PALEONTOLOGY

Middle-Late Triassic insect radiation revealed by diverse fossils and isotopic ages from China

Daran Zheng[1,2], Su-Chin Chang[2]*, He Wang[1], Yan Fang[1], Jun Wang[2], Chongqing Feng[2], Guwei Xie[3,4], Edmund A. Jarzembowski[1,5], Haichun Zhang[1], Bo Wang[1,6]*

The Triassic represented an important period that witnessed the diversification of marine and terrestrial ecosystems. The radiations of terrestrial plants and vertebrates during this period have been widely investigated; however, the Triassic history of insects, the most diverse group of organisms on Earth, remains enigmatic because of the rarity of Early-Middle Triassic fossils. We report new insect fossils from a Ladinian deposit (Tongchuan entomofauna) dated to approximately 238 to 237 million years ago and a Carnian deposit (Karamay entomofauna) in northwestern China, including the earliest definite caddisfly cases (Trichoptera), water boatmen (Hemiptera), diverse polyphagan beetles (Coleoptera), and scorpionflies (Mecoptera). The Tongchuan entomofauna is near the Ladinian-Carnian boundary in age, providing a calibration date for correlation to contemporaneous biotas. Our findings confirm that the clade Holometabola, comprising most of the modern-day insect species, experienced extraordinary diversification in the Middle-Late Triassic. Moreover, our results suggest that the diversification of aquatic insects (a key event of the "Mesozoic Lacustrine Revolution") had already begun by the Middle Triassic, providing new insights into the early evolution of freshwater ecosystems.

INTRODUCTION

The end-Permian mass extinction (EPME) caused a severe crisis in terrestrial ecosystems, possibly due to global wildfires at the Permian-Triassic boundary, long-term aridification, and short-term warming and acid rain during the Early Triassic (*1*, *2*). After the EPME, the Triassic is a period for the radiation of organisms in both marine and terrestrial ecosystems (*2*, *3*); it marks the first major step in the origin of modern ecosystems and is thus frequently known as the "Dawn of the Modern World" (*4*, *5*). For terrestrial ecosystems, many key modern vertebrates appeared during the Triassic (*2*), including two of the most important events: the origin and rise of the dinosaurs (*6*) and mammaliaforms (*7*). Plants experienced an especially important development during this period. Following the domination of the lycopsid plants during the Early Triassic, conifers, cycadophytes, and pteridosperms all radiated during the Middle Triassic, subsequently evolving into their modern forms (*8*, *9*).

The EPME led to changes in insect fauna at high taxonomic levels: a drop in abundance and overall diversity (*10*–*12*) and probably a severe extinction (*13*, *14*). After the EPME, Triassic insects probably kept pace with the megafloral development: Modern insects feeding on the pteridophytes and gymnosperms replaced ancient insects feeding on the pteridophytes and basal gymnosperms (*15*); plant-insect associations became significantly diverse during the Late Triassic (*16*–*18*). However, the scarcity of Early-Middle Triassic entomofaunas constrains our knowledge on the radiation of insects (*19*–*21*). In contrast to terrestrial plants and vertebrates, the evolutionary history of Triassic insects is still poorly understood. Little is known about the Triassic evolution of holometabolous and aquatic insects. These groups have the potential to provide insights into the early evolution of terrestrial (including freshwater) ecosystems (*22*, *23*) because the former is the most species-rich group of extant animals (*24*) and the latter is a key element of the "Mesozoic Lacustrine Revolution" (*25*).

Here, we report a late Ladinian Tongchuan entomofauna, with radioisotopically determined ages, and a Carnian Karamay entomofauna from northwestern China. Our results provide not only the earliest records of several modern insect elements but also a calibration point for correlation with contemporaneous biotas. These findings confirm that holometabolous and aquatic insects experienced extraordinary diversification during the Middle-Late Triassic.

RESULTS

Insect fossils

More than 800 insect fossils were collected from the upper part of the Karamay Formation in the Huayuangou outcrop (45°40′24″N, 84°55′57″E), Karamay City, Xinjiang (Fig. 1, A, C, and E), and the top of the lower part of the Tongchuan Formation in the Qishuihe outcrop (28°17′24″N, 117°52′32″E), Hejiafang Village, Jinsuoguan Town, Tongchuan City, Shaanxi Province (Fig. 1, B, D, and E, and fig. S1), Northwest China. The insect-bearing layer of the Tongchuan Formation is considered to be from the latest Ladinian stage [~238 to 237 million years (Ma) ago] and that of the Karamay Formation is regarded as Carnian in age. For detailed stratigraphic information, see the Supplementary Materials.

U-Pb geochronology

Two tuffaceous sandstone samples (TC-01 and TC-02), each weighing about 5 kg, were collected between insect fossil–bearing strata of the Qishuihe outcrop (Fig. 1D) and separated for LA-MC-ICP-MS (laser ablation–multi-collector–inductively coupled plasma mass spectrometry) U-Pb dating. The zircon grain sizes of sample TC-01 (Fig. 2, A and B) ranged from 80 to 120 μm. Most grains exhibited euhedral morphologies and oscillatory zoning patterns, indicating an igneous origin (Fig. 2B). Angular grain facets also suggest minimal abrasion during

[1]State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology and Center for Excellence in Life and Paleoenvironment, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing 210008, China. [2]Department of Earth Sciences, The University of Hong Kong, Hong Kong Special Administrative Region, China. [3]Institute of Exploration, Development and Research of PetroChina Company Limited Changqing Oilfield Branch, Xi'an SX 710018, China. [4]National Engineering Laboratory for Exploration and Development of Low-Permeability Oil and Gas Fields, Xi'an SX 710018, China. [5]Department of Earth Sciences, Natural History Museum, London SW7 5BD, UK. [6]Key Laboratory of Zoological Systematics and Evolution, Institute of Zoology, Chinese Academy of Sciences, 1, Beichen West Road, Beijing 100101, China.
*Corresponding author. Email: suchin@hku.hk (S.-C.C.); bowang@nigpas.ac.cn (B.W.)

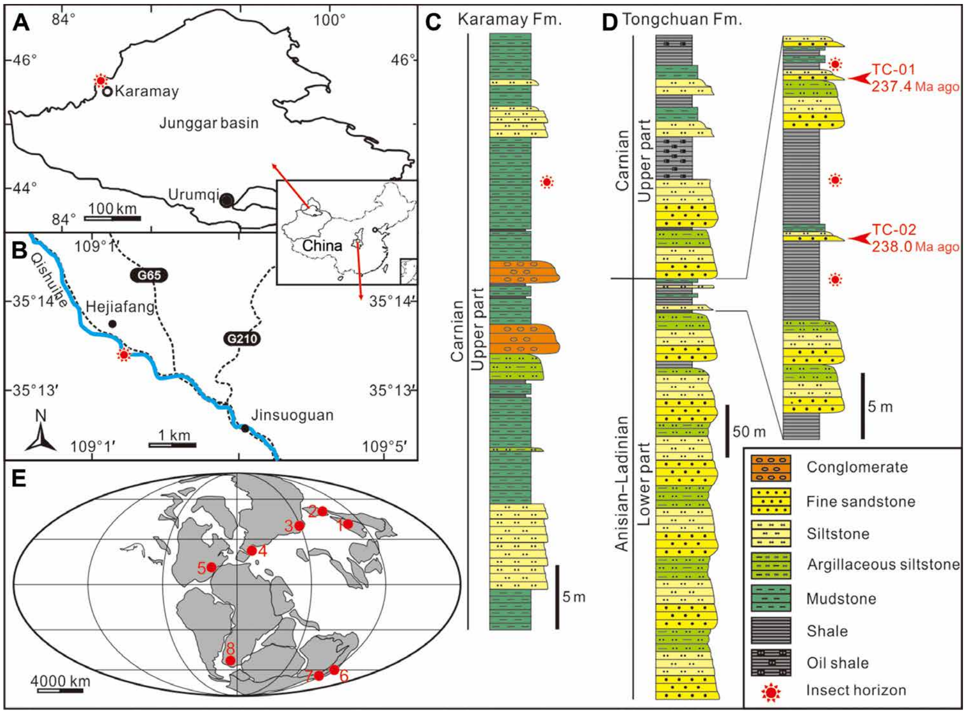

Fig. 1. Geology of Tongchuan and Karamay entomofaunas. Geological map showing the location of entomofauna in Karamay City in (**A**) Xinjiang and (**B**) Tongchuan City in Shaanxi, Northwest China. (**C** and **D**) Stratigraphic column showing lithologies, sample points, and age results. Global paleogeographic reconstructions [Carnian; after Rasnitsyn and Quicke (*33*) and Golonka (*62*)], highlighting main coeval insect–bearing localities (**E**): (1) Tongchuan, China (Ladinian); (2) Karamay, China (Carnian); (3) Madygen, Kyrgyzstan (Ladinian-Carnian); (4) Vosges, France (early Anisian); (5) Solite, USA (late Carnian); (6) Ipswich, Australia (Carnian); (7) Brookvale, Australia (Anisian); and (8) Molteno, South Africa (Carnian).

