ABSTRACT VOLUME

IIWXIV

14th International Ichnofabric Workshop

TPE \ TAIWAN

2017

KEY DATES

APR 28th	Registration & Icebreaker **18:00 @ Room 213 Geosciences, NTU**
APR 29th-2nd	Ichnofabric Workshop **@ White Palace**
MAY 1st	Intra-Workshop Fieldtrip to the Northeast Coast
MAY 3rd-7th	Post-Workshop Fieldtrip
	Bus back to Taipei around 19:00 on Sunday May 7th

VENUE

"White Palace" (Nanmen Park, National Taiwan Museum, NTM)
小白宮 (臺灣博物館南門園區)

No. 1, Sec. 1, Nanchang Rd., Taipei City
中正區南昌路一段1號
Metro: **G10** CKS Memorial Hall

The Goods Storehouse, referred to more commonly as the White Palace, is the oldest building in the Nanmen Park complex. It is also the last remaining structure in Taiwan where opium is known to have been processed, making it historically significant as a modern architecture.

HOTEL

Howard Civil Service International House (福華國際文教會館)

No. 30, Section 3, Xinsheng South Road, Da'an District, Taipei City
大安區新生南路三段30號
Telephone: +886 2 7712 2323

USEFUL PHRASES

I would like to have the receipt, thanks!
請給我收據，謝謝！ Shōu Jù

How much is it?
請問這個多少錢？ Duō Shǎo Qián?

I would like one, please.
請給我一個，謝謝！ Wǒ Yào Yī Gè.

Good morning! **早安** Zǎo Ān!
Good night! **晚安** Wǎn Ān!
Thank you! **謝謝** Xiè Xiè!
It's delicious! **好吃** Hǎo Chī!
It's beautiful! **漂亮** Piāo Liàng!

OK! **好** Hǎo! *Yes!* **對** Duì!
No! **不** Bú!
Good bye! **再見** Zài Jiàn!
I like it! **我喜歡** Wǒ Xǐ Huān!
Wait! **等一下** Děng Yī Xià!

TRAFFIC

Show to taxi driver

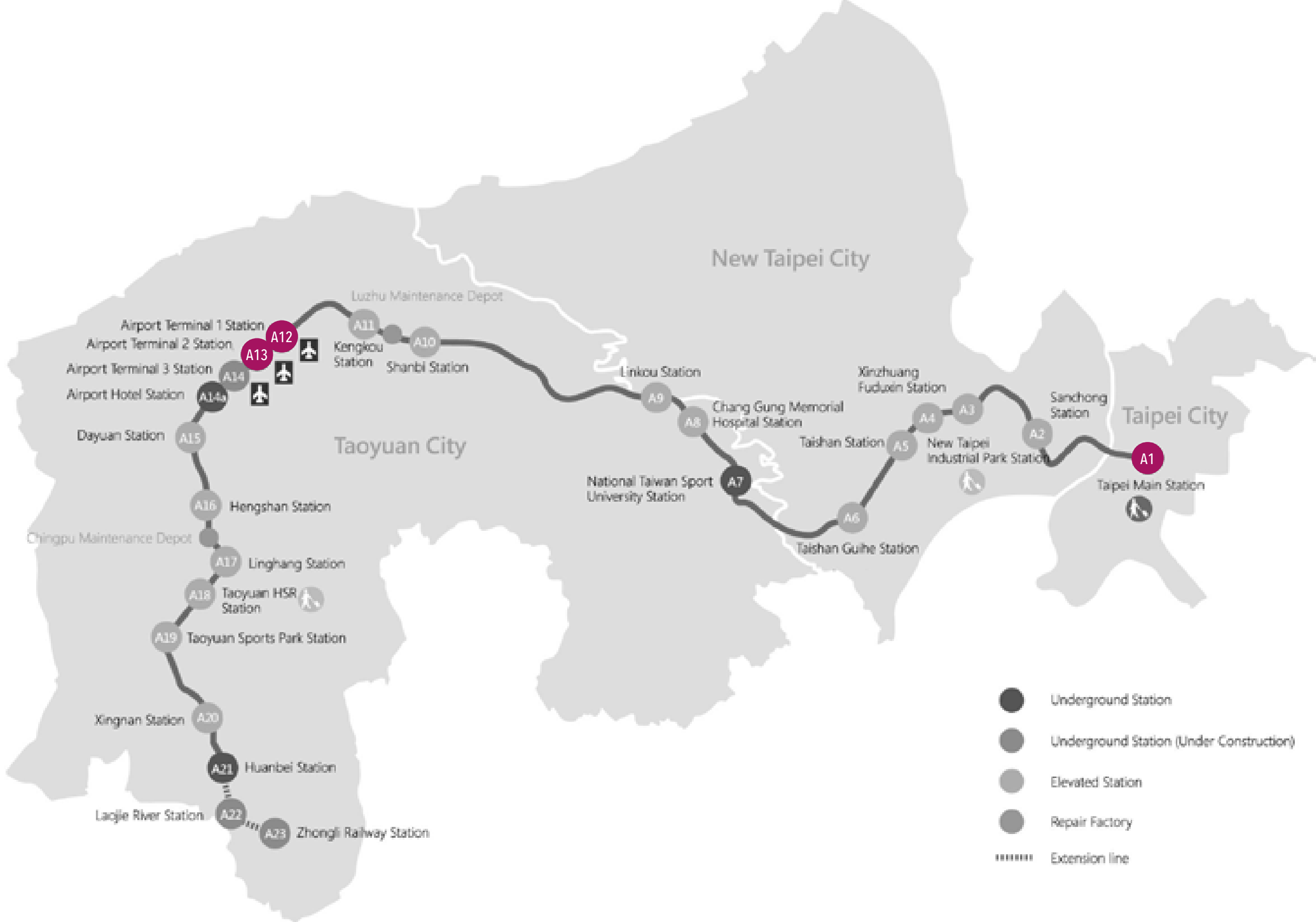
AIRPORT-HOTEL

By Taoyuan Airport MRT

- Airport (TPE) **A12**(T1) / **A13**(T2)
- 35 min, ~NT$ 80
- **A01** Taipei Main Station
- 4,3 km, 8 min, ~NT$ 250
- Howard International House

By taxi

- Taoyuan Airport (TPE) / Songshan Airport (TSA)
- 40 / 13 min, ~NT$ 1200 / NT$ 400
- *"Please take me to Howard International House."*
  請載我到『福華國際文教會館』。
  地址: 大安區新生南路三段30號
- Howard International House



TRAFFIC

Show to taxi driver

HOTEL-Icebreaker

By walk

- Howard International House
- walk 1,2 km, 15 min
- Geosciences buiding, NTU

By taxi

- Howard International House
- 1,2 km, 4 min, ~NT$ 85
- *"Please take me to Gongguan MRT exit 1"*
- **請載我到『捷運公館站1號出口』**
- **G07** Gongguan (Exit 1)
- walk 260 m, 3 min
- Geosciences buiding, NTU

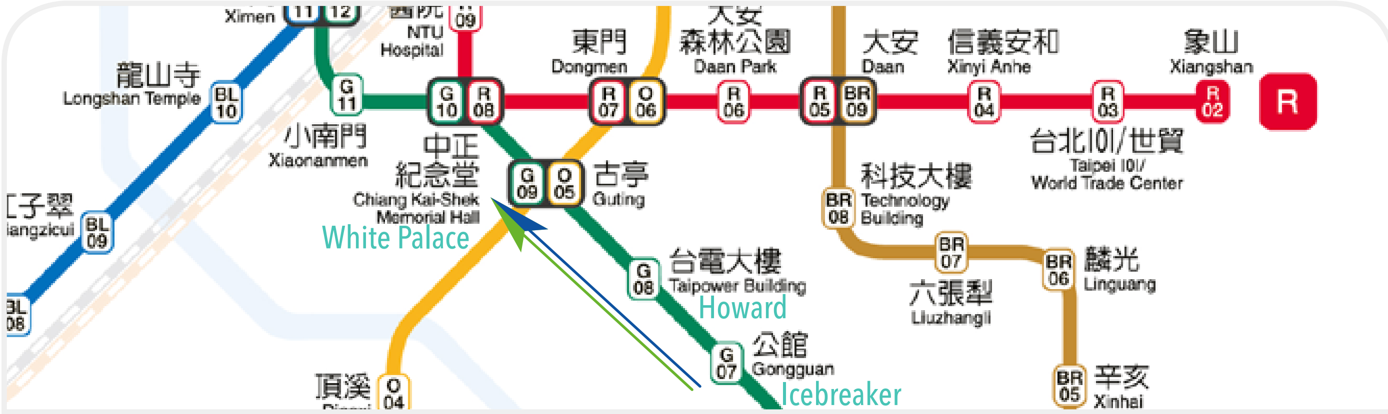
HOTEL-VENUE

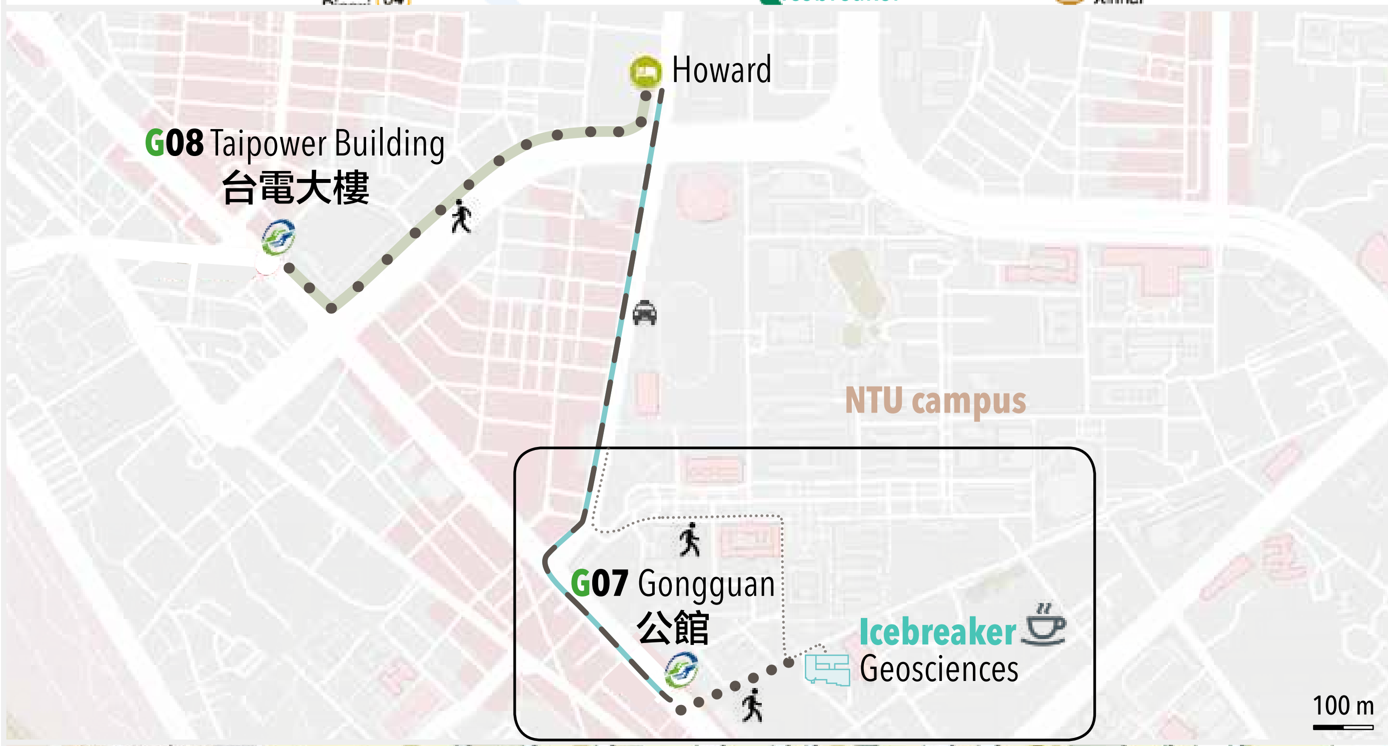
By walk + metro

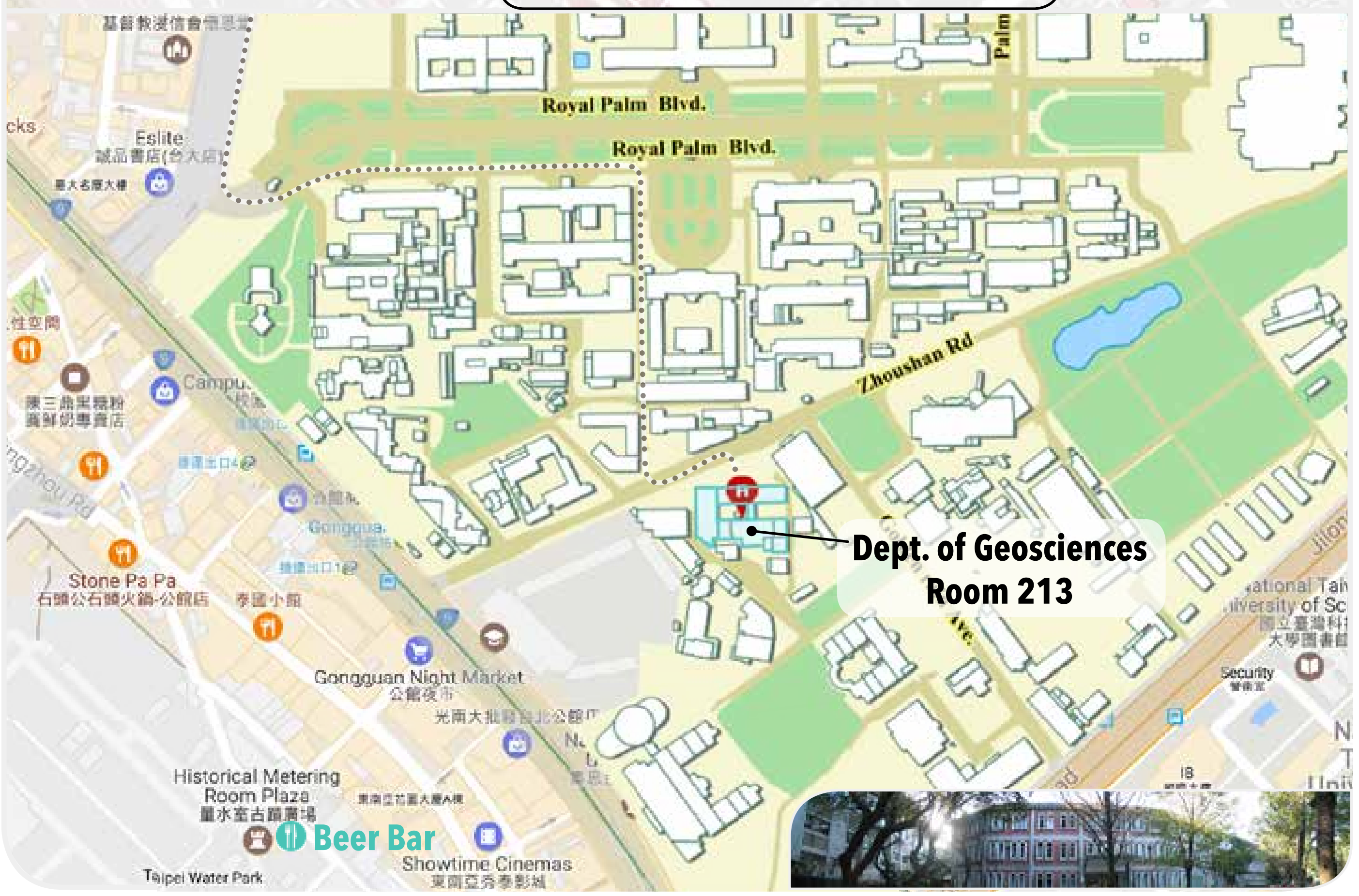
- Howard International House
- walk 850 m, 11 min
- **G08** Taipower Building (Exit 2)
- metro 4 min, NT$ 20
- **G10** CKS Memorial Hall (Exit 1)
- walk 300 m, 4 min
- White Palace

By taxi

- Howard International House
- 3 km, 10 min, ~NT$ 120
- *"Please take me to NTM Nanmen Park."*
- **請載我到『臺灣博物館南門園區』**
- **地址: 中正區南昌路一段1號**
- White Palace







