Chom Chert" in Pak Chom area, Loei Province, northeastern Thailand and the Saba Yoi-Kabang area, the southernmost part of peninsular Thailand. Based on the lithology, sedimentary structures, and lithostraligraphy, the oldest radiolarian-bearing rocks of Thailand are thought to have been deposited in a pelagic or hemipelagic environment. These radiolarian-bearing rocks with radiolarian faunas are evidence for the presence of a wide Palaeo-Tethys ocean existed between Shan-Thai and Indochina continental terranes in Middle Devonian to Early Carboniferous (Eifelian-Tournasian). This radiolarian evidence shows clearly that distal oceanic sediments existed, at least, since the Middle Devonian. Moreover, the Middle-Late Devonian radiolarians were discovered from Klaeng District, Rayong Province, eastern of Thailand. However, the depositional environment of these radiolarian-bearing rocks from eastern of Thailand has been suggested that was close to the continental margin, such as a continental slope or rise.

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