寒武紀化石二三事

A Few Things About Cambrian Fossils

國立臺灣師範大學
地球科學系
吳天偉
Department of Earth Sciences
National Taiwan Normal University
Tin-Wai Ng

國立中央大學
2015年3月10日

Outline

Cambrian Period

North China SPICE

Enrolment in Trilobite

“Eocrinoid” ossicles

Cladistics Analysis of Great Basin Trilobites

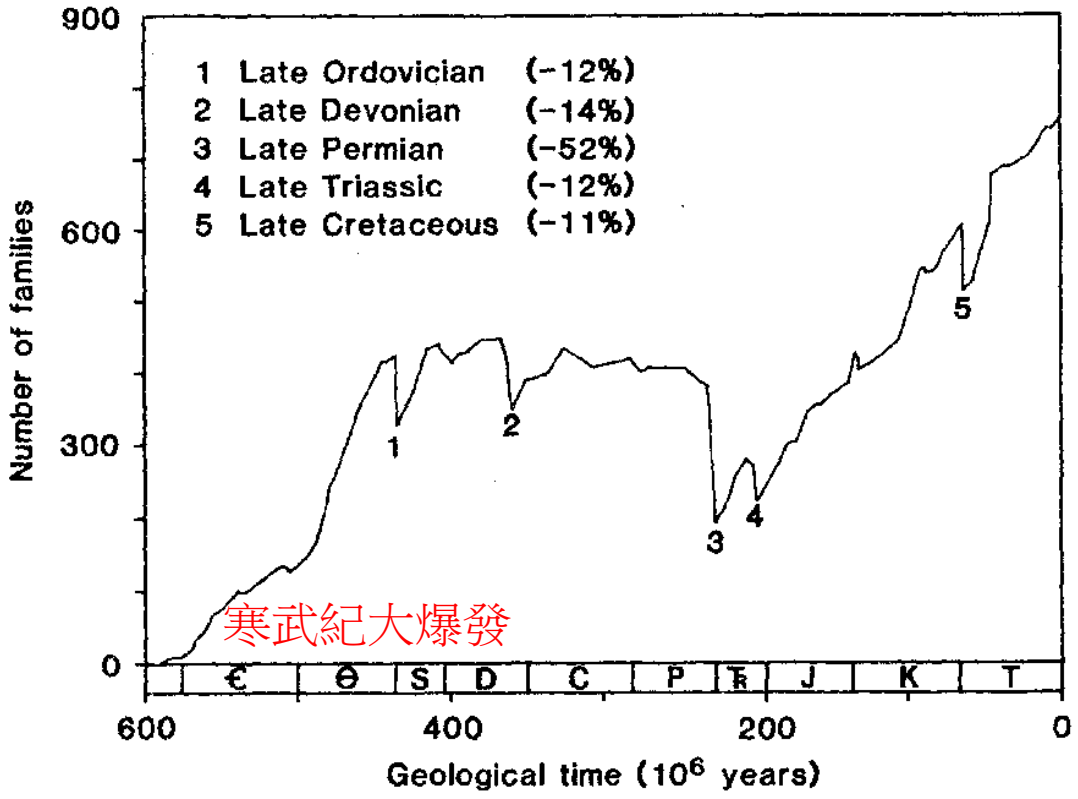
Paleoecology of Kangkou Limestone, eastern Taiwan

Anomalocaris 異蝦、奇蝦

Hallucigenia 怪誕蟲、哈魯奇蟲

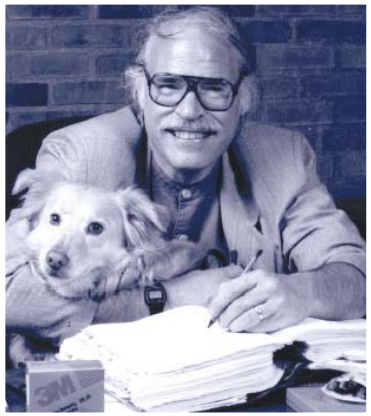
Sepkoski’ s Curve

Five great extinctions



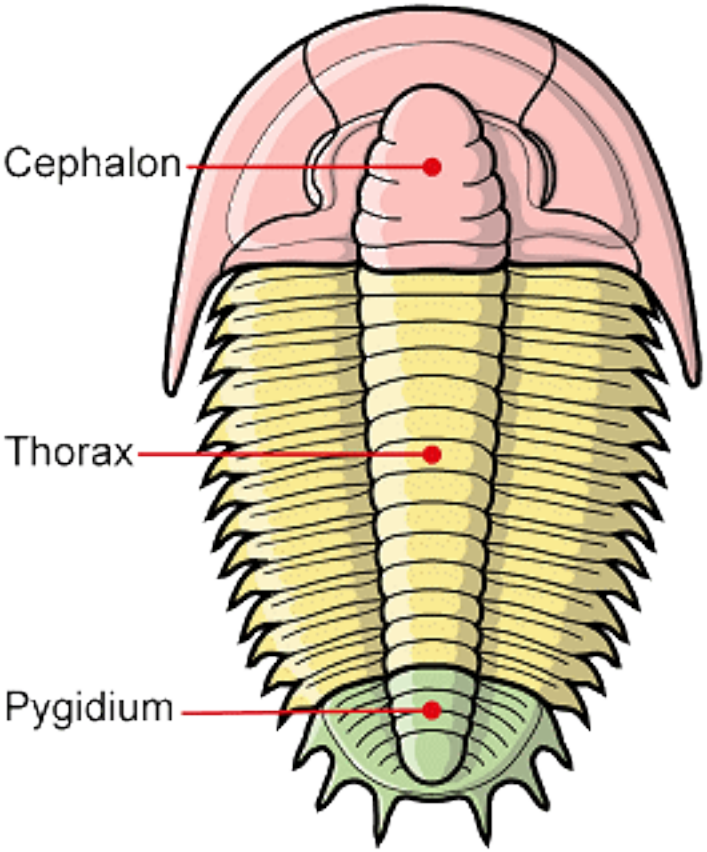
Marine faunas only!

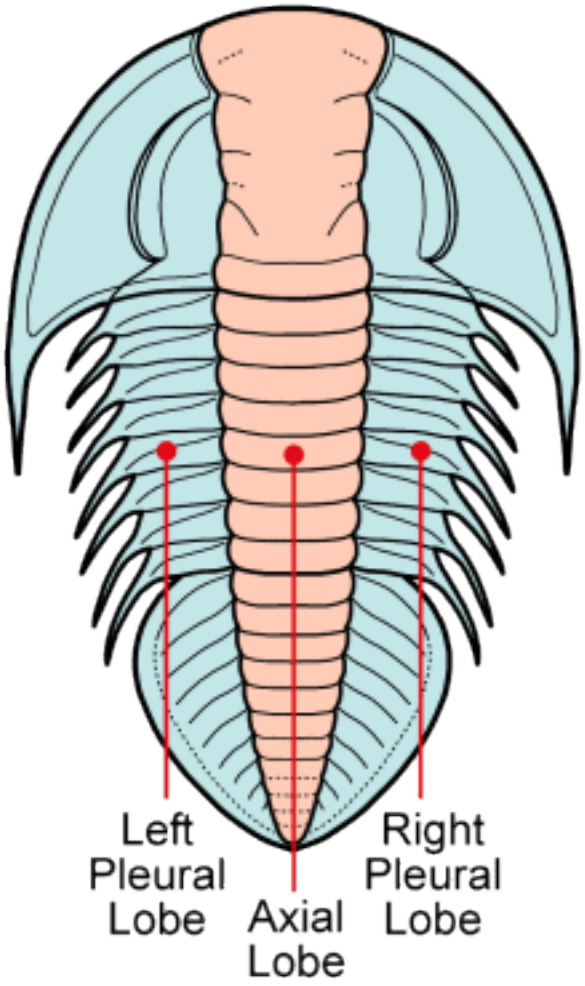
David M. Raup
1933-



J. John Sepkoski Jr
1950-1999

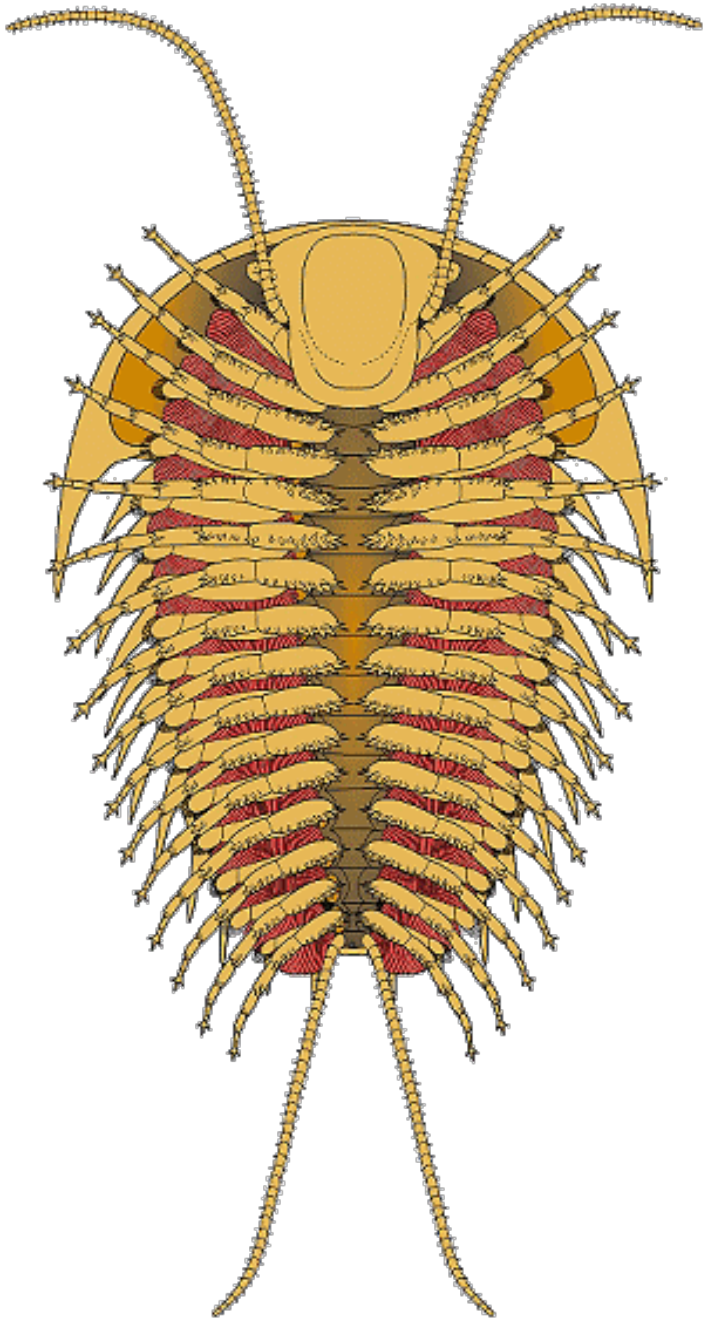
Raup and Sepkoski, 1982



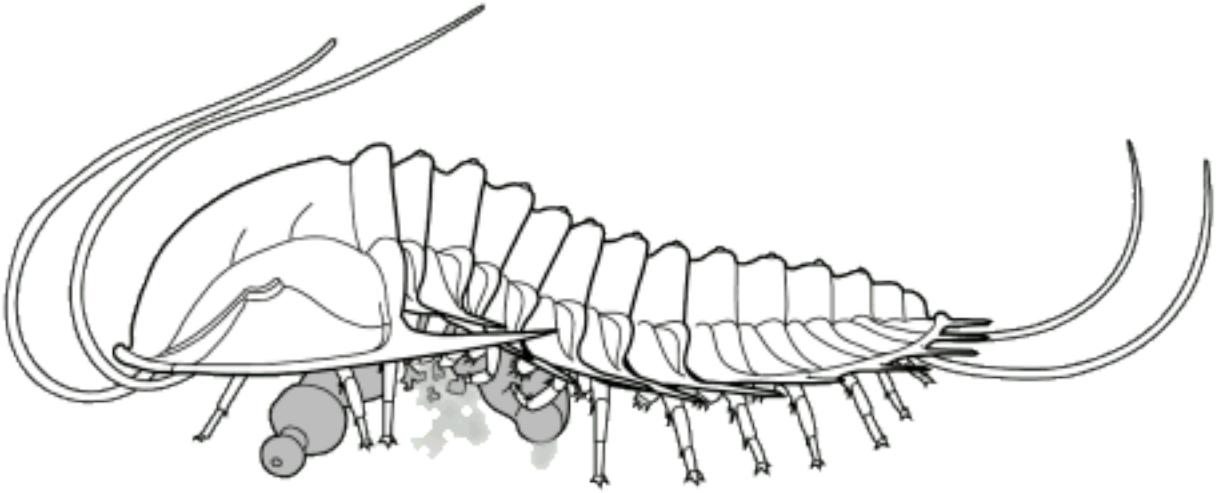


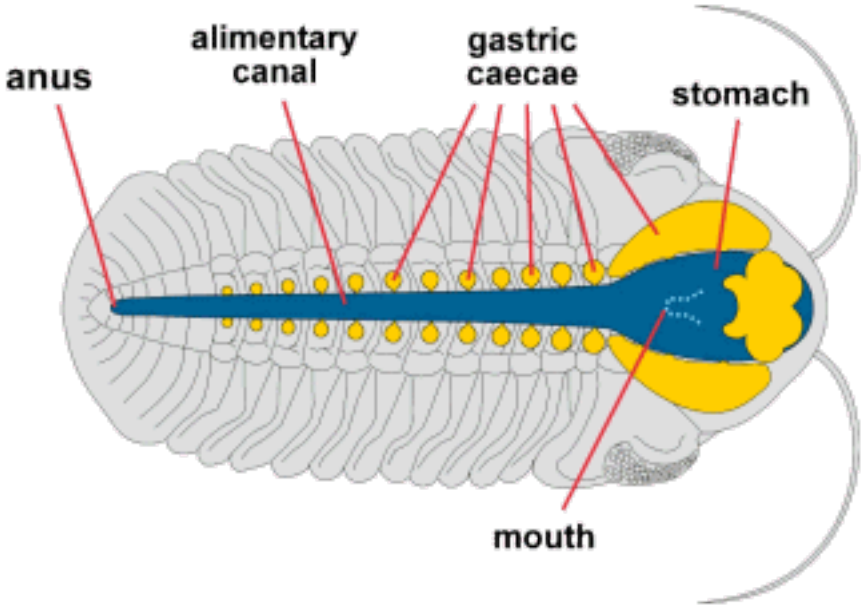
http://www.trilobites.info/

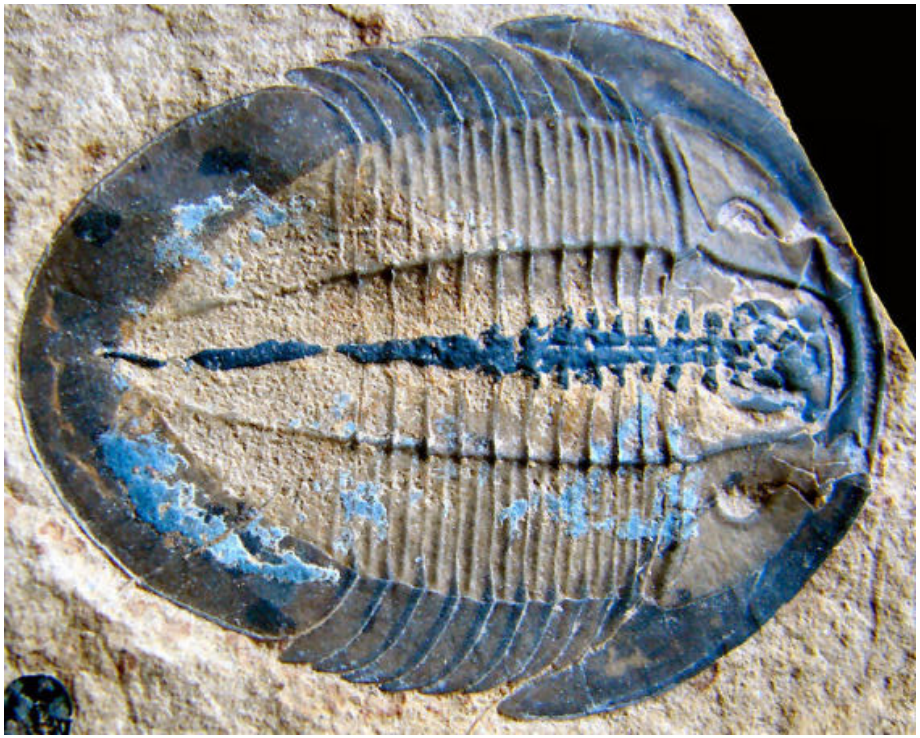
http://www.trilobites.info/



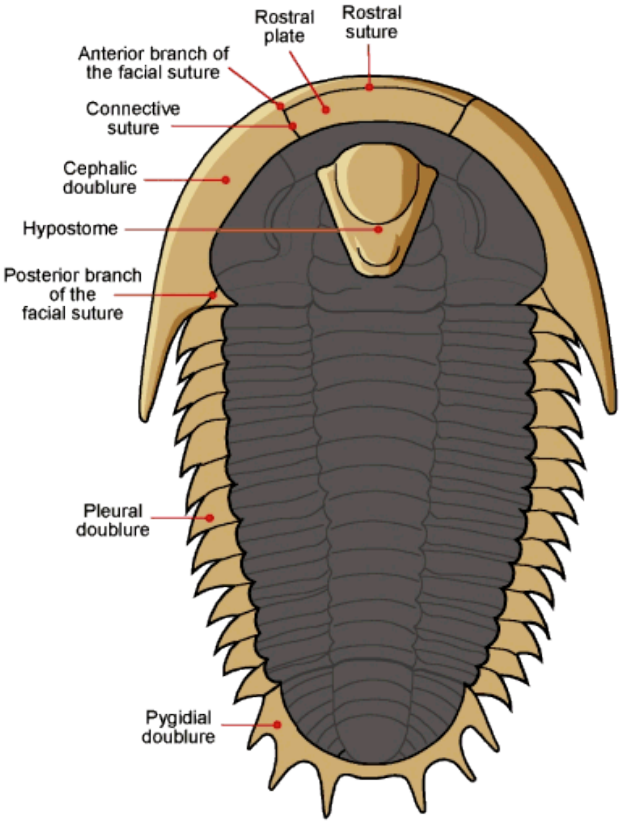
http://www.trilobites.info/



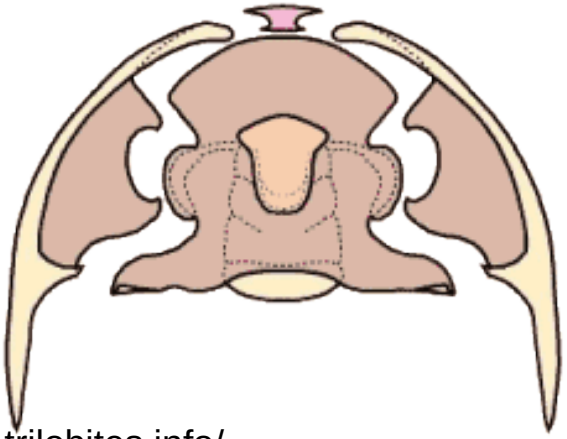


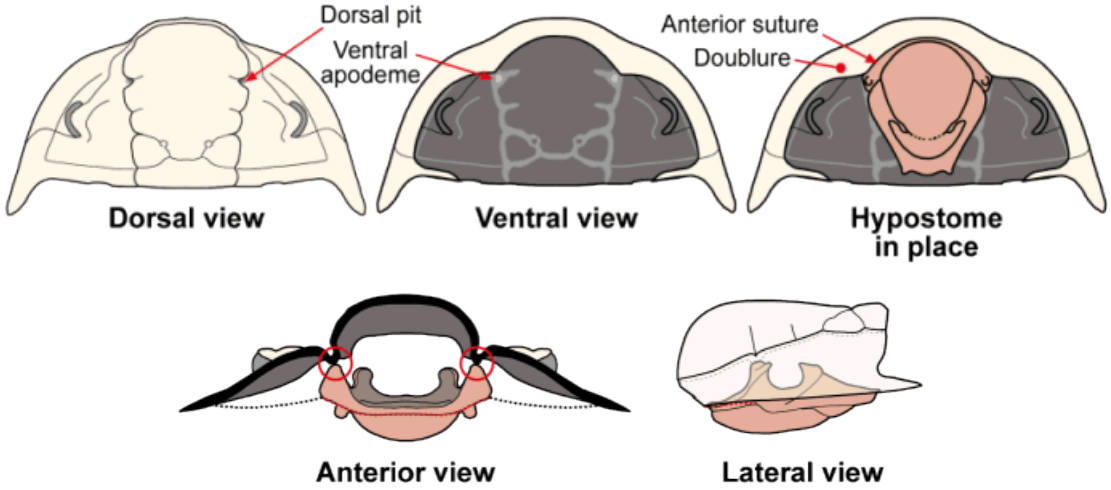


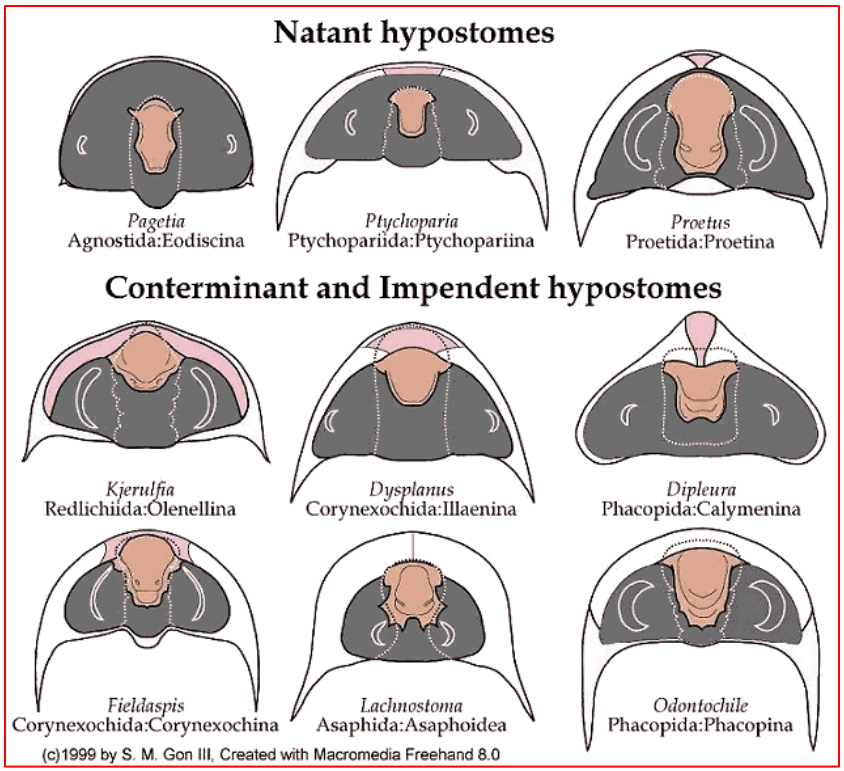
http://www.trilobites.info/



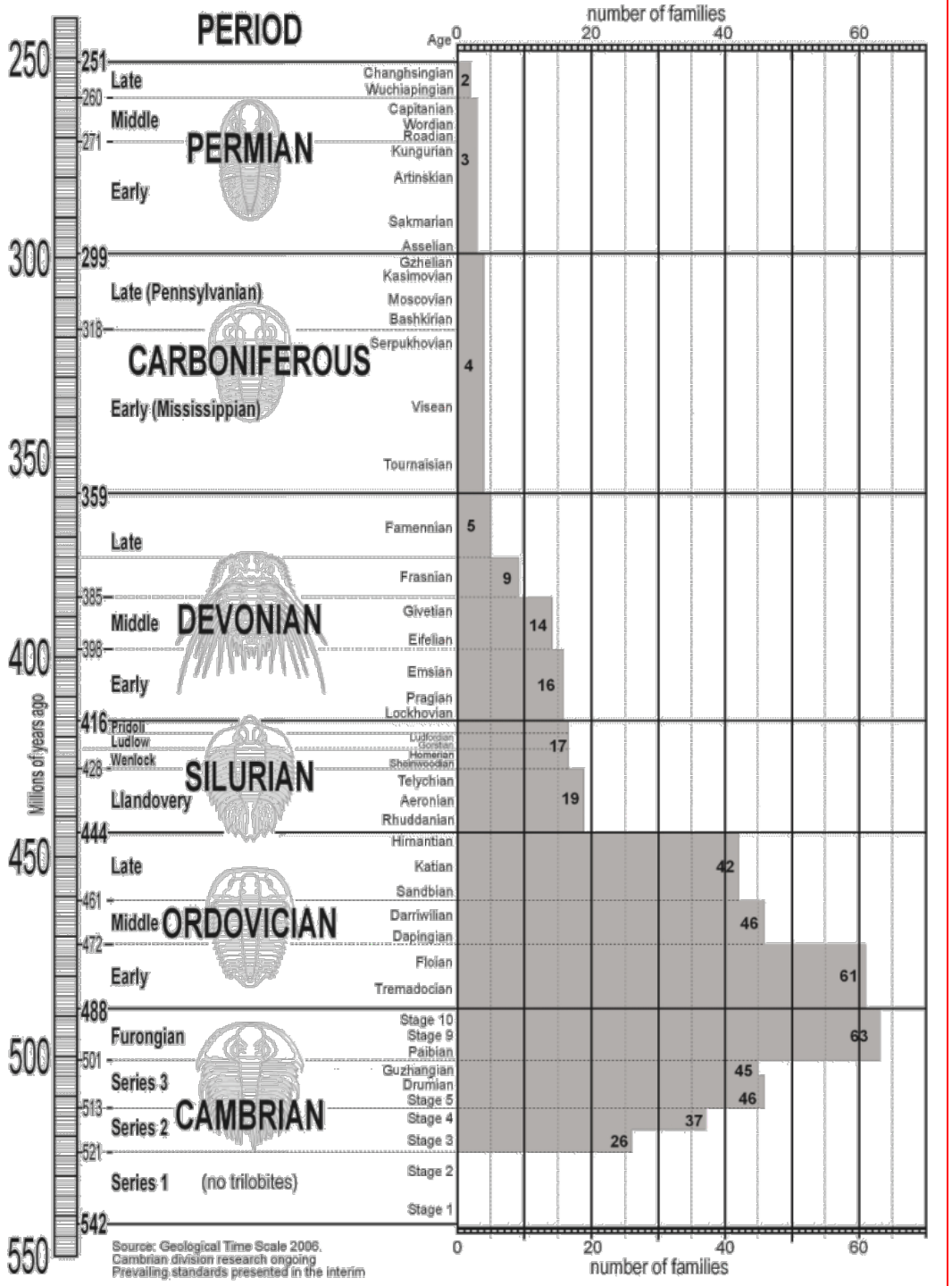
(c)1999 by S.M. Gon III
Created using Macromedia Freehand