Icebreaker: 28th April, Friday

18:00-21:00 Room 213, Dept. of Geosciences, National Taiwan University

Oral: 29th April, Saturday

Time	⏱	Speaker	Title
			Session Chair: Ludvig Löwemark
08:45-09:25	00:40	**Ludvig Löwemark**	Registration & Opening Address
09:25-10:10	00:45	**Andreas Wetzel**	**Keynote**: Ichnofabric analysis in sedimentology
10:10-10:40	00:30	*Coffee Break!*	
10:40-11:05	00:25	**Bhawanisingh G Desai**	Ichnofabric analysis reveals successive colonization of Shelf-continental slope in Subduction region during Upper Bathonian, Sudak region, Crimea
11:05-11:30	00:25	**F. J. Rodríguez-Tovar**	Establishment of a representative macrobenthic tracemaker community after the Chicxulub Impact: ichnofabric analysis at the IODP-ICDP Expedition 364
11:30-11:55	00:25	**Weng-Si Chao**	Ice-dammed Lake Outburst in the Arctic Ocean: Trace fossil Evidence - from a Distinct Gray Layer from on the Lomonosov Ridge off Greenland
11:55-13:20	01:25	*Lunch Break!*	
			Session Chair: Huriye Demircan
13:20-13:45	00:25	**Ery Arifullah**	Ichnofabric of tidal deposit in Balikpapan Formation, Kutai Basin (Indonesia)
13:45-14:10	00:25	**Luis Buatois**	Ichnology of an Upper Cretaceous prodeltaic lobe and channel complex from the Book Cliffs, Utah, United States: Assessing ichnofaunal variability of hyperpycnal deposits
14:10-14:35	00:25	**Rou-Ying Fan**	Quantitative morphological characterisation of the graphoglyptid trace fossil *Helminthorhaphe* and its palaeobiological implications
14:35-15:00	00:25	**Shahin Dashtgard**	Unbioturbated mudstones may record only slightly lowered oxygen conditions in warm, shallow basins
15:00-16:00	01:00	*Posters & Coffee Break!*	
			Session Chair: Al Curran
16:00-16:25	00:25	**Hui-Bo Song**	Types and Microbial Geneses of Carbonate Micro-Shapes in *Zoophycos* burrows from the Lower Permian Taiyuan Formation in North China
16:25-16:50	00:25	**Huriye Demircan**	An Example of Proximal And Intermediate Turbidite Trace Fossils: The Dizilitaşlar Formation (Paleocene), Kırıkkale Region, Central Anatolia
16:50-17:15	00:25	**Zhi-Feng Xing**	Microbial mat records in siliciclastic rocks: Examples from the Mesoproterozoic Yunmengshan Formation in China and their modern equivalents
17:15-17:40	00:25	**Alfred Uchman**	Ichnofabrics of Pleistocene carbonates on Favignana Island, southern Italy
17:40-18:05	00:25	**Sutieng Ho**	From endobenthic burrows down to petroleum systems – a journey of hydrocarbon traveling to the surface via authigenic carbonate tubes
18:30-21:00	02:30	*Workshop Dinner @ Beer Bar*	

Oral: 30th April, Sunday

Time	⏱	Speaker	Title
			Session Chair: Alfred Uchman
09:00-09:45	00:45	**Renata Netto**	**Keynote**: They will survive! Ichnofabrics uncover stress tolerance behavior
09:45-10:10	00:25	**Al Curran**	*Ophiomorpha*: Do We Need New Criteria to Define Its Ichnospecies?
10:10-10:40	00:30	*Coffee Break!*	
10:40-11:05	00:25	**Min Wang**	*Schaubcylindrichnus* heberti from Zhangxia Formation (Cambrian Series 3) in North China: a pioneer of thickly lined trace fossil
11:05-11:30	00:25	**Masakazu Nara**	Ichnology and palaeoecology of *Macaronichnus segregatis degiberti*
11:30-11:55	00:25	**Ludvig Löwemark**	Geology of Taiwan
11:55-13:20	01:25	*Lunch Break!*	
13:20-18:00	04:40	***Cultural activities***	Taipei 101, CKS Memorial Hall, Longshan Temple
18:00-21:00	03:00	***Night market tour***	

Oral: 2nd May, Tuesday

Time	⏱	Speaker	Title
			Session Chair: Luis Buatois
09:00-09:45	00:45	**Gabriela Mangano**	**Keynote**: The Cambrian explosion: Exploring animal-substrate interactions at the dawn of Phanerozoic
09:45-10:10	00:25	**F. J. Rodríguez-Tovar**	**Invited talk**: Advancing ichnofabric approach: The powerful use of high-resolution image treatment
10:10-10:40	00:30	*Coffee Break!*	
10:40-11:05	00:25	**Andrew Rindsberg**	Ventilation shafts in Paleozoic burrows
11:05-11:30	00:25	**Mutwakil Nafi**	New evidence of Ichnofossils from Late Carboniferous-Tertiary Age, Wadi Halfa and Argein Areas, Jebel Abyad Area, Karb El Toum Area, North and Northwestern Sudan
11:30-11:55	00:25	**Wei Zheng**	Microbial mats and associated metazoan lifestyle in the aftermath of the end-Permian mass extinction of North China
11:55-13:20	01:25	*Lunch Break!*	
			Session Chair: Masakazu Nara
13:20-13:45	00:25	**Hu Bin**	Ichnoassemblages in Lacustrine Deposits of China
13:45-14:10	00:25	**Shahin Dashtgard**	Preferential orientation of arthropod-generated *Diplocraterion Parallelum* and their statistical reliability as paleocurrent indicators
14:10-14:35	00:25	**Huriye Demircan**	Trace fossils of the Lower and Middle Miocene deep marine fan deposits at the Süller-İsmailli-Fırnız-Kürtül Regions (NW Kahramanmaraş, S Turkey)
14:35-15:00	00:25	**Yong-An Qi**	Biogenic structures from carbonate storm deposits of the middle Cambrian Mantou Formation, central China
15:00-16:00	01:00	*Posters & Coffee Break!*	
16:00-18:00	02:00	***Discussion***	Next workshop and the future of ichnofabrics
18:00-21:00	03:00	*Workshop Dinner: Venue TBA*	

Poster: 29th April, 2nd May

#	Authors	Poster Title	
1	**Justin N. Brundin**	Possible Occurrence of Ambrosia Beetle Borings in the Cretaceous Twin Mountains Formation, Bluffdale, Texas, USA	P34
2	**Tzu-Hsuan Chiu, Andrew Tien-Shun Lin, Wen-Rong Chi, Shih-Wei Wang**	Paleo-Environments of Late Pliocene to Early Pleistocene Foreland-Basin Deposits in the Western Foothills of South-Central Taiwan	P35
3	**Giraldo-Villegas, Carlos A., Celis, Sergio A., Rodríguez-Tovar, Francisco J., Pardo-Trujillo, Andres**	Ichnofabrics of *Phycosiphon* in Upper Miocene volcaniclastic rocks of prodelta deposits in the Colombian Pacific: paleoecological implications	P36
4	**Bhawanisingh G Desai**	Ichnofabric Analysis of the Early Miocene Deep Marine Sediments of Fore Arc Basin, Andaman Subduction zone, Andaman and Nicobar Islands, Northeast Indin Ocean	P37
5	**R. S. Hemanta, K. S. Kumar, S. Ibotombi**	Ichnological Features of the Eocene-Oligocene Transition Sediments of Manipur- Nagaland, Northeast India	P38
6	**Dirk Knaust, H. Allen Curran and Roger D. K. Thomas**	*Skolithos linearis* Haldeman, 1840: Investigations at the Type Locality, Chickies Rock, Pennsylvania	P39
7	**Pei-Chen Kuo, Chun-Chieh Wang, Cheng-Cheng Chiang, Ludvig Löwemark, Sheng-Rong Song**	Investigation of the Teeth Micro-Structure of Ancient Animals	P40
8	**Ludvig Löwemark**	Evolution of the trace fossil *Zoophycos*	P41
9	**Nafi M., El Dawi M., Salih K., Suliman T., EL Jzoli T., and Mohammed M.**	Trace Fossil Evidence from the Cambro-Ordovician Karkur Talih Formation, UmKaddada Area, Western Sudan	P42
10	**Yu-Yen Pan, Ludvig Löwemark, Masakazu Nara**	Analyzing the Peculiar Unknown Trace Fossil in the Taliao Formation, Taiwan	P43
11	**F.J. Rodríguez-Tovar, M.T. Whalen, J. Morgan, S. Gulick, C.L. Mellett, and Expedition 364 Scientists**	Ichnological Data Supporting Depositional Continuity After the Chicxulub Impact: the Paleocene Record at the IODP-ICDP Expedition 364	P44
12	**F.J. Rodríguez-Tovar, D.A. Hodell, J. Dorador**	Ichnofabric Analysis of Heinrich Layer 1 at IODP Site U1308: Bioturbational Disturbance and Paleoenvironmental Conditions	P45
13	**F.J. Rodríguez-Tovar, J. Dorador, E. Mayoral, A. Santos**	Outcrop and core integrative ichnofabric analysis: Paleoenvironmental conditions of Miocene sediments from Lepe, Huelva (SW Spain)	P46
14	**F.J. Rodríguez-Tovar, J. Dorador, A. Mena, F.J. Hernández-Molina**	Improving Ichnofabric Analysis in Cores: Computed Tomography Images and High Resolution Digital Treatment	P47
15	**Romy Ari Setiaji, Ery Arifullah, Andhika Chandra**	*Ophiomorpha* Characterization: Case Study from Samarinda Area	P48
16	**Chung-Ping Yeh, Ludvig Löwemark, Chih-Kai Chuang, Jyh-Jaan Huang, Charlie Y.C. Zheng**	The Frame of Objective Morphological Criteria of Trace Fossil *Ophiomorpha* isp. in Nangang Formation, Northeast Coast of Taiwan	P49
17	**Charlie Y.C. Zheng, Gabriela Mangano, Luis Buatois**	Ichnology and Depositional Environments of the Ordovician Stony Mountain Formation (Williston basin, Saskatchewan and Manitoba): Refining Ichnofacies and Ichnofabric Models for Epeiric Sea Carbonates	P50

Oral Presentation

D1 29th Apr Saturday

Intra-Workshop Fieldtrip

Ichnofabric Analysis in Sedimentology

A. Wetzel

Geologisches Institut, Universitaet Basel, Bernoullistrasse 32,
CH-4056 Basel, Switzerlan

Ichnofabrics are essential for sedimentologic studies as they may store environmental information that is otherwise not available from the sedimentary record. Besides erosional and depositional events, which have been addressed recurrently by ichnologic investigations, burrows may act as current indicators or their fill may document the influence of tides. Of particular interest, however, are 'extreme' depositional settings or fluctuating environmental factors that can be evaluated exclusively by ichnofabric analysis; among these settings there are oceanic red beds, 'black shales' or estuarine deposits.

Oceanic red beds do not contain any organic matter, but the preserved ichnofabrics document the former presence of benthic food otherwise there would be no bioturbational structures present. Furthermore, ichnofabrics may indicate, if organic matter delivery was continuous or fluctuating, if a RPD (Redox Potential Discontinuity) developed or not, and how nutritious the benthic food was. The RPD plays an important role because within the interval of the redoxcline microbial activity is enhanced. The position of the RPD can be deduced by considering both burrows having an open connection to the seafloor (normally emplaced below the RPD) and *Nereites missouriensis* produced just above the RPD.

For so-called 'black shales' the oxygen content at the sediment surface has been characterized by several ichnofabric models invoking successions of dis-/re-appearance of traces in consequence of de-/re-oxygenation, respectively. However, besides the oxygen content, sediment consistency that in turn is affected by sedimentation rate via self-weight consolidation is recorded by ichnofabrics. Rapid sedimentation results normally in a soupy sediment consistency, while in slowly accumulating sediments already the near-surface deposits are considerably affected by self-weight consolidation and hence, are soft to stiff. Besides oxygen content of the bottom water, the RPD affects the ichnofabric. Is the RPD located at the sediment surface or close to it, microbial mats may form, bind the sediment and enhance the slope of the geochemical gradient. Undermat miners could have produced burrows; MISS could be present.

Estuarine deposits experience changes of various factors such as salinity, sedimentation rate, sediment consistency, current velocity, organic matter deposition etc. As estuarine settings typically form during transgression, the variability of the environmental factors is well recorded, but only ichnofabric analysis allows to unravel them in detail. Erosion, deposition and by-pass of sediment is recorded by equilibrichnia and burrow fill, respectively. Salinity changes are recorded along the contact between seawater and freshwater. There clay minerals form aggregates and fluid mud may occupy the sediment surface. Furthermore, organic matter content is enlarged along the boundary of water bodies. Discharge modulates the upstream extent of the seawater entering the estuarine system. Ichnofabrics record seawater incursions. If not the burrowing depth of the bioturbating organisms is considered in detail the duration of such hydraulic changes is often overestimated.

Ichnofabric analysis is very useful to qualitatively evaluate changes of environmental factors, but in the moment there is an evident lack in the quantitative understanding of environmental processes. Consequently, to bridge this gap actualistic studies should, therefore, focus in addition on quantification of ichnologic and environmental aspects.

Ichnofabric Analysis Reveals Successive Colonization of Muddy Sediments in Late Bajocian Back arc Basin, Eastern Crimea

Bhawanisingh G Desai[1], Alexei P. Ippolitov[2] and Denis B. Gulyaev[3]

[1]School of Petroleum Technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat
[2]Geological Institute of Russian Academy of Sciences; Moscow, Russia
[3]Interdepartmental Stratigraphic Committee (ISC) of Russia, Yaroslavl, Russia

Subduction processes produces an unique geological environments. Especially the rapidly subducting plate margins produces various challenging sub-environment associated with slope failures, Pressure build-ups, hydrothermal activity, etc. The Crimea–Black Sea region was experiencing similar geological environment during the Late Bajocian age. The Middle Jurassic succession of Eastern Crimea is represented by unconformity bounded sequence starting from the Late Bajocian volcanic and volcanoclastic deposits (Karadag Formation, Parkinsoni ammonite Zone) continuing into volcanic-free deepwater Early Bathonian. During Late Bajocian, these sediments were formed directly on the volcanic belt of Back arc basin. The present study on Ichnofabric analysis was carried out on along various exposures of the Karadag Fm along the Eastern Crimean coast between settlements Koktebel' and Ordzhonikidze in 2015-2016. Karadag Formation is >100 meters thick succession consisting of tectonically disrupted alternate sequence of light and dark grey coloured mudstone interrupted by debris flow and sandy turbidite sequences containing volcanoclastic material and pillow lavas. The whole sequence contains intervals, characterized by remarkable cyclic bioturbation. Based on Ichno-diversity and ichnofabric, the studied succession located at eastern margin of Koktebel' can be subdivided into four sub-units, each consisting of asymmetrical cycle of Bioturbation. Each asymmetrical bioturbational cycle consists of Low (BI-0) to high bioturbation (BI-4/5) events. Low bioturbation events are characterized by occasional deep tier *Thalassinoides* or absence of any trace fossils. High Bioturbation events are characterized by Shallow tier *Palaeophycus, Planolites* and *Taenidium*. Trace fossil *Asterosoma* and *Thalassinoides* dominate the middle tier. Deep tier are characterized by *Chondrites, Zoophycos* and *Helminthopsis*. In the lower part of the succession *Thalassinoides* tends to shifts its tier position from deep tier in low bioturbated units to shallow tier in high bioturbatedunits, probably on account of diversification and competition from other bioturbators. In the upper part of the succession *Chondrites* also shifts its tier position to shallowing of tiers with increase in bioturbation, indicating establishment of restricted pore water oxygenation or easy exploitation of preserved organic matter. The youngest part of studied interval shows relatively higher bioturbation (BI-6) and deepening of tiering. Thus, the ichnofabric analysis reveals that the trace fossils including *Chondrites, Helminthopsis, Asterosoma, Palaeophycus, Planolites, Taenidium, Thalassinoides*, and *Zoophycos* commonly occurred in the volcanic belt associated with back arc basin of Late Bajocian age. Further, the data suggest that the persistently changing geological condition was adapted by trace makers by altering the tiering position and successively colonizing the muddy sediment of the back arc basin.

The investigation is supported by DST project No. INT/RUS/RFBR/P-206 and RFBR projects No. 15-55-45095, 15-05-03149.

Establishment of a Representative Macrobenthic Tracemaker Community After the Chicxulub Impact: Ichnofabric Analysis at the IODP-ICDP Expedition 364

F. J. Rodríguez-Tovar[1], J. Morgan[2], S. Gulick[3], C. L. Mellett[4], and Expedition 364 Scientists

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[2]Dept Earth Science and Engineering, Imperial College London, London (UK)
[3]Inst Geophysics, Jackson School of Geosciences, Univ. Texas at Austin, Texas (USA)
[4]British Geological Survey, The Lyell Centre, Edinburgh (UK)

The K/Pg boundary impact event, one of the "Big Five" mass extinction events, has been profusely studied, but some uncertainties concerning its effects, the selective incidence on faunal groups, the reestablishment of the palaeoenvironmental conditions, and the recovery of biota, are still unsolved. Ichnological research is a useful tool to interpret palaeoenvironmental changes associated with the K/Pg impact event [1-7]. Analysis of trace fossils across the K/Pg boundary transition in marine sections revealed a minor disruption in the macrobenthic tracemaker community, as well as a relatively rapid recovery in distal areas.
From April to May 2016, IODP and ICDP drilled the peak ring of the Chicxulub impact structure offshore during Expedition 364 at Site M0077A (21.45° N, 89.95° W). Approximately 110 m of post-impact, hemipelagic and pelagic, Paleogene sediments were recovered, ranging from middle Eocene (Ypresian) to basal Paleocene (Danian) [8]. The retrieved cores offer the possibility for a detailed ichnological study of the K/Pg boundary. Here we present a preliminary ichnofabric analysis focusing on macrobenthic tracemaker community establishment.

Studied Paleocene sediments belong to Unit 1F, which consists of interbedded light gray to light bluish-gray wackestone and packstone, and light to dark bluish-gray marlstone at the cm to dm scale [8]. The studied interval corresponds to Core 364/77A/40-R-1 (0-34 cm), Core 364/77A/39-R-3 (0-49 cm), and Core 364/77A/39-R-2 (0-136 cm) [8].

From the top of Unit 1G to the lower part of Unit 1F a progressive increase in ichnodiversity, abundance, density, and cross-cutting relationships is observed. At the base of the Paleocene materials (Core 364/77A/40-R-1, 26-34 cm) a mottled background overlapped by a relatively scarce and poorly diverse trace fossil assemblage mainly consisting of *Planolites* and *Palaeophycos*, is recognized, together with scarce small traces (?*Chondrites*). This assemblage is observed in the rest of Core 364/77A/40-R-1, in Core 364/77A/39-R-3, and in the lower part of Core 364/77A/39-R-2 (to around 109 cm). From here, a progressive increase in ichnodiversity and abundance of trace fossils is registered, mainly characterized by the record of *Chondrites* and the generalized presence of *Zoophycos*. This fact allows differentiation of a well-developed tracemaker community representative, typical, of the *Zoophycos* ichnofacies, just around 130 cm of the boundary between Units 1F and 1G.