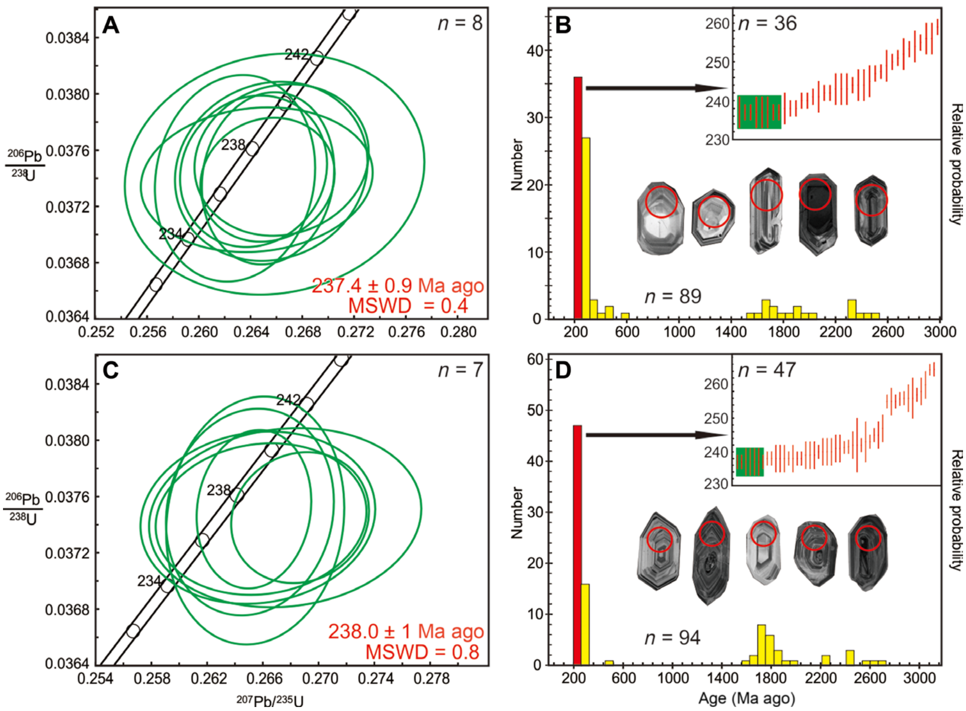

Fig. 2. U-Pb geochronology for samples from layers bearing Tongchuan entomofauna. U-Pb concordia plots for zircons in youngest ages (left) and frequency histograms (right) of detrital age populations from sample TC-01 (**A** and **B**) and sample TC-02 (**C** and **D**). Black arrows showing rank order plots (green bars represent youngest ages). Select cathodoluminescence (CL) images of zircons are in frequency histograms (age, 237 Ma ago; red circle diameter, 40 μm).

Fig. 3. Representative fossils from Tongchuan and Karamay entomofaunas. Tongchuan entomofauna (**A** to **C**, **E** to **J**, and **L** to **O**), and Karamay entomofauna (**D** and **K**). (A) *Zygophlebia* (Odonatoptera: Zygophlebiidae), NIGP163160; (B) Locustavidae (Orthoptera), NIGP162042; (C) *Prochoristella* (Mecoptera: Permochoristidae), NIGP162043; (D) Corixidae, NIGP162044; (E) *Boreocixius* (Hemiptera: Surijokocixiidae), NIGP162045; (F) Dunstaniidae (Hemiptera), NIGP162046; (G) Aphidoidea (Hemiptera), NIGP162047; (H) *Chauliodites* (Grylloblattida: Chauliodititidae), NIGP162048; (I) Cicadocorinae (Hemiptera: Progonocimicidae), NIGP162049; (J) Ichnogenus *Folindusia* (Trichoptera), NIGP162050; (K) Ichnogenus *Terrindusia* (Trichoptera), NIGP162051; (L) Myxophaga (Coleoptera), NIGP162052; (M) Elateriformia (Coleoptera), NIGP162053; (N) Dytiscoidea (Coleoptera), NIGP162054; (O) Cicadocorinae (Hemiptera: Progonocimicidae), NIGP162055. Scale bars, 5 mm (white), and 1 mm (black).

sedimentary transport and support the interpretation that the tuffaceous sandstone depocenter lays near the magmatic source of the zircons. Eighty-nine analyses provided concordant ages ranging from 2480 to 237 Ma ago (Fig. 2B). Eight youngest analyses gave a weighted mean of 237.4 ± 0.9 Ma ago [mean square weighted deviation (MSWD), 0.4; uncertainties are given at the 2σ level] as the maximum depositional age for sample TC-01. The major subpopulation of ages generally fell between 237 and 362 Ma ago, with some between 1538 and 2480 Ma ago. Several sporadic ages fell in the Devonian (404 Ma ago), Ordovician (472 Ma ago), and Cambrian (492 Ma ago). The zircon grain sizes of sample TC-02 (Fig. 2, C and D) were similar to those from sample TC-01. While some grains were intact, most exhibited fractured morphologies. Euhedral facets and oscillatory zoning patterns indicate an igneous origin and limited exposure to sedimentary processes (Fig. 2D). Ninety-four zircon grains gave concordant ages ranging from 2703 to 237 Ma ago (Fig. 2D). The seven youngest, with equivalent $^{206}Pb/^{238}U$ dates, gave a weighted mean of 238.0 ± 1 Ma ago (MSWD, 0.8; uncertainties are given at the 2σ level) as the maximum depositional age for sample TC-02. The largest subpopulation of ages generally fell between 237 and 307 Ma ago, and the second one fell between 1611 and 2703 Ma ago. The age distribution also included one outlier age of 503 Ma ago (Cambrian). The two youngest age populations with weighted means of 237.4 ± 0.9 Ma ago and 238.0 ± 1 Ma ago suggest a latest Ladinian age (*26*) for the top of the lower part of the Tongchuan Formation. For detrital zircons, the youngest age populations may not represent the most accurate depositional age (*27*), since the deposition should be later than youngest magmatic events (*28*, *29*), but may offer approximate constraints on deposition (*6*). The latest Ladinian age agrees with the previous isotopic age results (~236 to 234 Ma ago) (*30*) for the upper part of the Tongchuan Formation and the biostratigraphic correlation (Middle Triassic) for this formation and can approximately represent the depositional age (for detailed age discussions, see the Supplementary Materials).

DISCUSSION

Characters of two entomofaunas

The Tongchuan entomofauna contains at least 28 insect families in 11 orders, viz. Blattodea, Coleoptera, Diptera, Grylloblattida, Glosselytrodea, Hemiptera, Mecoptera, Miomoptera, Odonatoptera, Orthoptera, and Trichoptera (table S1), making it among the most diverse Triassic entomofaunas (typical coeval insect–bearing sites; see Fig. 1E). This entomofauna includes more than 14 families of holometabolous insects, which also distinctly outnumber other insects with respect to specimen numbers (approximately 65% of 520 specimens). The Tongchuan entomofauna has many typical Triassic elements, such as Zygophlebiidae (Odonatoptera), Locustavidae (Orthoptera), and Curvicubitidae (Hemiptera), which were widespread in the Ladinian-Carnian of Kyrgyzstan and the Carnian of Ipswich, Australia (*31*). It yields some Late Permian and Early Triassic components, such as Chaulioditidae (Grylloblattida: *Chauliodites*) (*21*), Surijokocixiidae (Hemiptera), Dunstaniidae (Hemiptera), and primitive Aphidoidea (Hemiptera), and the Aphidoidea is related to a Permian aphid from France (*32*). In addition, it yields the earliest Cicadocorinae (Hemiptera) (Fig. 3I), which are common moss bugs in the Jurassic and Early Cretaceous (*33*). The Karamay entomofauna yields 10 insect families in six orders, including caddisfly cases and the earliest known water boatmen. Aquatic beetles and bugs (Permosynidae, Schizocoleidae, and Corixidae) are quite abundant in this entomofauna, in which the diversity is dominated by beetles (five families). The complete and detailed descriptions of these fossils from the two entomofaunas will be published elsewhere.

Most of Triassic beetles are preserved as isolated elytra (*33*–*36*). However, there are diverse beetles with bodies in the Tongchuan entomofauna, including the earliest putative Myxophaga (characterized by an elongate body with short elytra and widely separated mesocoxae and metacoxae; Fig. 3L), Elateriformia (characterized by a robust body with a distinct prosternal intercoxal process and produced hind pronotal angles; Fig. 2M), and Dytiscoidea (characterized by a streamlined body with two eyes, smooth elytra, and second abdominal sternite divided by metacoxae; Fig. 2N). These fossils, therefore, are potential key calibration points for the molecular phylogenetic analysis of beetle phylogeny.