http://www.trilobites.info/



http://www.trilobites.info/

Cambrian Stratigraphy 寒武紀地層

Traditional “lower”, “middle”, and “upper” division

Trilobite-based biostratigraphy mainly

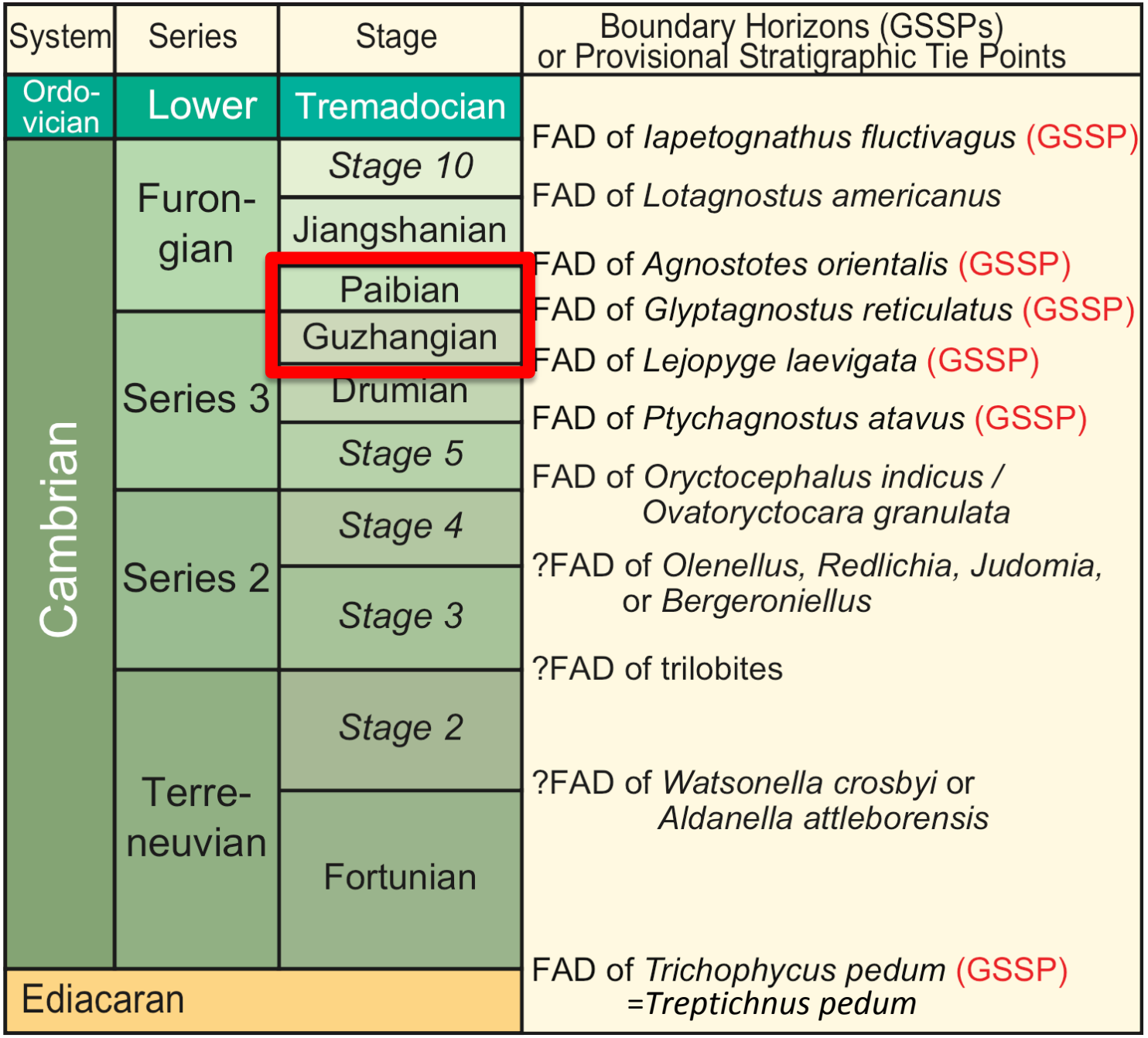
International Subcommission on Cambrian Stratigraphy - 4 series (統) and 10 stages (階)

Global Stratotype Section and Point (GSSP)

- “Golden Spike”

全球界線層型剖面和點位

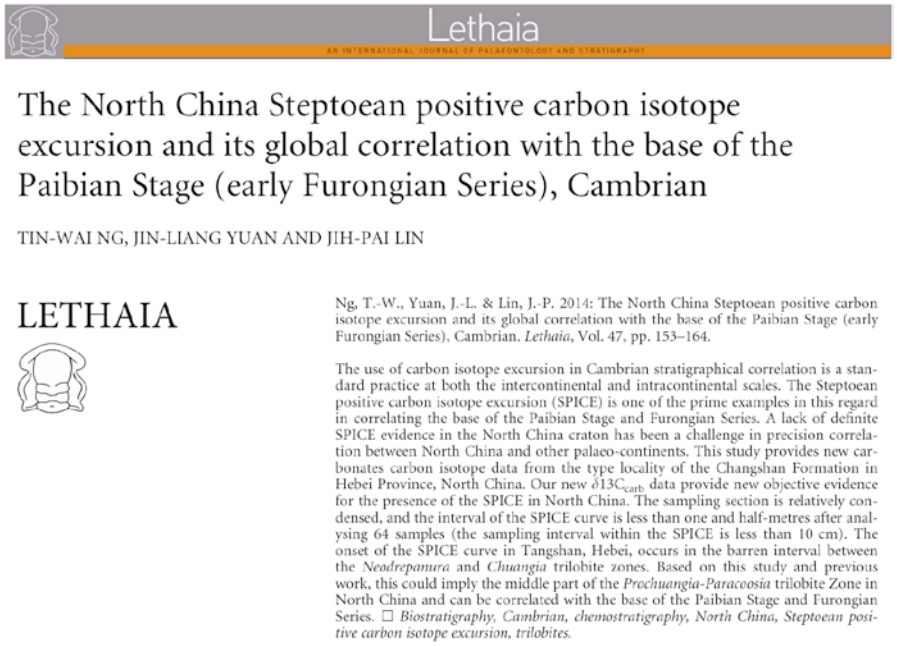
- 金釘子



Peng et al., 2012

North China SPICE & Its Implications

SPICE: Steptoean Positive Carbon Isotope Event



Lethaia

AN INTERNATIONAL JOURNAL OF PALAEONTOLOGY AND STRATIGRAPHY

The North China Steptoean positive carbon isotope excursion and its global correlation with the base of the Paibian Stage (early Furongian Series), Cambrian

TIN-WAI NG, JIN-LIANG YUAN AND JIH-PAI LIN

LETHAIA

Ng, T.-W., Yuan, J.-L. & Lin, J.-P. 2014: The North China Steptoean positive carbon isotope excursion and its global correlation with the base of the Paibian Stage (early Furongian Series), Cambrian. *Lethaia*, Vol. 47, pp. 153–164.

The use of carbon isotope excursion in Cambrian stratigraphical correlation is a standard practice at both the intercontinental and intracontinental scales. The Steptoean positive carbon isotope excursion (SPICE) is one of the prime examples in this regard in correlating the base of the Paibian Stage and Furongian Series. A lack of definite SPICE evidence in the North China craton has been a challenge in precision correlation between North China and other palaeo-continents. This study provides new carbonates carbon isotope data from the type locality of the Changshan Formation in Hebei Province, North China. Our new $\delta 13C_{carb}$ data provide new objective evidence for the presence of the SPICE in North China. The sampling section is relatively condensed, and the interval of the SPICE curve is less than one and half-metres after analysing 64 samples (the sampling interval within the SPICE is less than 10 cm). The onset of the SPICE curve in Tangshan, Hebei, occurs in the barren interval between the *Neadrepanura* and *Chuangia* trilobite zones. Based on this study and previous work, this could imply the middle part of the *Prochuangia-Paracoosia* trilobite Zone in North China and can be correlated with the base of the Paibian Stage and Furongian Series. ☐ *Biostratigraphy, Cambrian, chemostratigraphy, North China, Steptoean positive carbon isotope excursion, trilobites.*

Ng, T.-W., Yuan, J.-L., Lin, J.-P. (2014) The North China Steptoean positive carbon isotope excursion and its global correlation with the base of the Paibian Stage (early Furongian Series), Cambrian. *Lethaia.*

ELSEVIER

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com

GEOBIOS

Original article

The North China Steptoean Positive Carbon Isotope Event: New insights towards understanding a global phenomenon☆

CrossMark

Tin-Wai Ng[a,b], Jin-Liang Yuan[a], Jih-Pai Lin[c,*]

[a] Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China
[b] Department of Earth Sciences, National Taiwan Normal University, Taipei 11677, Taiwan
[c] State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

ARTICLE INFO

Article history:
Received 30 October 2013
Accepted 25 September 2014
Available online 24 October 2014

Keywords:
SPICE
Paibian
Furongian
Chemostratigraphy
Correlation
Trilobite

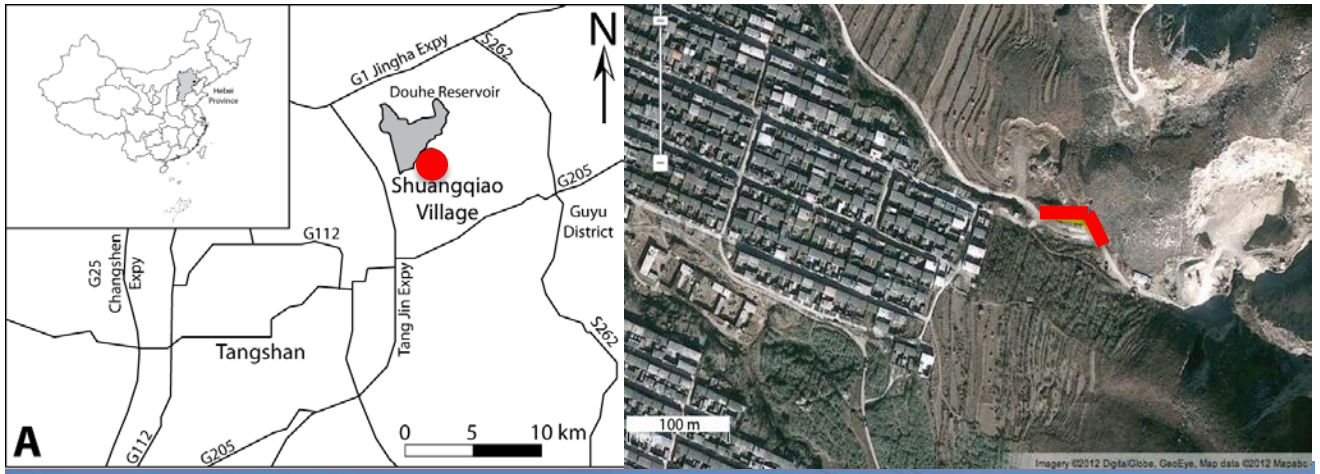
ABSTRACT

Precise biostratigraphic correlation of the base of the Paibian Stage, Cambrian, within and beyond the North China craton has been difficult, mostly because of the strong endemism of the trilobite fauna on the shallow platform facies. The use of the Steptoean Positive Carbon Isotope Excursion (SPICE) in defining the Guzhangian-Paibian stage boundary has become a standard practice. Thus, a chemostratigraphic study of the Huangyangshan section from North China has been carried out. This section in Shandong Province clearly records the SPICE, with the most detailed fossil and carbonate carbon isotope data to date. Compared to other sections in the world, all the published SPICE in North China display both reduced peak and reduced difference ($\Delta^{13}C$) values. These may imply unique conditions on the North China craton during the upper Guzhangian to Paibian stages. This study shows that the SPICE is recorded in relatively condensed sections in North China; thus, ≤ 0.5 m sampling density is suggested here in order to evaluate the presence of the SPICE in North China and condensed sections.

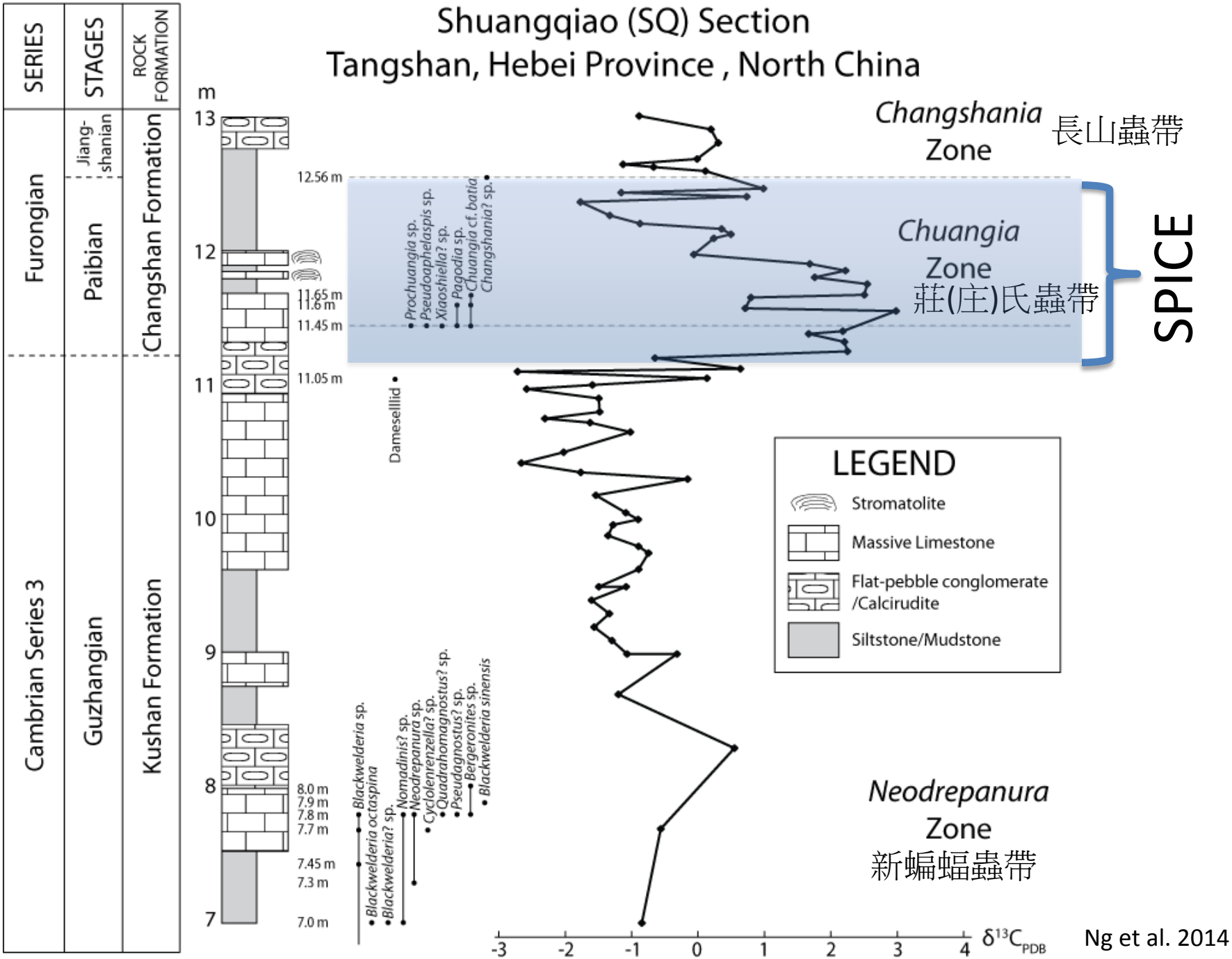
Ng, T.-W., Yuan, J.-L., Lin, J.-P. (2014) The North China Steptoean Positive Carbon Isotope Event: New insights towards understanding a global phenomenon. *Geobios.*