The Chicxulub drilling expedition was funded by the International Ocean Discovery Program as Expedition 364 with co-funding from the International Continental scientific Drilling Program. The European Consortium for Ocean Research Drilling (ECORD) implemented Expedition 364, with contributions and logistical support from the Yucatán state government and Universidad Autónoma de México (UNAM).

Expedition 364 Participating Scientists: J. V. Morgan (UK), S. Gulick (US), E. Chenot (France), G. Christeson (US), P. Claeys (Belgium), C. Cockell (UK), M. J. L. Coolen (Australia), L. Ferrière (Austria), C. Gebhardt (Germany), K. Goto (Japan), H. Jones (US), D. A. Kring (US), J. Lofi (France), X. Long (China), C. Lowery (US), C. Mellett (UK), R. Ocampo-Torres (France), L. Perez-Cruz (Mexico), A. Pickersgill (UK), M. Poelchau (Germany), A. Rae (UK), C. Rasmussen (US), M. Rebolledo-Vieyra (Mexico), U. Riller (Germany), H. Sato (Japan), J. Smit (Netherlands), S. Tikoo-Schantz (US), N. Tomioka (Japan), M. Whalen (US), A. Wittmann (US), J. Urrutia-Fucugauchi (Mexico), K. E. Yamaguchi (Japan), and W. Zylberman (France).

[1] Rodríguez-Tovar, F. J. and Uchman, A. (2004). *Geol. Mag., 141, 429–440.* [2] Rodríguez-Tovar, F. J. and Uchman, A. (2004). *Cretac. Res., 25, 647–655.* [3] Rodríguez-Tovar, F. J. (2005) *Geology, 33, 585–588.* [4] Sosa-Montes de Oca, C. et al. (2013). *PLoS One 8 (12), e82242.http://dx.doi.org/10.1371/journal.pone.0082242.* [5] Sosa-Montes de Oca, C. et al. (2017). [6] Łaska, W. et al. (2017). *Cretac. Res., 70, 96–110.* [7] Labandeira et al., Topics in Geobiology, 40, Springer, *265–300.* [8] Gulick, S., Morgan, J., and Mellett, C.L. and the Expedition 364 Scientists, 2017. *Exp. 364 Prelim. Rpt. IODP.*

Ice-Dammed Lake Outburst in the Arctic Ocean: Trace Fossil Evidence - from a Distinct Gray Layer on the Lomonosov Ridge off Greenland

Weng-Si Chao and Ludvig Löwemark

Department of Geosciences, National Taiwan University, Taipei, Taiwan

Due to the unique characteristics, sediment cores from the Arctic Ocean are an important archive for reconstructing paleoclimate and paleo-environmental conditions. However, biostratigraphy and chronostratigraphy are complicated in the Arctic because of the lack of foraminifera and the high fresh-water input resulting the strong overprint in isotope signals. Therefore, a new proxy to correlate between cores and for reconstructing the paleo-environmental record has to be developed.

Several cores from the central Arctic, the Lomonosov Ridge north of Greenland, and the Morris Jesup Rise contain a distinct layer of gray sediments. Radiographs of this sediments show abundant ice rafted debris (IRD) within the layer. A sharp lower boundary was clearly observed, suggesting an abrupt change in sedimentation. And the layer itself is void of any bioturbation or trace fossil, while the layer directly underneath showed opening upward curved trace which was believed to be escaping trace fossil in at least one core. The bioturbation returned after this layer was deposited. The layer was tentatively dated to around the boundary between MIS 4 and 3, indicating an abrupt ice dammed lake drainage from northern Siberia.

Ichnofabric of Tidal Deposit in Balikpapan Formation, Kutai Basin (Indonesia)

E. Arifullah, Y. Zaim, Aswan, Djuhaeni

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In Indonesia, the use of ichnology in sedimentological study is generally lacking. Ichnofabric aspects (e.g. bioturbation index, ichnofossil diversity, burrow diameter, penetration depth, ethology and tiering style) are a potential approach to scrutinize the environmental processes in tidal setting. In this context, penetration depth is used as an independent aspect and other ones as dependent aspects. The response of this approach to ancient tidal deposit has been studied for an outcrop of Balikpapan Formation, Kutai Basin (Indonesia). In this contribution, the nature examples of these applications are presented. The observation showing the penetration depth is unrelated to bioturbation index, ichnofossil diversity and ethology. Conversely, the correlation of penetration depth and burrow diameter and its disparity are indicated in the 4th tiering style (i.e. multiple of vertical partition, ethologies and ichnofossil diversity). The correlation may suggest the control of (i) biological aspect (e.g. consequences of deeper penetration by the bigger organism than the little one) and/or (ii) physico-chemical aspect (e.g. substrate consistency, water turbidity, oxygenation) in uppermost and lower tier. *Skolithos* and *Ophiomorpha* commonly is fabricated in uppermost tier. Conversely, *Thallasinoides, Planolites, Teichicnus-Rhizocorallium* and *Chondrites* are fabricated in the lower tier. Moreover, the ichnofabric model is an indicator of environmental conditions in tidal setting during colonization.

Keywords: Bioturbation index, ichnofossil diversity, burrow diameter, penetration depth, ethology, tiering style

Ichnology of an Upper Cretaceous Prodeltaic Lobe and Channel Complex from the Book Cliffs, Utah, United States: Assessing Ichnofaunal Variability of Hyperpycnal Deposits

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The Upper Cretaceous Aberdeen and Kenilworth members of the Blackhawk Formation, Book Cliffs, Utah, contain outstanding examples of turbiditic and hyperpycnal flow deposits, comprising both channel-fills and lobes emplaced in a prodelta setting. Sandstone-rich, heterolithic and mudstone-rich channel fills are present in outcrops of the Aberdeen Member near the northwest entrance to Tusher Canyon. Mudstone- and heterolithic-rich hyperpycnal channel deposits are mostly unbioturbated, locally displaying a few specimens of *Phycosiphon incertum* and *Protovirgularia dichotoma*. Sandstone-rich channel deposits consist of wave-reworked turbidites, containing *Helminthoidichnites tenuis*, *Lockeia siliquaria*, *Phycodes isp.*, *Phycosiphon incertum*, *Protovirgularia dichotoma*, *Rosselia socialis* and *Skolithos linearis*. High rates of episodic and sustained sedimentation, degree of substrate consolidation, freshwater discharge, and water turbidity are ranked as the most important stress factors in both channels and lobes. Strata of the Kenilworth Member outcropping along the southwest entrance of Tusher Canyon records deposition in a prodelta turbidite lobe, but far from its axis. With the exception of a few specimens of *Ophiomorpha isp.*, bioturbation in these deposits is restricted to the top of the succession, where *Curvolithus simplex*, *Gyrochorte comosa*, *Lockeia siliquaria*, *Palaeophycus tubularis*, and *Ptychoplasma excelsum* occur. Strata of the Kenilworth Member forming the Hatch Mesa succession record deposition in a hyperpycnal lobe, near to its axis. Sandstone beds include *Gyrochorte comosa*, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Phycosiphon incertum*, *Protovirgularia dichotoma*, *Ptychoplasma excelsum*, *Skolithos linearis*, and large specimens of *Rosselia socialis*, whereas *Chondrites isp.* is present in the interbedded mudstone. Overall, the Aberdeen and Kenilworth ichnofaunas show marked similarities with the previously defined Curvolithus Ichnofacies (i.e. association). Taxonomic composition, uneven distribution of bioturbation through the successions, and overall low ichnodiversity help to distinguish these prodeltaic deposits from bathymetrically equivalent offshore strata in the same basin. Simple ichnofabrics displaying poorly developed tiering structures are dominant. Hyperpycnal deposits are formed in a wide variety of environmental settings, therefore displaying high ichnological variability. Such variability is summarized by characterising ichnofaunas from four different depositional settings: (1) lakes, (2) shelf deltas, (3) shelf-edge deltas, and (4) deep-marine systems. In terms of the ichnofacies model, lacustrine hyperpycnites typifies the freshwater *Mermia* Ichnofacies, whereas shelf deltas are commonly dominated by the depauperate *Cruziana* Ichnofacies, particularly in hyperpycnal lobes. Shelf-margin deltas seem to be the most stressful of all settings affected by hyperpycnal flows, containing only sparsely distributed trace-fossils suites that illustrate the depauperate *Cruziana* Ichnofacies. In deep-marine settings the *Ophiomorpha rudis* ichnosubfacies of the *Nereites* Ichnofacies is present in high-energy, proximal channelized and levee areas of hyperpycnal systems, whereas the low-energy middle to distal zones tend to be dominated by the *Nereites* ichnosubfacies. Associated thin-bedded turbidites contain the *Paleodictyon* ichnosubfacies of the *Nereites* Ichnofacies.

Quantitative Morphological Characterisation of the Graphoglyptid Trace Fossil *Helminthorhaphe* and its Palaeobiological Implications

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Helminthorhaphe is a meandering trace fossil valuable to the study of movement behaviour and its neurobiological background in corresponding marine invertebrates (Raup and Seilacher, 1969). Inter- and intraspecific variation in representatives of this genus reflects instability of behaviours at the individual and/or population level. Considering the possible continuum of trace fossil morphospace, primary structural styles should be more important than overall shape in ichnotaxonomy (Miller, 2012). In this work, we studied systematically the morphology of *Helminthorhaphe* from the Upper Cretaceous to Miocene on the basis of character diagrams and morphometrics. Eleven morphological constructs were used to illustrate morphological features of the meanders (morphological codes). They encompass three aspects of meander arrangement, meander tip and meander course, corresponding to eleven distinct movement behaviour variations, from which the behavioural asymmetry is the most distinctive. Several parameters, string diameter, meander width and meander length, are extracted to explore the differentiation between ichnospecies or morphotypes. Meander width versus string diameter (MW/SD), and meander length versus meander width (ML/MW) ratios are chosen to represent the degree and adherence of thigmotaxis, respectively. Here we suggest using morphometrics to rationalize the identification of *Helminthorhaphe* in the sense of quantifying thigmotaxis. Within the redefined taxonomic frame, *H. japonica*, *H. flexuosa*, and *H. miocenica* represent a series of decreasing thigmotaxis. *H. japonica* and *H. miocenica* are capable of broad morphospace because of wider parameter range. And *H. flexuosa* is composed of highly diversified forms in a restricted parameter range. From the study, all the specimens of *Helminthorhaphe* follow approximately the same pattern with respect to the degree and adherence of thigmotaxis, which indicate deep homology in the behavioural ecology of their producers. Recent torquaratorid enteropneusts are restricted to the deep sea (Osborn et al., 2012) and produce meander structures similar to *Helminthorhaphe*, therefore they are proposed as possible trace makers of *Helminthorhaphe*, at least since the Late Cretaceous.

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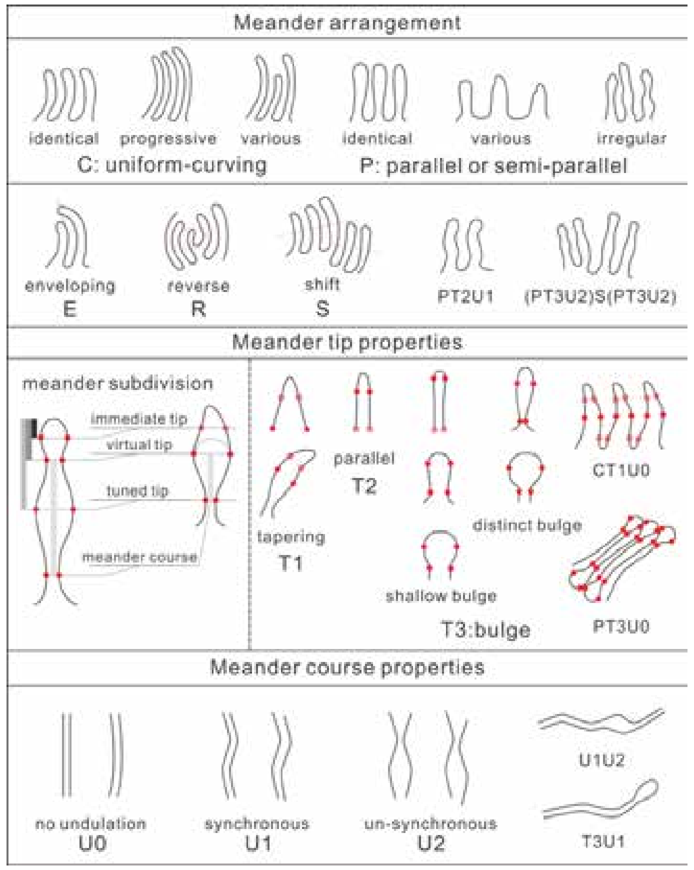

Figure 1. Morphological prototypes and constructs of *Helminthorhaphe*

Unbioturbated Mudstones May Record Only Slightly Lowered Oxygen Conditions in Warm, Shallow Basins

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Unbioturbated mudstones and highly bioturbated silty and sandy mudstones from the Late Albian, Alberta, Canada are characterized by their ichnological, foraminiferal and geochemical signatures. A comparison of these datasets is undertaken to isolate the dissolved oxygen (DO) conditions that led to the preservation of unbioturbated mudstones *versus* highly bioturbated silty and sandy mudstones. Highly diverse and abundant benthic foraminiferal assemblages, coupled with conclusive geochemical signatures indicate that unbioturbated mudstones were deposited under oxic bottom waters. The paucity of bioturbation in these rocks is attributed to the persistence of low-oxic conditions (5 > DO > 2 mg l-1) at the seafloor, comparable to the present-day Gulf of Mexico. We assert that unbioturbated mudstone should not automatically be attributed to oxygen deficiency (< 2 mg l-1). Instead, it may reflect oxygenation sufficient to support benthic microfauna (foraminifera) but insufficient to sustain a diverse ecosystem of macrofauna (burrowing fauna). Moreover, we propose that the distribution of unburrowed mudstones deposited below low-oxic waters is predictable. A paucity of bioturbation is normal in shallow marine (below fair-weather wave base to approximately 200 m water depth) deposits of sub-tropical to tropical ocean basins and/or semi-enclosed seaways.

Types and Microbial Geneses of Carbonate Micro-Shapes in *Zoophycos* Burrows from the Lower Permian Taiyuan Formation in North China

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The ichnofossil *Zoophycos* are common in carbonate rocks from the Lower Permian Taiyuan Formation in North China basin, meanwhile, many carbonate micro-shapes are found in four kinds of different-colour fillings of *Zoophycos* burrows on the basis of observation by SEM and determination by EDS. According to the morphologic characteristics, these carbonate micro-shapes can be divided into four groups, they are spheroids, framboids, rhabditiforms and areatus aggregates. Based on the surface structural features and individual or aggregates shape, the four group of carbonate micro-shapes can be further divided into fourteen types that include (1) the spheroid with smooth surface, (2) the spheroid with thorn fine grain surface, (3) the spheroid with unshaped fine grain surface, (4) the spheroid with flocculent surface, (5) the spheroid with vermiform surface, (6) the framboid monomer, (7) the framboid colonies, (8) the rhabditiform in a straight line with smooth surface, (9) the rhabditiform with smooth surface and expanding tail end, (10) the rhabditiform with biserial form, (11) the rhabditiform with spiral form, (12) the rhabditiform with thorn surface, (13) the branched rhabditiform micro-shapes, and (14) the druse-like carbonate aggregates. This paper discussed the possible microbial geneses of these micro-shapes, and suggested that the formation of different-colour fillings of *Zoophycos* burrows is closely related with the differences of the microbial taxa in different ecological environments, so to speak, it is likely to exsit a kind of mutually beneficial and symbiotic relationships between the *Zoophycos*-maker and microbes.

Keywords: Geomicrobiology; Carbonate micro-shapes; Lower Permian; Trace fossil; *Zoophycos*; the North China basin

An Example of Proximal And Intermediate Turbidite Trace Fossils: The Dizilitaşlar Formation (Paleocene), Kırıkkale Region, Central Anatolia

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The Dizilitaşlar Formation (lower Paleocene) from the Çankırı-Çorum Basin (Central Anatolia) represents proximal and intermediate turbidite facieses of a submarine fan composed of conglomerates, sandstones, marls and limestones. A lateral transistion from proximal turbiditic successions to distal, low-oxygen shaly mudstone can be observed. The conglomerates are gray, medium-thick bedded, coarse pebbly, matrix supported, poorly sorted, and small pebbly or medium sized, grain supported. Sandstones are thin-medium bedded and green, brown in colour. The marls are gray, the limestones thin bedded, dirty white or light gray. The formation contains olistoliths in the form of reefal limestone. Sedimentary structures include of parallel lamination, parting lineation, cross lamination, graded bedding, ripple marks, load casts, groove marks, flute casts. Diverse trace fossils are preserved on the lower and upper bedding surfaces of sandstones and siltstones including *Chondrites intricatus*, *Chondrites targionii*, *Chondrites* isp., *Cosmorhaphe* isp., *Halopoa annulata*, *Helminthopsis* isp., *Helminthorhaphe flexuosa*, *?Megagrapton submontanum*, *?Nereites* isp., *Ophiomorpha rudis*, *Ophiomorpha* isp., *Paleodictyon minimum*, *Paleodictyon strozzii*, *Palaeophycus* isp., *Paramoudra* isp., *Planolites beverleyensis*, *Planolites* isp., *Protopaleodictyon* isp., *Rhizocorallium* isp., *Scolicia prisca*, *Scolicia strozzii*, *Scolicia* isp., *Saerichnites* isp., *Thalassinoides suecicus*, *Thalassinoides* isp., *Zoophycos* isp., and a radial trace. The *Ophiomorpha rudis* ichnosubfacies and the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies and the *Zoophycos* ichnofacies have been identified.