Another interesting discovery is the earliest caddisfly cases (Trichoptera) in both entomofaunas (Fig. 3, J and K). Larval caddisflies construct cases using sand grains, shells, fish scales, coprolites, or vegetation cemented with the silk they secrete (*23*). The order Trichoptera is the sister to the Lepidoptera, of which the earliest record was near the Triassic-Jurassic boundary (*37*). The true Trichoptera was thought to have diverged from Amphiesmenoptera in the earliest Jurassic, and the earliest previously identified caddisfly case fossil was from the Early Jurassic of Siberia (Fig. 4) (*23*, *38*). The Permian and Triassic "trichopteran" most probably belongs to the stem group of Amphiesmenoptera (*39*). The Permian marine "caddisfly" cases (*40*) were probably incorrectly identified since the caddisfly larva cannot build these cases with short, thick silk bundles (maximum, 1 mm diameter) arranged in an overlapping manner and not transversely circular. These marine cases were probably constructed by worms. The ichnogenus *Folindusia* (narrow-long, straight case built mainly of densely packed plant fragments, with some transverse arranged; Fig. 3J) from the Tongchuan entomofauna and the ichnogenus *Terrendusia* (narrow-long, straight case built of small densely and irregularly packed sand grains; Fig. 3K) from the Karamay entomofauna suggest an unexpected Middle Triassic origin of the construction behavior, much earlier than previously proposed from molecular studies (*41*, *42*).

Middle-Late Triassic insect radiation

The Holometabola are the most diverse insects in the Tongchuan and Karamay entomofaunas, which are represented by diverse beetles and scorpionflies. Nowadays, holometabolous insects have the highest number of species of any clade and greatly contribute to the animal species biodiversity (*43*). Although they are already known from the Early Carboniferous (*41*, *43*) and diversified during the Early-Middle

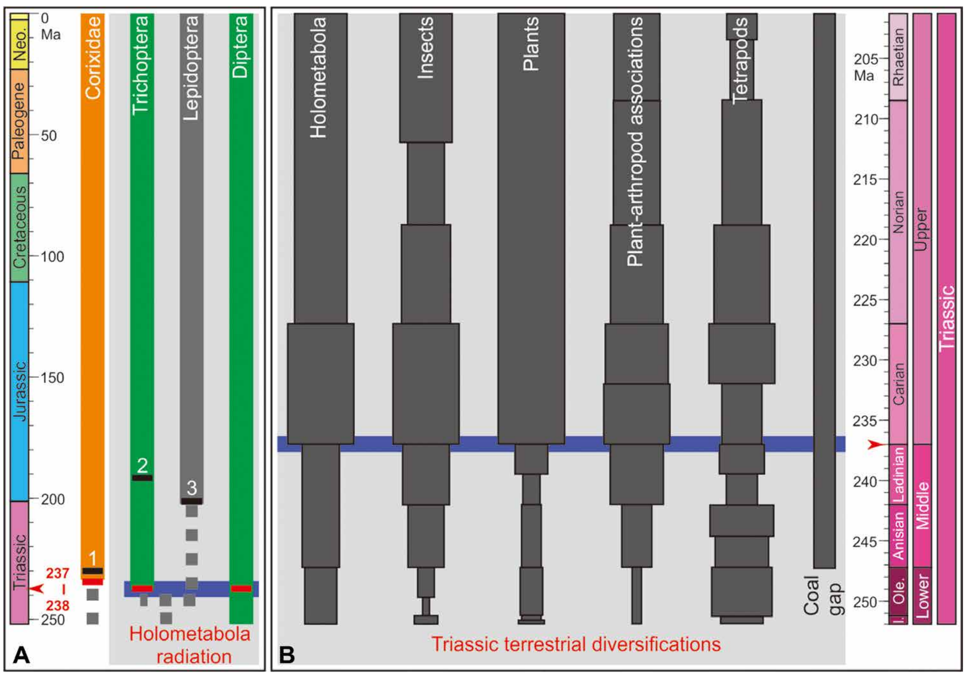

Fig. 4. Triassic terrestrial biodiversifications. (**A**) Middle Triassic Holometabola radiation and (**B**) Triassic terrestrial diversifications. The previously earliest records of (1) Corixidae (*45*), (2) Trichoptera (*38*), and (3) Lepidoptera (*37*) are marked by black rectangular bars, and the new records reported in the present study are marked by red rectangular bars. The Triassic terrestrial diversifications are based on the data of holometabola [family richness; (*63*)], insects [family richness; (*14*)], plants [generic richness; (*9*, *64*)], plant-arthropod associations [relative richness; (*15*)], tetrapods [generic richness; (*65*)], and coal gap (*66*). I., Induan; Ole., Olenekian; Neo., Neogene.

Triassic (*34*), Holometabola were thought to have become dominant in the global entomofauna starting in the mid-Mesozoic (*24*, *44*). Thus, its high diversity and abundance in Tongchuan and Karamay are relatively unexpected, revealing a radiation of Holometabola during the Middle Triassic, in correspondence to the results found from the Triassic of the Vosges (France) (*34*).

Aquatic insects also experienced substantial expansions in the Middle Triassic. Some key aquatic holometabolous clades, now comprising the bulk of modern freshwater biodiversity, can also be tracked back to the Middle Triassic origins, such as caddisflies and aquatic beetles (including Myxophaga and Dytiscoidea) found in both entomofaunas. In addition, water boatmen (characterized by fully sclerotized forewings with a distinct claval suture and no veins) are abundant in the Karamay entomofauna, and they are the earliest record of aquatic bugs (Fig. 3D). This finding is slightly earlier than those found from the Upper Triassic Huangshanjie Formation of Xinjiang (see the Supplementary Materials) (*45*) and the Cow Branch Formation of United States (*22*) and is earlier than the divergence times predicted on the basis of molecular studies (estimated to have occurred in the earliest Jurassic) (Fig. 4) (*46*). Together with true flies from other Early and Middle Triassic entomofaunas, these aquatic insects developed new herbivore and carnivore guilds that persist to the present day (*47*). The diversification of aquatic insects (mainly belonging to holometabolous insects) is thought to be part of the Mesozoic Lacustrine Revolution, which was dated as "Middle Mesozoic" (*25*, *48*). However, our results suggest that this diversification has already begun by the Middle Triassic, thus providing new insights into the early evolution of freshwater ecosystems.

In summary, our findings confirm that holometabolous and aquatic insects experienced a radiation event in the Middle Triassic. Compared to other insects, Holometabola (including some aquatic insects) were probably more resilient to Early Triassic environmental disturbances because their development would have allowed greater buffering from environmental variability [analogous to modern species with a protective pupal stage, faster development, higher population sizes, and reduced intraspecific competition between the adult and offspring (*49*)]. After the Early Triassic, various plants (including aquatic plants) started to appear during the Middle Triassic and spread later (*1*), probably further contributing to the radiation of holometabolous and aquatic insects (Fig. 4).

Terrestrial Ladinian-Carnian boundary

The marine GSSP (Global Boundary Stratotype Section and Point) of the Carnian Stage is defined by the first appearance of the ammonoid *Daxatina canadensis* in the Prati Di Stuores/Stuores Wiesen section in the Southern Alps, Northeast Italy (*50*). Chemical abrasion–thermal ionization mass spectrometry (CA-TIMS) gave a precise age of 237.77 ± 0.052 Ma ago for the ash bed from the Alpe di Siusi/Seiser Alm area, 24 km west of the GSSP. The ash bed is lower than the GSSP point, and the age of the boundary is estimated on the basis of sediment accumulation (*50*). The Ladinian-Carnian boundary, ~237 Ma ago, is also supported by previous dating work on several strata correlated with the GSSP (*51*–*53*). The insect-rich Tongchuan terrestrial biota dated to ca. 238 to 237 Ma ago (Fig. 2) is in greement with the marine Ladinian-Carnian boundary. It should be noted that the marine and land strata can be correlated not only by isotopic ages but also by similar spore-pollen compositions. The GSSP is indicated by typical Carnian spore and pollen species *Vallasporites ignacii* and *Patinasporites densus* (*50*), which are absent in the Tongchuan Formation. In contrast, the appearance of some common insect elements in the Tongchuan, Madygen, and Australian entomofaunas indicates the close relationship among these Middle-Late Triassic terrestrial biotas. Therefore, our new age can provide a calibration point for marine and terrestrial correlations near the Ladinian-Carnian boundary and for the correlation of contemporaneous biotas.

MATERIALS AND METHODS

Insect fossils

The insect fossils were prepared using sharp pins. Photographs were taken using a Sony α7 camera and a Zeiss Discovery V16 microscope system with specimens moistened in 95% alcohol or dry. The figures were prepared with CorelDRAW X7 and Adobe Photoshop CS6.