Shuangqiao (SQ), Tangshan, Hebei
河北省唐山市雙橋(村)剖面

Type locality of the Changshan Formation 長山組/層 &
Changshanian Stage 長山階

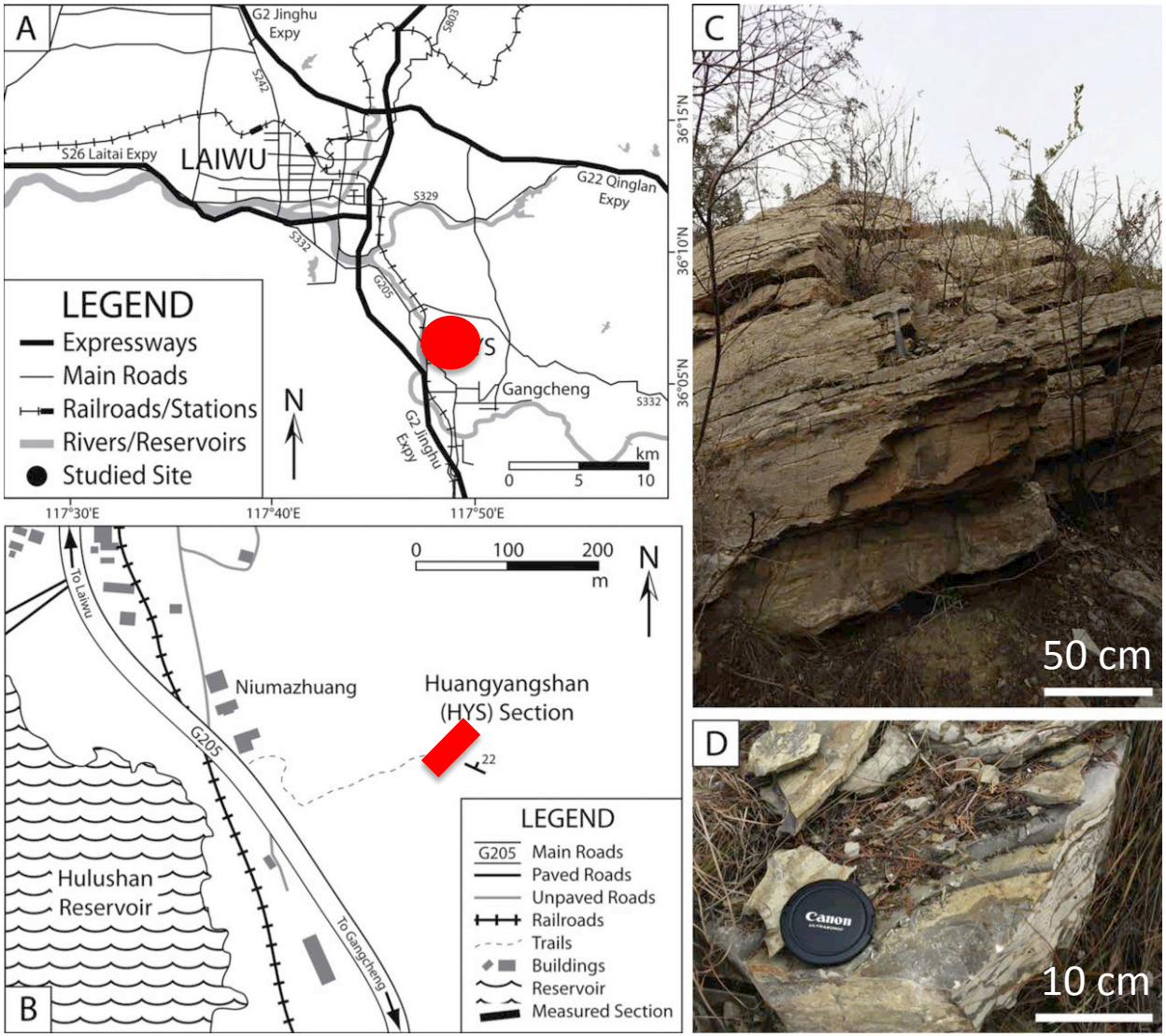


Ng et al. 2014
Lethaia

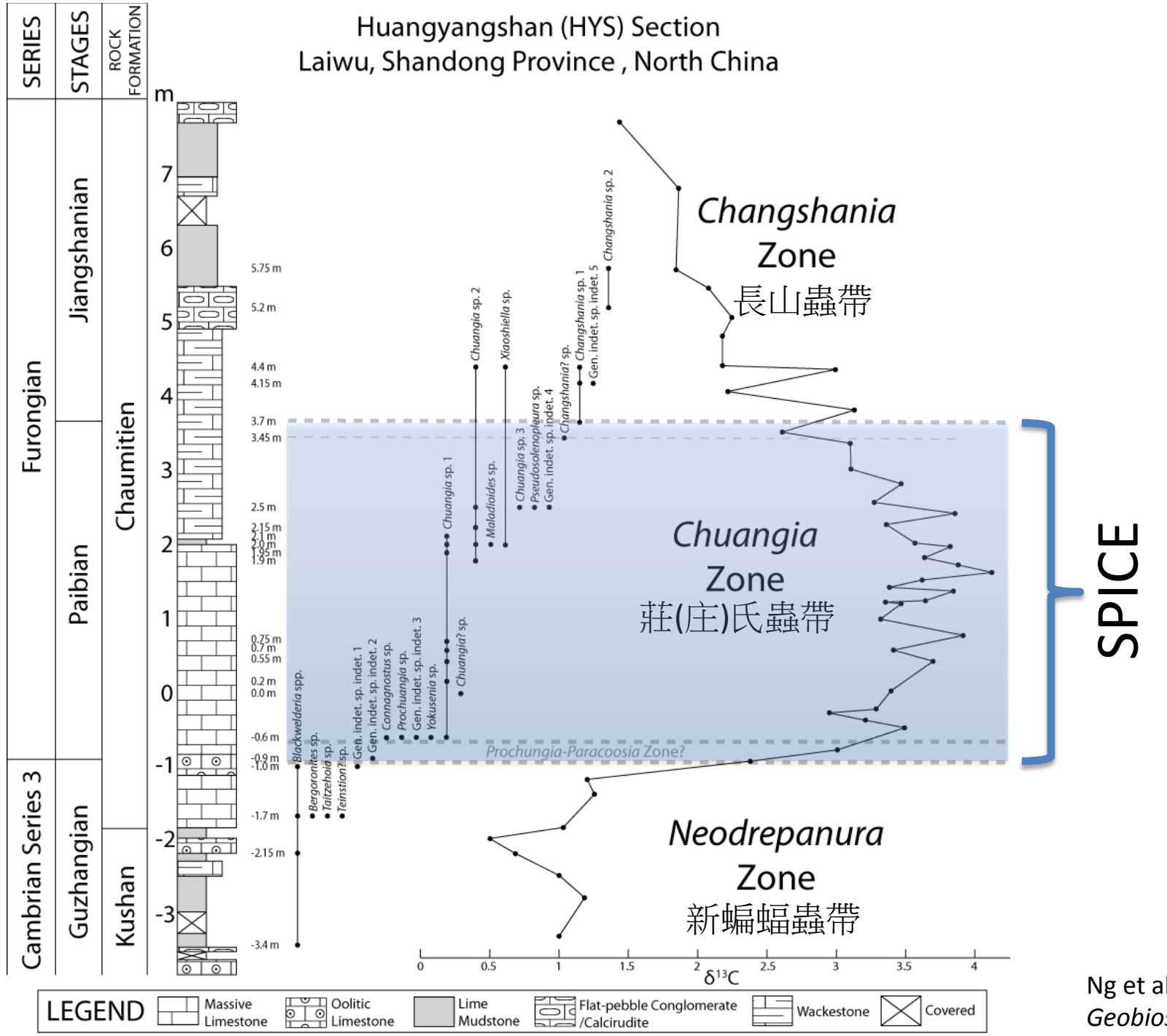


Ng et al. 2014
Lethaia

Huangyangshan (HYS), Laiwu, Shandong
山東省萊蕪市黃羊山剖面

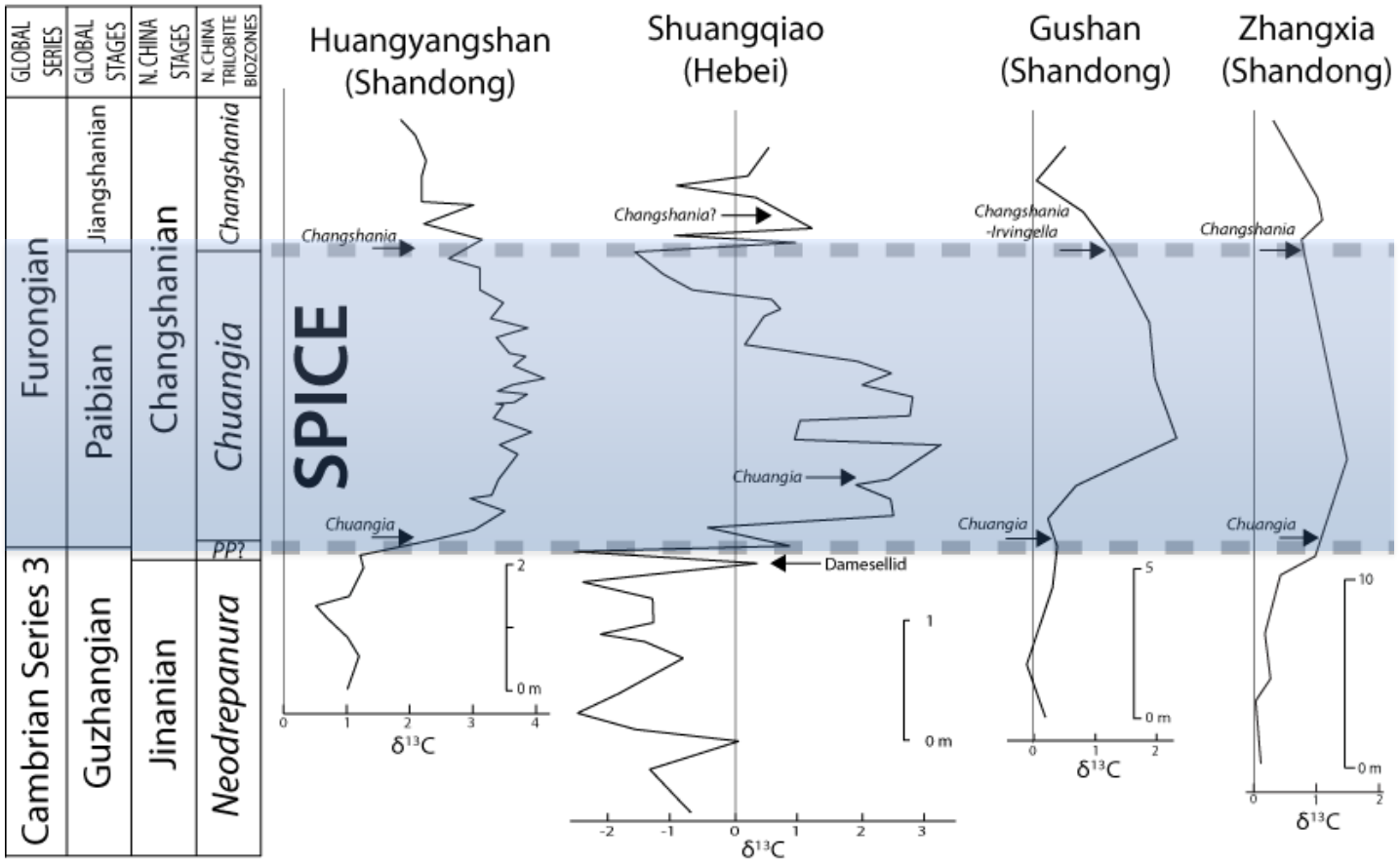


Ng et al. 2014
Geobios



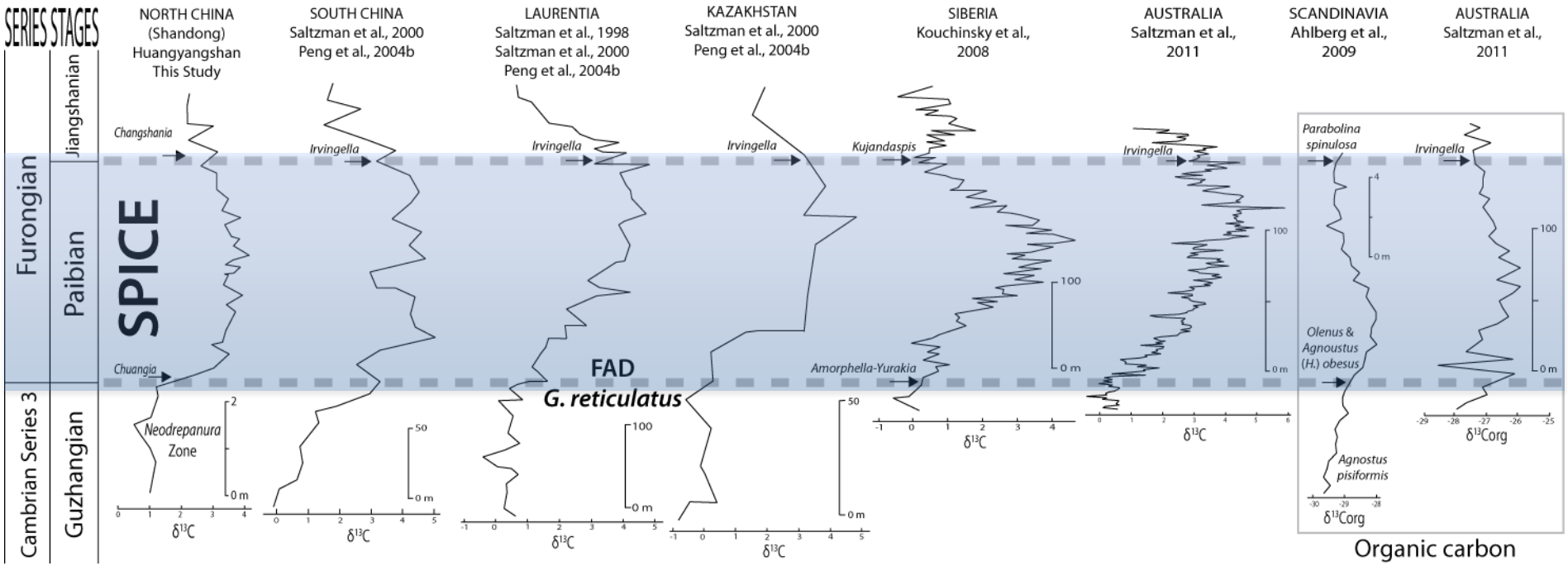
Ng et al. 2014
Geobios

North China SPICE Correlation
華北SPICE事件對比

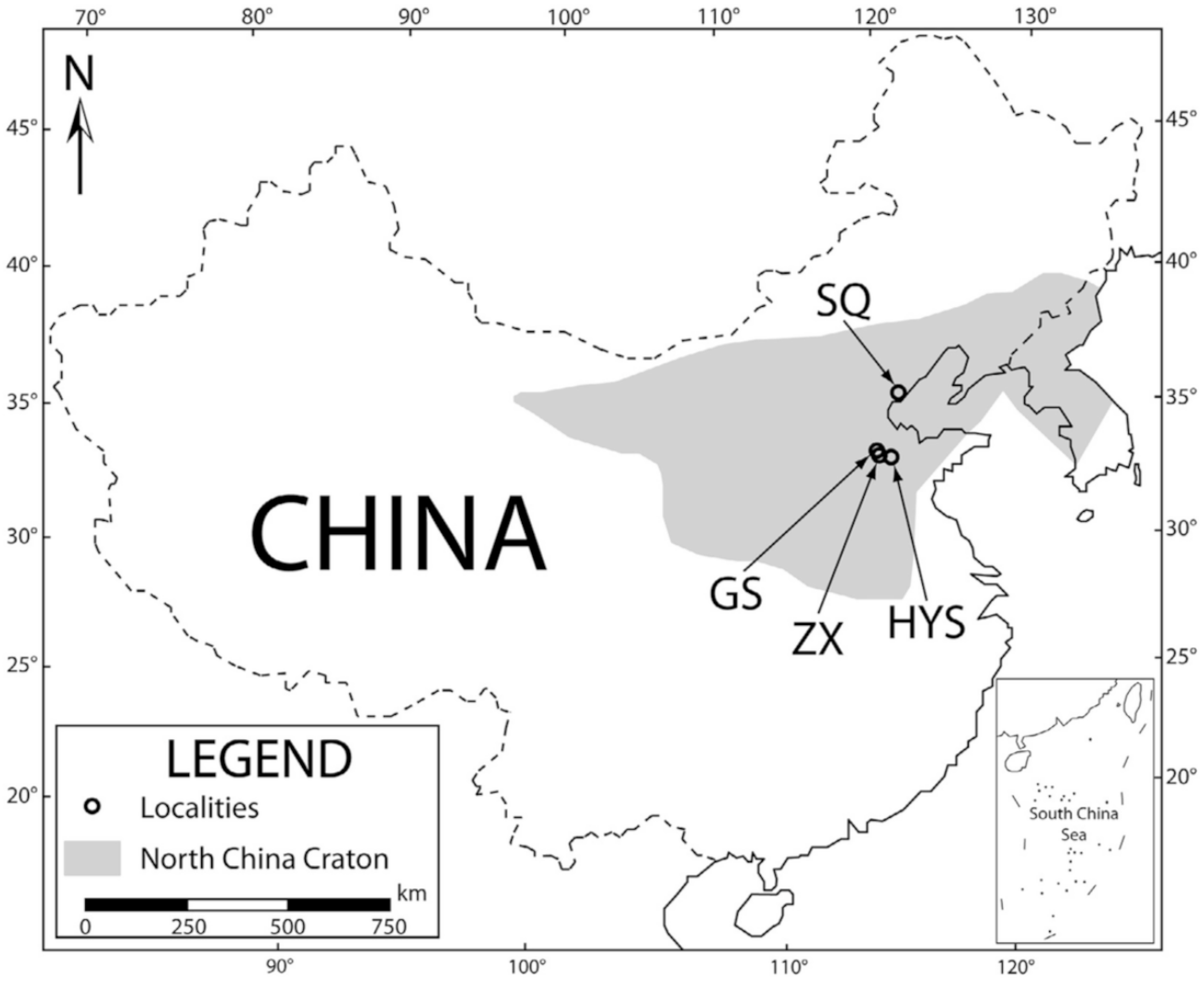


Ng et al. 2014 *Geobios*

Global SPICE Correlation
全球SPICE事件對比



Ng et al. 2014 *Geobios*



Ng et al. 2014 *Geobios*

Peak $\delta^{13}C$ and Difference $\Delta\delta^{13}C$

Normal SPICE:

Peak $\delta^{13}C$ ~+4 to +5 ‰

$\Delta\delta^{13}C$ ~4 ‰

Section	Peak $\delta^{13}C$ value (I)	Initial $\delta^{13}C$ value (II)	Difference $\Delta\delta^{13}C$ (I-II)
Shuangqiao (SQ)	+3.22 ‰	+0.87 ‰	2.35 ‰
Huangyangshan (HYS)	+4.144 ‰	+2.413 ‰	1.731 ‰
Gushan (GS)	+2.226 ‰	+0.416 ‰	1.81 ‰
Zhangxia (ZX)	+1.58 ‰	-0.2 ‰	1.78 ‰

Ng et al. 2014 *Geobios*

Possible Reasons

Regional changes in ocean environment (Holmden et al. 1998; Panchuk et al. 2006; Young et al. 2005)

Aquafacies variations (Holmden et al. 1998; Young et al. 2005; Young et al. 2008)

Oxidation of organic matter (Hayes et al. 1999; Young et al. 2008; Saltzman et al. 2011)

Isolation of water masses (Patterson & Walter, 1994)

More restricted and higher salinity due to sea-level fluctuations (Sial et al., 2013)

Diagenesis (Ralisback et al, 2003)

Volcanic activities (Shen et al. 2012)

Weathering of siliciclastic or carbonitic rocks, change in organic carbon burial rate (Kump and Arthur, 1999)

Ng et al. 2014 *Geobios*

Implications

More sampling horizons for both fossil and isotope data (≤ 0.5 m) in condensed sections

More intensive study on the taxonomy of biostratigraphically important taxa (mostly trilobites)

More sections from a broader geographic context would be useful to discuss any intracontinental variations

Different kinds of isotope data for more in-depth discussion on the environmental changes in North China

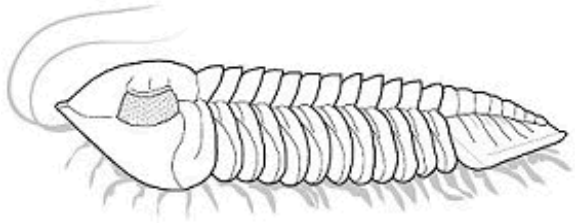
Ng et al. 2014 *Geobios*

Enrolment in Trilobite

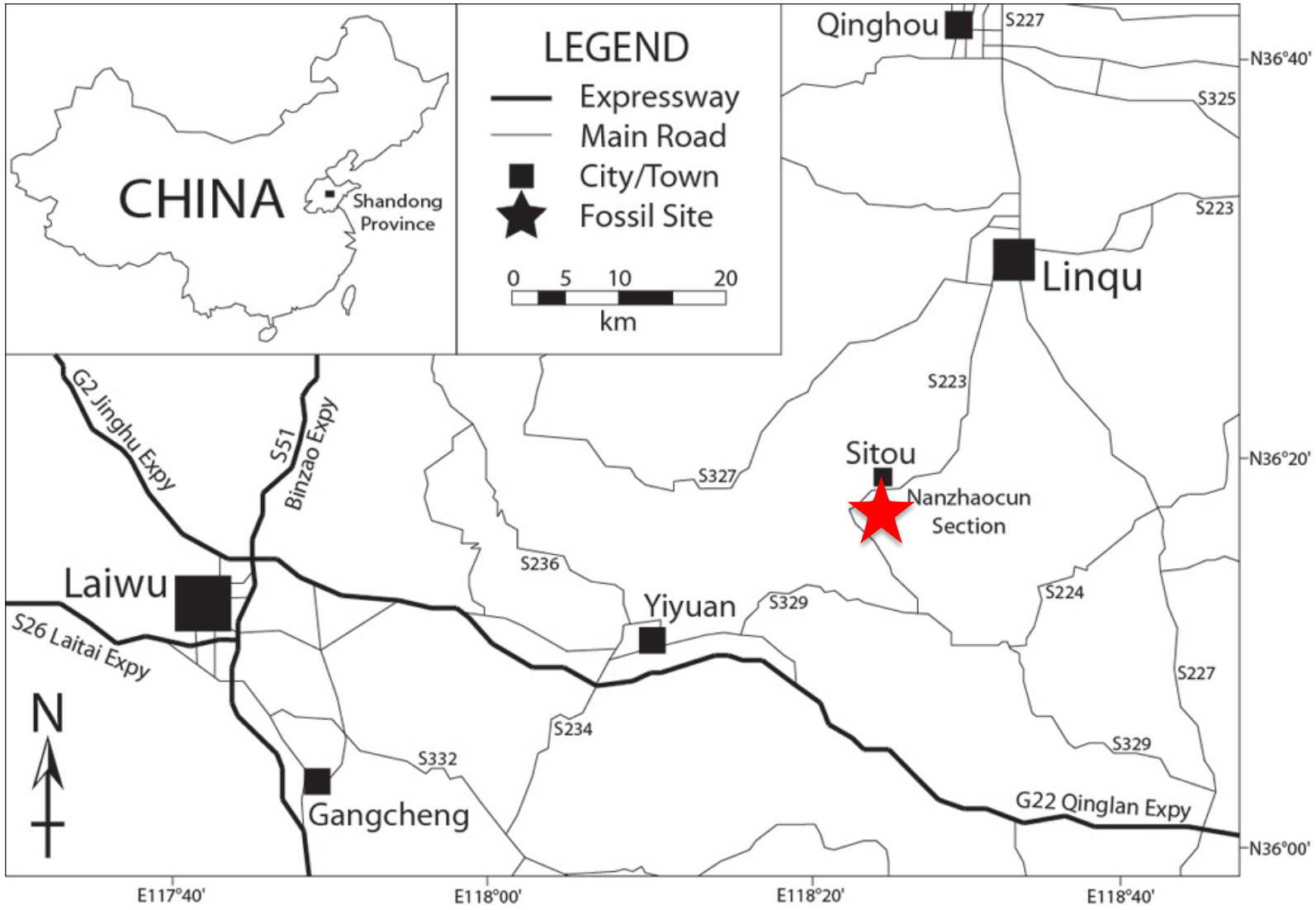
Enrolment – protective behavior

Enrolment of Cambrian trilobites not well studied

New middle Cambrian enrolled trilobite from Shandong Province, North China



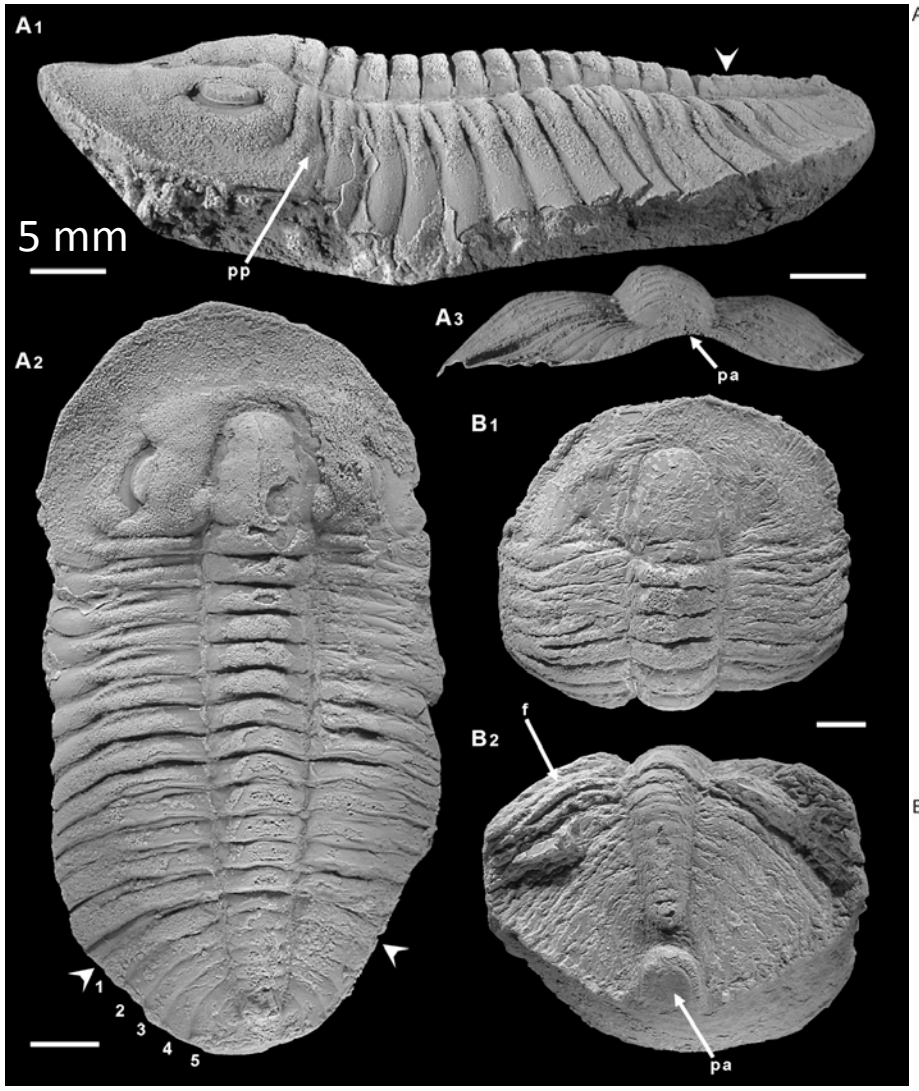
Yuan, J.-L., J. Esteve, and T. -W. Ng (2014) Articulation, interlocking devices and enrolment in *Monkaspis daulis* (Walcott, 1905) from Guzhangian, middle Cambrian of Shandong Province, North China. *Lethaia*, 47, 405-417.

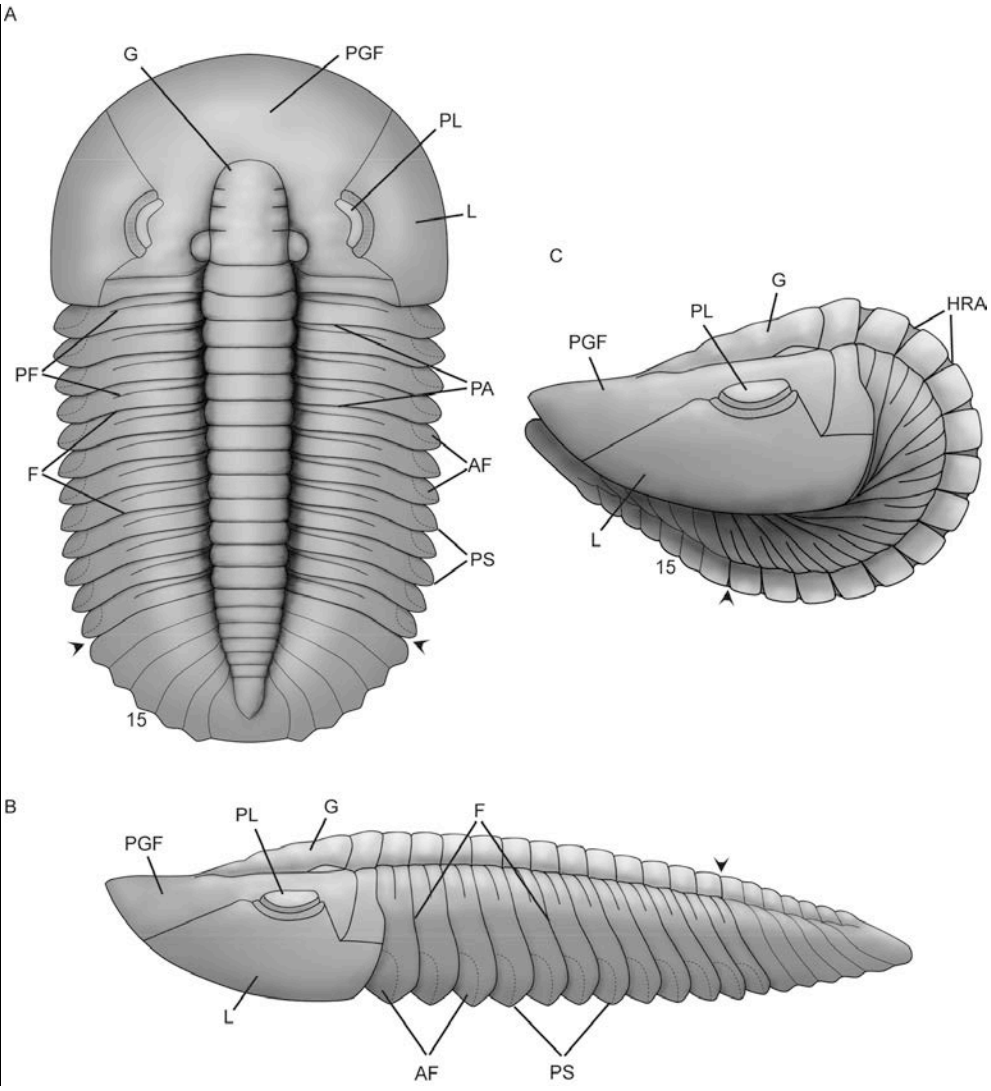


GPS: N36°17’52.6, E118°24’24.6

Yuan et al. 2014 *Lethaia*

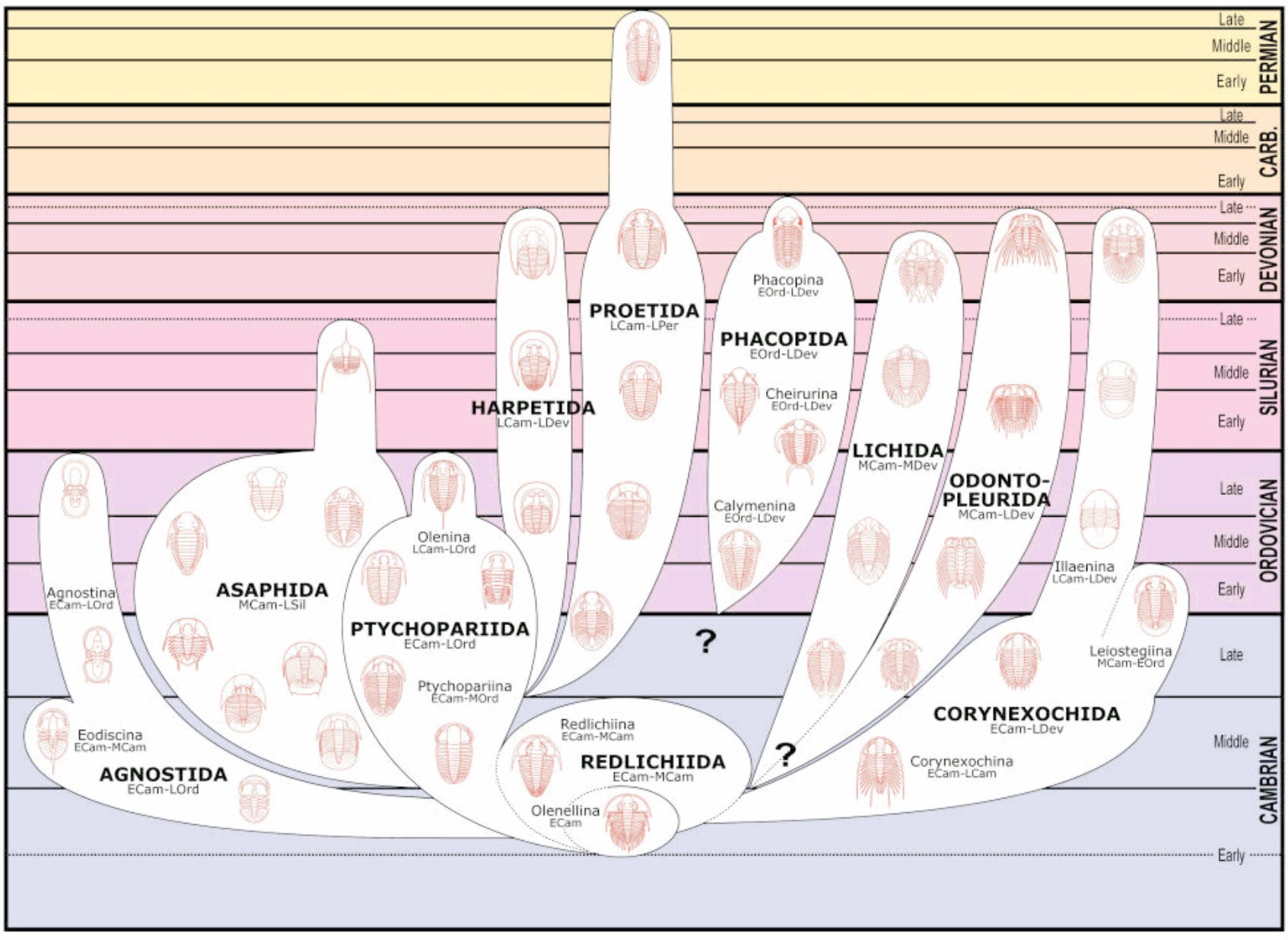
Yuan et al. 2014 *Lethaia*





Monkaspis daulis (Walcott, 1905)