Keywords: Trace fossils, turbidites, ichnofacies, Dizilitaşlar Formation, Central Anatolia.

Microbial Mat Records in Siliciclastic Rocks: Examples from the Mesoproterozoic Yunmengshan Formation in China and Their Modern Equivalents

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Activities of benthic prokaryotes in response to the sedimentary dynamics could form the characteristic structures known as "Microbially Induced Sedimentary Structures (MISS)", arising syndepositionally from the interactions of biofilms and microbial mats with the sedimentary grains due to the variations in hydraulic parameters in siliciclastic aquatic environments. In a sense these structures are analogous to trace fossils in that they record the microbial community induced changes in the mechanical and chemical behavior of the substrate. The Yunmengshan Formation, belonging to Mesoproterozoic Ruyang Group in China, well-preserved structures include mat growth features, mat metabolism features, mat destruction features and mat decay features. Additionally, Microbially Induced Sedimentary Structures (MISS) were also presented from the terrestrial Liujiagou Formation of Induan (Early Triassic) age in the Henan Province, North China. They all associated with the lack of ichnofossils. So MISS became more common as a response to periods of lower benthic biodiveversity and reduced bioturbation.

Study of the modern equivalents of Microbially Induced Sedimentary Structures (MISS) provides useful insights for understanding the exact genetic process of the wide ranging non actualistic structures reflecting the unusual cohesiveness of mat growth on sediments. Observations made in modern environment supplements provided better resolution to palaeogeographic interpretations of microbially induced sedimentary structures (MISS). According to the study of their modern equivalents in the marsh of Huanghe River in China, we revealed some MISS's origin and environment sense including mat growth feature, sand chips, wrinkle structures, gas domes, etc. From this study, we have also built the origin model of gas domes, reticulate growth ridge etc.

Keywords: Microbial mat; Microbially Induced Sedimentary Structures (MISS); modern equivalents; Yunmengshan Formation

Acknowledgments:
This study was by the National Natural Science Foundation of china (Nos. 41102008, 41202071, 41472083) and PHD Fundation of Henan Polytechnic University, Project No. B2012-083).

Ichnofabrics of Pleistocene Carbonates on Favignana Island, Southern Italy

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Favignana Island belongs to the Egadi Archipelago that represents an emerged part of the Egadi Thrust Belt. Its Mesozoic–Late Cenozoic carbonate deposits are unconformably overlain by the Middle–Upper Pliocene bluish marls and shales followed by the Lower Pleistocene light calcarenites and calcirudites. They are covered with a reddish unconformity by Tyrrhenian calcarenites and biorudites with *Strombus bubonius* The Lower Pleistocene calcarenites of Favignana Island are a part of a wide shoal that is attached to the western Sicily and embraces the Egadi Archipelago. They represent a variety of facies referred to high energy coast with beach, moving bar system with a transition to offshore successions.

In several outcrops, very high energy calcarenites which show large scale cross bedding and erosional truncations between cross bedded sets are not bioturbated at all. Less energetic, cross bedded calcarenites are partly bioturbated, mostly with *Bichordites*, which is produced by irregular echinoids. Totally bioturbated layers are present in the basal part or on the lee side of the cross bedded units. These deposits are referred to subtidal migrating dunes on a carbonate shoal. Their colonization was possible in the troughs between the dunes or on their slopes when the dunes were stabilized.

Less energetic units, showing smaller scale cross bedding, parallel bedding or a massive fabric are partly or totally bioturbated. They display a larger variability of trace fossils, including, *Ophiomorpha nodosa*, *Thalassinoides* isp., *Teichichnus* isp., *Macaronichnus* isp., *Palaeophycus* isp., *Ancorichnus* isp., *?Taenidium* isp., *Bichordites* isp., *?Scolicia* isp., *?Taenidium* isp., and *Skolithos* isp.. They represent environments differing in energy and belong to the *Skolithos* and the *Cruziana* ichnofacies. Deposits of higher energy settings, possibly sandy shores or shoals, are characterized by the *Skolithos* ichnofacies, mostly with *Ophiomorpha*, *Skolithos*, and *Macaronichnus*. Deposits of less energetic settings, which may include bays and lagoons, show more members of the *Cruziana* ichnofacies, foremost *Thalassinoides* isp., *Teichichnus* isp., *Ancorichnus* isp., *?Taenidium* isp., *Bichordites* isp., and *?Scolicia* isp. Episodes of at least local emergence are marked by root structures, including large structure *Favichnus favignanus* and *Egadichnus egadicus* (see Uchman et al., 2012). The calcarenites contain also bioclasts bored with *Entobia* ispp. Produced by clionaid sponges, *Caulostrepsis* isp. and *Maeandropolydora* isp. produced by spionid polychaetes, and *Gastrochaenolites torpedo* produced by bivalves.

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From Burrows to Petroleum Systems – Using Combination of Fossil Seep Carbonate Conduits and Acoustic Seismic Amplitudes to Trace Hydrocarbon Migrations

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Methane-derived authigenic carbonate (MDAC) and fossilised cold seep figures provide evidences of hydrocarbon migration to the surface in numerous locations worldwide. In this study we examine the wide-ranging morphologies of MDAC's in outcrops and seismic data. We discuss what implication they have in our understanding of hydrocarbon migration and petroleum exploration.

MDAC's are shown from three case-study areas; France, USA and the Offshore Angola in oil-gas-bearing basins. At the seismic-scale (from several hundred of meters to several kilometres), MDACs are expressed by positive high-amplitude anomalies which occur as isolated features or vertically stacked successions. The plan form geometries of MDAC's vary from linear to sub-circular or even irregular. The plan form geometries can serve as a tool to define the palaeo-dynamics of gas venting and migration regimes (Ho et al., 2012). At outcrop-scale, the morphology of MDAC's can present as principally massive concretions, as slabs, individual or clustered nodules or have tubular forms (Blouet et al., 2016).

MDAC tubes have been widely considered as direct products derived from overpressured fluid migrations in the subsurface (Hovland and Judd, 1988). In the literature, tubular MDACs are interpreted as cementation along faults/fractures (e.g. Aiello, 2005) or bioturbations (e.g. Wiese et al., 2015). The former interpretation has been confirmed by observations from outcrop but none of the MDAC tubes contain remains of fauna that can attest for sure to an origin related to bioturbation. Recently, a vertical MDAC tube connected to a chemosynthetic bivalve *Loripes goliath* (Yokoyama) has been found in a mountainous area of Central Taiwan. We interpret the central channel in the tube concretion as the infill of the siphon that *Loripes* used for exhalation/inhalation and filtering particles. As an open pathway in sediments, the siphons were used by upward migrating hydrocarbons as a pathway around which seep carbonates precipitated. This represents so far a unique example demonstrating tubular seep carbonates of biological origin, related to burrowing organisms.

This discovery sheds light on the origin of pathways in the shallow sub-seafloor which were used by hydrocarbon to migrate upward to the seafloor from underlying permeable intervals or shallow accumulations. In addition, the paragenetic sequences of MDAC tubes record variations of fluid leakage dynamics and leakage episodes in the sub-seafloor over time (Blouet et al., 2016) whilst the vertical evolutions of MDAC geometries and organisations visualised in both seismic- and outcrop-scale reflect fluctuations of methane pulses over vast areas or at focusing points (Blouet et al., 2016; Ho et al., 2012).

Combining and integrating observations of the structural morphology and petrographic character of MDAC's from acoustic seismic amplitudes and outcrops respectively can aid the reconstruction of hydrocarbon migration from the basin-scale down to the microscopic scale. This study presents a new way of tracking petroleum system activities over time that has been developed by Ho (2013) and Blouet (2017).

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Oral Presentation

D2

30th Apr
Sunday

Intra-Workshop Fieldtrip

They Will Survive! Ichnofabrics Uncover Stress Tolerance Behavior

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Trace fossils are widely known as useful tools to evaluate tracemaker's behavior. In the case of invertebrate burrows, even the ecological niche of some producers can be interpreted. There are many examples of burrows resulting from the activity of r-selected (opportunists) and k-selected (biotically competent or equilibrium) organisms in the geological record. The record of bioturbation generated by stress-tolerant organisms, however, is still poor and has been represented mostly by the occurrence of a crowded Rosselia ichnofabric (CRI) in shallow marine settings. A dense colonization of Zoophycos reported recently in Devonian beds of the Paraná Basin (southern Brazil) shares similar features with those observed in the CRI, allowing suspect of another case of stress-tolerance behavior. Opportunistic species reproduce early, have a short life span and their dispersion and colonizing potential is much higher than that of equilibrium species. For this reason, they commonly are pioneers in new ecospaces, being successful in colonize stressing or ephemeral settings. Consequently, dense monospecific colonization of invertebrate burrows has been largely assumed in the ichnological literature as a response to opportunistic behavior. Stress-tolerant organisms, otherwise, share similar attributes with equilibrium species. They typically are slow to colonize available new ecospaces, but overall, they adapt more successfully than faster, opportunistic colonizers. They usually show lower reproductive and growth rates and narrower environmental tolerance than opportunistic burrowers, and most of them have specialized trophic habits adapted for occupation of specific niches. In addition, stress-tolerant species are long-lived organisms with high tolerance to chronic physiological stress, forming stable populations in naturally stressed environments. The waning of the non-tolerant species during specific events of stress will enhance the burrowing activity of the stress-tolerant species which will survive. This enhancement will result in a dense colonization of a single type of burrow, producing the same bioturbation pattern generated by the opportunistic colonization. But how to differentiate these occurrences from those that should represent opportunistic behavior? Opportunistic populations will form a post-event trace fossil suite that does not share or rarely shares ichnotaxa with the pre-event suite and that represents preferentially shallow-tier structures. Stress-tolerant populations will form an event trace fossil suite that is composed of ichnotaxa that belong to the pre-event trace fossil suite, whose tracemakers will survive while the stressing conditions that decimate the pre-event community will persist. These ichnotaxa will also be part of the new, post-event trace fossil suite. These changes in composition of pre- and post-events trace fossil suites are not always perceptible in outcrops with preferential horizontal exposure. However, they are enhanced by ichnofabrics in vertical exposure. Thus, the ichnofabric analysis is the best approach to differentiate opportunistic and stress tolerance behavior. Opportunistic behavior will result in a sharp shift between pre- and post-event trace fossil suites, the former usually showing a bigger ichnodisparity and the latter normally monospecific, composed mostly of shallow-tier burrows. Stress tolerance behavior will result in the preservation of the event trace fossil suite, which is composed of ichnotaxa that are part of the pre-event suite and that might be part of the post-event suite as well if they survive.

Ophiomorpha: Do We Need New Criteria to Define Its Ichnospecies?

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As one of the best known invertebrate trace fossils recording burrowing activity, specimens of the ichnogenus *Ophiomorpha* consist of well-lined, branching shaft and tunnel systems that are distinctly pelleted on the exterior and smooth on the inside. Outside burrow diameters typically are 1-3 cm. However, in Pleistocene shallow-marine carbonate grainstones of the wider Caribbean region, including the Bahamas and South Florida, *Ophiomorpha* diameters commonly reach 5-6 cm, with large shaft/tunnel segments reaching lengths of 10s of centimeters and creating megaporous ichnofabrics. *Ophiomorpha* is widely interpreted as representing the dwelling burrows of callianassid (ghost) shrimp [Decapoda: Axiidea: Callianassidae]. Today, this family is globally distributed and represented by 200+ species, mainly from shallow marine environments in tropical to temperate latitudes. Ophiomorpha is known from the early Mesozoic onward, and its common occurrence, particularly in shallow subtidal to lower foreshore, sandy siliciclastic and carbonate deposits, indicates the important role of callianassids as a dominant bioturbator within endobenthic faunas that characterize the Mesozoic Marine Revolution. Zoologists identify callianassid species primarily on the basis of differences in exoskeleton morphology, commonly with emphasis on the first and second pereiopods. A given pattern of burrow architecture is considered to be species specific. In contrast, there are only six ichnospecies of *Ophiomorpha* commonly identified by ichnologists, with the primary differentiating feature being variations in pellet morphology. One way to rectify this problem of apparent under-representation of *Ophiomorpha* ichnospecies would be for ichnologists to put more emphasis on the architectural differences present within overall *Ophiomorpha* burrow systems. Distinctive shaft/tunnel terminus structures commonly preserved in late Pleistocene shallow-marine grainstones of the Grotto Beach Formation at Harry Cay on Little Exuma, Bahamas provide an example of a characteristic burrow-architecture feature that could be used as the basis for defining a new ichnospecies of *Ophiomorpha*. These terminus structures typically consist of a shaft or tunnel that ends in a cluster of relatively short, robust, horizontally-oriented branches (commonly 3 or 4), with closed, blunt ends. Such structures can have an overall diameter of up to 20+ cm, with branch diameters of 4-5 cm (see Figs. A, B). Other examples of these characteristic terminus structures have been found in Pleistocene strata of equivalent age on Rum Cay, Bahamas, the Ironshore Formation of the Cayman Islands, and the Miami Limestone of South Florida. This indicates a significant geographic range for the callianassid species that formed these distinctive *Ophiomorpha* structures.

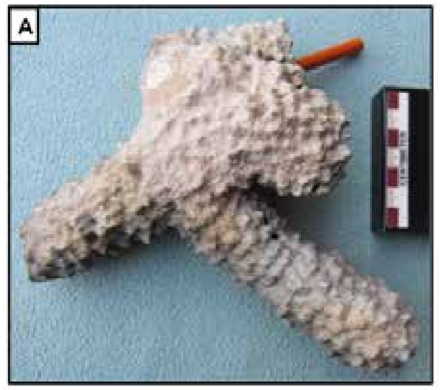

Fig. A: Large *Ophiomorpha* terminus structure from the Pleistocene Grotto Beach Formation, Harry Cay, Little Exuma, Bahamas. Pencil marks entry point to the structure.

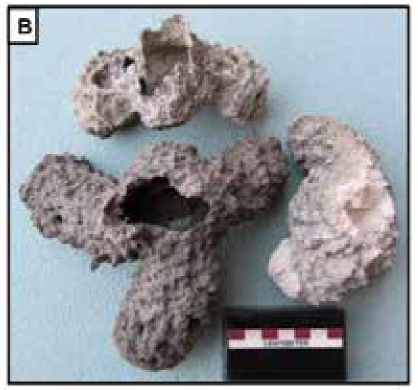

Fig. B: Several more examples of the distinctive *Ophiomorpha* terminus structures from Harry Cay.

Schaubcylindrichnus heberti from Zhangxia Formation (Cambrian Series 3) in North China: A Pioneer of Thickly Lined Trace Fossil

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Well-preserved trace fossils with thick lining are found in Zhangxia Formaton of Cambrian Series 3 in North China. Those specimens are thickly lined; I-, J-, or U-shaped burrows that bend from horizontal to vertical orientation. Most of them are solitary, but clusters also common. The burrows belong to Schaubcylindrichnus heberti, and they are the single trace fossils, but with middle to high abundance in the strata. The structures of a single tube are constituted of three contrasting parts: dark grey filling with sparry calcite cemtnt, lighter lining with micrite, and dark grey appendant with microcrystalline calcite and dolomite. According to structures and morphology, the trace fossil was probably a burrow system of opportunist species. The burrow is interpreted as an open tunnel while the trace marker occupied it. The lining is formed by animal capture and arrangement finer sediments and secreted mucus in order to reinforce the tube wall. Appendant is influenced by bioturbation but no mucus. Tubes in bundle were not burrowed by gregarious animals, but rather that they were formed by a solitary producer for reproduction and the process of the later generations growing up. Schaubcylindrichnus is a common trace fossil occurring in post-Carboniferous shallow marine sandstone, but now it is found in Cambrian limestone, and it is the first appearance of thick lining in a trace fossil. This is the strong evolution evidence of the Cambrian biological behavior.

Keywords: Trace fossil; Schaubcylindrichnus; burrow wall; Cambrian; China

Acknowledgments:
This study was by the National Natural Science Foundation of china (Nos. 41440016 ,41472083,41502106).

Ichnology and Palaeoecology of *Macaronichnus segregatis degiberti*

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The trace fossil *Macaronichnus* is a nearly straight to strongly curved, fossil cylindrical burrow, lying horizontal to vertical to bedding, and is characterised by a lighter-coloured core and a dark-coloured mantle. It has been interpreted to be a pascichnial trace fossil formed through selective feeding and excretion of a deposit-feeding and free-living polychaete, such as the opheliids. Apart from the type ichnospecies *Macaronichnus segregatis*, having 2–5 mm in diameter and occurring exclusively in foreshore sediments, the other type of *Macaronichnus* characterised by relatively larger size (5–15 mm in diameter) have also been reported (cf. Seike et al., 2011, and references therein). Seike et al. (2011) shed light on this large morphotype and found comparable burrows from modern subtidal sand bar deposits of Japan. They also found their trace makers, the large polycahete worms *Travisia japonica*. Recently, it is formally described as *Macaronichnus segregatis degiberti*, based on the Cenozoic specimens of southern Spain (Rodríguez-Tovar and Aguirre, 2014). Here ichnological and palaeoecological studies of *M. s. degiberti* are reported mostly based on the specimens in Palaeozoic to Recent sediments of the North America, East Asia, and Europe.

The sand grains of the core and the mantle of *M. s. degiberti* are rich in light and heavy minerals, respectively, although some exceptional specimens also exist (see, Nara, 2014). In the core, imbricate lamellae, each of which shapes like a shallow trough, are characteristically developed. On the other hand, the mantle actually consists of evenly-spaced hemispherical protuberances filled with darker-coloured sand grains. In some parts of the burrow, the mantle may be very thin or completely missing. The single lamella in the core is interpreted to be formed by a single pulse of excretion. And the mantle protuberances are interpreted to be formed through tracemaker's probing behaviour.