U-Pb geochronology

The tuffaceous sandstone samples were crushed and separated to isolate the 80- to 200-μm grain size fraction (*54*). A total of 200 inclusion-free zircon grains from each sample were then picked under a binocular microscope and mounted in epoxy resin. Hardened mounts were polished to expose zircon grain midsections at about two-thirds to one-half of their widths. CL imaging documented grain morphologies and internal structure for in situ analysis. U-Pb isotopic data from zircons were obtained at the Department of Earth Sciences, The University of Hong Kong, using a Nu Instruments MC-ICP-MS with a Resonetics RESOlution M-50-HR Excimer Laser Ablation System. The analyses used a beam diameter of 30 μm, a repetition rate of 4 Hz, and an energy density of 5 J/cm^2 on sample surface. Average ablation time was ca. 40 s, and pit depths reached about 30 μm. The Harvard reference zircon 91500 (1065.4 ± 0.3 Ma ago) (*55*) and GJ-1 zircon (609 Ma ago) (*56*) were used for preliminary calibration and second reference, respectively. Detailed operational procedures are found by Xia *et al.* (*57*). We used ICPMSDataCal (*58*) to process the offline signal selection, quantitative calibration, and time-drift correction. We used a function given by Anderson (*59*) to correct for common Pb in Microsoft Excel. Isoplot v. 3.0 (*60*) was used to construct concordia diagrams and probability density plots. Within the overall detrital age distribution, we cited ^{206}Pb/^{238}U ages for zircon grains younger than 1000 Ma ago and ^{207}Pb/^{206}Pb ages for older grains. Here, 100 zircon grains were randomly selected from each sample, so the results were expected to reflect the characteristics of the age populations. Ages with a discordance degree of >10% were excluded from the analysis (*61*).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/9/eaat1380/DC1

Supplementary Materials and Methods

Fig. S1. Photographs showing outcrops bearing Tongchuan and Karamay entomofaunas.

Table S1. Insect list of the Tongchuan entomofauna.

Table S2. U-Pb analytical results for samples from the Tongchuan outcrop.

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Supplementary Materials for

Middle-Late Triassic insect radiation revealed by diverse fossils and isotopic ages from China

Daran Zheng, Su-Chin Chang*, He Wang, Yan Fang, Jun Wang, Chongqing Feng, Guwei Xie, Edmund A. Jarzembowski, Haichun Zhang, Bo Wang*

*Corresponding author. Email: suchin@hku.hk (S.-C.C.); bowang@nigpas.ac.cn (B.W.)

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This PDF file includes:

Supplementary Materials and Methods

Stratigraphic information

The Tongchuan Formation conformably underlies the Upper Triassic Yanchang Formation and overlies the Lower-Middle Triassic Ermaying Formation in the Tongchuan outcrop. The fossil-bearing layer of the Tongchuan Formation is a series of greyish green sandstones, interbedded with shale and mudstone (fig. S1a), yielding bivalves, spinicaudatans, ostracods, insects, tadpole shrimps, fishes, reptiles, chrysophyte cysts, sporopollen, and plants (*67*–*69*). Approximately 30 insect families in 11 orders, including Blattodea, Coleoptera, Diptera, Grylloblattida, Glosselytrodea, Hemiptera, Mecoptera, Miomoptera, Odonatoptera, Orthoptera, and Trichoptera, are herein recorded (table S1). The lower part of the Tongchuan Formation is considered to be Anisian-Ladinian in age, and the upper part is considered to be Carnian (this paper). It should be noted that there are some earlier studies of the insects from the same section (e.g., *70*, *71*); nearly all the earlier attributions, however, were questionable and the studied specimens are not accessible. Thus, we did not consider these earlier data but based on our collections.

The upper part of the Karamay Formation conformably underlies the Upper Triassic Baijiantan Formation and unconformably overlies the Paleozoic granite in the Huayuangou outcrop. The fossil-bearing layer of the Karamay Formation is composed of yellow mudstone (fig. S1b), yielding kazacharthrans, insects, sporopollen and plants (*72*). Approximately 10 insect families in six orders, including Blattaria, Coleoptera, Hemiptera, Mecoptera, Odonata, and Trichoptera, have been found. Based on diverse biostratigraphical work on both the surface and subsurface in the northwestern Junggar Basin, the age of the Karamay Formation is considered to be late

Middle to Late Triassic for the lower part, and Late Triassic for the upper part (*72*). The upper part is probably Carnian in age based on the megaspore fossils (*72*, *73*).

Previous geochronology of the Tongchuan Formation

The Triassic in the Ordos Basin contains abundant tuff or tuffaceous sandstone, especially in the Middle Triassic Tongchuan Formation (*74*). In previous geochronological studies, some radioisotopic results were obtained from both surface and subsurface specimens (*30*, *75*–*77*). Liu *et al*. (*77*) obtained a weighted mean age of 243.1 ± 3.9 Ma for the lower part of the Tongchuan Formation and ages of 234.6 ± 6.5 Ma to 238.6 ± 2.6 Ma for the upper part based on SHRIMP U-Pb dating of tuffs. However, the ages with a mean value of 234.6 ± 6.5 Ma are scattered and not concordant; consequently, they do not reliably represent the real depositional ages of the strata. The ages with a weighted mean of 238.6 ± 2.6 Ma are slightly concordant but also scattered. Zhang *et al*. (*30*) obtained an age range between 234.3 ± 2.8 Ma and 236.1 ± 2.7 Ma for the Chang-7 Member (upper part of the Tongchuan Formation; *79*) using ICP-MS U-Pb dating on tuff samples, reflecting a Carnian age. Wang *et al*. (*76*) obtained a range of 241.3–239.7 Ma for the lower part of the Chang-7 Member based on using SHRIMP U-Pb analyses of two tuff samples. According to the data, these ages are concordant but scattered, and two concordant age ranges, 246–227 Ma and 246–229 Ma, were obtained for these samples. However, Wang *et al*. (*76*) subjectively selected the older age range of 241–239 Ma as the depositional age based on the assumption that the specimens were mixed with younger zircons. This explanation is obviously unreliable, and the absolute age of the tuff should be within the youngest range of 229–227 Ma, indicating a Late Triassic age (Carnian). Therefore, the previous dating actually indicates a Carnian age for the base of the upper part of the Tongchuan Formation.

Biostratigraphic age of the Tongchuan Formation

Recent paleontological work indicated a Middle–Late Triassic age for the Tongchuan Formation (*69, 77*). Deng *et al*. (*77*) identified the obvious differences in the sporopollen assemblages between the two parts of the Tongchuan Formation: the assemblage from the lower part resembles that from the Lower Triassic Zifang Formation, reflecting a Middle Triassic age, while the upper part bears abundant Late Triassic elements, which is consistent with other sporopollen results based on samples from different areas in the Ordos Basin (*78–80*). An early Late Triassic age for the upper part was also supported by the presence of the reptile *Yonghesuchus sangbiensis* (*80*). The Tongchuan entomofauna was recently considered to be Ladinian in age (*69*). In conclusion, paleontological evidence indicates a Middle Triassic age for the lower part of the Tongchuan Formation, and a Late Triassic age for the upper part.

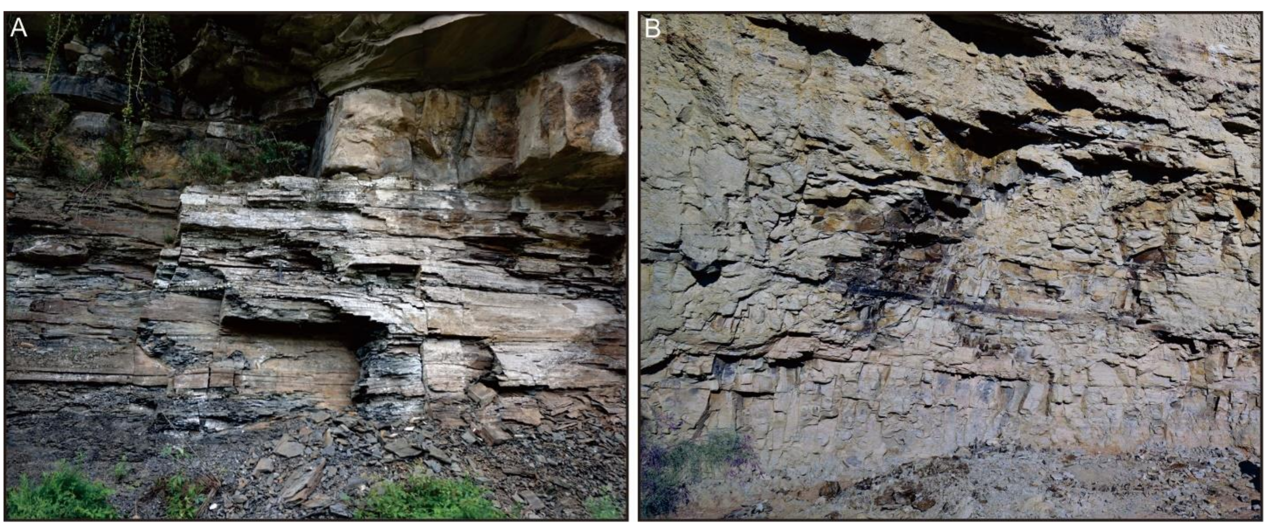

Fig. S1. Photographs showing outcrops bearing Tongchuan and Karamay entomofaunas.

Photo Credit: Daran Zheng, The University of Hong Kong

Table S1. Insect list of the Tongchuan entomofauna.

Order	Family
Odonatoptera	Zygophlebiidae
Blattodea	Mylacridae
Grylloblattida	Chauliodititidae
Orthoptera	Locustavidae
Hemiptera	Dracaphididae, Surijokocixiidae, Curvicubitidae, Scytinopteridae, Ipsviciidae, Dunstaniidae, Hylicellidae, Progonocimicidae (Cicadocorinae)
Glosselytrodea	Jurinidae
Miomoptera	Permosialidae
Mecoptera	Mesopsychidae, Pseudopolycentropodidae, Parachoristidae, Thaumatomeropidae, Permochoristidae
Diptera	Vladipteridae
Trichoptera	Families uncertain (earliest caddisfly case)
Coleoptera	Cupedidae, Ademosynidae, Schizophoridae, Tricoleidae, Adephaga (families uncertain), Staphylinidae, other Polyphaga (families uncertain)

Table S2. U-Pb analytical results for samples from the Tongchuan outcrop.