Yuan et al. 2014 *Lethaia*



http://www.trilobites.info/triloclass.htm#orders

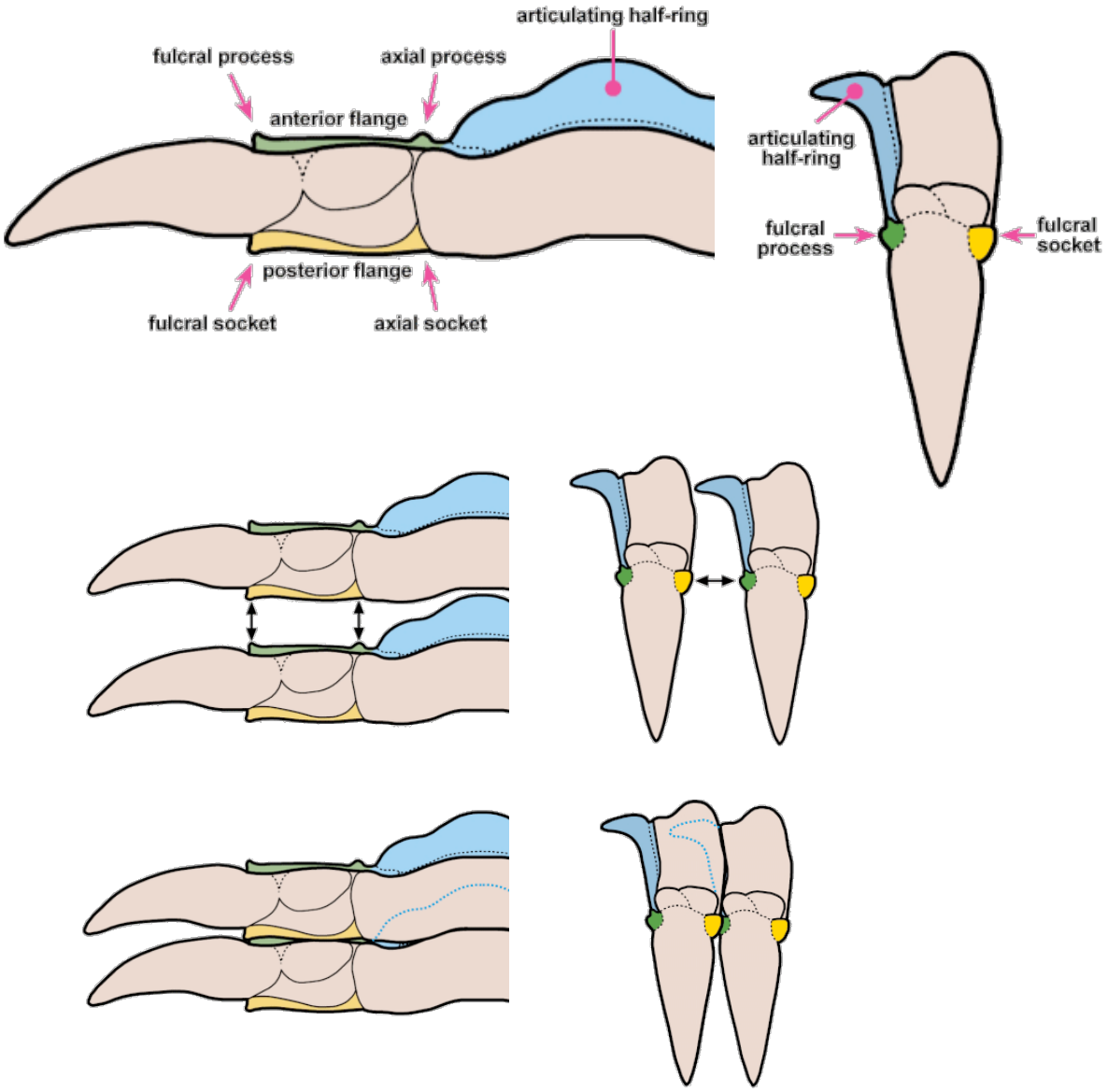
micropygous

isopygous

macropygous

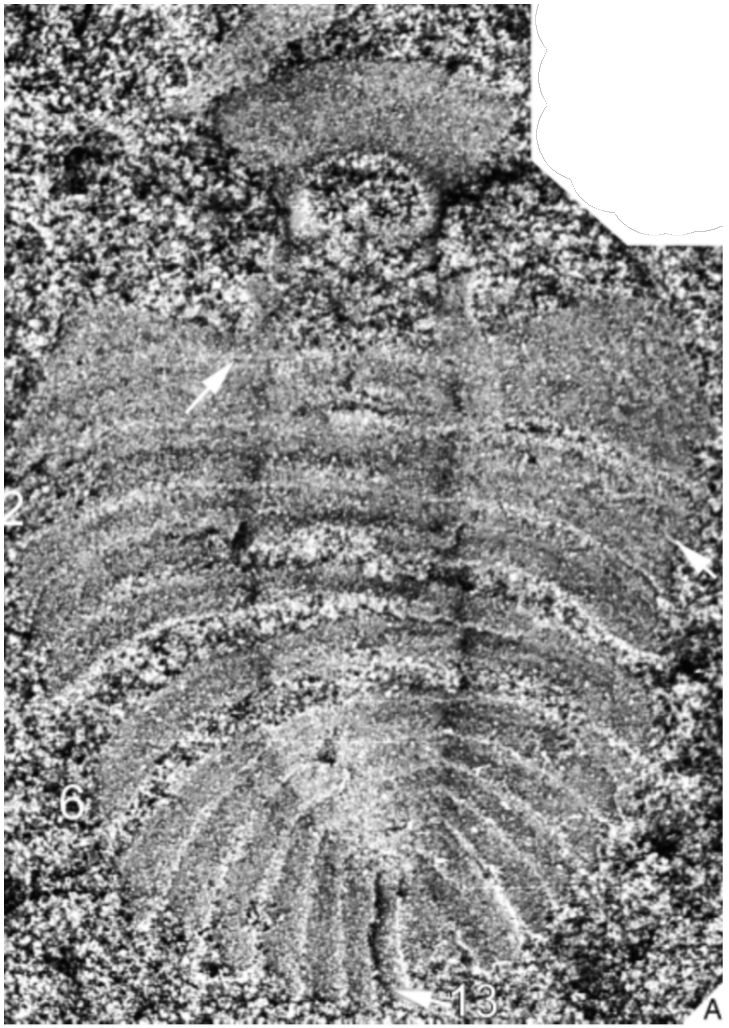
http://www.trilobites.info/pygyterms.htm