This ichnosubspecies occurs in sandy substrates of wide environmental range, i.e., tidal flats, tidal channels, upper to lower shorefaces, shelves, and shelf sandridges. However, it never occurs in foreshore sands, as noted above. Even in continuous shoreface to foreshore successions of many outcrops, *M. segregatis*- and *M. s. degiberti* occur separately. This strongly suggests that habitat segregations between those producers were clearly established.

Several (mostly two) individuals of *M. s. degiberti* tend to occur side-by-side. Commonly one individual follows mostly along the side of the other one. They may be slightly tangled together. Cross-cutting or penetration of those specimens are common. Such specimens may easily be misidentified as branched ones especially when they lack mantles. This characteristic mode of occurrence is interpreted to be the traces of reproductively-motivated behaviour of the tracemakers; namely, the dioecic and direct-developmental scalibregmatid polychaetes, such as *Travisia*, probably need to be mating in the sand. This would be the first report of intraspecific stalking traces.

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Seike, K., Yanagishima, S., Nara, M., and Sasaki, T., 2011. Large *Macaronichnus* in modern shoreface sediments: Identification of the producer, the mode of formation, and paleoenvironmental implications. Palaeogeography Palaeoclimatology Palaeoecology **311**, 224–229.

Oral Presentation

Intra-Workshop Fieldtrip

D4

2nd May
Tuesday

The Cambrian Explosion: Exploring Animal-Substrate Interactions at the Dawn of Phanerozoic

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Although most of our knowledge of the Cambrian explosion emerges from the study of the body-fossil record, trace-fossil data are highly valuable as an independent line of evidence to explore the nature of this event. Whereas an approximately 20 Ma gap exists between the youngest exceptional preservation of Ediacaran body-fossil assemblages (549–541 Ma) and that of the Cambrian Stage 3 Burgess Shale-type assemblages (521–514 Ma), the trace-fossil record across the Ediacaran-Cambrian boundary is remarkably continuous. In particular, the trace-fossil record shows a remarkable increase in both global and alpha ichnodiversity and ichnodisparity of bioturbation structures in the so-called “pre-trilobite” early Cambrian. Although body-fossil information places the appearance of the main animal body plans by Cambrian Epoch 2, the ichnologic record shows than the main diversification event occurred during the Fortunian. In spite of a wide variety of new trace-fossil morphologies reflecting innovations in body plans and locomotory mechanisms, Fortunian ecology was relict in nature, being intimately linked to microbial matgrounds (i.e. “Ediacaran ecology”). This diversification event was decoupled from the major shift in benthic ecologic structure that took place later, during Cambrian Age 2 (i.e. Agronomic revolution). The Cambrian Age 2 event in ecosystem engineering involves an evolutionary breakthrough in ecologic structuring, including the establishment of deep-tier infaunal suspension-feeding communities, a more complex tiering structure consisting of multiple ichnoguilds, and more intense bioturbation along the whole depositional profile. The Cambrian explosion is best depicted in shallow marine environments formed under normal-marine conditions (i.e. marine salinity and fully oxygenated), being typified by the establishment of the archetypal marine ichnofacies. However, ichnologic information indicates that the benthos of deep-water and marginal-marine environments, the latter including both shallow intertidal settings connected to the open sea and brackish-water embayed settings, were also affected by this evolutionary event. Although Burgess Shale (BS)-type faunas were originally regarded as transported from shallower water to an anoxic deeper-water setting, recent work has documented the occurrence of trace fossils in BS-type deposits, providing uncontroversial evidence of an *in situ* benthic community. Based primarily on distinct preservational styles and secondarily by morphology and size range, a variety of trace fossil assemblages can be recognized. Of these types of BS biogenic structures, the most diagnostic are: (1) trace fossils associated to non-mineralized body fossils, and (2) burrows and tubes containing their own producers. These two types of biogenic structures seem to be a distinctive ichhnologic signature of BS-deposits recording ecologic and taphonomic conditions uncommon during the rest of the Phanerozoic. Burgess Shale- type ichnofaunas reflect fluctuating oxygen conditions (albeit with dominance of oxygen deficiency) and reveal significant clues on the evolution of early Phanerozoic benthic community structure. However, these ichnofaunas cannot be fully explained without considering unique macroevolutionary, taphonomic and ecologic controls.

Advancing Ichnofabric Approach: The Powerful Use of High-Resolution Image Treatment

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In the Symposium in honour of Richard G. Bromley and Ulla Asgaard held in Bornholm, Denmark in 14th-16th May 2014, an abstract entitled "*Improving ichnofabric analysis in cores: A novel method on digital image treatment*" was presented. The idea was to show a novel methodology – the digital treatment of high-resolution images – as a very useful tool for ichnofabric approach of modern marine cores. The proposed method allows: 1) differentiation between biodeformational structures and trace fossils, as well as distinction between passively and actively infilled structures, 2) better identification of trace fossils and cross-cutting relationships, 3) estimation of the percentage of bioturbation associated to each ichnotaxon and to the whole ichnocoenosis, and 4) evaluation of the penetration depth of particular structures. During previous years (from 2011) this method has been successfully applied to IODP cores from Expedition 339, favoring the use of the ichnofabrics to palaeoenvironment interpretations.

During the last three years, after the presentation, a significant advance has been experimented based on the application of this methodology to numerous and variable cases. Thus, digital image treatment has been applied to images not only from modern marine cores, but also to Miocene carbonate rock cores to improve sequence stratigraphy analysis, or to Cretaceous well cores to evaluate reservoir characterization. Moreover, the usefulness of the methodology has been also proved for ichnofabric characterization on X-ray images applied to palaeoenvironmental research, and recently to Computed Tomography images. In the last case, X-ray CT images from IODP cores were treated to integrate ichnofabric analysis in the characterization of the Heinrich Event 1, 2D sections of CT images of from gravity cores have been studied to evaluate short-distance lateral variations in some ichnofabric attributes, and ichnofabric analysis of treated 3D images from IODP cores is being conducted to approach differentiation between current deposits.

All these examples put in evidence the powerful use of high-resolution image treatment to ichnofabric approach, allowing a significant advance of this ichnological paradigm and opening new perspectives to the fields in which this approach is applied.

Ventilation Shafts in Paleozoic Burrows

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Animals that make no permanent, open burrow, but live their lives buried within a substrate, must acquire oxygen in one way or another. Some acquire oxygen by absorbing it from oxic porewater; some periodically visit the surface. Still others (e.g., some mollusks and irregular echinoids) maintain a shaft to the surface through which a relatively narrow siphon or other organ pumps water to the gills. The excavation and moving of these shafts create distinctive traces that can be recognized in the fossil record. A growing number of simple, linear deposit-feeding burrows with series of narrow shafts or shaft-produced spreites have been discerned in Paleozoic strata of Alabama and Georgia (USA). Examples include ichnospecies of Silurian *Dictyodora* and Mississippian *Hillichnus*, *Psammichnites*, and *Nereites*. In addition, at least one Mississippian cubichnion, *Alph hartselleanus*, displays ventilation shafts. Recognition of these structures depends on preservation of the upper part of the burrow. As more trace fossils are studied in a functional context, we will gain more information about the evolution of substrates as well as their inhabitants.

Figure 1. Epichnial *Nereites* from the Mississippian Hartselle Sandstone of Alabama shows a series of oblique shafts, two of which are indicated by arrows. Scale in cm.

New Evidence of Ichnofossils from Late Carboniferous-Tertiary Age, Wadi Halfa and Argein Areas, Jebel Abyad Area, Karb El Toum Area, North and Northwestern Sudan

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New evidence of trace fossils from Late Carboniferous-Tertiary age has been reported here from Wadi Halfa and Argein Areas, Jebel Abyad Area and Karb El Toum Area, North and Northwestern Sudan. The sediments of the Late Carboniferous to Tertiary age are consisting of shallow marine facies intercalated with continental facies. Two ichnofacies were recognized: Skolithos Ichnofacies and Cruziana Ichnofacies. The *Skolithos* Ichnofacies include ichnogenera: *Skolithos, Conichnus, Diplocraterion* and *Monocraterion*. *Cruziana* Ichnofacies consist of ichnogenera: *Thalassinoides, Planolites, Rhizocorallium* and *Zoophycos*.

Keywords: Late Carboniferous-Tertiary, Ichnofacies, Sudan, Trace fossils

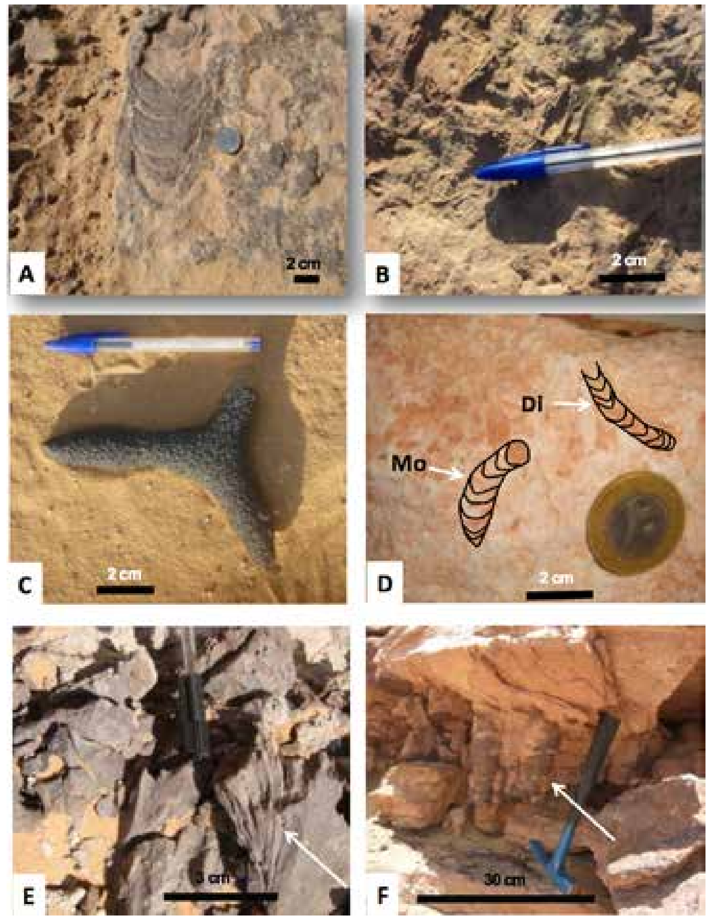

Fig. (1): Trace fossils from Wadi Halfa and Argein Areas, Jebel Abyad Area and Karb El Toum Area, North and Northwestern Sudan, (A) *Rhizocorallium*, Wadi Halfa Area, (B) *Planolites*, Wadi Halfa Area, (C) *Thalassinoides*, Jebel Abyad Area, (D) *Diplocraterion* (Di) and *Monocraterion* (Mo), Karb Al Toum Area, (E) *Zoophycos* Abyad Area, (F) *Conichnus*, Argein Area.

Microbial Mats and Associated Metazoan Lifestyle in the Aftermath of the end-Permian Mass Extinction of North China

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The increase in the intensity and depth of bioturbation through the Proterozoic-Phanerozoic transition changed the substrates on which benthic metazoans lived from the relatively firm "matground" to the blurry "softground". And the changes in substrates has been termed the "agronomic revolution" or "Cambrian substrate revolution". Three kinds of typical opportunistic trace fossils occurred in the terrestrial Middle Liujiagou Formation of Induan (Early Triassic) age in the Dengfeng area, Henan Province, North China. Meanwhile six types of well-preserved microbially induced sedimentary structures (MISSs) were found, including mat growth feature, laminated leveling structure, wrinkle structures, palimpsest ripples, gas domes, shrinkage cracks, in this formation. Microanalysis shows that these MISSs are characterized by thin clayey laminae and filamentous mica grains arranged parallel to bedding plane as well as oriented matrix supported quartz grains, which are indicative of biogenic origin. This evidence suggests the abnormal hydrochemical and physical environments and the presence of microbial mat after the Permian-Triassic crisis in the studied sections. These trace fossils were currently preserved together with the microbial mats in study area. The slight bioturbation and diversity of grazing trace fossils *Skolithos* indicated possibly a firm, microbial mat-bound substrate. The relatively tense bioturbation of trace fossils *Planolites* is dominated by horizontal burrows, which could represent undermat mining behavior. Namely the trace producer of *Planolites* made tunnels underneath the microbial mat and probably fed on its decomposing lowermost zone. Two associated lifestyle and survival mode between microbial mat and metazoans after the end-Permian mass extinction was established. The evidenced for the presence of microbial mats and trace fossil together in the Middle Liujiagou Formation, and for metazoan lifestyle associated with such mat-bound lake floor, reveals that normal siliciclastic shallow lacustrine settings dominated by typical Proterozoic-style "matground" still existed aftermath of P-Tr mass extinction.

Keywords: Microbial mat Trace fossil Lifestyle end-Permian North China

Acknowledgments:
This study was by the National Natural Science Foundation of china (Nos. 41202071, 41472083).

Ichnoassemblages in Lacustrine Deposits of China

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The Mesozoic-Cenozoic lacustrine deposits of China are extensively exposed. Large and middle scale lacustrine basins are distributed in the north-east, north, north-west, the south-west and south-east of China. It is well known that these lacustrine basins are very important sources areas of the fossil-fuel and mineral resources in China. A lot of petroleum, natural gas and coal resources developed in the Song-liao Basin, North China Basin, Jiang-han Basin, Si-chuan Basin, Erdos Basin, Tarrim Basin and Qaidam Basin. Within the last 30 years, there have been great progress in lacustrine ichnological research in China, and 59 ichnogenera of trace fossils in lacustrine deposits are found in these basins, which consist of feeding, grazing, crawling, dwelling, resting traces and rhizoliths. Based on the composition, occurrence and distribution characteristics of the trace fossils in the lacustrine basins of China, 6 ichnoassemblages have been proposed as follows(Fig.1): (1) *Scoyenia—Skolithos* ichnoassemblage always developed in the periodically exposed extremely shallow lakeshore and interdistributary bay of lake delta plain under drought or semiarid climate conditions; (2) *Palaeophycus—Arenicolites* ichnoassemblage formed in the lakeshore to the upper part of shallow lake, corresponding to the lake delta plain to delta front; (3)*Planolites—Teichichnus* ichnoassemblage generated in the lower part of shallow lake, restricted lake bay or the distal front delta; (4) *Vagorichnus—Helminthopsis* ichnoassemblage developed in the deeper lacustrine (profundal) turbidite sedimentary environment; (5) *Mermoides—Neonereites* ichnoassemblage occurring in the quiet deep or deeper lacustrine sedimentary environment; (6) *Semirotundichnus—Chondrites* ichnoassemblage formed in the even deeper lacustrine sedimentary environment with lower oxygen content.

Keywords: Ichnofacies, Ichnoassemblage, Lacustrine Deposits, Mesozoic, Cenozoic

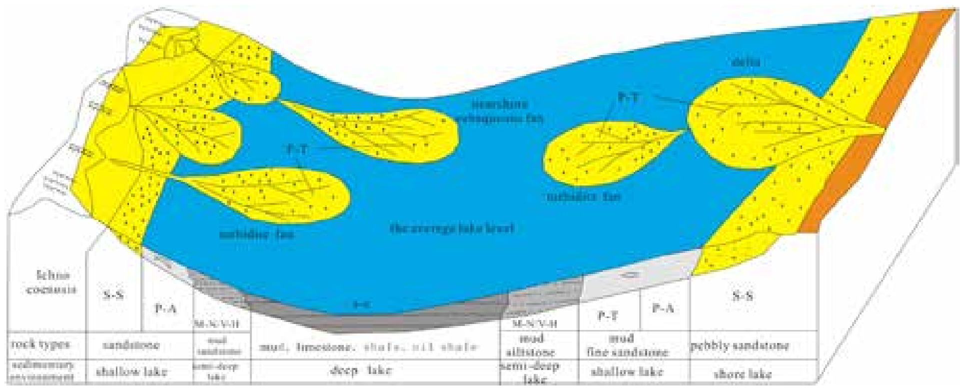

Fig.1. A model of the distribution of ichnoassemblages in the lacustrine deposits of China
S-S: *Scoyenia—Skolithos* ichnoassemblage;
P-A: *Palaeophycus—Arenicolites* ichnoassemblage;
P-T: *Planolites—Teichichnus* ichnoassemblage;
V-H: *Vagorichnus—Helminthopsis* ichnoassemblage;
M-N: *Mermoides—Neonereites* ichnoassemblage;
S-C: *Semirotundichnus—Chondrites* ichnoassemblage

Acknowledgments:
This paper was supported by the National Science Foundation of China (No. 41272117,41102002) and by The Basic and Frontiers Research Program of Henan province (162300410256).

Preferential Orientation of Arthropod-Generated *Diplocraterion Parallelum* and Their Statistical Reliability as Paleocurrent Indicators

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Arthropods from the early Maastrichtian (Late Cretaceous) of the Western Interior Seaway produced U-shaped *Diplocraterion parallelum* in mudstones along two closely spaced surfaces (10 cm apart), one of which corresponds to a maximum flooding surface. *D. parallelum* are widely distributed across both surfaces, and significant variations in burrow orientations are identified. Based on a comparison of paleocurrent indicators to burrow orientations, we demonstrate that *D. parallelum* are preferentially oriented parallel to the prevailing fair-weather wave propagation direction (wave-forced currents) that acted upon the colonized surfaces. Statistically, there is an apparent though weakly defined, minimum (4%) and maximum (34%) preferential orientation of burrows, attributed to population dynamics in high population density areas (minimum), and to the fact that wave-force currents represent only one of several factors controlling shrimp burrowing behavior (maximum). We propose that in the absence of paleocurrent data, *Diplocraterion* and other U-shaped burrows can be used to resolve flow directions, and that preferential burrow orientations ≥ 2% above random scatter are significant. However, it is noted that it is only possible to resolve 2-way flow directions (trajectories) from U-shaped burrows, as there is no way to resolve vector orientations.