Samples	Isotopic ratios							U-Pb Ages(Ma)					
	Th/U	$^{207}Pb/^{206}Pb$	±1σ	$^{207}Pb/^{235}U$	±1σ	$^{206}Pb/^{238}U$	±1σ	$^{207}Pb/^{206}Pb$	±1σ	$^{207}Pb/^{235}U$	±1σ	$^{206}Pb/^{238}U$	±1σ
TC-01, gray-green tuffaceous sandstone													
91500	0.35052	0.07491	0.0002	1.85649	0.0089	0.17969	0.0007	1066	6	1066	3	1065	4
91500	0.34648	0.07509	0.0002	1.8583	0.0086	0.17949	0.0008	1072	6	1066	3	1064	4
91500	0.34383	0.07464	0.0002	1.83581	0.0097	0.17834	0.0008	1059	6	1058	3	1058	4
GJ	0.03289	0.05976	0.0001	0.81597	0.0048	0.099	0.0005	594	10	606	3	609	3
GJ	0.03309	0.05999	0.0002	0.81245	0.0041	0.09821	0.0005	611	6	604	2	604	3
NIST	0.98777	0.90425	0.0017	33.683	0.136	0.2701	0.0010			3601	4	1541	5
TC-01-1	0.83034	0.05246	0.0012	0.36302	0.0081	0.05018	0.0003	306	54	314	6	316	2
TC-01-2	0.70787	0.05118	0.0004	0.26423	0.0023	0.03745	0.0002	249	10	238	2	237	1
TC-01-3	1.02226	0.05328	0.0002	0.29243	0.0017	0.03983	0.0003	341	6	260	1	237	2
TC-01-4	0.62527	0.05234	0.0003	0.28215	0.002	0.0391	0.0002	300	7	252	2	247	1
TC-01-5	1.59265	0.05321	0.0003	0.29095	0.0018	0.03965	0.0002	338	7	259	1	251	1
TC-01-6	1.06092	0.10783	0.0014	4.42742	0.0514	0.29779	0.0015	1763	24	1717	10	1680	8
TC-01-7	0.59142	0.05163	0.0002	0.28702	0.0017	0.04031	0.0002	269	6	256	1	255	1
TC-01-8	0.7197	0.05144	0.0002	0.26535	0.0021	0.0374	0.0003	261	8	239	2	237	2

TC-01-9	0.96614	0.05444	0.0003	0.43422	0.0031	0.05783	0.0002	389	10	366	2	362	1
TC-01-10	0.73722	0.10916	0.0024	4.50988	0.0857	0.29964	0.0035	1785	41	1733	16	1690	17
TC-01-11	0.54098	0.0515	0.0012	0.27278	0.006	0.03841	0.0003	263	54	245	5	243	2
TC-01-12	1.31117	0.05239	0.0004	0.27767	0.0029	0.03844	0.0003	302	12	249	2	243	2
TC-01-13	1.39648	0.05861	0.0026	0.36145	0.0159	0.04472	0.0003	553	99	313	12	282	2
TC-01-14	0.30825	0.11469	0.0003	5.04023	0.0296	0.31863	0.0018	1875	5	1826	5	1783	9
TC-01-15	2.20103	0.06086	0.0004	0.33484	0.0024	0.03992	0.0002	634	8	293	2	252	1
91500	0.34222	0.07477	0.0003	1.84361	0.0102	0.17882	0.0008	1062	9	1061	4	1061	4
91500	0.35175	0.07499	0.0003	1.85679	0.0102	0.17952	0.0008	1133	7	1066	4	1064	4
GJ	0.02734	0.06005	0.0002	0.82076	0.0046	0.0991	0.0005	606	7	608	3	609	3
GJ	0.03293	0.06001	0.0002	0.81685	0.0039	0.09871	0.0004	606	6	606	2	607	2
TC-01-16	0.41546	0.14456	0.0025	3.0967	0.0458	0.15537	0.0013	2283	30	1432	11	931	7
TC-01-17	0.84557	0.05488	0.0003	0.2895	0.0023	0.03823	0.0002	407	10	258	2	242	1
TC-01-18	0.30206	0.16402	0.0005	9.8276	0.0556	0.43443	0.0023	2498	4	2419	5	2326	10
TC-01-19	0.94539	0.1646	0.0003	10.6517	0.0757	0.46918	0.0031	2503	5	2493	7	2480	14
TC-01-20	1.38182	0.10505	0.0016	4.13034	0.0587	0.28515	0.0014	1715	28	1660	12	1617	7
TC-01-21	0.56959	0.15187	0.0004	9.10984	0.0627	0.4348	0.0024	2367	5	2349	6	2327	11
TC-01-22	0.70594	0.18173	0.0005	5.49274	0.0251	0.21919	0.0012	2669	4	1899	4	1278	7

TC-01-23	0.54344	0.05532	0.0007	0.32088	0.0036	0.04209	0.0003	425	14	283	3	266	2
TC-01-24	0.68196	0.05208	0.0012	0.30309	0.0065	0.04221	0.0003	289	52	269	5	266	2
TC-01-25	0.66805	0.05315	0.0002	0.33843	0.0025	0.04619	0.0004	335	8	296	2	291	2
TC-01-26	0.64366	0.10194	0.0002	4.15029	0.0252	0.29508	0.0015	1660	5	1664	5	1667	7
TC-01-27	1.17478	0.05175	0.0005	0.27076	0.0026	0.03795	0.0002	274	11	243	2	240	1
TC-01-28	0.56847	0.05833	0.0004	0.37331	0.0026	0.04651	0.0004	542	7	322	2	293	2
TC-01-29	1.12458	0.05248	0.0005	0.29063	0.0033	0.04018	0.0003	306	13	259	3	254	2
TC-01-30	0.52436	0.10856	0.0004	5.02669	0.0355	0.33593	0.0025	1775	6	1824	6	1867	12
91500	0.34207	0.07478	0.0003	1.84947	0.0098	0.17935	0.0007	1063	9	1063	4	1063	4
91500	0.35191	0.07498	0.0003	1.85093	0.0104	0.17899	0.0008	1133	7	1064	4	1061	4
GJ	0.02818	0.06029	0.0002	0.81668	0.0039	0.09821	0.0003	613	7	606	2	604	2
GJ	0.0326	0.06034	0.0002	0.82136	0.0037	0.0987	0.0003	617	12	609	2	607	2
TC-01-31	0.8368	0.09849	0.0024	3.66022	0.0813	0.26955	0.0027	1596	47	1563	18	1538	14
TC-01-32	0.76627	0.05369	0.0003	0.34104	0.0033	0.04607	0.0004	358	10	298	3	290	2
TC-01-33	0.64298	0.05265	0.0003	0.32498	0.0027	0.04478	0.0003	314	8	286	2	282	2
TC-01-34	0.88099	0.10724	0.0004	4.62699	0.0415	0.31284	0.0026	1753	7	1754	7	1755	13
TC-01-35	0.74437	0.05218	0.0003	0.27567	0.0019	0.03831	0.0002	293	7	247	2	242	1
TC-01-36	0.74064	0.05377	0.0004	0.37679	0.0032	0.05082	0.0002	361	11	325	2	320	1

TC-01-37	0.35524	0.05633	0.001	0.31123	0.0051	0.04007	0.0002	465	38	275	4	253	1
TC-01-38	0.6481	0.14834	0.0016	6.44191	0.06	0.31496	0.0018	2327	19	2038	8	1765	9
TC-01-39	1.08716	0.05423	0.0008	0.34439	0.0034	0.04607	0.0006	381	13	300	3	290	3
TC-01-40	1.09438	0.05506	0.0005	0.311	0.0033	0.04096	0.0002	414	14	275	3	259	1
TC-01-41	0.99788	0.0555	0.0006	0.35831	0.0062	0.04678	0.0006	432	18	311	5	295	4
TC-01-42	0.56934	0.16778	0.0017	10.0292	0.0855	0.43354	0.0023	2536	17	2437	8	2322	10
TC-01-43	0.69691	0.05259	0.0002	0.32585	0.0024	0.04504	0.0004	311	9	286	2	284	2
TC-01-44	1.0225	0.05295	0.0004	0.29585	0.0023	0.04058	0.0003	327	8	263	2	256	2
TC-01-45	1.16842	0.05328	0.0003	0.34583	0.003	0.04721	0.0005	341	11	302	2	297	3
91500	0.33821	0.07485	0.0003	1.848	0.01	0.17904	0.0008	1065	7	1063	4	1062	5
91500	0.35609	0.07491	0.0003	1.8524	0.0105	0.1793	0.0008	1066	8	1064	4	1063	4
GJ	0.02981	0.06025	0.0002	0.81803	0.0035	0.09844	0.0003	613	7	607	2	605	2
GJ	0.03356	0.06015	0.0002	0.81357	0.0037	0.09807	0.0003	609	3	604	2	603	2
TC-01-46	1.2764	0.05094	0.0003	0.2628	0.0025	0.0374	0.0003	238	10	237	2	237	2
TC-01-47	1.29404	0.05189	0.0006	0.27263	0.0038	0.0381	0.0003	281	17	245	3	241	2
TC-01-48	0.53991	0.05401	0.0003	0.34325	0.0031	0.04609	0.0004	371	9	300	2	290	2
TC-01-49	0.7663	0.05683	0.0012	0.50682	0.0103	0.06468	0.0004	485	47	416	7	404	2
TC-01-50	0.8147	0.05307	0.0004	0.3328	0.0027	0.04548	0.0002	332	11	292	2	287	1