Articulation structures



http://www.trilobites.info/thorax.htm

Articulation structures

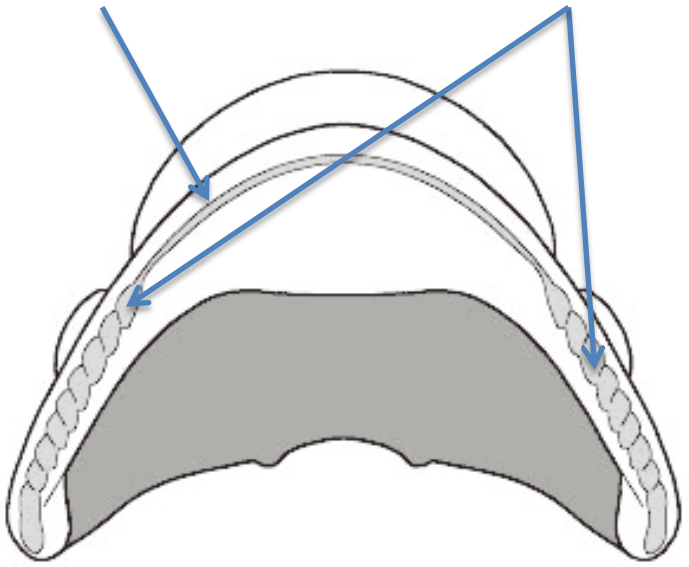


Burlingia jagoi Whittington, 1994

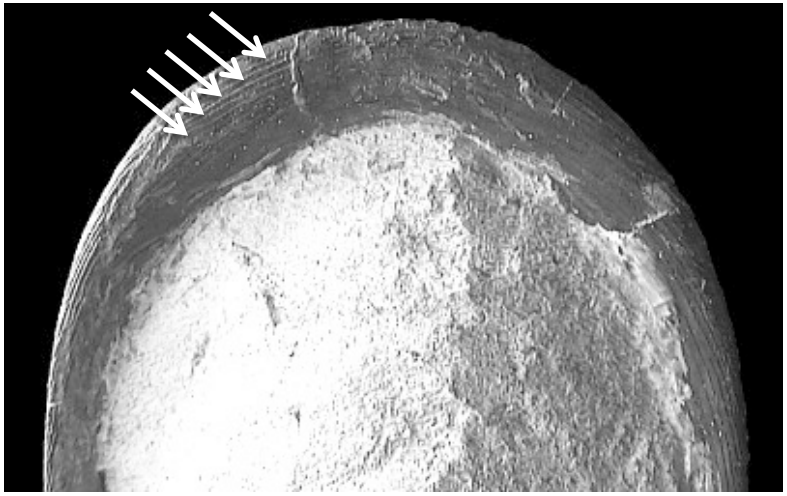
Ebbestad & Budd 2002, text-fig. 3A

Interlocking Devices

Phacopid trilobite

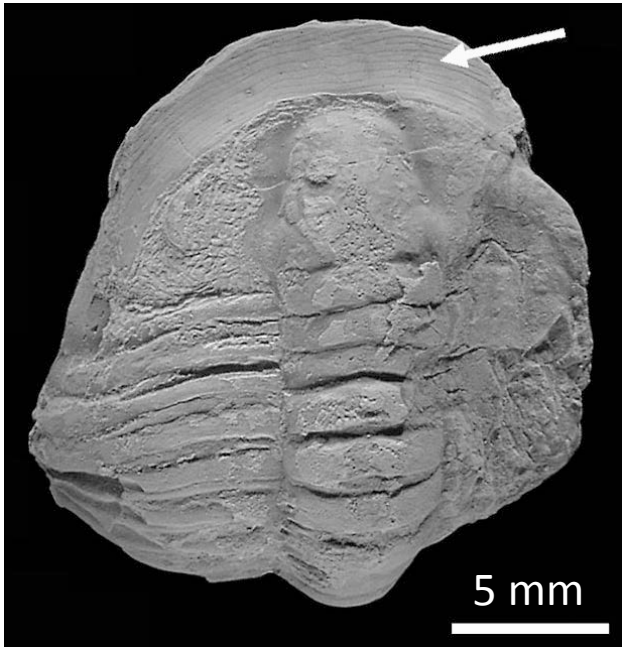


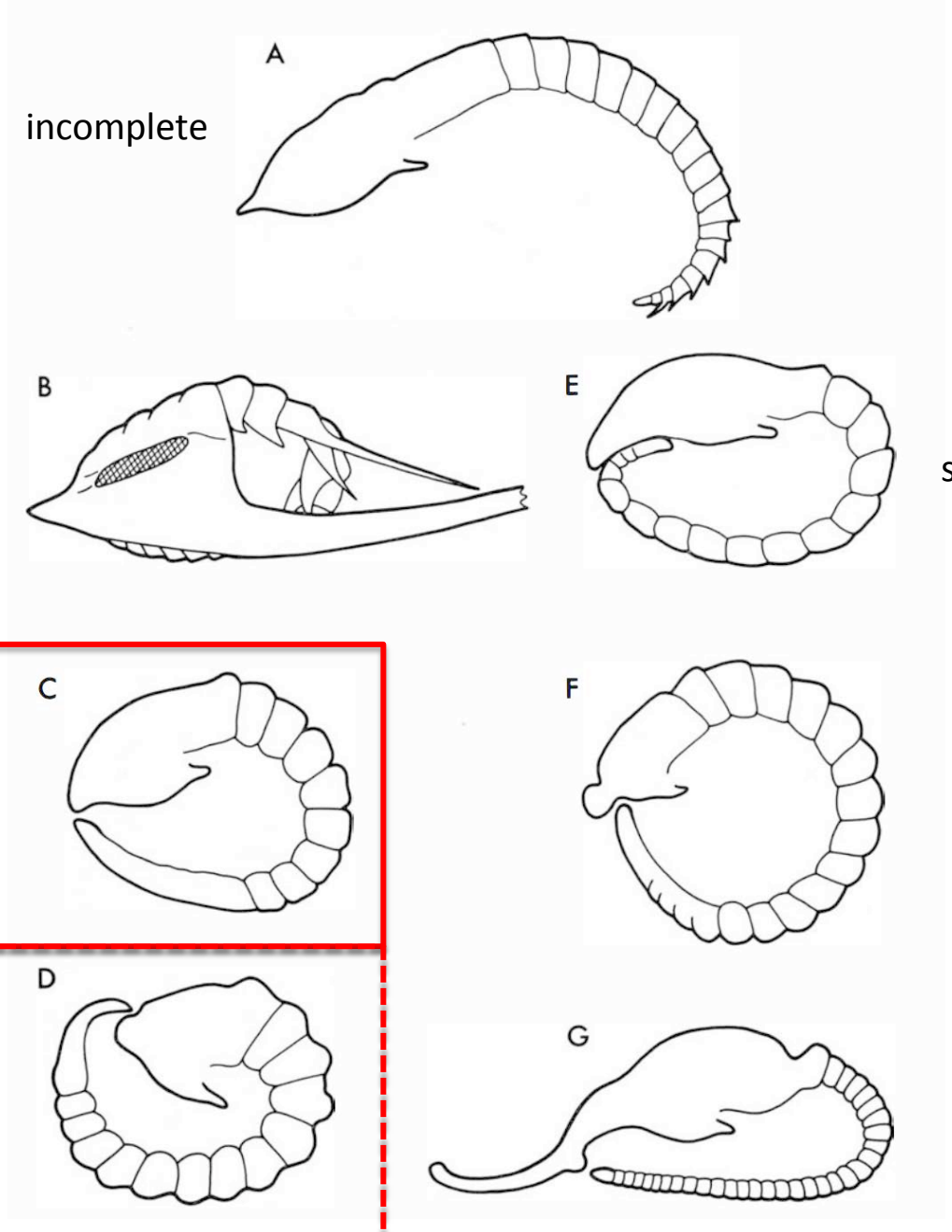
Terrace lines



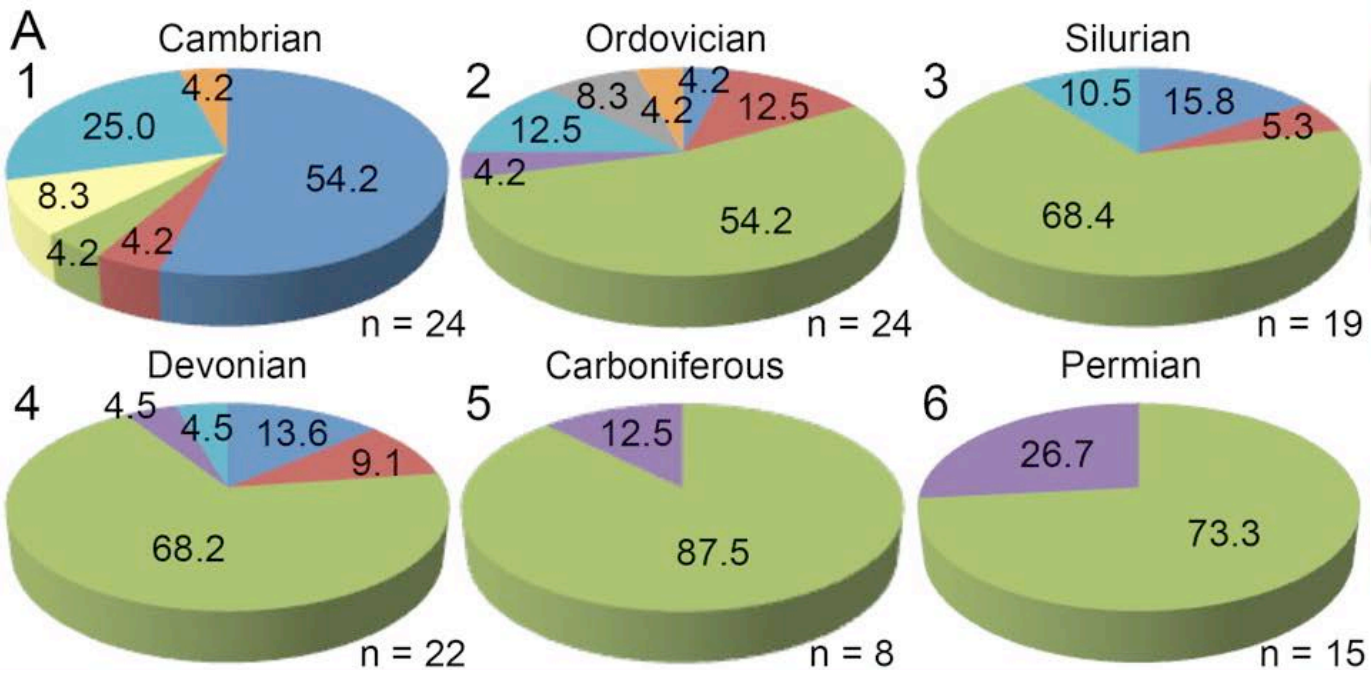
trilobite doublure terrace lines

Terrace lines

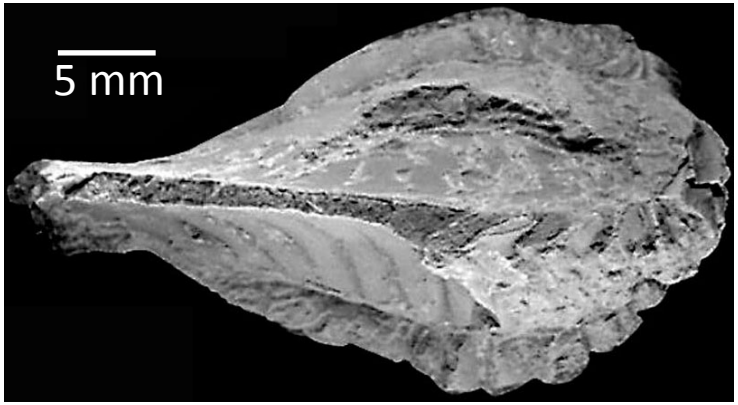


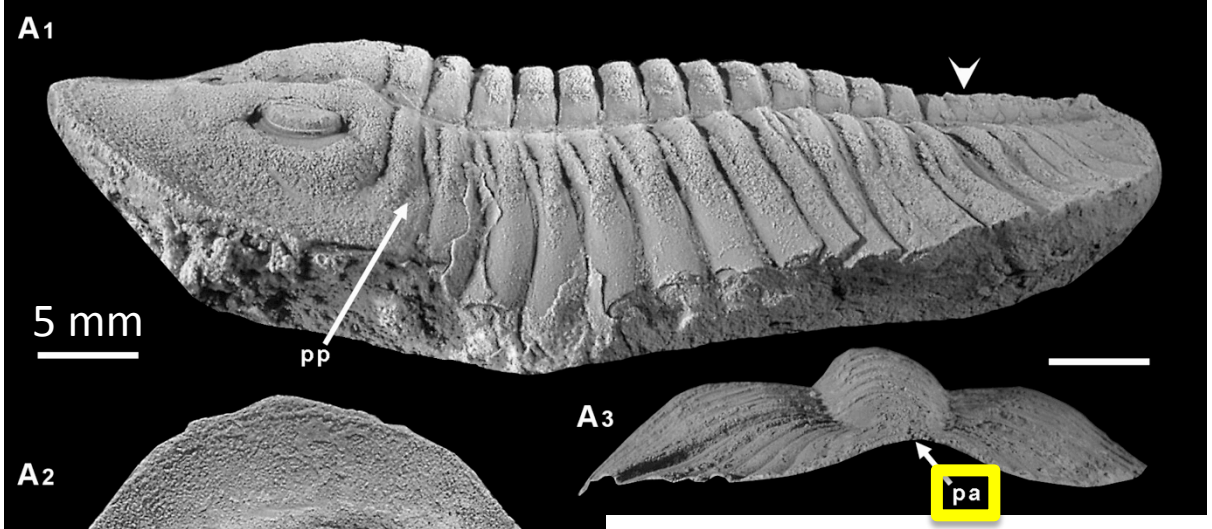


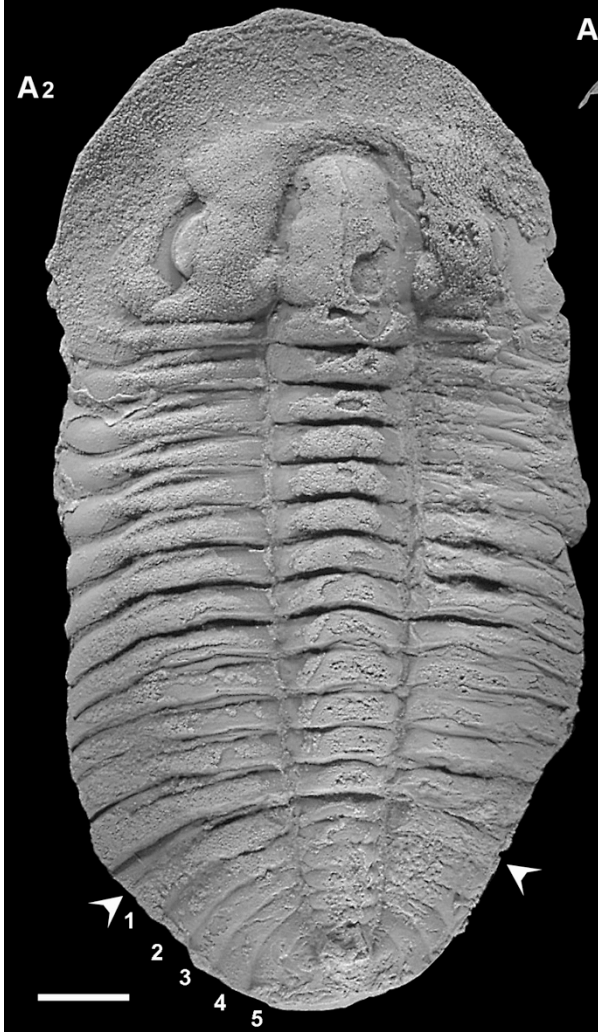
Bergström, 1973, fig. 8

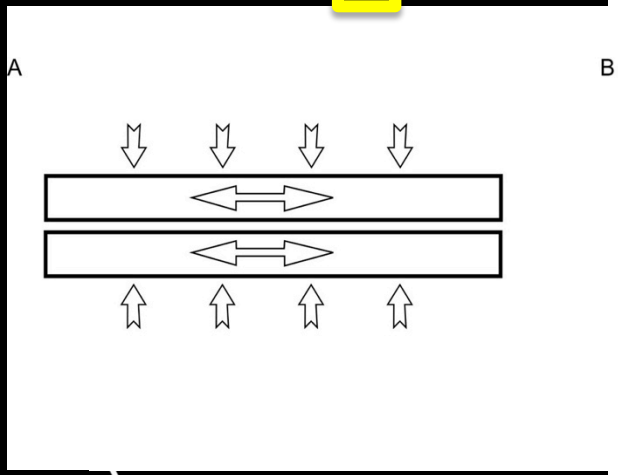


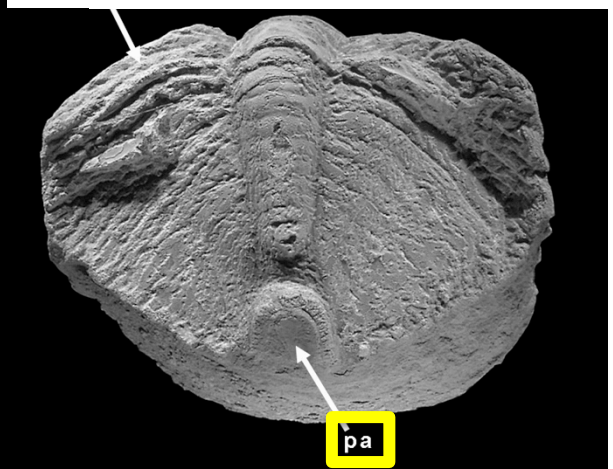
Esteve et al., 2011
Geology



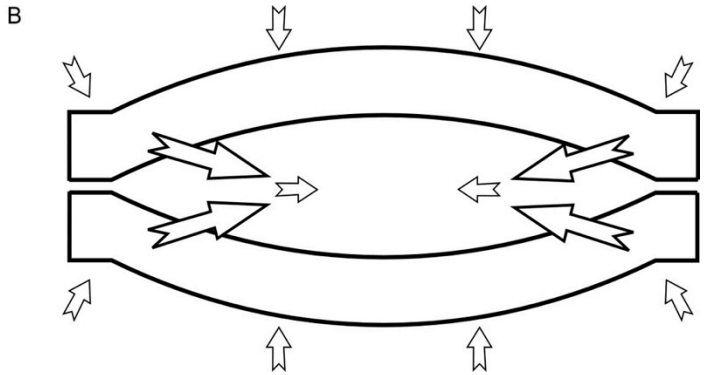






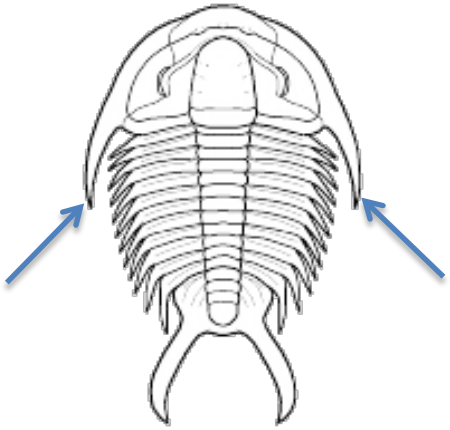


Posterior arch, PA

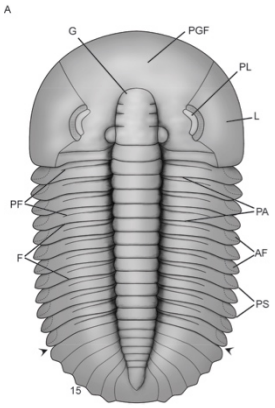


Yuan et al. 2014 *Lethaia*

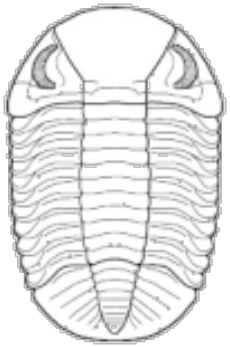
Genal spines



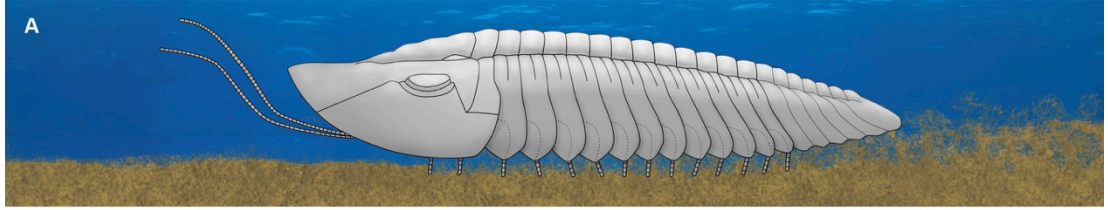
Tricrepicephalus

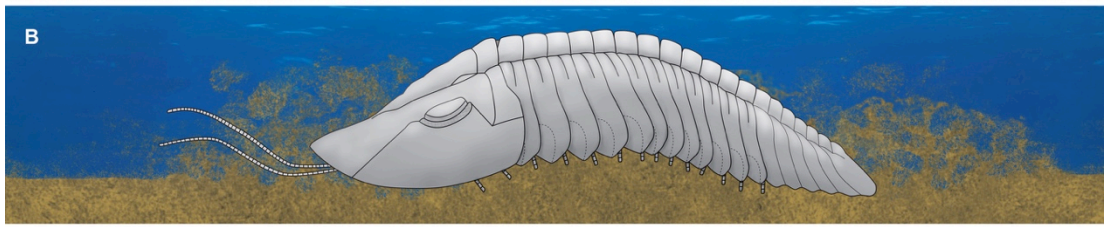


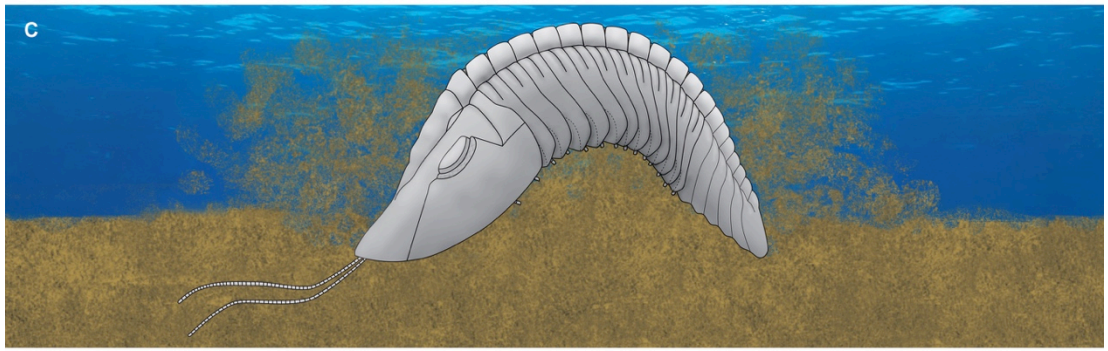
Monkaspis daulis

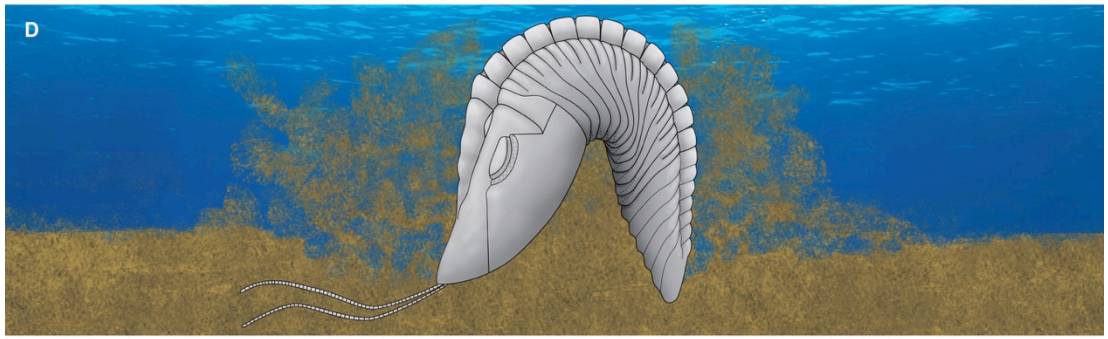


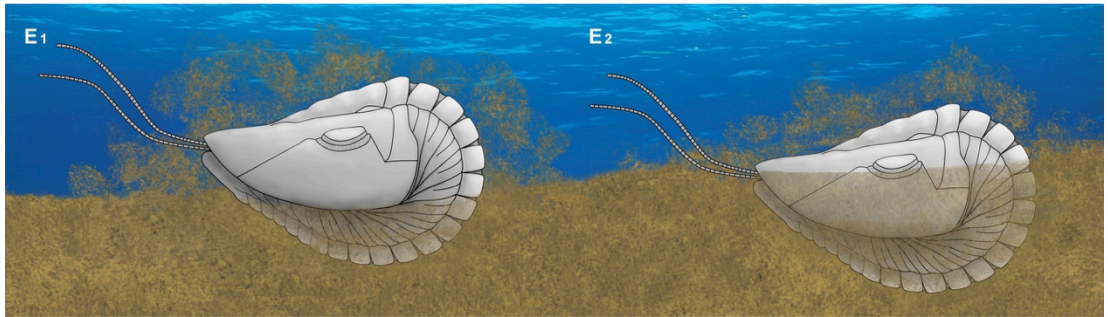
Phacops

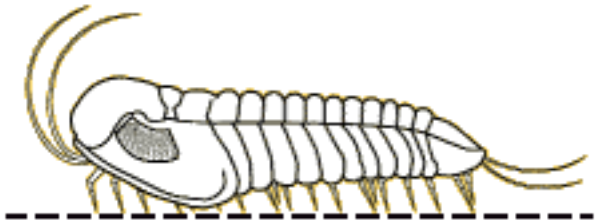


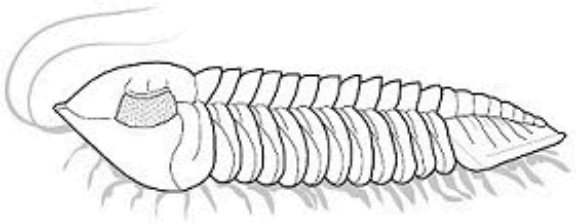












Yuan et al. 2014 *Lethaia*

Conclusions

First enrolled trilobite documented from Kushan Formation (Guzhangian, Cambrian Series 3) of North China

Articulation structures very well developed

Interlocking devices poorly developed, except terrace lines and novel structure “posterior arch” to reduce shear

Absence of genal spines (inhibited sinking into substrate) enabled the use of enrolment procedure to excavate in sediment for shelter

Yuan et al. 2014 *Lethaia*

New discoveries on Cambrian pelmatozoan echinoderm ossicles from North China

Tin-Wai Ng[a, b], Joseph P. Botting[a, c], Jin-Liang Yuan[a], and Jih-Pai Lin[d, *]

[a]Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

[b]Department of Earth Sciences, National Taiwan Normal University, Taipei 11677, Taiwan

[c]Chatsworth, Spa Road, Llandrindod Wells LD1 5EY, UK

[d]State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

Ng et al. (In review) *Palaeoworld*

棘皮動物分類

依生活方式：

- 游在亞門（Eleutherozoa [遊走亞門、無柄亞門或活動亞門]）
- 有柄亞門（Pelmatozoa [固著亞門]）：

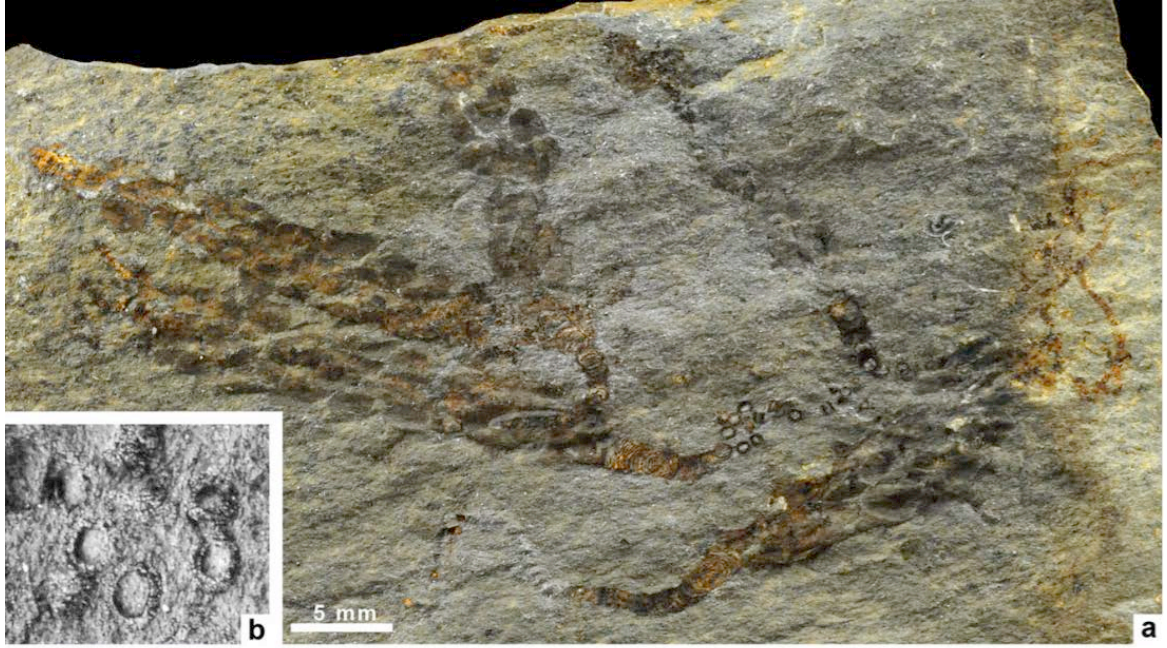
遊在亞門（Eleutherozoa）

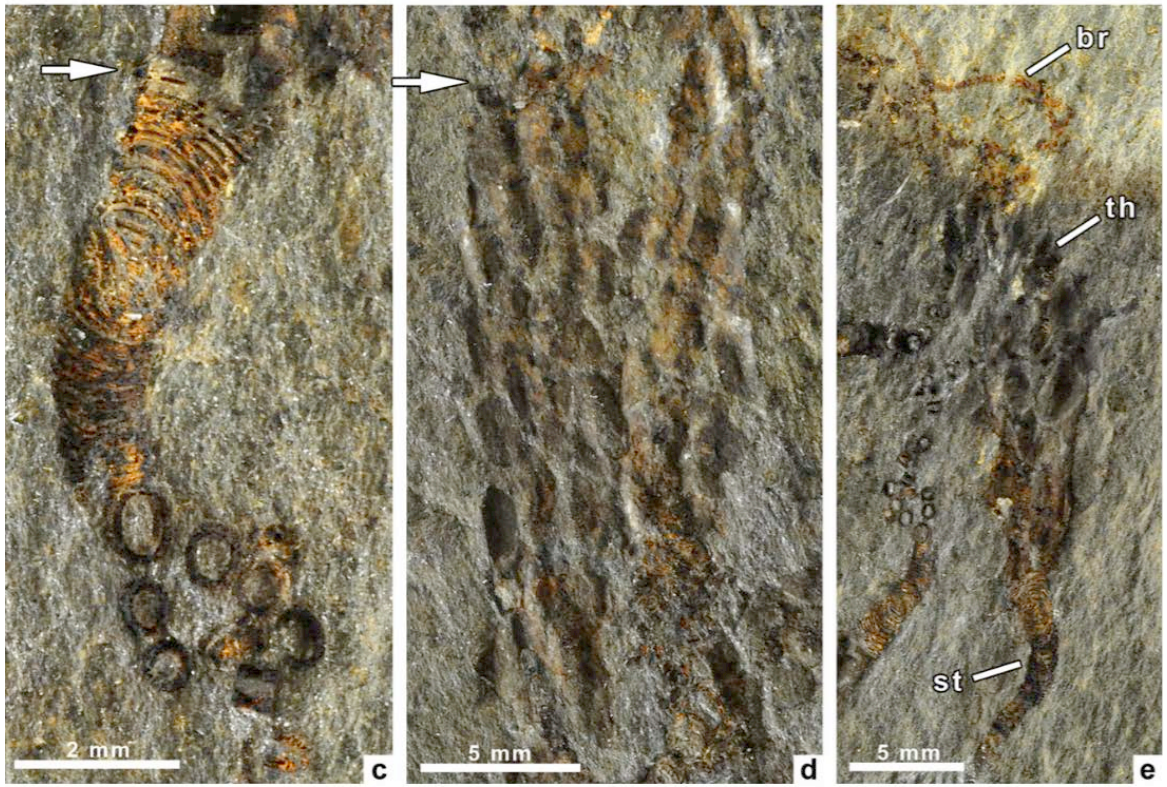
- 海星綱（Asteroidea）
- 同心綱（Concentricycloidea）
- 海膽綱（Echinoidea）
- 海參綱（Holothuroidea）
- 蛇尾綱（Ophiuroidea）

有柄亞門（Pelmatozoa）

- 海蕾綱（Blastoidea）
- 海百合綱（Crinoidea）
- 座海星綱（Edrioasteroids）

Wikipedia





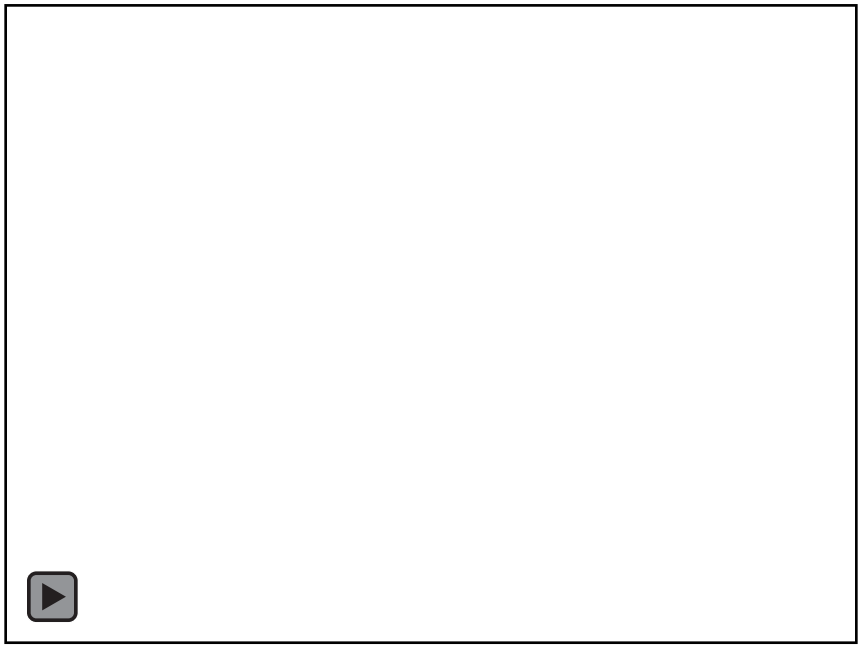
“Furongian (late Cambrian) echinoderms are extremely rare in the fossil record and only two previous reports have been described from the Paibian Stage worldwide.”

Zamora 2012
Britain
U. Cambrian

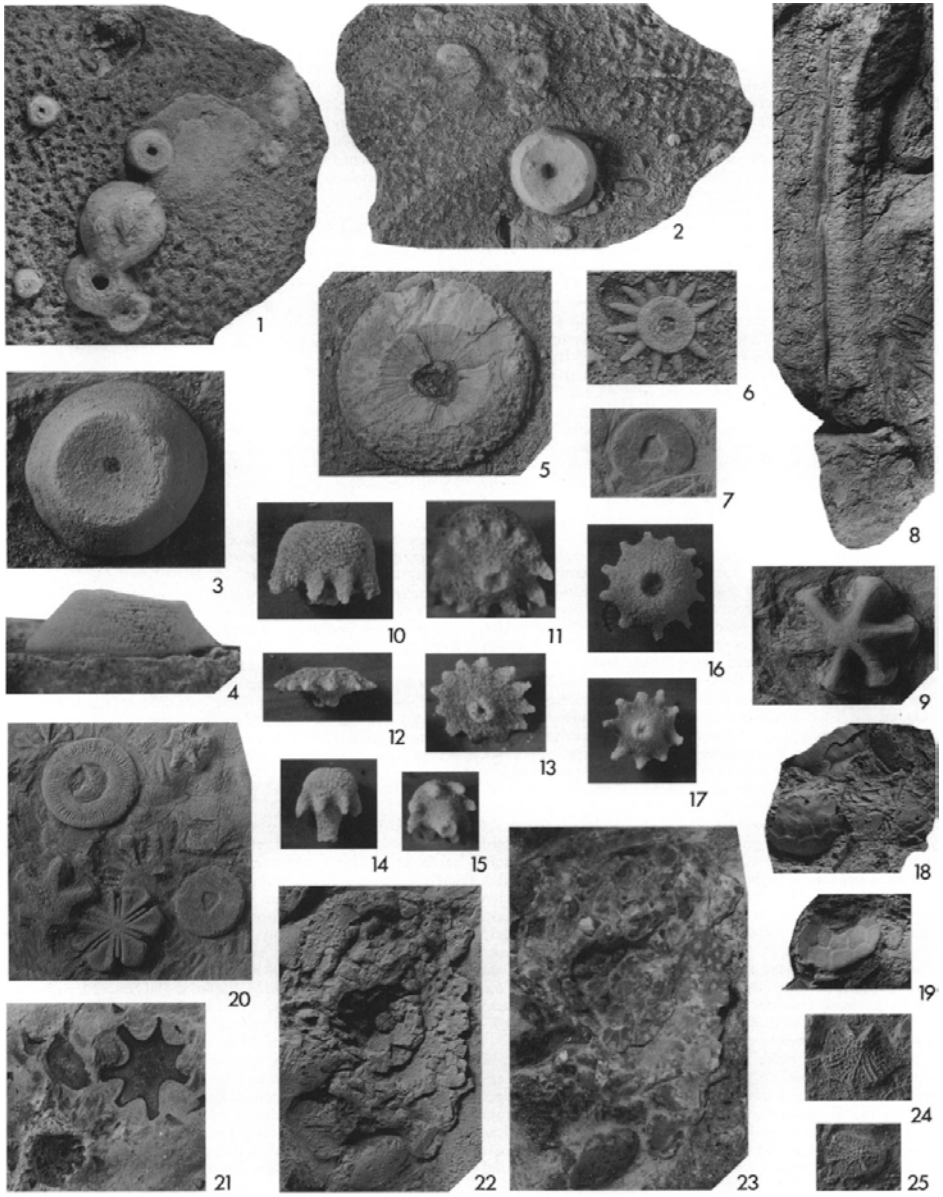
Tomasz K. Baumiller & Charles G. Messing (2007)
STALKED CRINOID LOCOMOTION, AND ITS ECOLOGICAL AND EVOLUTIONARY IMPLICATIONS

http://palaeo-electronica.org/2007_1/crinoid/index.html

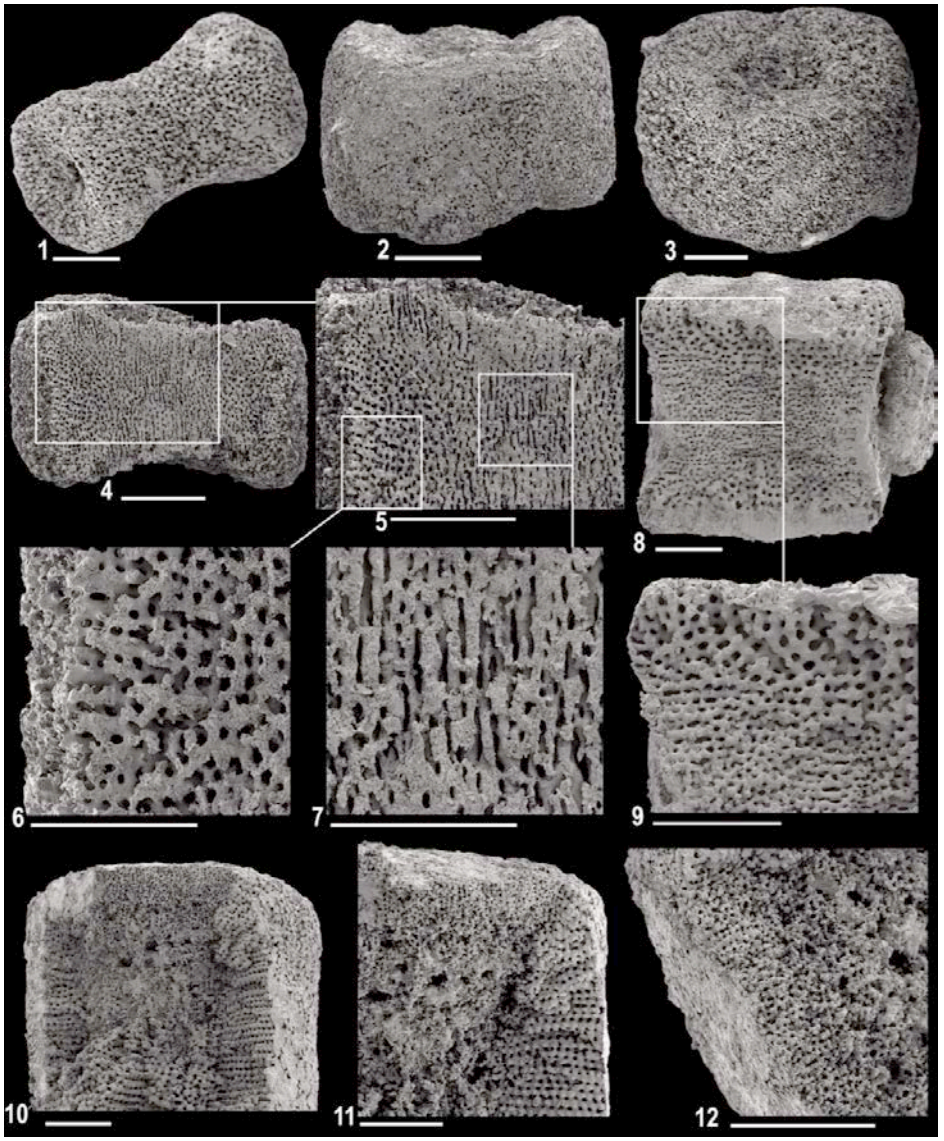
Location: Grand Bahama Island
Depth: 420 m
Speed: ~10-30 mm sec^{-1}