Trace Fossils of the Lower and Middle Miocene Deep Marine Fan Deposits at the Süller-İsmailli-Fırnız-Kürtül Regions (NW Kahramanmaraş, S Turkey)

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The Lower-Middle Miocene turbiditic Karataş Formation crops out in the Süller-İsmailli-Fırnız-Kürtül regions. It contains trace fossils which have been recognized and determined for the first time in this study. Trace fossils occur in a sequence identified as a deep-sea fan deposits. Twenty-six ichnotaxa have been identified in the different part of the submarine fan. They include *Chondrites* isp., *Chondrites intricatus*, *Cosmorhaphe* isp., *Desmograpton* isp., *Halopoa annulata, Helminthoidichnites* isp., *Helminthorhaphe flexuosa, Helminthopsis* isp., *Ophiomorpha annulata, Ophiomorpha rudis, Ophiomorpha* isp., *Palaeophycus* isp., *Paleodictyon* isp., *Planolites* isp., *Protopaleodictyon submontanum, Scolicia plana, Scolicia prisca, ?Spirophycus bucornis, Thalassinoides* isp., *Urohelminthoida* isp., and *Urohelminthoda dertonensis*, which occur in the mid fan-distal of the mid fan *Cardioichnus* isp., *?Diplocraterion* isp., *Echinospira* isp., *Halopoa annulata, Ophiomorpha* isp., *Ophiomorpha annulata, Ophiomorpha rudis, Planolites* isp., *Thalassinoides* isp., and *Zoophycos* isp., helped to distinguish inner fan. The abundance and diversity of trace fossils found in the study area increase in the middle fan interchannel and channel margin deposits. In the outer fan and slope facies associations, the abundance and diversity of trace fossils are lower. Distribution and relative abundance of the trace fossils are compared with the interpretations of depositional environment and trace fossils associations were found to be related to the various parts of the deep sea fan.

Keywords: Trace fossils, deep marine fan deposits, Lower-Middle Miocene, NW Kahramanmaraş, Turkey.

Acknowledgments:
This study was by the National Natural Science Foundation of china (Nos. 41440016 ,41472083,41502106).

Biogenic Structures from Carbonate Storm Deposits of the Middle Cambrian Mantou Formation, Central China

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A large amounts of biogenic structures occur in the carbonates of the Mantou Formation(Cambrian Series 3), Dengfeng, western Henan,China. The microbially induced stromatolites are preserved in marlstone and display varied and laterally discontinuous small columns. The columns are approximately 4-7 cm high and 1 -2 cm in diameter, and have irregular laminations. The gaps among the columns are small and filled with 20% to 45% of marl, 10% to 35% of quartz grains, 6% to 10% of bioclasts and 6% ~ 9% of ooids. The columns mainly grew up on the erosional bases of storm or flat-pebble conglomerates.

The metazoan vertical burrows such as *Skolithos* and *Arenicolites* widely occur in oolitic limestones and display vertical or near-vertical distributions. They have clear lings and are passively filled with sparry crystalline calcites and a small amount of quartz grains and other rock clasts. The burrows cut down the ooidal sediments and various cross-beddings and are interrupted by irregular storm bases. The overall disturbance intensity in oolitic limestones is weak to medium. The amount of disturbance ranges from 5% to 30%, and the BI(Bioturbation Index) is usually between 1 and 3.The abundance and disturbance intensity increase gradually upward in the oolitic limestones.

The storm deposits consist of scoured bases, flat-pebble conglomerates, oolitic limestones containing various cross-beddings and vertical burrows, and marlstone containing stromatolites. The scoured bases and flat-pebble conglomerates considered to be generated by the contemporaneous tearing and crushing of seabed sediments by storm flows. The oolitic limestones represent gravity-differentiated deposition or storm deposition during storm attenuation. The marlstones were formed in normal weather after storm process.

The microbially induced stromatolites and metazoan vertical burrows were developed alternatively in storm deposits and separated by irregular storm bases. They are the different life records on totally different ecosystems. The alternate development of these two kinds of biogenic structures in the carbonates of study area means that both metazoa and microbes are the major components of shallow marine carbonates in Cambrian Period. The changes of environmental factors like storm processes in study area are the principal factors for the development of microbially induced structures or metazoan disturbed structures. This study will provide the basis for understanding the coevolution of microbe, metazoan and environments in the specially transitional period from Cambrian to early Ordovician before the “Ordovician Radiation.”

Keywords: Cambrian, carbonate, Mantou Formation, storm deposit, stromatolites, vertical burrows.

Acknowledgments:
This study was fund by the National Natural Science Foundation of china (No. 41472083).

A Historical Perspective of 34 Years of Ichnofabric Research, and a View to Future Possibilities

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The science of ichnology can act as a bridge that spans interesting gaps between the related fields of paleontology, biology, sedimentology and stratigraphy. Ichnofabric in particular represents the sedimentary record of biologic activity that may or may not be amenable to confident identification of recognizable ichnotaxa. Ichnofabric is what results from the dynamic processes of bioturbation, bioerosion and diagenesis, which create a distinctive signature of animal-sediment interrelationships that contributes significant insight for our interpretation of depositional and post-depositional conditions of the paleoenvironment and nature of the paleocommunity.

The ichnofabric approach grew out of intriguing questions that were posed about the sedimentologic and sedimentary petrologic effects of organism activity on sediment texture, composition and structure. The ichnofabric concept originated in the early 1980s, and ichnofabric studies quickly diverged along several different azimuths. These included (among other things) attempts to quantify intensity of bioturbation, to reconstruct tiered infaunal communities, to recognize and correlate recurrent ichnofabrics within stratigraphic and paleogeographic contexts, and so forth. Following an initial seminal symposium on ichnofabrics and ichnofacies at the International Sedimentologic Congress in Nottingham, England, in 1990, the biannual International Ichnofabric Workshops (IIW) were launched. The first IIW was held in Norway, and the success and enthusiasm that grew out of that first workshop spawned subsequent biannual workshops in the United States, Denmark, Bahamas, England, Venezuela, Switzerland, New Zealand, Canada, China, Spain, Turkey, Japan and Taiwan. Ichnofabric research now is occurring in all corners of the globe by paleontologists and sedimentologists with a wide spectrum of orientations.

Future directions in ichnofabric research are limited only by the imagination of us workers in the field. Prospects for fruitful advances in our recognition and characterization of ichnofabrics continue to expand as new visualization technologies become available. The importance of contributions rising from ichnofabric investigations to major topics of broad scope in the Earth sciences, such as global climate change, mass extinction episodes, evolution of sedimentary basins, and exploration for energy resources, are becoming more and more apparent as more and more workers become involved in ichnofabric research.

Hillichnus Ichnofabric in the Paleogene of California (USA): A Complex Ichnofabric Produced by a Monoichnospecific Trace Fossil Association

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Hillichnus lobosensis, Bromley, Uchman, Gregory & Martin, 2003, is a complex bivalve trace fossil that consists of several different endichnial components that were produced in the sediment simultaneously by different body parts (siphons, foot, shell, etc.) of a single individual. The tracemaker of *Hillichnus* was a deep-burrowing siphonate bivalve, most likely a tellinacean, such as *Macoma* or *Tellina*. The feeding, resting and locomotion activities of the single burrowing bivalve with different body parts performing different activities in the sediment create a complex ichnofabric, despite comprising a single continuous ichnofossil.

The type ichnospecies of *Hillichnus*, *H. lobosensis*, is known from several occurrences in California, with a stratigraphic range from Paleocene to Middle Eocene and a paleoenvironmental range from deep-water turbidite to shallow-marine nearshore facies. Another related ichnospecies, *H. agrioensis*, is known from shallow-marine deposits of Lower Cretaceus age in Argentina. Also, complex ichnofabrics that may represent *Hillichnus* have been noticed in drill cores in the North Sea.

Hillichnus has been considered to be a fairly rare trace fossil, but we believe that circumstance is due more to its lack of recognition on account of its morphological complexity rather than to its actual rarity in the sedimentary record. Infaunal deposit-feeding bivalves, such as *Macoma* and *Tellina*, are quite common and widespread in the body fossil record. Thus, it is reasonable to assume that their burrows and resultant ichnofabrics likewise should be common and widespread in the trace fossil record.

Poster Presentation

Possible Occurrence of Ambrosia Beetle Borings in the Cretaceous Twin Mountains Formation, Bluffdale, Texas, USA

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Auburn University

In numerous wood borings have been discovered within logs found in a sandstone of the Lower Cretaceous Twin Mountains Formation exposed in Erath County, Texas, USA. These borings are unique with respect to the discoloration of the wood immediately adjacent to the borings. As previously hypothesized, this feature may represent a taphonomic signature of symbiotic fungi associated with ambrosia beetles (Subfamily Scolytinae). To test this, thin sections of borings were made to evaluate the origin of discoloration, search for preserved rhizoids, sporangium, or hyphae, and look for preserved ambrosia beetle fecal pellets. Results will shed further light on the evolution of this symbiotic relationship.

Ichnofabrics of *Phycosiphon* in Upper Miocene volcaniclastic rocks of prodelta deposits in the Colombian Pacific: paleoecological implications

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The Colombian Pacific area is formed by two sedimentary basins: Tumaco and Chocó basins. Tumaco is a forearc basin associated with the Colombian Pacific subduction zone. In a sequence drilling by the ANH-Tumaco-1-ST-P well in this basin, was documented the *Cruziana* ichnofacies, and according to ichnological and sedimentological criteria a platform-prodelta environment was interpreted. In this well were recognized some levels with volcanic material, massive and occasionally normal graded, characterized by ichnofabrics with very abundant, near exclusive, *Phycosiphon*. *Phycosiphon* occur as patches or as densely packed burrows, forming a meandering complex into the volcanic intervals. The burrows are horizontal and curved, with a halo of light color and darker interior filling, with thickness up to 0.4 cm and length shorter than 1 cm (Figure 1). The volcanic levels were classified as tuffaceous sandstones, composed by quartz, plagioclase, biotite, hornblende and eventually pyroxene and feldspat, embedded in a chlorite-smectite altered volcanic glass matrix. Under scanning electron Microscope (SEM), volcanic scoria, broken glass and glass crusts incrusted into the crystals can be observed.

Phycosiphon has been interpreted as produced by deposit feeders, usually showing an opportunistic strategy, frequently associated with food availability and oxygen conditions, and being considered as a pascichnia/fodinichnia structure, and sensitive to variations in grain size. The producer is considered to selectively ingest the clay material from the sediment leaving halos of sandy grains and depositing a continuous fecal chain rich in clay. The direct relation between *Phycosiphon* and tuffaceous sandstones can be interpreted as reflecting that the volcanic sediments arrived loaded with high contents of nutrients to the basin, as well as showing unfavourable paleoecological conditions inside the sediment for other tracemarkers.

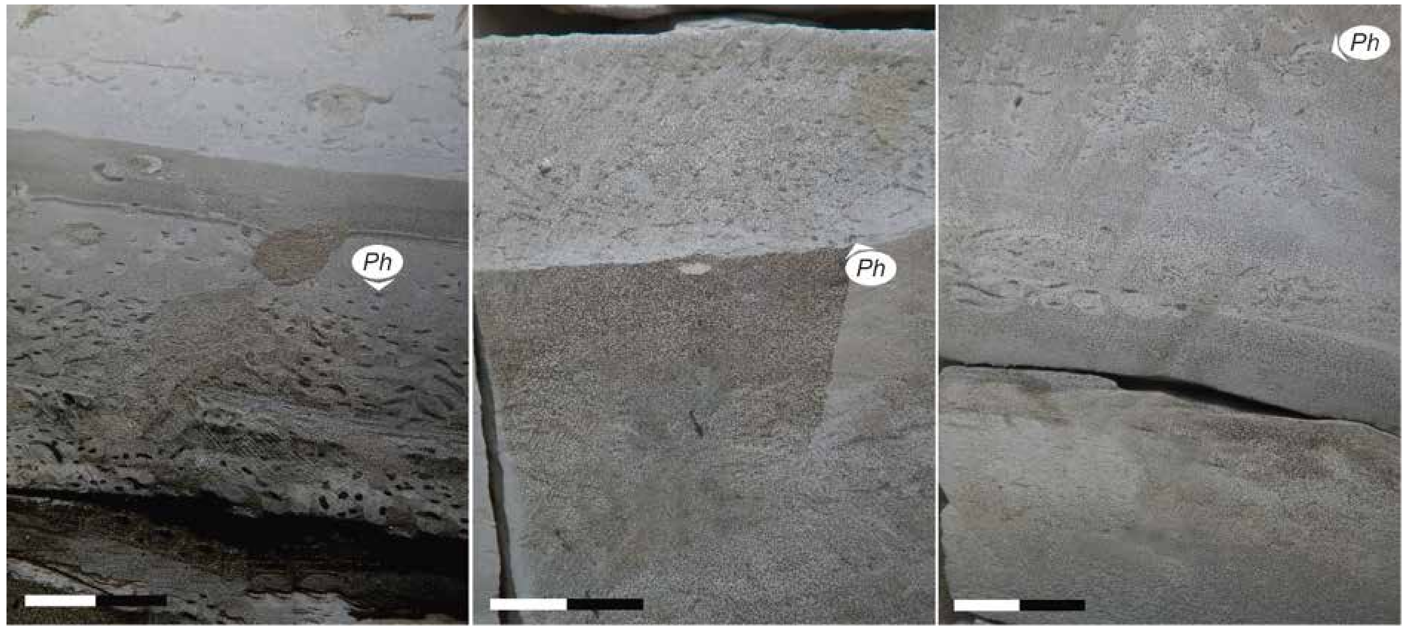

Figure 1. *Phycosiphon* in volcanic levels of the ANH-Tumaco-1-ST-P well (scale bar: 2 cm).

Paleo-Environments of Late Pliocene to Early Pleistocene Foreland-Basin Deposits in the Western Foothills of South-Central Taiwan

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Lithofacies and paleo-environmental analyses of the Pliocene-Pleistocene deposits of Taiwan provide a framework to understand the stratigraphic development of foreland basin to the west of the orogenic belt. In this study, we performed lithofacies analyses and biostratigraphic studies on calcareous nannofossils in two areas in south-central Taiwan, the Jhuoshuei River and the Hushan Reservoir, respectively. The studied lithostratigraphic units are the Chinshui Shale, the Cholan Formation, and the Toukoshan Formation, in an ascending order, with a total stratigraphic thickness more than 3500 m in central Taiwan. Sixteen lithofacies and four lithofacies associations are identified, pertaining to tide-dominated deltaic systems bordering a shallow marine setting in the foreland basin. A few wide-spread layers of thickly-bedded sandstones featuring ball-and-pillow structures are interpreted as resulting from earthquake shaking (i.e., seismites). In addition, the vertical facies change shows a coarsening and shallowing-upward succession, indicating the gradually filling up of the foreland basin by sediment progradation. The progradation is interpreted to result from westward migrating orogenic belt and an increase in sediment supply. The top 2000-m thick foreland succession (i.e., the uppermost part of the Cholan Formation, and the Toukoshan Formation) is dominantly fluvial deposits with occasional intercalations of shoreface sediments, indicating an extremely rapid and balanced rate of basin subsidence and sediment supply for the past ~1.5 Ma. Vertebrate fossils of deer and elephants are identified in the upper Cholan Formation deposited in coastal to fluvial settings.

Keywords: Pliocene-Pleistocene Epoch, lithofacies, foreland basin, Taiwan

Ichnofabric Analysis of the Early Miocene Deep Marine Sediments of Fore Arc Basin, Andaman Subduction zone, Andaman and Nicobar Islands, Northeast Indin Ocean

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The Andaman and Nicobar are group of Island situated in Bay of Bengal. It represents central part of the 5000 km long Burma–Sunda–Java subduction complex. The rocks of the Andaman and Nicobar island comprises of Ophiolites, Flysch sediments along with deep marine sediments that were scrapped off the subducting Indian plate forming an accretionary prism on the outer arc ridge of the subduction zone. Stratigraphically, the Andaman and Nicobar Islands exposes sediments ranging in age from Jurassic to Recent. The stratigraphic sequence starts with metasedimentaries and Ophiolite suites followed by turbidite sequences along with foraminiferal and nanoplankton ooze. Previous published literature on these deposits based on microfossils (including Foraminifera and Nanaoplankton) estimated water depth of between 2000 to 3000 meters for the deposition of the chalk. The present study of trace fossils and ichnofabric are described from these thick bedded Chalk belonging to Early to Middle Miocene and known as Inglis Formation. These chalks are highly to moderately bioturbated and comprises of several weak discontinuity surfaces in the form of ferugenioused layers. The studied section shows recurring occurrence of ichnospecies belonging to *Astereosoma, Chondrites, Cladichnus Ophiomorpha, Palaeophycus, Planolites, Saerichnites, Taenidium, Thalassinoides* and *Zoophycos*. It shows four prominent ichnoassociaiton (a) *Thalassinoides-Chondrites* Association (b) *Zoophycos* Association (c) *Zoophycos-Chondrites* Association (d) *Astereosoma* Association. Ichnofabric data on tiering profile reveals that the middle tier *Astereosoma* and *Zoophycos* although first to colonize the sediment, were quiet abundant in the units with discontinuity surfaces, while these were cross-cut by deep tier *Chondrites* and *Palaeophycus* which were among the last to colonize the sediment. Additionally it also indicates control of various factors like organic matter, pore water and bottom water oxygenation as the controlling factor. Thus the ichnofabric analysis of the Early Miocene deep marine sediments of fore arc setting from Andaman and Nicobar Island gives first-hand information regarding poorly known sediments belonging to abyssal plain of pre-bengal fan stage during subduction of Indian plate.