TC-01-51	1.03372	0.05134	0.0007	0.26448	0.0037	0.03739	0.0002	256	22	238	3	237	1
TC-01-52	1.50794	0.05274	0.0006	0.28009	0.0034	0.03853	0.0003	318	15	251	3	244	2
TC-01-53	1.15522	0.05147	0.0006	0.2656	0.003	0.03745	0.0003	262	14	239	2	237	2
TC-01-54	0.75423	0.05379	0.0003	0.33515	0.0023	0.04523	0.0004	362	8	293	2	285	2
TC-01-55	0.32003	0.05163	0.0003	0.28115	0.0022	0.03949	0.0002	269	9	252	2	250	1
TC-01-56	0.50285	0.16627	0.001	10.2352	0.0461	0.44645	0.0017	2520	10	2456	4	2379	7
TC-01-57	0.91898	0.11174	0.0015	4.66482	0.057	0.30278	0.0017	1828	25	1761	10	1705	8
TC-01-58	0.54876	0.05166	0.0003	0.31182	0.0031	0.04376	0.0003	270	10	276	2	276	2
TC-01-59	0.89102	0.07768	0.0005	0.42262	0.0038	0.03943	0.0002	1139	11	358	3	249	1
TC-01-60	0.55478	0.12096	0.0003	6.05067	0.041	0.36279	0.0025	1970	6	1983	6	1995	12
91500	0.34986	0.07467	0.0003	1.84725	0.0112	0.17939	0.0009	1061	6	1062	4	1064	5
91500	0.34403	0.07509	0.0002	1.85315	0.01	0.17895	0.0008	1072	6	1065	4	1061	4
GJ	0.02774	0.0601	0.0003	0.82044	0.006	0.09897	0.0004	606	13	608	3	608	2
GJ	0.02989	0.05988	0.0002	0.81595	0.0039	0.09881	0.0004	598	6	606	2	607	2
TC-01-61	0.84156	0.05303	0.0003	0.3444	0.0026	0.04709	0.0003	330	8	300	2	297	2
TC-01-62	1.18043	0.05147	0.0005	0.2664	0.0028	0.03753	0.0002	262	13	240	2	237	1
TC-01-63	0.60822	0.14112	0.0018	6.64541	0.0767	0.34152	0.0020	2241	23	2065	10	1894	10
TC-01-64	0.82624	0.05416	0.001	0.37459	0.0084	0.05011	0.0004	378	36	323	6	315	2

TC-01-65	0.4188	0.05185	0.0002	0.31191	0.0021	0.04362	0.0002	279	7	276	2	275	1
TC-01-66	0.1788	0.21316	0.058	10.1811	2.2553	0.3464	0.0548	2930	518	2451	205	1917	262
TC-01-67	0.73563	0.05482	0.0003	0.3777	0.0025	0.04997	0.0003	405	7	325	2	314	2
TC-01-68	1.52145	0.05537	0.0005	0.34652	0.0043	0.04534	0.0002	427	18	302	3	286	2
TC-01-69	0.92672	0.0528	0.0004	0.27663	0.0026	0.03799	0.0002	320	14	248	2	240	1
TC-01-70	0.61334	0.05942	0.0003	0.31341	0.0022	0.03828	0.0003	583	8	277	2	242	2
TC-01-71	0.71309	0.05253	0.0004	0.32614	0.0035	0.04505	0.0004	308	11	287	3	284	3
TC-01-72	0.40291	0.05245	0.001	0.32414	0.0052	0.04482	0.0004	305	42	285	4	283	2
TC-01-73	0.91965	0.05163	0.0008	0.30408	0.0056	0.0427	0.0004	269	25	270	4	270	2
TC-01-74	0.92075	0.12208	0.0003	5.85881	0.0303	0.34795	0.0016	1987	4	1955	4	1925	7
TC-01-75	0.7902	0.05163	0.0003	0.27463	0.0016	0.03859	0.0002	269	6	246	1	244	1
91500	0.34031	0.07498	0.0003	1.85426	0.0104	0.17934	0.0008	1133	7	1065	4	1063	4
91500	0.35379	0.07478	0.0002	1.84614	0.0109	0.179	0.0009	1063	38	1062	4	1062	5
GJ	0.02854	0.05997	0.0002	0.81533	0.004	0.09858	0.0004	611	7	605	2	606	2
GJ	0.03206	0.06018	0.0002	0.81743	0.0039	0.0985	0.0004	609	6	607	2	606	2
TC-01-76	0.4771	0.05749	0.0002	0.60185	0.0044	0.07594	0.0006	511	7	478	3	472	3
TC-01-77	1.3001	0.0527	0.0003	0.27284	0.0022	0.03755	0.0002	316	8	245	2	238	1
TC-01-78	0.496	0.05784	0.0003	0.63259	0.004	0.07931	0.0004	524	7	498	2	492	2

TC-01-79	0.82201	0.14711	0.0011	7.37743	0.0463	0.3637	0.0012	2313	13	2158	6	2000	6
TC-01-80	0.6918	0.0612	0.0002	0.78667	0.0042	0.09324	0.0006	646	6	589	2	575	3
TC-01-81	0.49367	0.05315	0.0007	0.30595	0.0036	0.04175	0.0002	335	30	271	3	264	1
TC-01-82	0.49116	0.05152	0.001	0.26586	0.0047	0.03743	0.0004	264	47	239	4	237	2
TC-01-83	0.99655	0.05781	0.0007	0.37334	0.005	0.04682	0.0003	522	18	322	4	295	2
TC-01-84	0.96782	0.15942	0.0003	10.0487	0.0529	0.45702	0.0024	2450	4	2439	5	2426	11
TC-01-85	0.91756	0.05177	0.001	0.30744	0.0064	0.04306	0.0003	275	35	272	5	272	2
TC-01-86	1.0209	0.05166	0.0002	0.27168	0.0017	0.03814	0.0002	270	7	244	1	241	1
TC-01-87	1.04168	0.05237	0.0002	0.2838	0.0024	0.03931	0.0003	301	9	254	2	249	2
TC-01-88	1.82917	0.05668	0.0007	0.30361	0.006	0.03859	0.0004	479	28	269	5	244	2
TC-01-89	0.81173	0.05392	0.0009	0.37964	0.0061	0.05107	0.0003	368	25	327	4	321	2
TC-01-90	1.17825	0.05221	0.0006	0.28188	0.0031	0.03915	0.0002	295	18	252	2	248	1
91500	0.35067	0.07505	0.0002	1.85392	0.0096	0.17911	0.0009	1070	6	1065	3	1062	5
91500	0.34325	0.07471	0.0002	1.84648	0.0087	0.17923	0.0007	1061	40	1062	3	1063	4
GJ	0.02855	0.06008	0.0002	0.82182	0.0037	0.09917	0.0004	606	1	609	2	610	2
GJ	0.03099	0.06005	0.0002	0.82101	0.0035	0.09913	0.0004	606	6	609	2	609	2
TC-01-91	0.53147	0.05067	0.0011	0.26888	0.0055	0.03848	0.0003	226	52	242	4	243	2
TC-01-92	1.0251	0.05177	0.0004	0.26873	0.0024	0.03765	0.0003	275	9	242	2	238	2