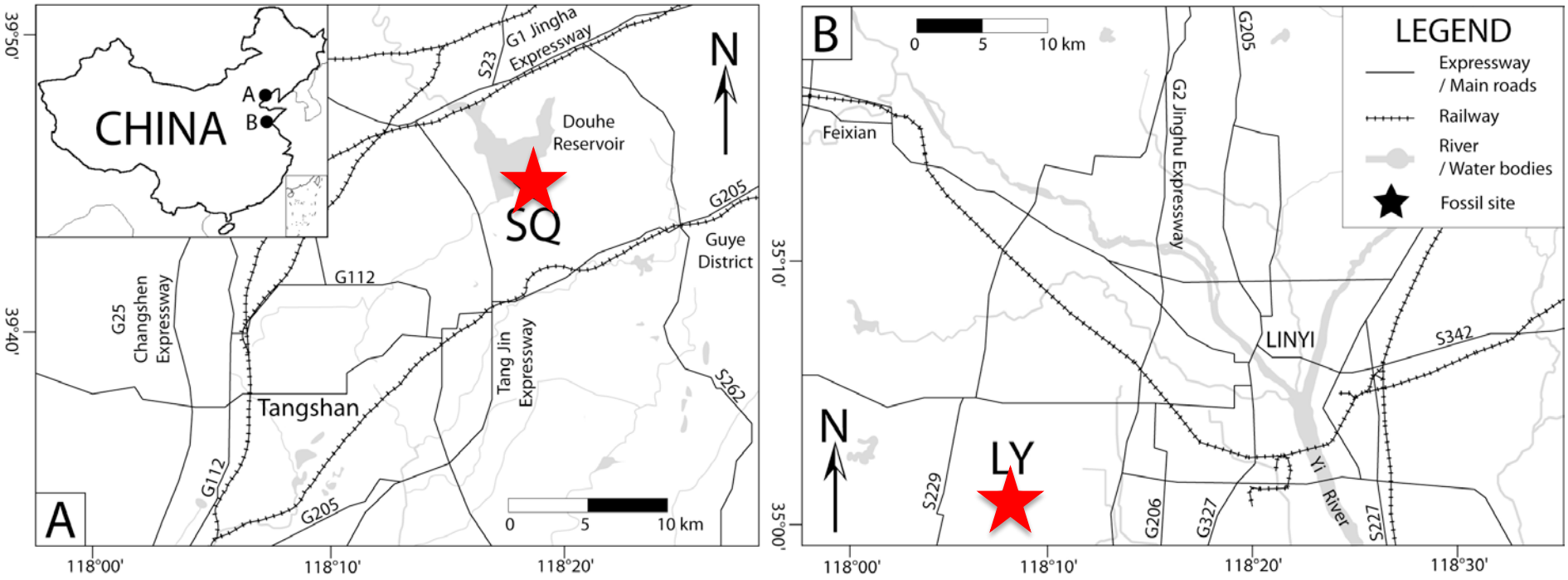
http://palaeo-electronica.org/2007_1/crinoid/fig3.htm



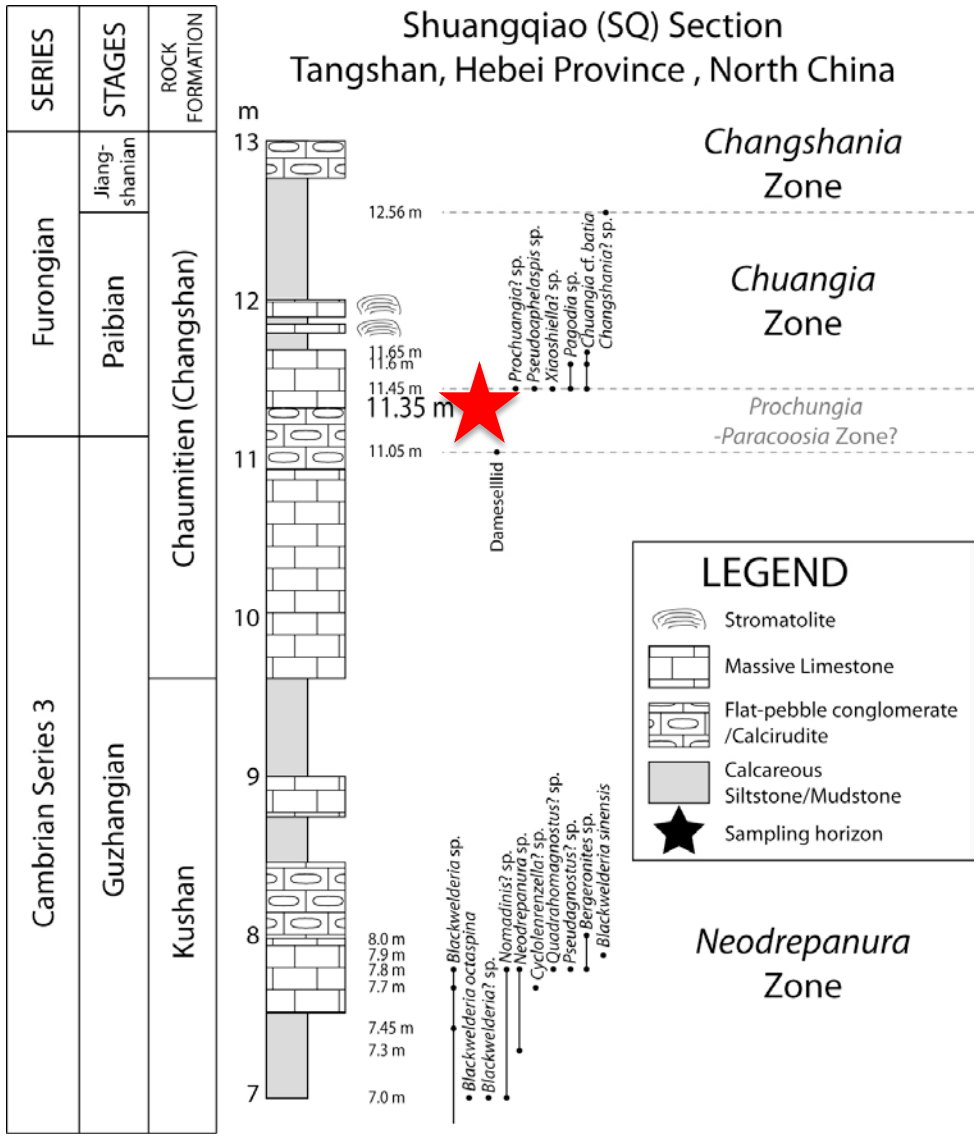
Sumrall et al. 1997
USA, U. Cambrian



Clausen & Smith 2008
Morocco
M. Cambrian



Ng et al. (In review) *Palaeoworld*



Ng et al. (In review) *Palaeoworld*

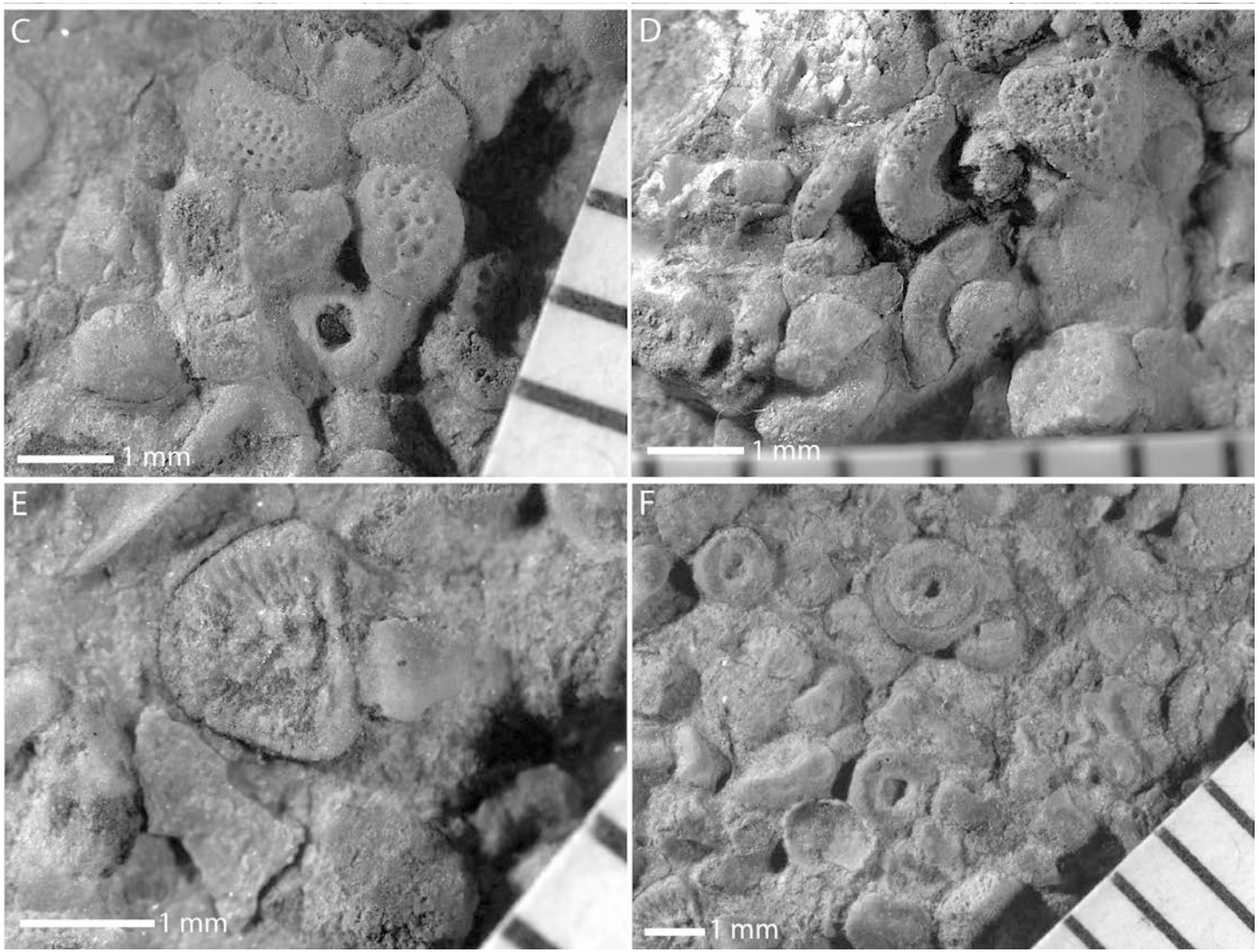
GLOBAL SERIES	GLOBAL STAGE	N. CHINA STAGE	ROCK FORMA -TION	BIOZONE
Furongian	Paibian	Changshanian	Chaumitien (Changshan)	*Chuangia*
				Prochuangia -Paracoosia
Cambrian Series 3	Guzhangian	Jinanian	Kushan	*Neodrepanura*

Echinoderm horizons

SQ

? LY

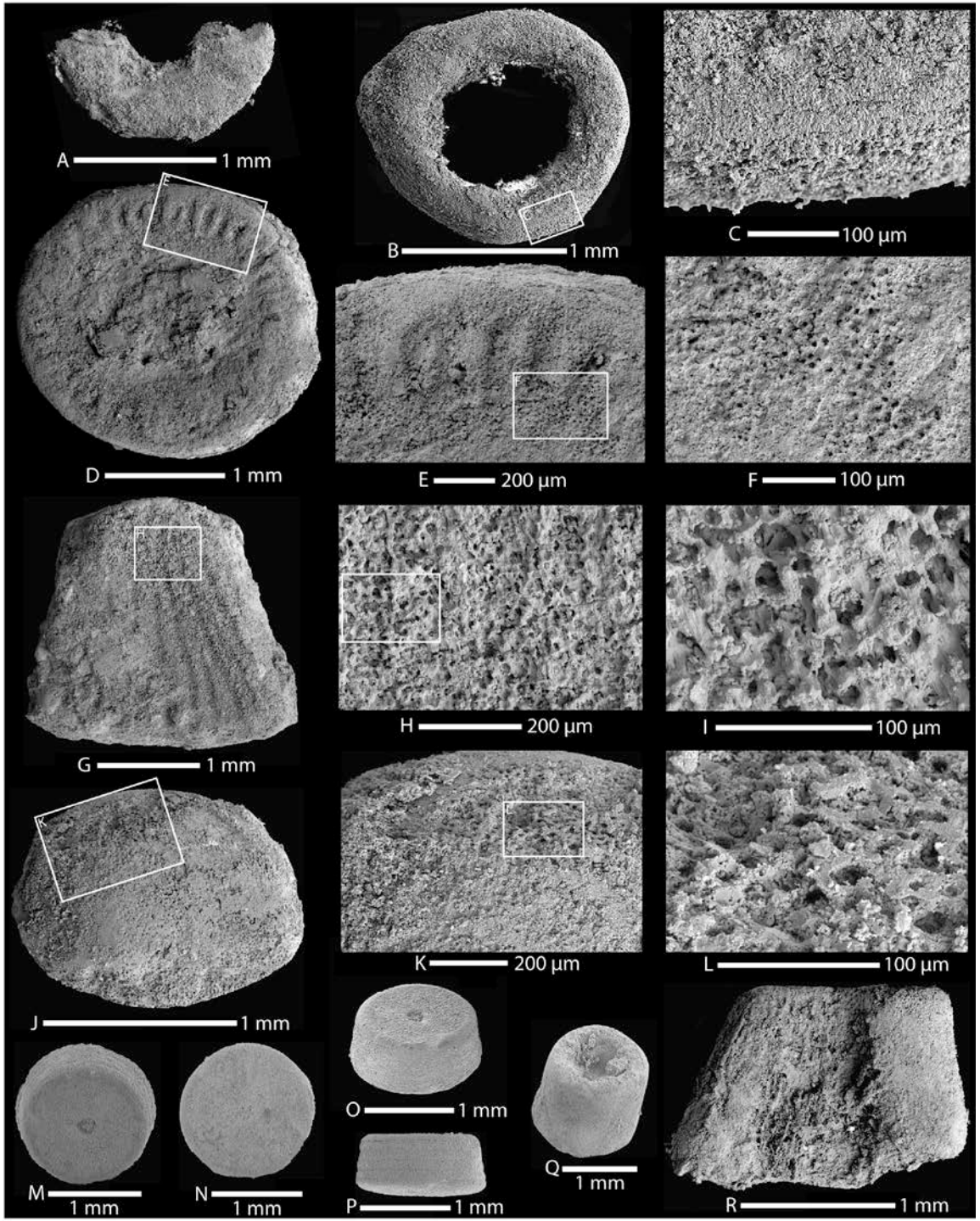
Ng et al. (In review) *Palaeoworld*



SQ

Ng et al. (In review) *Palaeoworld*

LY



Ng et al. (In review)
Palaeoworld

Conclusions

First record of echinoderms from late Cambrian North China

Only disarticulated ossicles

Interesting features: holomeric columnals with crenulated articulating

Our ossicles resemble later groups such as crinoids or rhombiferans

But absence of distinctive plates and structure

May belong to a currently unknown derived lineage of “eocrinoids”

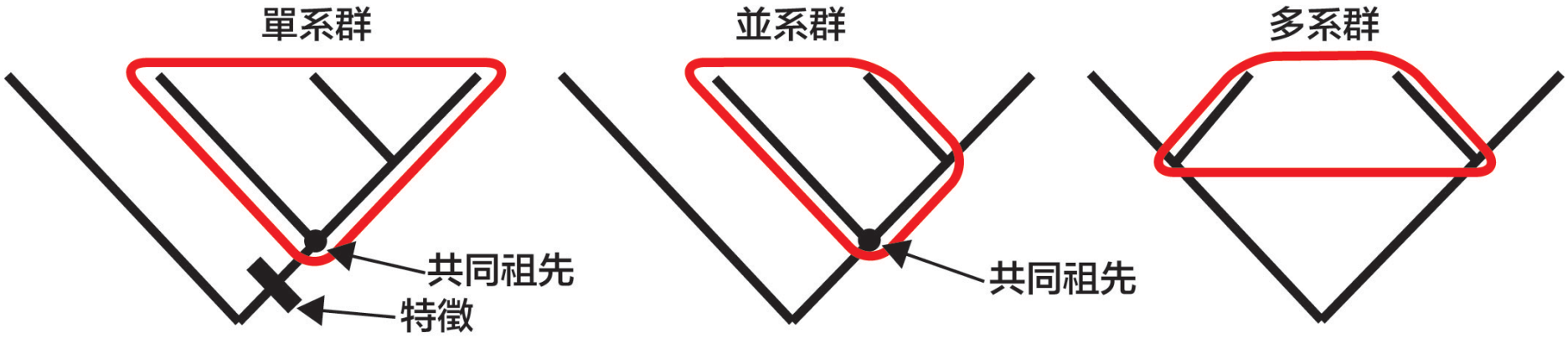
Preliminary Cladistic Analysis of Upper Cambrian Trilobite Families Crepicephalidae and Tricrepicephalidae

The phylogenetic relationship between the marjumiodean trilobites Families Crepicephalidae (*Crepicephalus*, *Coosella*, *Coosina*, *Coosia*) and Tricrepicephalidae (*Meteoraspis* and *Tricrepicephalus*) has long been discussed (e.g. Palmer, 1955; Pratt, 1992)

The monophyly of these genera is always in question and their relationship is still highly debatable (e.g. Poulsen, 1927; Kobayashi, 1935; Lochman and Duncan, 1944; Palmer, 1955; Pratt, 1992; Westrop, 1992)

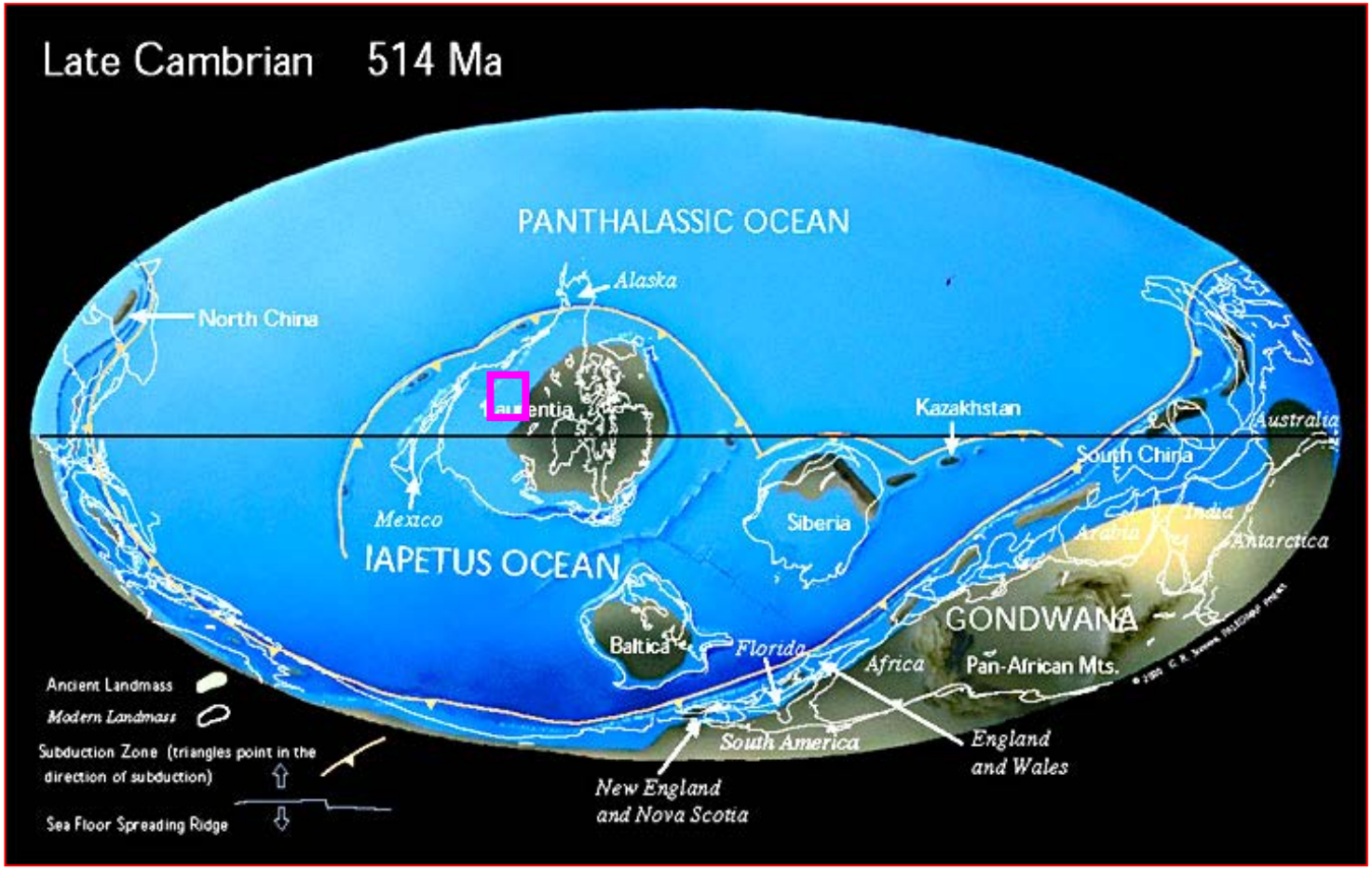
There was no cladistic attempt to tackle this problem

Ng, unpublished data

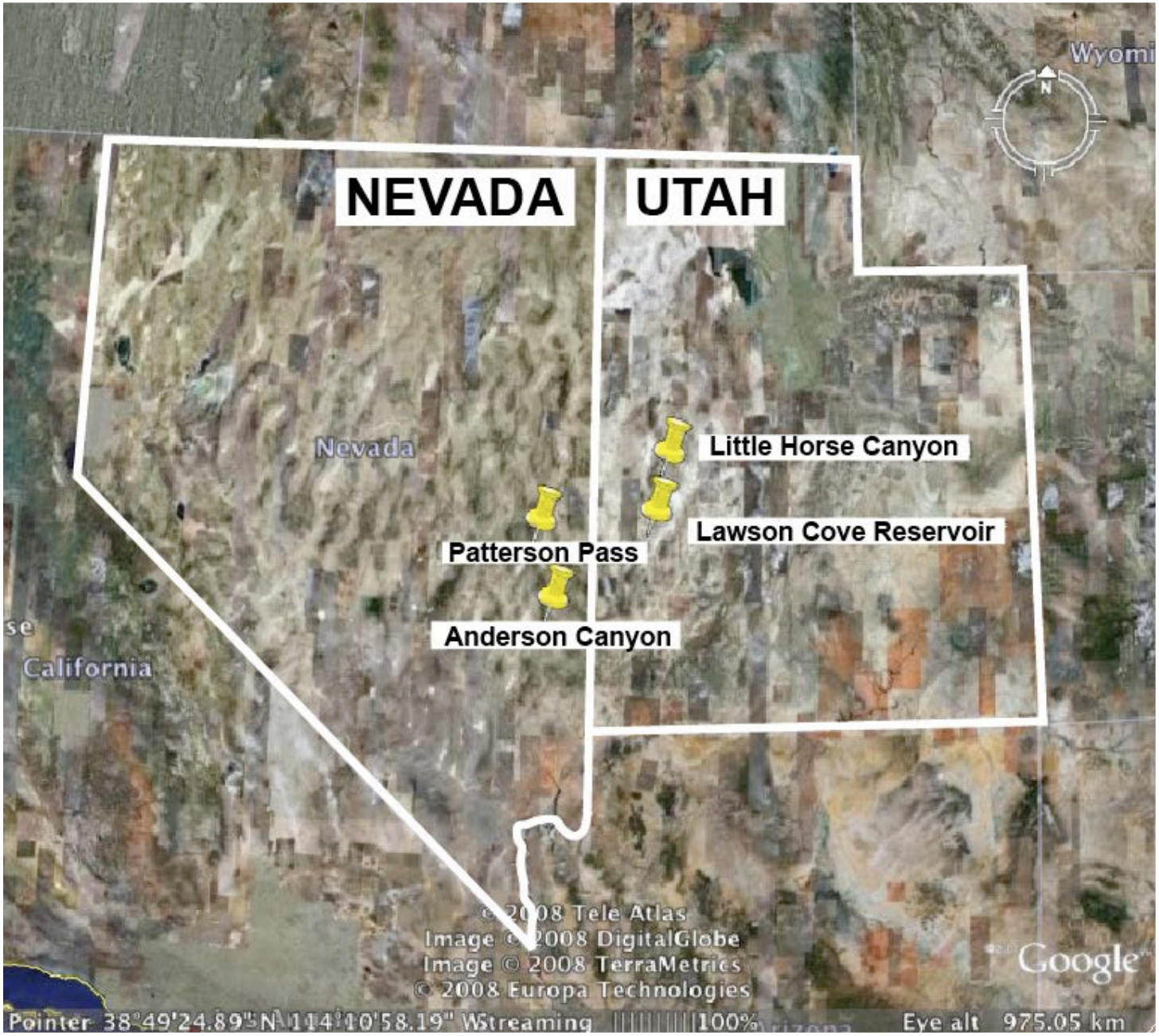


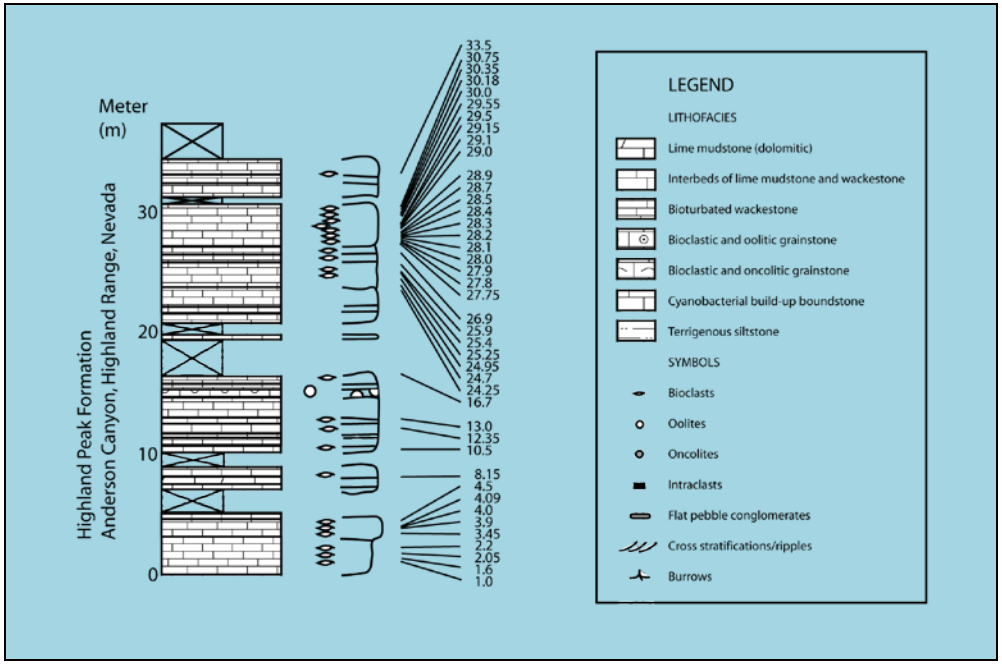
單系群(monophyletic group)
分類單元(taxon；複數taxa)中的所有成員均可追索到單一個最接近現代的共同祖先(most recent common ancestor)並包括該祖先的所有後代