Ichnological Features of the Eocene-Oligocene Transition Sediments of Manipur-Nagaland, Northeast India

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The Eocene-Oligocene Transition (EOT) sediments of Manipur and Nagaland, Northeast India (Fig. 1), contain a relatively diverse trace fossils comprising of 38 ichnospecies belonging to 34 ichnogenera which can be grouped into mud dwelling pre-depositional structures, typical of fairly stable environmental conditions and sand dwelling post-depositional structures associated with turbidites and higher hydrodynamic environment where opportunistic dwellers exist. Besides there are some typical traces which are yet to assign proper ichnologic status. The ichnospecies belong to the *Skolithos, Skolithos-Cruziana, Cruziana, Glossifungites, Zoophycos* and *Nereites* ichnofacies, which are linked to three important lithofacies, i.e. dark grey shale facies, silty shale facies and sandstone facies (Fig. 2). They implied depositional environment range from sublittoral to offshore settings, from proximal to distal delta fan regime, with relatively nutrient-rich, medium- to fine-grained sediments. The *Glossifungites* ichnofacies marks intertidal and shallow marine settings that immediately followed sea level lowstands. The alternate occurrence of mud dominated and sand dominated sediments also suggest a basin that experienced highly pulsating crustal stretching during the EOT times (Soibam et al., 2013), which is also evident from the sequence stratigraphic successions in the Thongjaorok section of Manipur and the Kiruphema section of Nagaland, that show general upward coarsening, typical of a prograding delta or shoreline. The report of *Chiloguembelina cubensis* from the Disang-Barail Transition, Leimaram section, suggests the Priabonian-Rupelian Transition for the EOT (approximately 34Ma; Brown et al., 2016). Petrographic analyses of the host and infill sediments of traces indicate rapidly eroding granitic and metamorphic terrains in a cold climate.

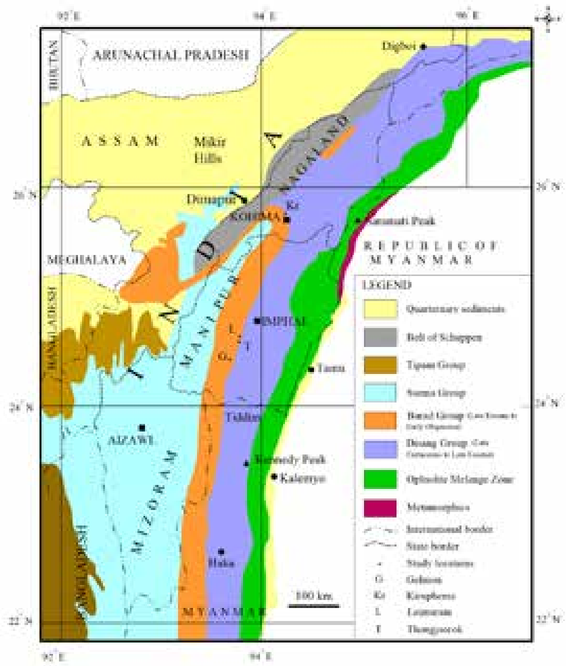

Fig. 1. Geological map of Northeast India showing the Disang-Barail Transition.

Fig. 2. Intercalations of dark grey shale facies, silty shale facies and sandstone facies in Gelmon section, Manipur.

Keywords: Eocene, Oligocene, fan delta, trace fossils, Manipur-Nagaland

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Skolithos linearis Haldeman, 1840: Investigations at the Type Locality, Chickies Rock, Pennsylvania

Dirk Knaust, H. Allen Curran and Roger D. K. Thomas

Skolithos is one of the most commonly reported trace fossils, supposed to occur globally in Cambrian to Holocene strata and from freshwater to deep sea palaeoenvironments. As one of the oldest valid ichnotaxa, it presents challenges with respect to its diagnosis and description. According to current understanding, *Skolithos* is a simple, sub-vertical, cylindrical tube with or without lining and passive fill, but it remains poorly defined because of its weak diagnostic characteristics. As a result, the ichnogenus *Skolithos* has become a "wastebasket", embracing many ichnospecies, likely produced by a myriad of organisms belonging to different phyla, including even plants. Consequently, *Skolithos* has lost its usefulness as a palaeoenvironmental indicator because of its very general definition.

For these reasons alone, revision of the ichnogenus *Skolithos* is long overdue but this has been hampered by the lack of a holotype, available lectotype, or appropriate neotype. We are attempting to achieve a better understanding of the type ichnospecies, *Skolithos linearis*, by conducting investigations at its type locality, Chickies Rock, just above Columbia, on the Susquehanna River, Pennsylvania, USA. Here, *Skolithos* is prolific in medium- to coarse-grained quartzite with shale partings, constituting the Chickies Formation of Early Cambrian age. Stratigraphic control is limited. The Chickies Formation overlies either more immature clastics, locally the Hellam Conglomerate, or crystalline rocks generated by the Grenville Orogeny. It is overlain by the Harpers Phyllite that has so far yielded no fossils, and above that the Antietam Formation, in the uppermost part of which *Olenellus* Zone fossils have been recorded.

The goals of this project are: (1) to provide a succinct description of the type locality; (2) to designate and describe a neotype; and (3) to suggest a way forward for revision of the ichnogenus *Skolithos*.

Investigation of the Teeth Micro-Structure of Ancient Animals

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Previous paleontological studies on for the morphology of fossil teeth have focused on feeding habits and, identification for phylogenetic purposes. Our recent study investigates the teeth of two genera of Mosasauridae from Morocco, *Mosasaurus* and *Globidens*, which were living at the end of the Cretaceous period. We bought two teeth from the Hansa. The teeth were analyzed by nanno-penetrating high-resolution X-ray microscopy techniques.

In the past, *Globidens* was believed to be durophagous, feeding primarily on hard-shelled organisms, while *Mosasaurus*, on the other hand, preying on fish, turtles, ammonites, and possibly smaller Mosasaurs. Our study confirms that there are two layers, enamel and dentin, in the teeth of *Globidens*, and we also find enamel tufts, which help releasing stress from the dentofacial side. In contrast, the teeth of the *Mosasaurus* genus has three layers, enamel, dentin and coronal dentin. We do not yet know the relationship between Tomes' granular layer and the feeding habits of the *Mosasaurus*, but we hypothesize that it helped to enhance the strength of the Mosasaurs teeth on the buccal side. We also construct the tomography images of the dentinal tubule of the *Globidens* and the coronal dentin of the *Mosasaurs* by means of the X-ray. It provides comparison with other species in the future researches.

The results of our study demonstrate that even within the same family of organisms, different genera have different eating habits that may exert strong influence on the development of the external and internal tooth microstructure.

Keywords: *Mosasaurus*, *Globidens*, teeth, enamel tuff, coronal dentin

Acknowledgments:
This study was by the National Natural Science Foundation of china (Nos. 41440016 ,41472083,41502106).

Evolution of the trace fossil *Zoophycos*

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Recent studies have shown a strong connection between the evolution of morphology and habitat of the trace fossil *Zoophycos* and major changes in the marine ecosystem over the Phanerozoic. However, these studies do not provide a viable explanation for occurrence of *Zoophycos* that are clearly deposit feeding structures, while other *Zoophycos* convincingly can be shown to not be deposit feeders, but rather represent cache, gardening, or refuse-dump behaviors. Here it is proposed that *Zoophycos*-producing behaviors evolved from shallow and simple strip-mining deposit feeding in shallow environments in the earliest Paleozoic to a cache and gardening behavior on continental slopes at the end of the Mesozoic. The strip-mining program developed in the Cambrian, before the rise of bulldozing deposit feeders, and became an essential preadaptation for colonizing deeper environments when increased competition from deep-burrowing deposit feeders and predators pushed the *Zoophycos* producers into deeper environments. Moreover, the shifts to deeper habitats and more complex morphologies correspond with increased food flux to the deep sea as a result of the evolution of new lineages of planktonic organisms in the Mesozoic. In this context, the *Zoophycos* producers' ability to maintain complex structures and store food over long time periods deep in the sediment was essential in their colonization of an ecological niche with seasonally pulsed food supply. Thus, the *Zoophycos* morphological evolution reflects both the gradual shift from a deposit feeder to a cache behavior and an adaptation to increasingly deeper habitats.

Trace Fossil Evidence from the Cambro-Ordovician Karkur Talih Formation, UmKaddada Area, Western Sudan

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The ichnology of the Karkur Talih Formation of Cambro-Ordovician age, Um Kaddada Area, Western Sudan is here reported. The Cambro-Ordovician stratigraphy is composed of continental and marine facies. Ten ichnogenera have been identified in this formation: *Scoyenia*, *Treptichnus*, *Petroxestes*, *Planolites*, *Helminthopsis*, *Taenidium*, *Tomaculum*, *Thalassinoides*, *Rusophycus* and *Skolithos*. The regressive nearshore to shoreface sandstone facies are characterized by occurrences of high abundant *Skolithos* ichnofacies and *Scoyenia* trails (continental). The transgressive intervals are dominated by horizontal burrows and trails characteristic of the *Treptichnus*, *Planolites*, *Helminthopsis*, *Rusophycus*, *Taenidium*, *Tomaculum*, *Thalassinoides* and *Petroxestes* ichnofacies.

Keywords: Cambro-Ordovician, Ichnofacies, Karkur Talih Formation, Siliciclastic rocks, Sudan, Trace fossils

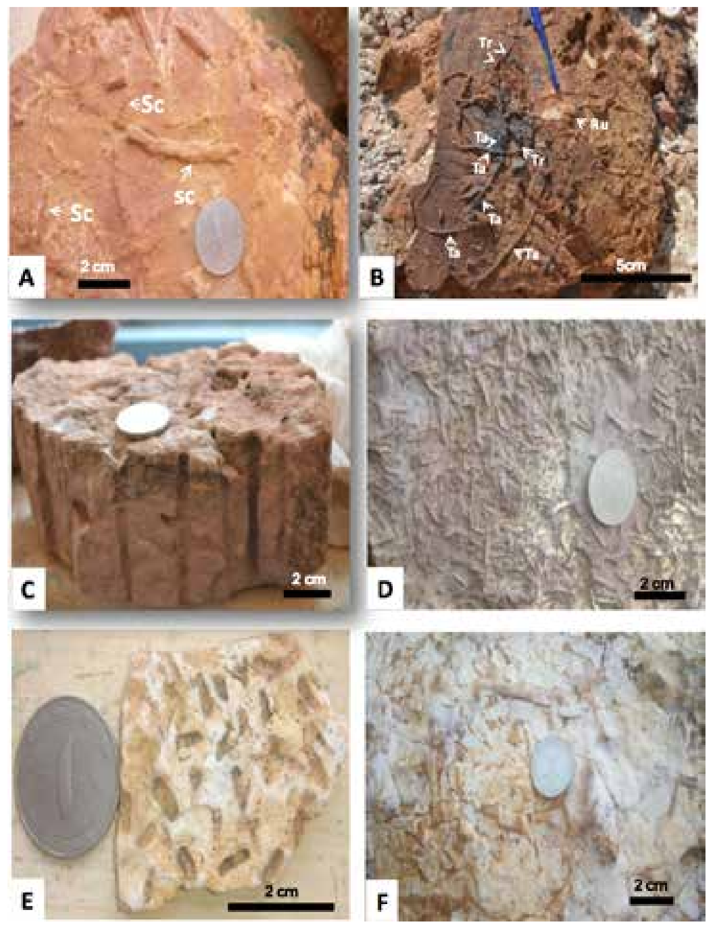

Fig. (1): Trace fossils from the Karkur Talih Formation of Cambro-Ordovician age, Um Kaddada Area, Western Sudan, (A) *Scoyenia* (Sc), (B) *Rusophycus* (Rs), *Treptichnus* (Tr) and *Taenidium* (Ta), (C) *Skolithos*, (D) *Helminthopsis*, (E) *Petroxestes*, (F) *Planolites*.

Analyzing the Peculiar Unknown Trace Fossil in the Taliao Formation, Taiwan

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In north-eastern Taiwan, multifarious species of fossils are widely distributed over the Miocene strata. Among them, the early Miocene Taliao Formation (20-22Ma) which is encased between the Mushan and the Shitih Formations represents a shallow, nearshore marine environment influenced by storms according to the primary sedimentary structures and trace fossils such as *Schaubcylindrichnus, Ophiomorpha, Diplocraterion*. In certain sandstone beds of the Taliao Formation, abnormal funnel-like burrows were observed. From bird's eye view, the burrow situates in the center of the knoll which is made up of well-cemented sandstone (Figure 1). Observing from the side, a tube that sizes 2-3cm in diameter extends for some distance before gradually bending to horizontal presents a J-shaped burrow system. Also, the lateral extension of the J-shaped burrow is about 70-80 centimeters. The size of the tube shrinks slightly downward from the opening and there are some feather-like (or funnel-like) structures around the upper vertical part of the tube (burrow head) (Figure 2). After doing some cutting to the burrow head, we found some thinner tubes scattering around the main burrow (Figure 3) and some of them even cut through each other. Also, the results from CT scanning that there is at least one branch support the surmise that these tubes may be different generations of the burrow system. For the next step, CT scanning, cutting and thin section will be continue processing in order to construct the 3D structure and figure out the potential explanation of what kind of animals' behavior contribute to this burrow system.

Figure 1. Bird's eye view, the burrow situates in the center of the knoll.

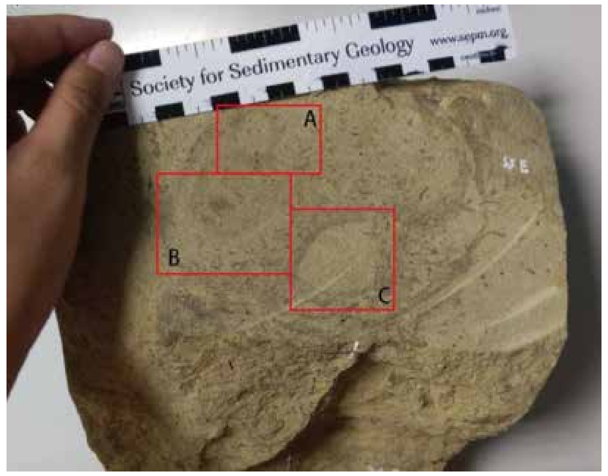

Figure 3. Horizontal cross cutting.
(A) Two thinner tubes connect to each other that may indicate different generation of the burrow systems. (B) Blurry tube-impression (C) Main tube.

Figure 2. Burrow head, which consist of a main tube and surrounding funnel-like structure.

Ichnological Data Supporting Depositional Continuity After the Chicxulub Impact: the Paleocene Record at the IODP-ICDP Expedition 364

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Precise interpretation of the K/Pg boundary impact requires expanded and continuous sections characterized by the absence of hiatuses, such as at distal sections like Agost and Caravaca outcropping in Spain [1, 2]. From April to May 2016, the IODP and ICDP drilled the peak ring of the Chicxulub impact structure offshore during Expedition 364 at Site M0077A (21.45° N, 89.95° W). Approximately 110 m of post-impact, hemipelagic and pelagic Paleogene sediments were recovered, ranging from middle Eocene (Ypresian) to basal Paleocene (Danian). Paleocene materials include Unit 1G and Unit 1F above. The base of Unit 1F is a sharp contact at the base of the greenish claystone at 616.58 mbsf, below the top of core 40R-1 [3]. The lower Paleocene is complete, ranging from Zone 3b to Pα, and below Zone Pα is a 40-cm brown siltstone corresponding to Unit 1G, that can reflect the probable continuity of sedimentation between Unit 1G and Unit 1F [3]. However, for a high-resolution analysis of the K/Pg impact event, information below biostratigraphic resolution (intrasubzone level) is fundamental.

Ichnological data are an informative tool to improve biostratigraphic characterization of the K/Pg boundary, revealing, for example, the redistribution of microfossils [4, 5], or the existence of missing material in biostratigraphical continuous sections [6].

Here, a detailed ichnofabric analysis has been focused on the interval from the uppermost part of Unit 1G to the lowermost part of Unit 1F, showing the presence of isolated traces (probably *Planolites*) in the uppermost part of Unit 1G, and comparatively more frequent structures (*Planolites* and *Chondrites*) in the lowermost Unit 1F. Two ichnological features are especially informative: the flattening of the structures and the infilling material. Discrete traces located in the uppermost part of the Unit 1G show infilling material with different color than the host, and a flattened shape. In some cases color is similar to that of the topmost Unit 1G (light brown), but in other similar to that of the lowermost Unit 1F (light bluish grey), allowing interpretation that traces were produced during deposition of the Unit 1G and 1F, respectively. Deformation is registered in both cases, and can be associated with bioturbation in softgrounds, unconsolidated sediments. After that, traces were flattened during compaction. This reflects that macrobenthic colonization occurred continuously through the studied interval, without any break in sedimentation that could determinate any early lithification (stiff/firmgrounds), supporting the absence of hiatuses below biostratigraphic resolution.

The Chicxulub drilling expedition was funded by the International Ocean Discovery Program as Expedition 364 with co-funding from the International Continental scientific Drilling Program. The European Consortium for Ocean Research Drilling (ECORD) implemented Expedition 364, with contributions and logistical support from the Yucatán state government and Universidad Autónoma de México (UNAM).

Expedition 364 Participating Scientists: J. V. Morgan (UK), S. Gulick (US), E. Chenot (France), G. Christeson (US), P. Claeys (Belgium), C. Cockell (UK), M. J. L. Coolen (Australia), L. Ferrière (Austria), C. Gebhardt (Germany), K. Goto (Japan), H. Jones (US), D. A. Kring (US), J. Lofi (France), X. Long (China), C. Lowery (US), C. Mellett (UK), R. Ocampo-Torres (France), L. Perez-Cruz (Mexico), A. Pickersgill (UK), M. Poelchau (Germany), A. Rae (UK), C. Rasmussen (US), M. Rebolledo-Vieyra (Mexico), U. Riller (Germany), H. Sato (Japan), J. Smit (Netherlands), S. Tikoo-Schantz (US), N. Tomioka (Japan), M. Whalen (US), A. Wittmann (US), J. Urrutia-Fucugauchi (Mexico), K. E. Yamaguchi (Japan), and W. Zylberman (France).