TC-01-93	1.0477	0.05325	0.0005	0.34191	0.0033	0.04657	0.0002	340	13	299	2	293	1
TC-01-94	0.98577	0.05146	0.0004	0.26531	0.0021	0.03739	0.0002	262	10	239	2	237	1
TC-01-95	1.86602	0.05217	0.0007	0.27074	0.0034	0.03763	0.0002	293	20	243	3	238	1
TC-01-96	1.25619	0.05104	0.0019	0.28558	0.0106	0.04058	0.0004	243	90	255	8	256	2
TC-01-97	0.91214	0.05139	0.0016	0.27436	0.0081	0.03872	0.0003	258	72	246	6	245	2
TC-01-98	1.23296	0.07209	0.0098	0.30058	0.0407	0.03024	0.0004	989	293	267	32	192	3
TC-01-99	0.82277	0.14338	0.0019	2.64022	0.032	0.13355	0.0007	2268	23	1312	9	808	4
TC-01-100	0.91407	0.06089	0.0017	0.31928	0.0089	0.03803	0.0002	636	62	281	7	241	1
91500	0.331	0.07497	0.0003	1.8518	0.0098	0.17909	0.0007	1133	7	1064	3	1062	4
91500	0.35897	0.07467	0.0002	1.84633	0.0101	0.17929	0.0009	1061	6	1062	4	1063	5
91500	0.35204	0.07499	0.0002	1.85246	0.0085	0.17914	0.0007	1133	6	1064	3	1062	4
GJ	0.02937	0.06008	0.0002	0.83287	0.0055	0.10052	0.0006	606	8	615	3	617	3
GJ	0.02786	0.06012	0.0003	0.83536	0.0082	0.10075	0.0009	609	13	617	5	619	5
NIST	0.98824	0.90256	0.0069	33.575	0.4388	0.26974	0.0031			3598	13	1539	16
TC-02, gray-green tuffaceous sandstone													
91500	0.33294	0.07507	0.0002	1.85121	0.0093	0.1788	0.0007	1072	6	1064	3	1060	4
91500	0.35568	0.0747	0.0002	1.84415	0.0091	0.17902	0.0008	1061	5	1061	3	1062	4
91500	0.35305	0.07487	0.0002	1.85524	0.0088	0.17968	0.0007	1065	4	1065	3	1065	4

GJ	0.02957	0.06002	0.0001	0.83231	0.0034	0.10056	0.0004	606	6	615	2	618	2
GJ	0.02806	0.06009	0.0001	0.83326	0.0035	0.10055	0.0004	606	1	615	2	618	2
NIST	0.99312	0.90173	0.0015	33.5306	0.1209	0.26965	0.0009			3596	4	1539	5
TC-02-1	0.80336	0.05129	0.0002	0.26579	0.0018	0.03757	0.0002	254	7	239	1	238	1
TC-02-2	1.05289	0.15386	0.0004	4.95855	0.0206	0.23369	0.0008	2389	3	1812	4	1354	4
TC-02-3	0.49028	0.05159	0.0002	0.2679	0.0016	0.03766	0.0002	267	6	241	1	238	1
TC-02-4	0.55871	0.105	0.0017	4.40766	0.059	0.30445	0.0027	1714	30	1714	11	1713	13
TC-02-5	0.96037	0.05321	0.0004	0.28011	0.0023	0.03817	0.0002	338	12	251	2	242	1
TC-02-6	0.6749	0.10739	0.0015	4.34054	0.0521	0.29315	0.0021	1756	26	1701	10	1657	10
TC-02-7	0.82493	0.05245	0.0003	0.33253	0.0022	0.04599	0.0003	305	7	291	2	290	2
TC-02-8	0.80397	0.05211	0.0002	0.26974	0.0017	0.03753	0.0002	290	6	242	1	238	1
TC-02-9	1.12169	0.05203	0.0003	0.26867	0.002	0.03745	0.0002	287	9	242	2	237	1
TC-02-10	1.24707	0.05228	0.0007	0.27208	0.0043	0.03774	0.0003	298	23	244	3	239	2
TC-02-11	0.52561	0.05222	0.0008	0.29644	0.0043	0.04117	0.0003	295	37	264	3	260	2
TC-02-12	0.83069	0.05492	0.0008	0.2846	0.0045	0.03755	0.0002	409	27	254	4	238	1
TC-02-13	0.43635	0.11427	0.0002	5.09848	0.038	0.32359	0.0025	1868	6	1836	6	1807	12
TC-02-14	0.67332	0.10712	0.0002	4.56389	0.0268	0.30897	0.0017	1751	5	1743	5	1736	8
TC-02-15	1.3291	0.05458	0.0002	0.2825	0.0014	0.03756	0.0002	395	5	253	1	238	1

91500	0.34449	0.0748	0.0002	1.85563	0.0094	0.17987	0.0007	1065	38	1065	3	1066	4
91500	0.34938	0.07496	0.0002	1.84477	0.0093	0.17847	0.0007	1133	6	1062	3	1059	4
GJ	0.02735	0.05998	0.0001	0.82627	0.0046	0.0999	0.0005	611	6	612	3	614	3
GJ	0.03309	0.06018	0.0001	0.82855	0.0034	0.09985	0.0003	609	6	613	2	614	2
TC-02-16	0.35891	0.17942	0.0004	12.3479	0.0599	0.49907	0.0023	2648	4	2631	5	2610	10
TC-02-17	0.46543	0.09245	0.0008	0.89785	0.0093	0.07045	0.0006	1477	9	651	5	439	4
TC-02-18	0.88913	0.05236	0.0005	0.33783	0.0032	0.04682	0.0003	301	11	296	2	295	2
TC-02-19	0.97485	0.05348	0.0005	0.283	0.0026	0.03843	0.0002	349	11	253	2	243	1
TC-02-20	0.36359	0.0515	0.0007	0.26587	0.0031	0.03744	0.0002	263	31	239	2	237	1
TC-02-21	0.61372	0.16412	0.0003	10.269	0.0507	0.45369	0.0020	2499	4	2459	5	2412	9
TC-02-22	1.00738	0.1044	0.0002	4.37998	0.0222	0.30428	0.0015	1704	4	1709	4	1712	7
TC-02-23	0.94662	0.10802	0.0002	4.83946	0.0261	0.32496	0.0018	1766	5	1792	5	1814	9
TC-02-24	0.74002	0.05131	0.0002	0.26536	0.0017	0.03751	0.0002	255	7	239	1	237	1
TC-02-25	0.68653	0.05204	0.0002	0.30058	0.0014	0.0419	0.0002	287	5	267	1	265	1
TC-02-26	1.35716	0.05268	0.0005	0.29459	0.0046	0.04056	0.0006	315	16	262	4	256	3
TC-02-27	0.58499	0.10416	0.0003	4.34018	0.0262	0.30217	0.0017	1700	5	1701	5	1702	8
TC-02-28	1.08872	0.11152	0.0003	4.97428	0.0319	0.32339	0.0019	1824	5	1815	5	1806	9
TC-02-29	0.3929	0.05138	0.0002	0.28573	0.0018	0.04033	0.0002	258	7	255	1	255	1

TC-02-30	0.92644	0.05208	0.0003	0.3457	0.0038	0.04813	0.0005	289	11	301	3	303	3
91500	0.33419	0.07493	0.0003	1.85286	0.0096	0.17931	0.0007	1066	6	1064	3	1063	4
91500	0.36066	0.07483	0.0002	1.84754	0.0096	0.17903	0.0008	1065	6	1063	3	1062	4
GJ	0.02807	0.05958	0.0002	0.81808	0.0042	0.09957	0.0005	587	6	607	2	612	3
GJ	0.03302	0.05981	0.0001	0.80993	0.0037	0.0982	0.0004	598	10	602	2	604	2
TC-02-31	0.79694	0.05272	0.0017	0.27613	0.0084	0.03799	0.0003	317	73	248	7	240	2
TC-02-32	0.92837	0.10698	0.0004	4.63188	0.0372	0.3141	0.0025	1749	7	1755	7	1761	12
TC-02-33	0.26738	0.13787	0.0005	7.82873	0.1186	0.41107	0.0050	2201	12	2212	14	2220	23
TC-02-34	0.7949	0.0521	0.0003	0.27772	0.0019	0.03867	0.0002	290	7	249	1	245	1
TC-02-35	1.05464	0.05323	0.0003	0.32798	0.0025	0.0447	0.0003	339	8	288	2	282	2
TC-02-36	1.30552	0.1079	0.003	4.35963	0.1151	0.29303	0.0027	1764	52	1705	22	1657	13
TC-02-37	0.71311	0.11226	0.0003	4.92844	0.0383	0.31834	0.0023	1836	6	1807	7	1782	11
TC-02-38	0.6802	0.05215	0.0003	0.27639	0.0036	0.03843	0.0004	292	13	248	3	243	3
TC-02-39	0.81876	0.11578	0.0017	5.23399	0.068	0.32786	0.0021	1892	27	1858	11	1828	10
TC-02-40	0.56047	0.10503	0.0016	4.37066	0.0576	0.30181	0.0024	1715	29	1707	11	1700	12
TC-02-41	1.71003	0.0514	0.0005	0.26564	0.0034	0.03745	0.0003	259	18	239	3	237	2
TC-02-42	0.79398	0.05196	0.0004	0.27384	0.0029	0.03823	0.0004	284	11	246	2	242	2
TC-02-43	0.71519	0.05248	0.0006	0.28011	0.0035	0.03873	0.0003	306	15	251	3	245	2