Geologic Background



http://www.scotese.com/newpage12.htm


NEVADA
UTAH
Little Horse Canyon
Lawson Cove Reservoir
Patterson Pass
Anderson Canyon
Nevada
California
Wyomi
© 2008 Tele Atlas
Image © 2008 DigitalGlobe
Image © 2008 TerraMetrics
© 2008 Europa Technologies
Google
Pointer 38°49'24.89" N 114°10'58.19" W
Streaming
100%
Eye alt 975.05 km



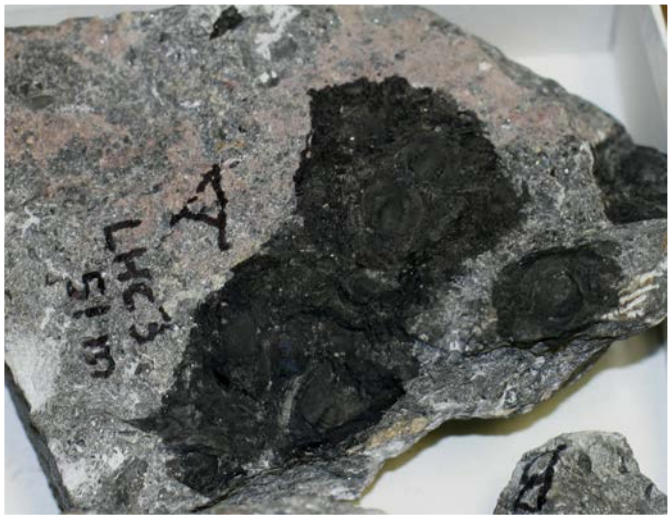
Anderson Canyon, Highland Range, Nevada

Ng, unpublished data

Photographing trilobite specimens

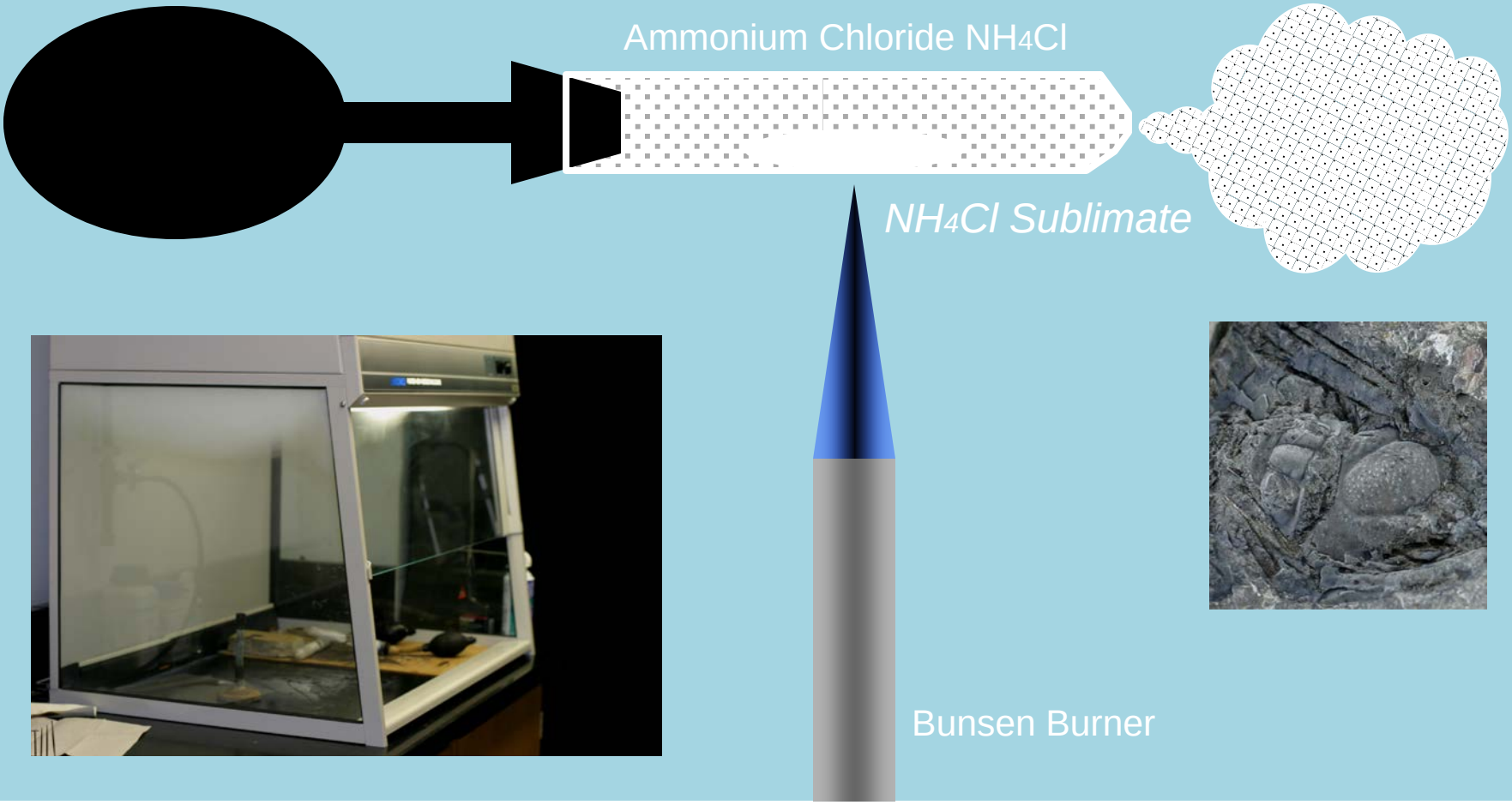
1. Mechanical preparation

2. Blackening specimen



Label *all* specimens!!

3. Whitening specimen



4. Photography

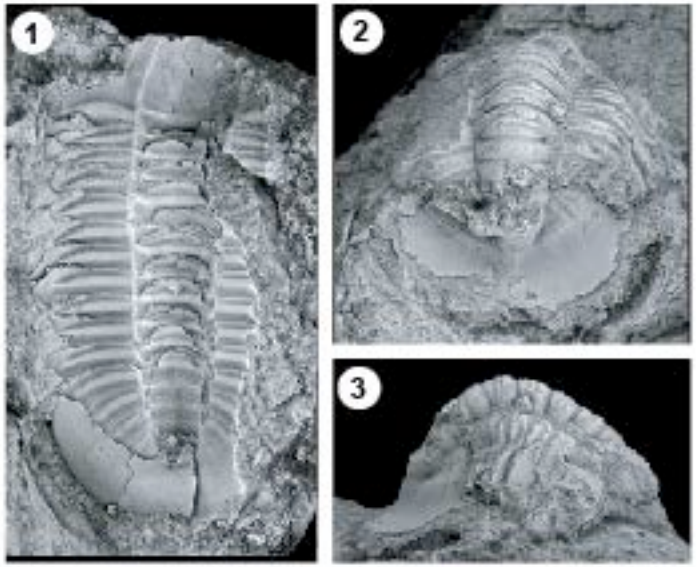
5. Photo processing

Trilobite Specimens

Over 1 metric ton bulk samples

Over 11,000 sclerites

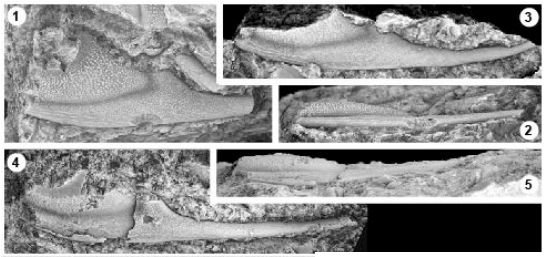
Over 7,400 individuals



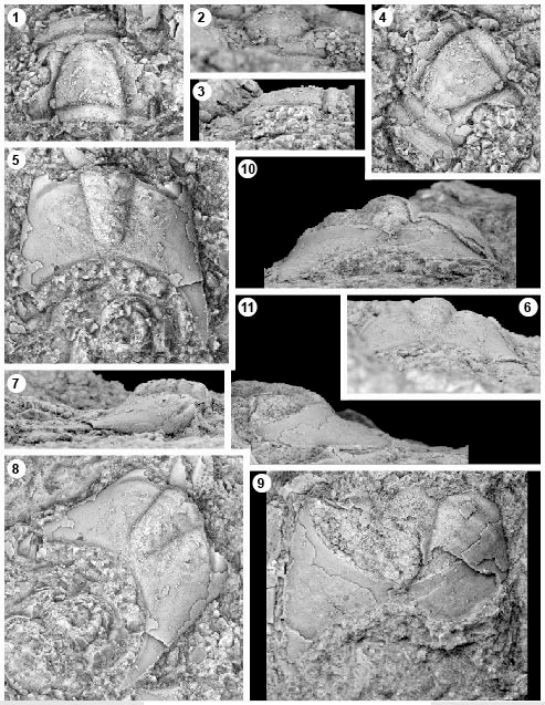
Ng, unpublished data

Crepicephalus zone

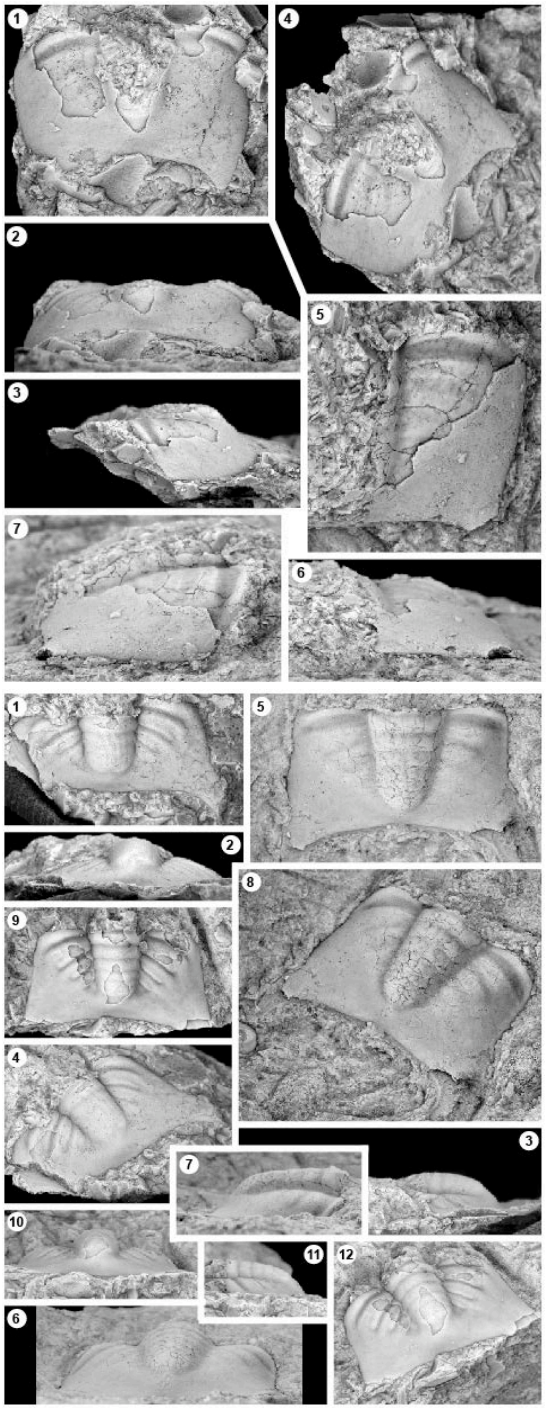
Crepicephalus



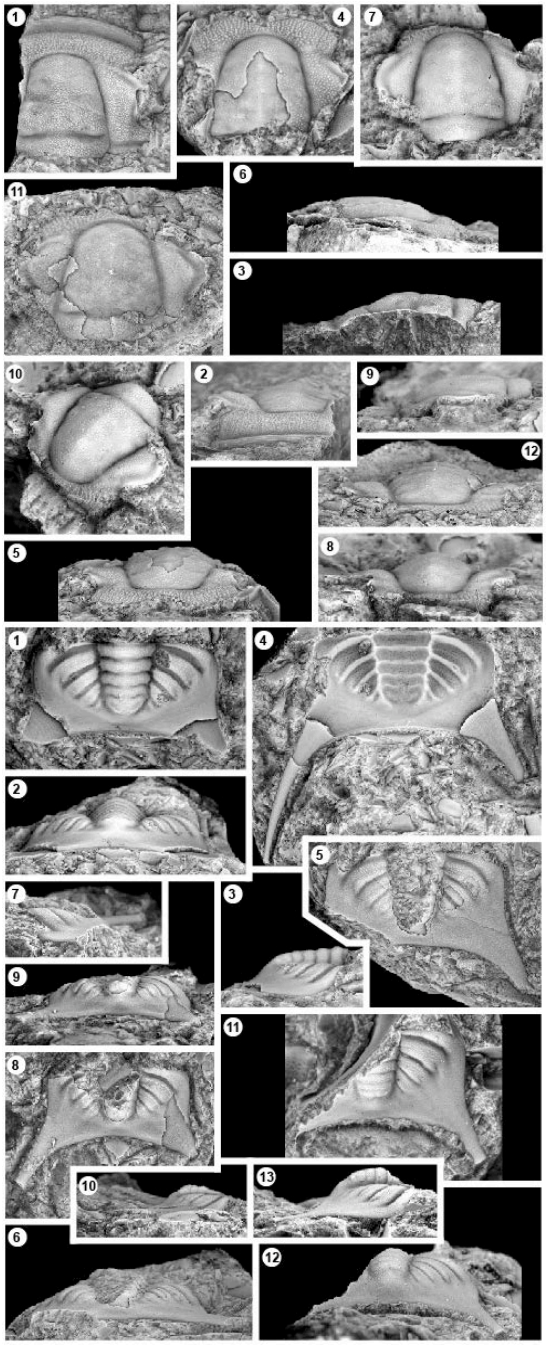
AC-24.25m



LHC-3-113.5m



LHC-3-109.62m



Ng, unpublished data

Data Matrix

36 taxa (including outgroup)

Outgroup *Modocia dubia*

54 characters

28 coded on the cranidium

7 coded on the librigena

18 coded on the pygidium

29 binary characters

25 multistate characters

Outgroup character states all set to 0

Ng, unpublished data

Data Matrix

	Taxa		Character																																																					
			Cranidium																												Librigena							Pygidium																	
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
0	*Modocia*	*dubia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	*Coosella*	*helena*	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	?	0	1	1	1	0	1	1	1	1	1	2	1	1	1	1	1	1	2	0	0	0	0	0	0	0	0
2	*Coosella*	*magna*	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	1	1	1	1	2	0	1	1	1	1	0	1	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0
3	*Coosella*	*orbis*	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	2	2	1	1	2	0	1	0	?	1	1	1	1	2	0	?	?	1	0	0	0	1	1	2	1	1	1	2	0	0	0	0	0	0	0	0
4	*Coosella*	*paraperplexa*	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	2	1	0	0	0	1	0	1	1	2	0	1	1	1	0	0	2	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0
5	*Coosella*	*perplexa*	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	?	0	0	1	1	2	1	0	0	0	1	0	1	1	2	0	1	1	1	1	0	2	1	1	2	0	1	1	2	0	0	0	0	0	0	0	0
6	*Coosella*	*planicauda*	0	1	0	1	1	0	0	1	0	0	0	1	0	?	0	0	0	0	1	1	1	1	1	0	0	1	?	?	1	?	?	?	?	?	?	?	1	0	3	0	1	2	1	1	1	2	0	0	0	0	0	0	0	0
7	*Coosella*	*quadrata*	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	2	2	1	1	2	1	0	0	1	0	1	?	?	?	?	?	?	?	1	1	1	1	1	1	1	1	1	2	0	0	0	0	0	0	0	0
8	*Coosella*	*trapezia*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	2	2	1	1	1	0	0	0	1	1	1	?	?	?	?	?	?	?	1	0	1	1	1	1	1	1	1	2	0	0	0	0	0	0	0	0
9	*Coosia*	*alethes*	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	2	2	1	1	1	0	0	0	1	1	1	?	?	?	?	?	?	?	0	0	3	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0
10	*Coosia*	*macro*	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	2	1	1	1	0	2	0	1	1	1	1	1	2	0	1	1	0	0	0	3	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
11	*Coosina*	*amage*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	2	1	0	0	1	0	1	?	?	?	?	?	?	?	1	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
12	*Coosina*	*ariston*	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	1	1	1	1	2	0	0	1	1	0	0	0	0	1	1	0	2	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
13	*Coosina*	*kindlei*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2	0	0	1	0	0	0	0	0	1	1	1	1	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
14	*Crepicephalus*	*cf. C. iowensis*	0	2	0	1	1	1	1	1	0	0	0	1	1	0	0	1	1	0	2	2	1	0	1	1	0	0	1	0	2	1	2	1	1	1	2	1	0	0	1	1	1	2	0	1	0	0	1	1	1	1	1	1	1	0
15	*Crepicephalus*	*charliebrowni*	0	2	0	1	1	1	1	0	0	0	0	1	1	0	0	1	1	0	1	1	1	0	1	1	0	0	1	0	2	1	2	1	0	1	1	1	0	0	1	1	1	2	0	1	0	0	1	2	1	1	1	1	2	0
16	*Crepicephalus*	*columbiensis*	0	2	0	1	1	1	1	0	0	0	0	1	1	0	0	1	1	0	1	1	1	0	1	0	0	0	1	0	2	1	2	1	0	1	1	1	0	0	2	1	1	2	0	1	0	0	1	1	2	1	1	0	0	0
17	*Crepicephalus*	*linusvanpelti*	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2	2	1	1	0	1	0	0	1	0	1	1	2	1	0	1	1	1	1	0	1	1	1	2	0	1	0	0	1	2	2	1	1	0	0	0
18	*Crepicephalus*	*lucyvanpeltae*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	1	1	2	0	0	1	1	1	?	?	?	?	?	?	?	1	1	1	1	1	2	1	1	0	0	1	1	2	1	1	0	0	0
19	*Crepicephalus*	*narrisicanus*	0	2	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	2	1	0	1	1	0	0	0	1	1	1	2	1	1	0	0	1	2	2	1	1	0	0	0
20	*Crepicephalus*	*rabbitkettlei*	0	1	0	1	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	0	0	2	0	1	0	0	1	2	1	0	1	1	1	0	1	1	1	1	2	1	1	0	0	1	1	2	1	1	0	0	0
21	*Crepicephalus*	*rerunvanpelti*	0	2	0	1	1	1	1	1	0	0	0	1	1	0	0	1	1	0	2	2	1	0	1	0	0	0	1	1	2	1	2	2	1	1	1	1	0	0	0	1	0	0	0	1	0	0	1	2	1	1	1	0	0	0
22	*Crepicephalus*	*schroederi*	0	2	0	1	1	1	1	0	0	0	0	1	0	0	0	1	1	0	2	2	1	0	1	1	0	0	1	0	2	1	2	1	1	1	2	1	0	0	1	1	1	2	0	1	0	0	1	2	1	1	1	1	2	0
23	*Crepicephalus*	*sallybrownae*	0	2	0	1	1	1	1	0	0	0	0	1	1	0	0	1	1	0	2	2	0	0	0	1	0	0	1	0	2	?	?	?	?	?	?	?	0	0	0	1	0	0	0	1	0	0	1	1	1	1	1	1	1	0
24	*Crepicephalus*	*snoopyi*	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	0	1	2	0	0	1	1	1	1	2	0	1	1	1	1	0	0	1	1	2	0	1	0	0	1	2	2	1	1	0	0	0
25	*Crepicephalus*	*snowyensis*	0	1	0	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	0	2	0	1	0	0	1	2	1	0	1	1	0	1	0	1	1	1	2	0	1	0	0	1	2	2	1	1	0	0	0
26	*Crepicephalus*	*spikei*	0	2	0	1	1	1	1	0	0	0	0	1	0	0	0	1	1	0	?	?	?	?	1	1	0	0	?	0	2	1	2	1	1	1	2	1	0	0	1	1	1	2	0	1	0	0	1	1	1	1	1	1	2	0
27	*Crepicephalus*	*woodstocki*	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	?	2	2	1	1	2	2	2	0	1	1	1	?	?	?	?	?	?	?	1	0	1	1	1	2	0	1	0	0	1	2	2	1	1	0	0	0
28	*Meteoraspis*	*brevispinosa*	1	0	2	0	0	0	0	1	1	1	2	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1	1	1	1	?	?	?	?	?	?	?	3	1	0	0	0	0	0	1	0	0	1	2	2	1	1	0	0	0
29	*Meteoraspis*	*mutica*	1	0	2	0	0	0	0	0	1	1	2	0	0	1	0	0	0	1	1	0	1	0	0	0	1	0	?	?	1	?	?	?	?	?	?	?	2	1	1	0	0	0	0	1	0	0	1	2	2	1	1	0	0	0
30	*Meteoraspis*	*rasettii*	1	0	2	0	0	0	0	1	1	1	1	0	0	1	0	0	0	1	0	1	?	0	0	0	0	0	1	0	1	1	1	2	0	1	1	2	3	1	0	0	0	0	0	1	0	0	1	2	2	1	1	0	0	0
31	*Meteoraspis*	*walcotti*	1	0	2	0	0	0	0	0	1	1	2	0	1	1	0	0	0	1	0	0	1	0	0	0	1	0	1	?	1	1	1	2	0	?	?	1	3	1	1	0	0	0	0	1	0	0	1	1	2	1	1	0	0	0
32	*Tricrepicephalus*	*beethoveni*	0	0	0	0	0	1	2	0	1	2	1	0	0	0	0	1	2	0	2	0	1	1	2	1	1	0	1	0	2	1	2	1	1	0	0	1	3	1	1	0	0	0	0	1	0	0	1	1	1	2	2	1	1	1
33	*Tricrepicephalus*	*brahsmi*	0	0	0	0	0	1	2	0	1	2	1	0	0	0	0	1	2	0	0	0	1	1	2	1	1	1	?	?	2	1	1	1	1	0	0	0	1	1	1	0	0	0	0	1	0	0	1	?	?	2	2	0	0	0
34	*Tricrepicephalus*	*schummani*	0	0	0	0	0	1	2	0	1	2	1	0	0	0	0	1	2	0	0	1	1	1	2	1	0	1	1	0	2	1	2	1	1	0	0	0	1	1	3	0	0	0	0	1	0	0	1	1	1	2	1	0	0	0
35	*Tricrepicephalus*	*thoosa*	0	0	0	0	0	1	2	0	1	2	1	0	0	0	0	1	2	0	2	0	1	1	1	1	0	0	1	0	2	?	?	?	?	?	?	?	2	1	3	0	0	0	0	1	0	0	1	1	1	2	2	1	1	1