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Ichnofabric Analysis of Heinrich Layer 1 at IODP Site U1308: Bioturbational Disturbance and Paleoenvironmental Conditions

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Heinrich events (*sensu stricto*) are climate events produced by a massive discharge of the Laurentide Ice Sheet through Hudson Strait. Heinrich events occurred during some stadials, which were part of millennial-scale Dansgaard-Oeschger oscillations during the last glaciation. Heinrich layers, the physical manifestation of Heinrich events, are identified in North Atlantic sediment cores by coarse layers that are almost devoid of foraminifera and contain large amounts of ice-rafted detritus, which is rich in detrital carbonate. Recently, a detailed analysis of the structure of Heinrich Stadial 1 (HS1) was conducted at IODP Site U1308 (49°52.6661′N; 24°14.2875′W), located 2800 km from the mouth of Hudson Strait that represents a distal location for deposition by icebergs originating from the Labrador Sea. Heinrich layers are relatively thin in distal deposits and, consequently, bioturbation can easily blur the signal or obliterate internal structure of the event. Thus, a high-resolution ichnofabric analysis of the section involving the HS1 reveals essential to evaluate disturbance by bioturbation, as well to approach the incidence of the associated paleoenvironmental changes during the event to the macrobenthic tracemaker community.

Ichnofabric analysis was conducted in Holes U1308A, characterized by a distinct double peak in detrital carbonate, and U1308B, showing a broad single peak, using digital image analysis. Trace fossil assemblage consists of *Chondrites*, *Mycellia/Trichichnus*, *Planolites, Phycosiphon*, and *Thalassinoides*; Core U1308B presents more abundant large traces than U1308A, being *Thalassinoides* dominant in U1308B, and *Planolites* in U1385A. Ichnofabric analysis allows differentiation of three intervals from bottom to top of the studied section of the cores. Interval A, corresponding to the lower part, is characterized by the abundance of small traces in both cores, with *Chondrites* as the dominant structure. The ichnofabric looks like a mottled background on which discrete traces determine a Bioturbation Index around 2. Interval B, corresponding to the middle part, is mainly characterized by the presence of large structures (*Planolites* and *Thalassinoides*). In this Interval B, a significant difference between both cores is the presence of 2 intervals without traces in U1385A, while in U1308B always large traces (even sometimes scarce) were observed. This interval is, in part, characterized by a lower BI. Interval C, corresponding to the upper part, is also characterized by small traces, being *Phycosiphon* in U1308A and *Mycellia*/*Trichichnus* in U1308B the dominant ichnotaxa. In general BI is higher than that recognized in Interval B, but decreasing upward in the interval C.

According to the ichnofabric analysis, the distinct double peak in Hole U1308A can be interpreted as primary in origin, and not caused by upward dispersal of detrital carbonate from the lower peak by bioturbation. However, the absence of a double peak in Hole U1308B, can be attributed to bioturbational disturbance that has mixed the two peaks in this hole. This information must be considered to avoid misinterpretations when history for Heinrich Stadial 1, and the associated paleoenvironmental conditions, want to be approached.

Outcrop and core integrative ichnofabric analysis: Paleoenvironmental conditions of Miocene sediments from Lepe, Huelva (SW Spain)

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Ichnofabric analysis has been conducted in Miocene sediments from Lepe (Huelva, SW Spain) based on integrative outcrop and core research, in order to improve interpretations of depositional and paleoenvironmental conditions, with special attention to the sequence stratigraphy framework.

Studied sediments belong to the lithological unit 2 (informally known as “Lepe White Silts”) from the area of Cabezo de La Zarcilla, mainly characterized by siliciclastic facies. Outcrop research was carried based on stratigraphic and ichnological features, allowing the differentiation of seven intervals, consisting of two ichnofabrics. *Ophiomorpha-Thalassinoides-Spongeliomorpha* ichnofabric, identified for intervals 1, 2, 6, 7 and 8, shows a moderate to high trace fossil diversity, and a low Bioturbation Index (0-2), and occasionally moderate (3). *Palaeophycus-Planolites-Phycosiphon* ichnofabric characterizes intervals 3, 4 and 5, showing a trace fossil diversity slightly lower, and a degree of bioturbation low to moderate (BI=0-3). On the other hand, core analysis, mainly based on lithological features, including ferruginous material and grain size, and ichnological data as mottled background, ichnotaxa, and Bioturbation Index, allows the characterization of fourteen ichnofabrics. Variations in appearance, distribution, and relative abundance between ichnofabrics along the core are significant.

In general, according to both ichnofabrics differentiated in outcrop, and the fourteen recognized in the core, a continuous siliciclastic deposition with punctual variations in the sedimentation rate can be interpreted that, associated with favorable paleoenvironmental parameters such as aerobic conditions and nutrient availability, allows the maintenance of a well-developed and diverse macroinvertebrate trace maker community. Softgrounds are dominant, but punctually loosegrounds and even firmgrounds could be developed.

Ichnofabric comparison between the entire outcrop section and the correlated core interval (the upper 13.5 m), corresponding to the uppermost Tortonian-lowermost Messinian interval, reveals the presence of long- and short-scale patterns in the ichnofabric distribution, that can be interpreted according to the sequence stratigraphy context. Long-scale patterns in the distribution of ichnofabrics from outcrop and core suggest the last phases of a transgressive system tract (intervals 1 and 2), with a “maximum flooding zone” at the end (mainly intervals 3 to 5), and then the highstand normal regression (intervals 6 to 8). High-frequency, short-scale, repetitive patterns in ichnofabrics from core, mainly between ichnofabrics 6 and 8 (below) and 9 (above), may be related to “local flooding surfaces”, subdividing the “maximum flooding zone” into parasequences.

Improving Ichnofabric Analysis in Cores: Computed Tomography Images and High Resolution Digital Treatment

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Ichnological analysis of well cores has grown significantly in the second half of the twentieth century, especially in those cases where it has been applied to deep-sea drilled cores obtained during Ocean Drilling Program (ODP), Deep Sea Drilling Project (DSDP) and Integrated Ocean Drilling Program or International Ocean Discovery Program (IODP) expeditions, being a very useful tool to obtain information from the subsurface material. However, ichnological analysis of cores presents important disadvantages, including the limited size, restricted surface (narrowness), the almost exclusive availability of two-dimensional core slabs perpendicular or oblique to bedding, and the absence of 3D information. Usually, when working with well cores only 2D, individual slabbed sections, are available, in most of cases that corresponding to the central part of the core, having a very short, few centimeters of lateral extent. This is the only information for ichnofabric characterization, meaning that a partial, limited, image of the core is obtained, that difficult recognition of some of the ichnofabric attributes, as trace-fossil identification, cross-cutting relationships, or bioturbation abundance. All of this could determine misinterpretations if short-distance lateral changes in the ichnofabric attributes are significant.

To improve ichnofabric characterization in cores, and then interpretations, a new method is being developed based on the application of 3D high-resolution digital image treatment to computed tomography images. The method evaluates the possible existence of important short-distance lateral changes in ichnofabric features, based on the study of close selected images belonging to several sections from the same interval of the core. Averages of the obtained data improve significantly the resolution and allow a more precise and objective characterization of ichnofabrics.

The presented methodology has been applied in the gravity core SEL08-02 (44.01ºN; 8.98ºW; 1127 m water depth), recovered during A'SELVA-08 (2008) cruise on board of the RV Sarmiento de Gamboa in A Selva, NW of the Iberian Peninsula. The A Selva middle slope is strongly influenced by the Mediterranean Outflow Water (MOW), being contourites one of the registered sediments. Core SEL08-02 has a total length of 165 cm, mainly consisting of sandy mud and muddy sand sediment poorly sorted. Two cases have been studied corresponding to perpendicular sections from the same interval of 4.95 cm long from 24-29 cm of the core, and three selected slice images from CT conducted on the core have been analyzed in any of the sections. Short-distance lateral changes in ichnofabric attributes have been observed at a distance of 1.5 and 2.5 cm, affecting trace fossil composition, cross-cutting relationships, and especially, percentage of bioturbation with variations in the ichnofabric index between 3 and 4. According to this, and more objective, average percentage of bioturbation considering the 3 images has been calculated, corresponding to an ii of 3.

The applied methodology provides a new perspective of the ichnofabric analysis in cores, improving information obtained by a unique image of the core section. This allows a more objective ichnofabric characterization, that benefits the application of ichnofabric approach to paleoecology, sedimentary basin analysis or reservoir characterization.

Ophiomorpha Characterization: Case Study from Samarinda Area

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Palaran area is includes Balikpapan Formation, characterized by alternating quartz sandstone- mudstone and intercalated by limestone and coal. the depositional environment is from litoral to shallow marine. Outcrop well exposed at road cutting and we used measuring section to collecting data. One of ichnofossil has founded is *Ophiomorpha nodosa*. On the field, *Ophiomorpha* associated with estuary sandstone, characterized by subvertical orientation, 5 – 30 cm of length, and coarse pelleted burrow lining.

Based on thin section observation, burrow fill of *Ophimorpha* consists of fine – very fine material and presence of pore, dissolution of matrix and grain. The grain are quartz, feldspar, chert, and clay material. Burrow fill shows the backfill, stratification between fine sand and very fine sand to silt material The contact between burrow fill with burrow lining has show orientation of grain, more compact from the other, inferred about how to organism adaptation and survive.

The Frame of Objective Morphological Criteria of Trace Fossil *Ophiomorpha* isp. in Nangang Formation, Northeast Coast of Taiwan

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The trace fossil *Ophiomorpha* isp. is commonly used as a paleoenvironment indicator in offshore mudstone to upper-shoreface sandstone environment. Each ichnospecies of *Ophiomorpha* is believed to be restricted to a certain range of environments. However, the definition of each ichnospecies of *Ophiomorpha* seldom contains the morphological difference. The morphological criteria used to distinguish between different species of the trace fossil *Ophiomorpha* still remain almost unchanged. The Miocene Nangang Formation on the northeast coast of Taiwan provides clear outcrops with abundant *Ophiomorpha* isp and other tubular lined ichnofossils, allowing different types to be observed and measured. Through the field work in Nangang Formation, more than 300 specimens of lined, tubular trace fossils have been analyzed and their representative diameter, size of junctions, the distance between junctions, and branching angles have been measured.

This research attempts to build objective criteria to distinguish among the different characteristic of *Ophiomorpha*, and then clarify the connection between morphological differences, ichnospecies of *Ophiomorpha*, and sedimentary facies. The statistic of the morphological data reveals a certain ratio between outer and inner tube wall with high correlation. The whole database could be separated into two groups with a manifest boundary of 2 centimeters in tube diameter. The difference in size could be different ichnospecies or the different burrow made by juvenile and adult shrimp. Although half samples of the smaller group could not be ensured that they belong to ichnogenus *Ophiomorpha* yet because their pellet walls are hard to be seen in naked eyes, the structure of these small tube sample are being observed with petrographic analysis.

These two groups have many difference in morphology including branching frequency, branching pattern. The branching frequency of group in small size is slightly lower than the other group. Besides, in small group, specimens which contain obvious pellet balls on wall share same branching pattern with big group, but those which do not contain pellets present alternating mode in branching pattern. This consequence seems to imply the different size of burrows or whether containing obvious pellet ball result from different behavior.

Keywords: Nangang Formation, *Ophiomorpha*, Morphology, Sedimentary facies

Ichnology and Depositional Environments of the Ordovician Stony Mountain Formation (Williston basin, Saskatchewan and Manitoba): Refining Ichnofacies and Ichnofabric Models for Epeiric Sea Carbonates

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During the Ordovician, the low-relief Laurentia (North America) was situated across the Equator. A greenhouse climate at the time allowed for the highest sea-level during the Paleozoic, and continental flooding was extensive. Vastly extended shallow seas (epeiric seas) were characterized by pervasive carbonate deposits in North America. These epeiric sea deposits are enigmatic since the depositional settings of the ancient carbonates are fundamentally different from typical shelf margin settings. Furthermore, the absence of modern analogs for oceanic conditions and hydrodynamic modeling in that period leaves their origin equivocal, despite the large amount of research performed to date. Origin of common carbonate-evaporite cycles in the Williston Basin is still under debate; some studies termed them "shallowing-upward" sequences, others named them "brining-upward" sequences. The disparity is a result of contradicting interpretation of the sedimentary environments. Since existing models of epeiric seas cannot satisfy the interpretation of facies variation in the Stony Mountain Formation, reappraisal of the models is crucial. Multiple approaches, are essential in order to better understand the depositional setting of these ancient epeiric seas. Whereas ichnology has proved a powerful tool in delineating sedimentary environments in siliciclastic systems, it is currently burgeoning within the field of carbonate systems. With most studies dealing with the characterization of carbonate parasequences in modern and Quaternary Bahamian-type carbonates, ancient examples, in the early Paleozoic in particular, are scarce.

The purpose of this study is to document trace fossils and apply ichnologic tools to the study of this formation, aiming to refine the depositional setting of Ordovician epeiric seas. The results demonstrate the utility of ichnology for delineating sedimentary sub-environments of epeiric seas. Six facies are interpreted by different ichnofabric patterns which illustrate dynamics of sub-environments, and ichnofacies illustrating open-restricted conditions along the epeiric platform. Furthermore, through careful integration of ichnodiversity and degree of bioturbation, more precise environmental expression is possible, for instance, differentiating flooding events and stressful conditions in shallow subtidal areas. The facies distribution of the inner platform is expected to be better understood by recognizing palimpsest surface through taphonomic assessment of trace fossils. Finally, a refined facies model of the Stony Mountain Formation will be proposed and the transgressive-regressive trend of the succession will be delineated.

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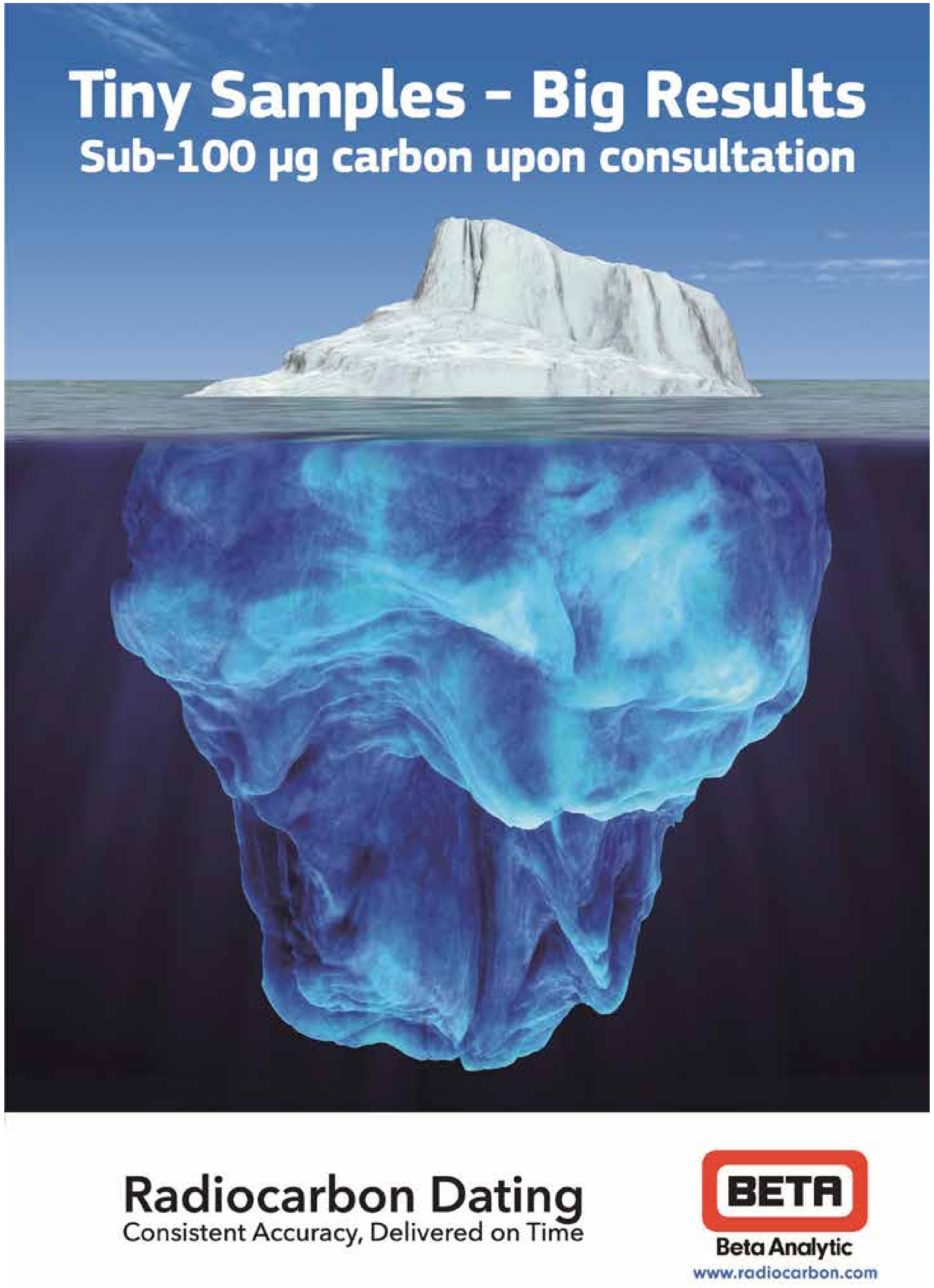

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