Ng, unpublished data

Analysis

Tree Analysis Using New Technology (TNT), v. 1.1 (Goloboff et al., 2003)

Collapsing rule set to none

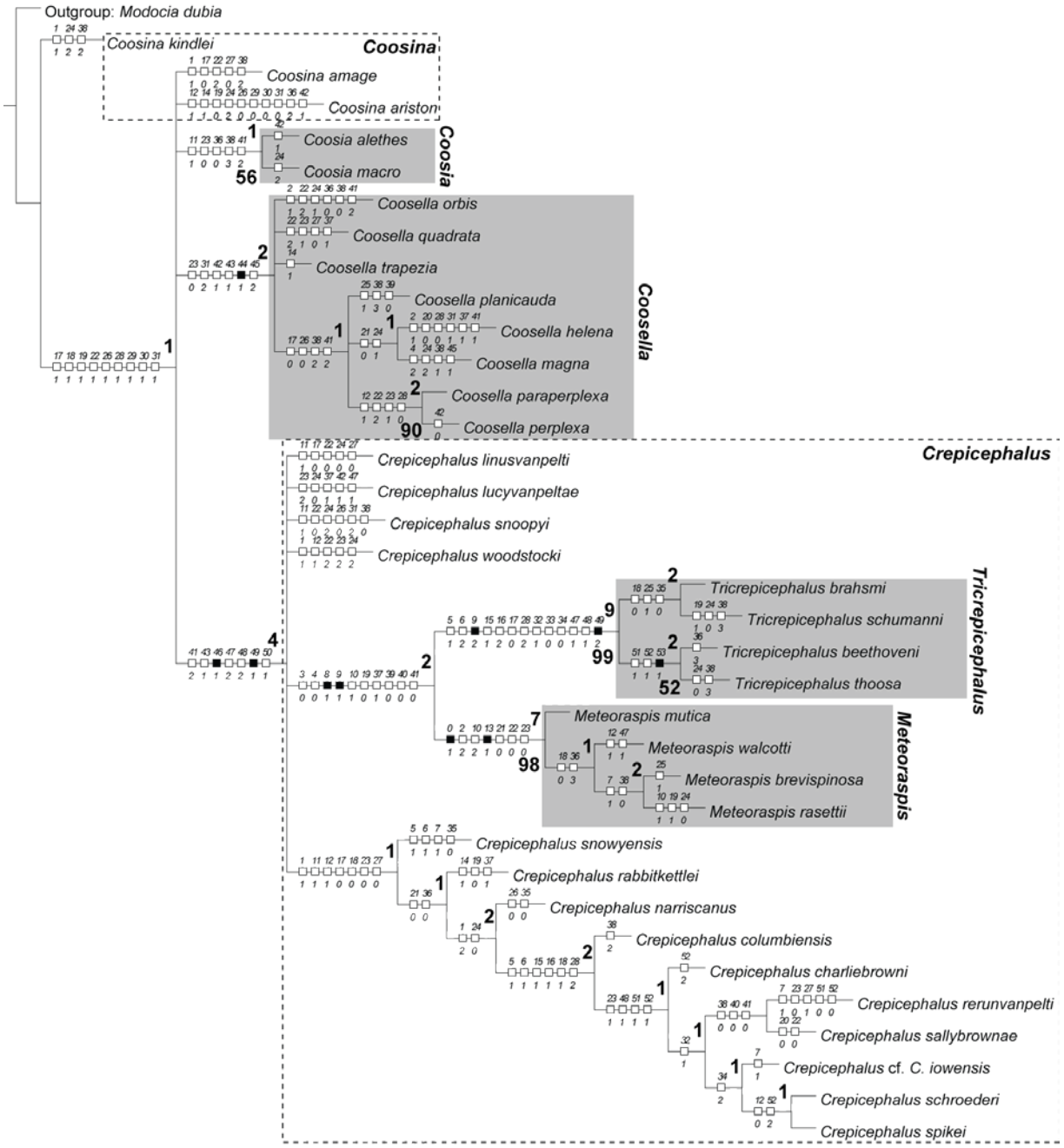
Traditional search with starting trees – Wagner trees with 1,000 random seeds and 1,000 repls.

Standard nonparametric bootstrapping with 5,000 replicates

Bremer support evaluated using PAUP* v. 4.0 (Swofford, 2004) & TreeRot v. 2.1 (Sorenson, 1999)

Strict consensus tree constructed by Winclada, v. 1.00.08 (Nixon, 2002)

Ng, unpublished data



Strict consensus tree with unambiguous characters

Tree Length = 252
Consistency Index = 0.31
Retention Index = 0.71
No. of MPTs = 43

Ng, unpublished data

Conclusions & Implications

First attempt at cladistic analysis of the genera *Coosia*, *Coosella*, *Coosina*, *Crepicephalus*, *Meteoraspis*, and *Tricrepicephalus*

Robust result shows that *Meteoraspis*, and *Tricrepicephalus* are sister taxa and both monophyletic

Coosella and *Coosia* are also monophyletic but with weak character support

Coosina and *Crepicephalus* are paraphyletic(?)

Further investigation with broader taxon sampling is needed to further test these preliminary results

Ng, unpublished data

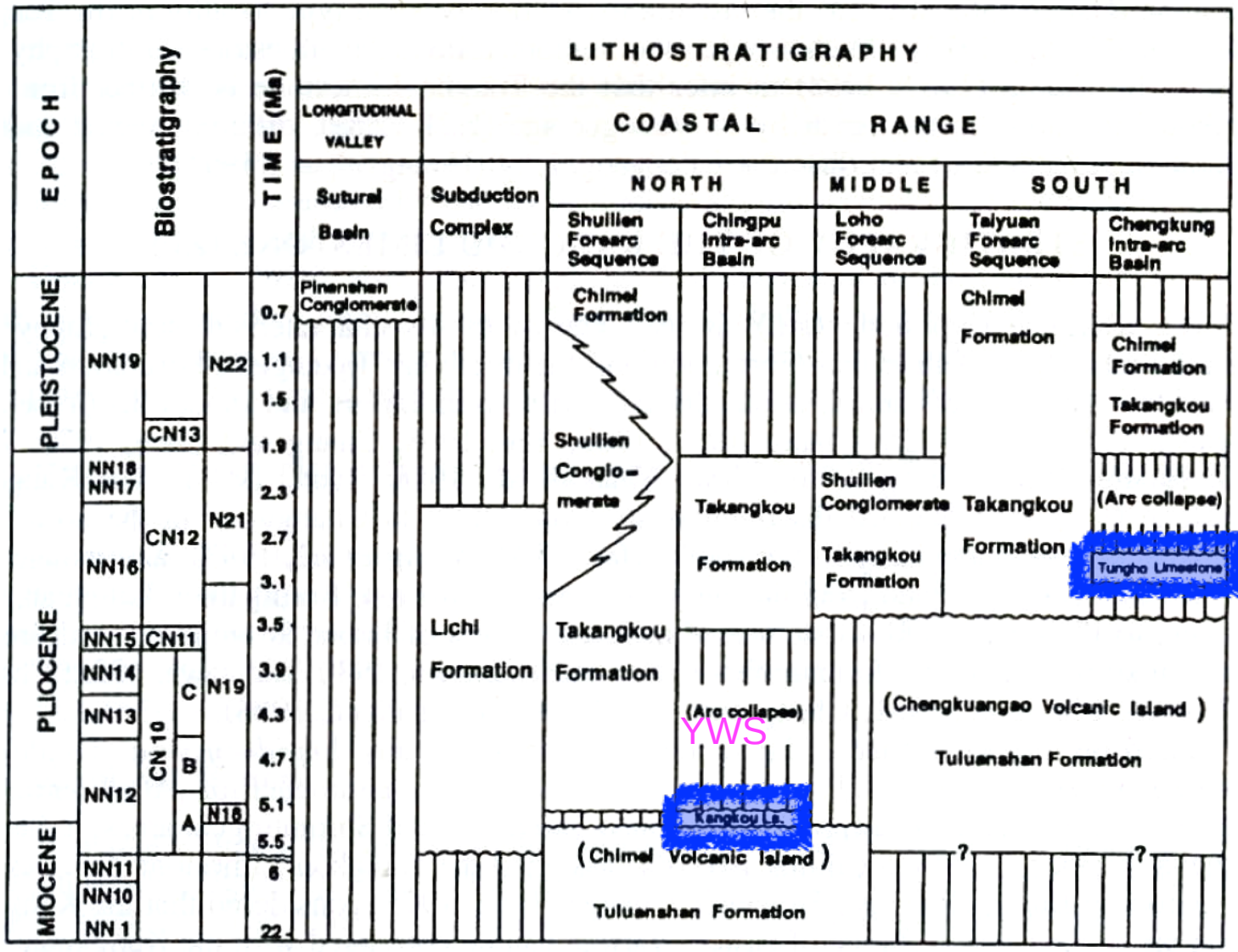
Quantitative paleontological analyses and implications of fossil assemblages of the Late Neogene Kangkou Limestone, Coastal Range, eastern Taiwan

臺灣東部海岸山脈晚新近紀港口石灰岩化石群集之古生態學定量分析

吳天偉 Tin-Wai Ng [a,b,c]
鄧屬予 Louis Suh-yui Teng [b]

[a] Department of Earth Sciences, National Taiwan Normal University
[b] Department of Geosciences, National Taiwan University
[c] Nanjing Institute of Geology and Palaeontology, CAS (NIGPAS)

Ng & Teng (2014) *Palaeoworld*, 23, 69-89 *d*x.doi.org/10.1016/j.palwor.2013.10.003



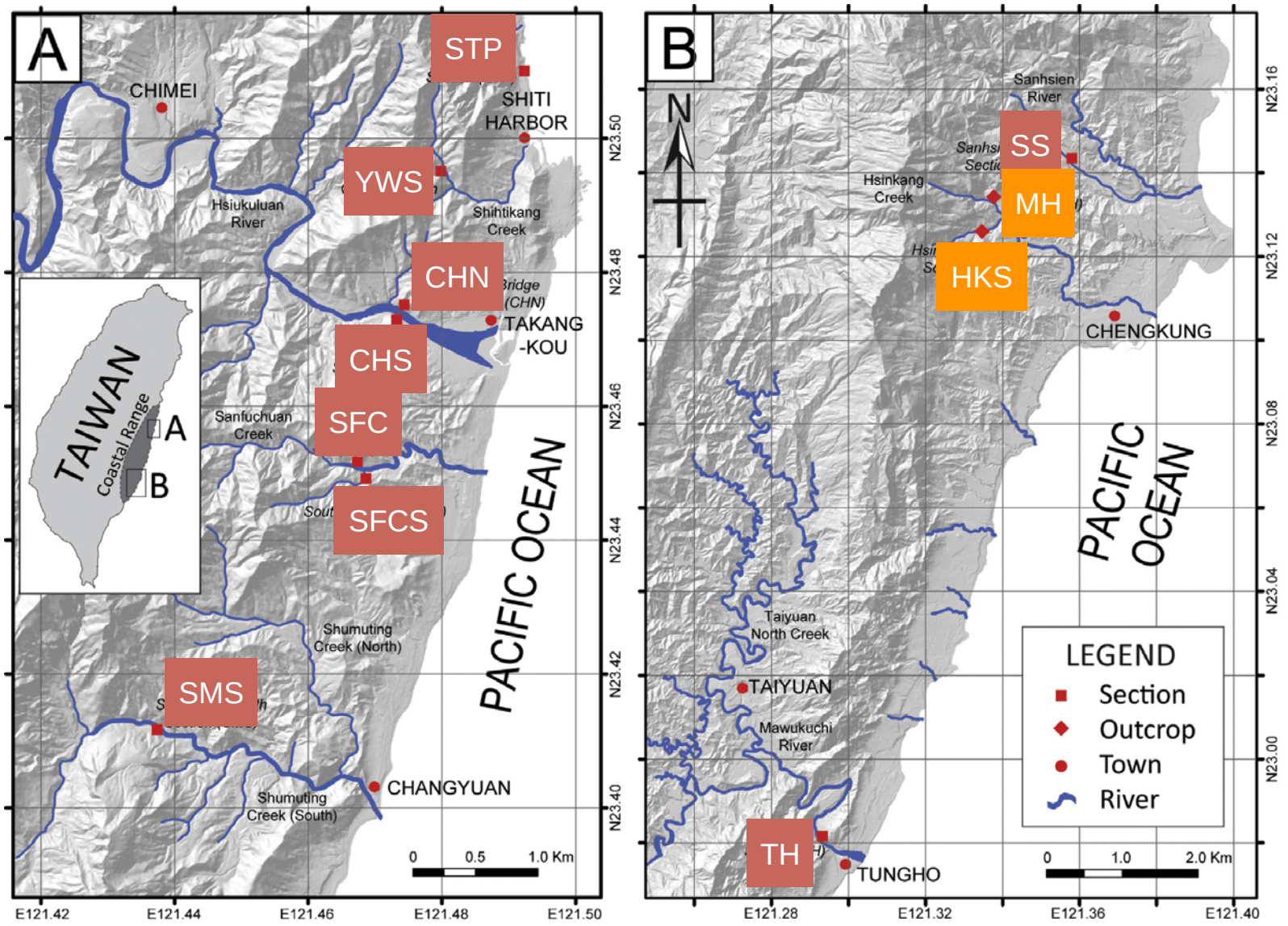
3.1-2.9 Ma

4.3-3.5 Ma

5.2-5.1 Ma

Huang & Yuan, 1994

Localities



Ng & Teng 2014 *Palaeoworld*

Methods

PAleontological STatistics (PAST)

Cluster analysis

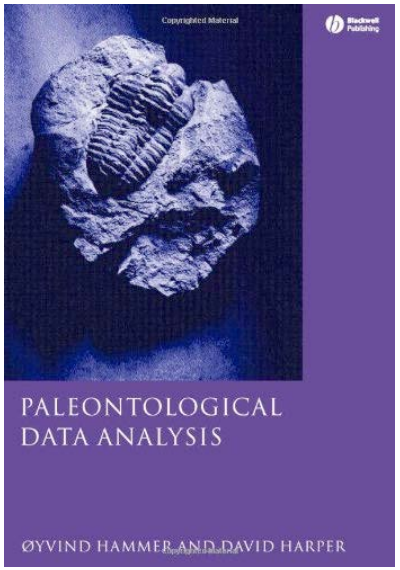
Non-metric Multi-dimensional Scaling (NMS)

Palaeontologia Electronica
http://palaeo-electronica.org

PAST: PALEONTOLOGICAL STATISTICS SOFTWARE PACKAGE FOR EDUCATION AND DATA ANALYSIS

Øyvind Hammer, David A.T. Harper, and Paul D. Ryan

Øyvind Hammer. Paleontological Museum, University of Oslo, Sars gate1, 0562 Oslo, Norway
David A. T. Harper. Geological Museum, Øster Voldgade 5-7, University of Copenhagen, DK-1350 Copenhagen K, Denmark
Paul D. Ryan. Department of Geology, National University of Ireland, Galway, Ireland



Ng & Teng 2014 *Palaeoworld*

Methods

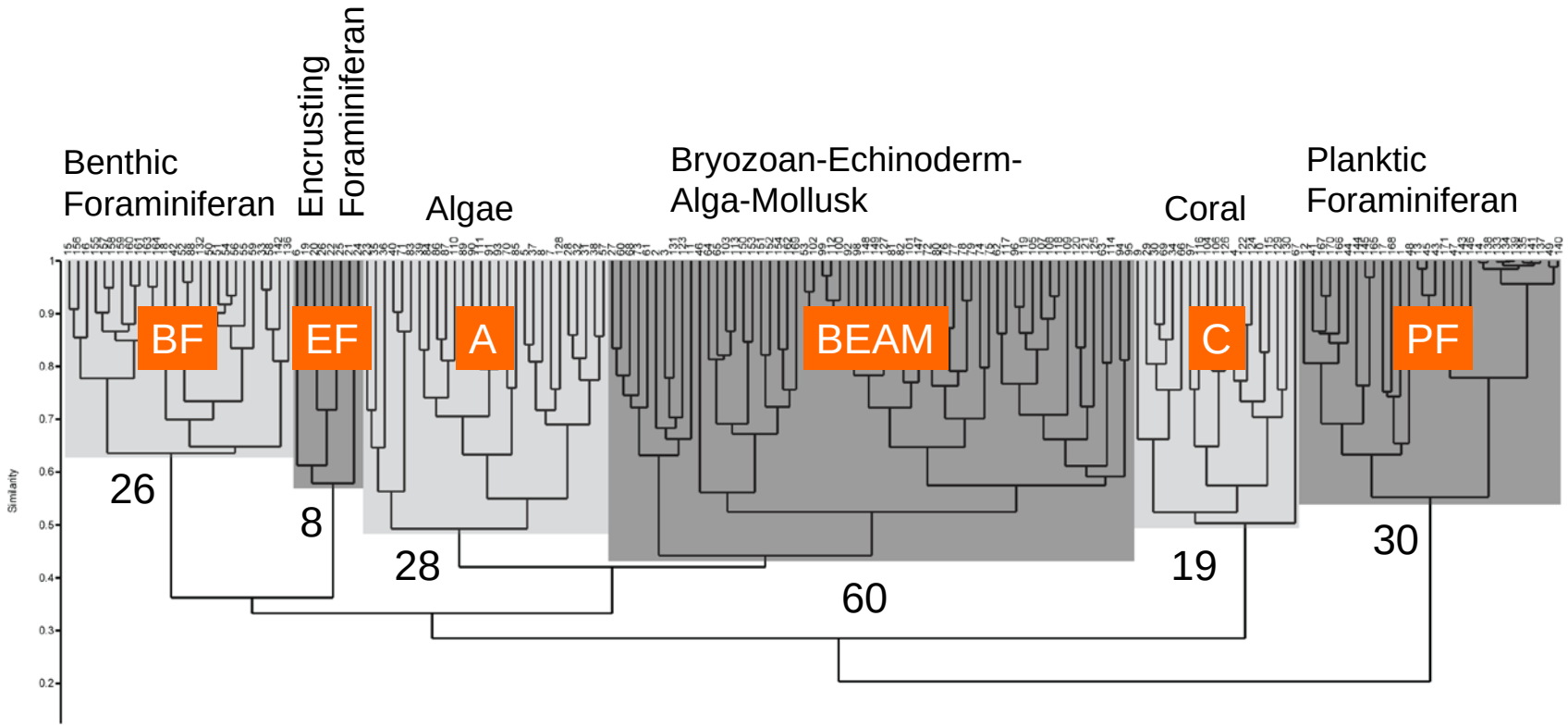
Intel PC with Windows 7

Cluster analysis with “Paired group” (UPGMA, Unweighted Pair Group Method with Arithmetic Mean)

Non-metric multi-dimensional scaling (NMS) with 3-dimensions

Bray–Curtis similarity index

Cluster Analysis



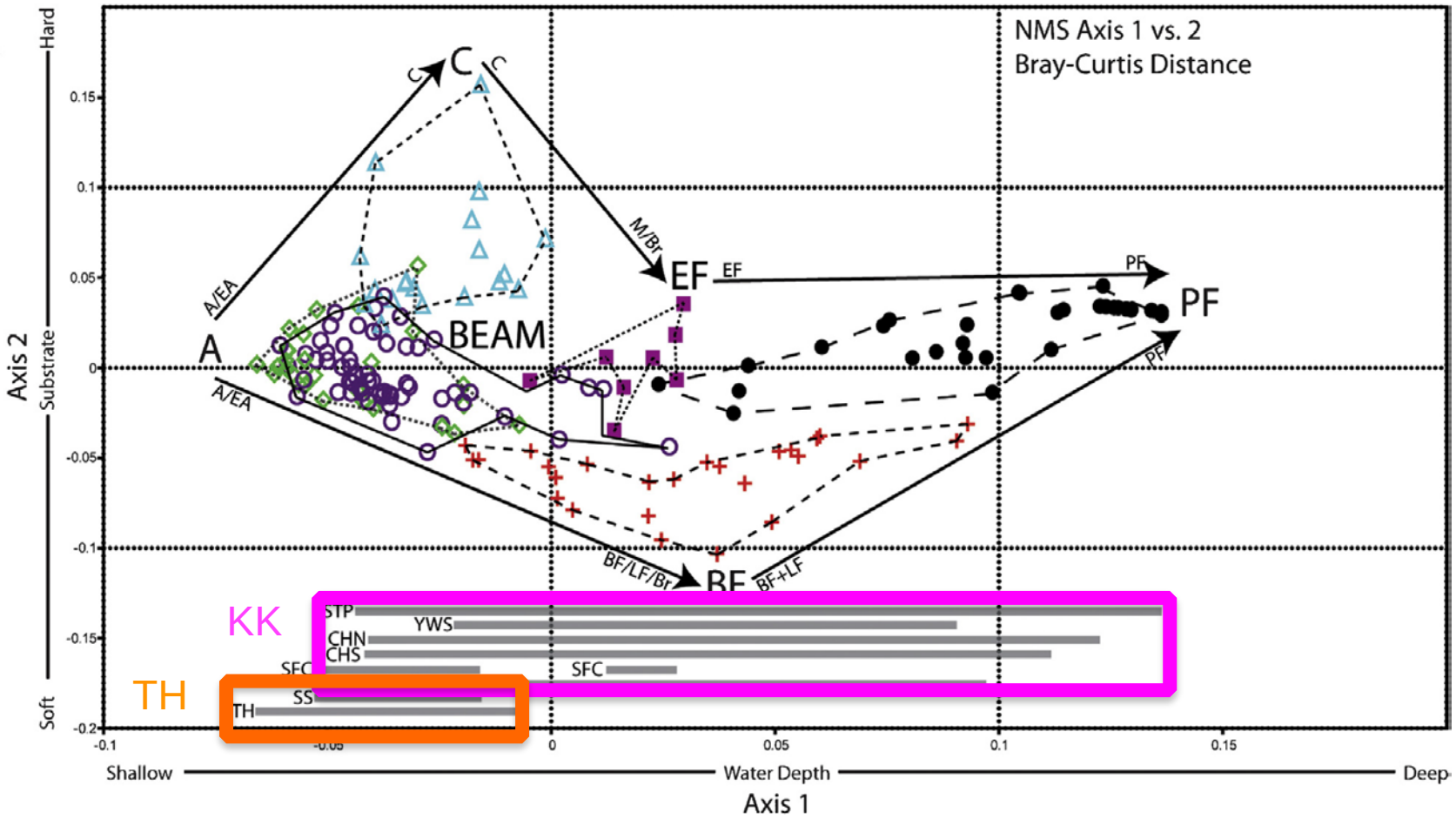
Ng & Teng 2014 *Palaeoworld*

Fossil Assemblages

Fossil assemblages	Coral	BEAM	BF	EF	PF	A
Water depth (relative to FWWB)	Above	Below	Around - Below	Below	Below	Around - Below
Estimated water depth range (m)	<50	<50-100	60-100	80-150	100-150 (200)	<50-80
Substrate	Hard	Hard: C, A Loose: Debris	Loose	Hard	Indet.	Hard
Biodiversity level	H	H - VH	L - M	M - H	L - M	M - H
Major faunas	C, A, EA, M, Br	Br, A, EA, M, E, BF	BF, LF, Br, M	EF, BF, M, Br	PF, BF	EA, A, C, Br, BF

Ng & Teng 2014 *Palaeoworld*

Water Depth & Substrate



Ng & Teng 2014 *Palaeoworld*

Conclusions

New relative abundance fossil data for Tungho Limestone

First quantitative analyses: cluster & NMS

Six fossil assemblages: PF, BF, EF, BEAM, C, & A

Paleoecological gradients: water depth & substrate

KK: wider water depth range

TH: only shallow deposits

KK (formal) → KK (north) + TH (south) (Huang & Yuan, 1994)

Ng & Teng 2014 *Palaeoworld*

Ongoing & Potential Projects

Sulfur isotopes – SQ and HYS samples

Paleoecology on Cambrian North China Craton

More North China sections

Revisions on Cambrian Trilobites (US + China)

Cladistics Analysis

Paleobiogeography of North China Cambrian Trilobites

Paleoecology of Limestone Bodies of Taiwan

Bryozoans Fossils of Taiwan

Acknowledgement

Ministry of Science and Technology (Taiwan MOST 103-2811-M-003-014)
National Sciences Council (Taiwan NSC 102-2811-M-003-030)
National Natural Science Foundation of China (40930211, 41372022 and 41362002)
Young International Scientists – Chinese Academy of Sciences (2012Y1ZB0010)
China Postdoctoral Science Foundation (20110491466)
Chinese Academy of Sciences Project-Oriented Hundred Talents Programme (KZCX2-YW-BR-23)
State Key Laboratory of Palaeontology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, CAS (20131103)
Geological Society of America (GSA)
Evolving Earth Foundation
Institute of Cambrian Studies
Department of Geoscience, University of Iowa
Dr. Jonathan M. Adrain (University of Iowa)
Dr. Stephen R. Westrop (University of Oklahoma)
Dr. Ann F. “Nancy” Budd (University of Iowa)
Dr. Allison R. Palmer (Institute of Cambrian Studies)
Dr. Mark Webster (University of Chicago)
Dr. Thomas A. Hegna (Western Illinois University)
Gao J., Tang Y., Liu Y.and Liu X.: field assistance
Isabel Perez (MEC-FSE, Universidad de Zaragoza): tech support with figures