TC-02-44	0.67297	0.10652	0.0005	4.80949	0.0531	0.32744	0.0033	1741	9	1787	9	1826	16
TC-02-45	0.45879	0.05276	0.0003	0.33483	0.0036	0.04605	0.0005	318	11	293	3	290	3
91500	0.33338	0.07472	0.0005	1.85022	0.0181	0.17959	0.0012	1061	10	1064	6	1065	6
91500	0.36161	0.07504	0.0005	1.85018	0.0174	0.17875	0.0011	1069	13	1063	6	1060	6
GJ	0.03339	0.06027	0.0002	0.80663	0.0052	0.09706	0.0005	613	7	601	3	597	3
GJ	0.02772	0.06016	0.0002	0.80156	0.0051	0.09662	0.0005	609	3	598	3	595	3
TC-02-46	0.40169	0.164	0.0006	9.45364	0.0721	0.418	0.0027	2497	6	2383	7	2251	12
TC-02-47	1.32372	0.05288	0.0008	0.34506	0.0048	0.04736	0.0004	324	18	301	4	298	2
TC-02-48	0.89328	0.05199	0.0006	0.26955	0.0036	0.0376	0.0003	285	18	242	3	238	2
TC-02-49	0.88653	0.05163	0.0005	0.28877	0.0026	0.04058	0.0003	269	10	258	2	256	2
TC-02-50	1.12826	0.05146	0.0003	0.26545	0.0026	0.03743	0.0004	262	10	239	2	237	2
TC-02-51	0.47059	0.05273	0.0003	0.34104	0.0033	0.04692	0.0004	317	10	298	3	296	2
TC-02-52	0.92545	0.05231	0.0008	0.27422	0.0043	0.03803	0.0003	299	23	246	3	241	2
TC-02-53	0.76819	0.16914	0.0004	11.5001	0.1115	0.49302	0.0046	2549	7	2565	9	2584	20
TC-02-54	1.29976	0.06126	0.0003	0.3109	0.0019	0.03681	0.0002	648	6	275	1	233	1
TC-02-55	0.78767	0.05228	0.0004	0.33067	0.0031	0.04588	0.0002	298	12	290	2	289	2
TC-02-56	0.6798	0.16954	0.0003	12.1758	0.1286	0.52079	0.0054	2553	8	2618	10	2703	23
TC-02-57	0.55797	0.12174	0.0003	6.10376	0.0533	0.36358	0.0031	1982	7	1991	8	1999	15

TC-02-58	1.12127	0.05197	0.0003	0.2891	0.0023	0.04039	0.0004	284	9	258	2	255	2
TC-02-59	1.64925	0.05139	0.0004	0.28722	0.0022	0.04054	0.0002	258	9	256	2	256	1
TC-02-60	0.65005	0.05127	0.0002	0.26507	0.0025	0.03749	0.0003	253	10	239	2	237	2
91500	0.34768	0.07469	0.0002	1.84913	0.0111	0.17952	0.0009	1061	6	1063	4	1064	5
91500	0.34617	0.07507	0.0003	1.85127	0.0105	0.17882	0.0007	1072	9	1064	4	1061	4
GJ	0.02779	0.05978	0.0001	0.81672	0.0047	0.09905	0.0005	594	10	606	3	609	3
GJ	0.03162	0.05982	0.0002	0.81702	0.0036	0.09905	0.0004	598	10	606	2	609	2
TC-02-61	0.88782	0.05385	0.0006	0.30161	0.0033	0.04063	0.0002	365	15	268	3	257	1
TC-02-62	1.50852	0.05099	0.0006	0.26822	0.0035	0.03814	0.0003	241	18	241	3	241	2
TC-02-63	1.54795	0.05526	0.0003	0.31919	0.0021	0.04189	0.0001	423	9	281	2	265	1
TC-02-64	0.69326	0.0528	0.0005	0.34632	0.0037	0.04762	0.0004	320	11	302	3	300	2
TC-02-65	1.1563	0.05152	0.0007	0.27704	0.0034	0.03913	0.0004	264	13	248	3	247	2
TC-02-66	1.27575	0.05244	0.0009	0.27481	0.0056	0.03796	0.0003	305	32	247	4	240	2
TC-02-67	0.78159	0.05106	0.0005	0.28758	0.0032	0.04085	0.0003	244	15	257	3	258	2
TC-02-68	0.83408	0.1066	0.0005	4.44393	0.0406	0.30225	0.0024	1742	7	1721	8	1702	12
TC-02-69	0.53115	0.05572	0.0013	0.29008	0.0062	0.03776	0.0004	441	54	259	5	239	2
TC-02-70	0.70862	0.05614	0.0013	0.29653	0.0068	0.03831	0.0002	458	53	264	5	242	1
TC-02-71	0.25881	0.0508	0.0006	0.26516	0.003	0.03786	0.0002	232	29	239	2	240	1

TC-02-72	0.26181	0.06164	0.0008	0.68972	0.0077	0.08116	0.0004	662	27	533	5	503	2
TC-02-73	0.63098	0.11485	0.0003	5.07736	0.0391	0.32052	0.0022	1878	6	1832	7	1792	11
TC-02-74	1.2708	0.05186	0.0005	0.27003	0.0026	0.03779	0.0003	279	11	243	2	239	2
TC-02-75	0.96508	0.05269	0.0005	0.35458	0.0029	0.04882	0.0003	316	10	308	2	307	2
91500	0.3497	0.07492	0.0002	1.85438	0.0112	0.17948	0.0009	1066	6	1065	4	1064	5
91500	0.34419	0.07484	0.0002	1.84602	0.0103	0.17886	0.0009	1065	7	1062	4	1061	5
GJ	0.02668	0.05985	0.0001	0.81779	0.0051	0.09908	0.0006	598	8	607	3	609	3
GJ	0.03172	0.05978	0.0002	0.81375	0.0038	0.09871	0.0004	594	10	605	2	607	2
TC-02-76	0.85757	0.1067	0.0002	4.50589	0.0332	0.3061	0.0021	1744	6	1732	6	1722	10
TC-02-77	0.85728	0.05226	0.0004	0.29096	0.0021	0.04038	0.0002	297	9	259	2	255	1
TC-02-78	1.08274	0.05261	0.0022	0.32237	0.0133	0.04444	0.0005	312	99	284	10	280	3
TC-02-79	0.37881	0.11272	0.0002	5.12804	0.0313	0.32989	0.0020	1844	5	1841	5	1838	10
TC-02-80	1.28971	0.05208	0.0005	0.27392	0.003	0.03814	0.0002	289	17	246	2	241	1
TC-02-81	0.74402	0.05198	0.0005	0.29016	0.0029	0.04048	0.0002	284	16	259	2	256	1
TC-02-82	1.94217	0.10543	0.0003	4.12783	0.0167	0.2839	0.0009	1722	3	1660	3	1611	4
TC-02-83	1.11699	0.05161	0.0005	0.26768	0.0033	0.0376	0.0003	268	14	241	3	238	2
TC-02-84	1.21065	0.05236	0.0017	0.30369	0.0094	0.04207	0.0003	301	75	269	7	266	2
TC-02-85	1.23895	0.04605	0.0086	0.24279	0.0448	0.03824	0.0007		318	221	37	242	4

TC-02-86	1.4984	0.17025	0.0005	10.7125	0.057	0.45627	0.0021	2560	4	2499	5	2423	9
TC-02-87	1.09581	0.05238	0.0003	0.27361	0.0025	0.0379	0.0003	302	9	246	2	240	2
TC-02-88	0.81266	0.05242	0.0004	0.32477	0.0036	0.04493	0.0004	304	12	286	3	283	2
TC-02-89	0.9711	0.05713	0.0004	0.36659	0.0033	0.04656	0.0003	497	9	317	2	293	2
TC-02-90	0.43692	0.05258	0.0004	0.32271	0.0038	0.04454	0.0004	311	12	284	3	281	3
91500	0.35047	0.0746	0.0003	1.84649	0.0113	0.17946	0.0009	1057	7	1062	4	1064	5
91500	0.34344	0.07516	0.0003	1.85391	0.0098	0.17888	0.0007	1072	7	1065	3	1061	4
GJ	0.02727	0.06033	0.0002	0.82555	0.0046	0.09922	0.0005	617	6	611	3	610	3
GJ	0.03307	0.06004	0.0002	0.81347	0.0038	0.09826	0.0004	606	6	604	2	604	2
TC-02-91	1.03771	0.06297	0.0027	0.53648	0.0227	0.06179	0.0003	707	93	436	15	387	2
TC-02-92	1.03248	0.05803	0.0026	0.30241	0.0128	0.0378	0.0005	531	99	268	10	239	3
TC-02-93	1.00115	0.05253	0.0004	0.33902	0.003	0.04681	0.0003	308	11	296	2	295	2
TC-02-94	1.47785	0.10942	0.0007	4.54461	0.0701	0.30069	0.0034	1790	14	1739	13	1695	17
TC-02-95	0.53531	0.1691	0.0004	10.8285	0.0602	0.46427	0.0022	2549	4	2509	5	2458	10
TC-02-96	1.06526	0.07926	0.0009	0.28015	0.0036	0.02564	0.0002	1179	13	251	3	163	1
TC-02-97	1.11783	0.05178	0.0006	0.2676	0.004	0.03745	0.0003	276	22	241	3	237	2
TC-02-98	0.77641	0.05174	0.0003	0.26775	0.002	0.03753	0.0003	274	8	241	2	238	2
TC-02-99	0.45808	0.11525	0.0003	5.55394	0.048	0.34942	0.0030	1884	7	1909	7	1932	14

TC-02-100	1.07014	0.05162	0.0018	0.26773	0.009	0.03762	0.0003	269	81	241	7	238	2
91500	0.33431	0.07523	0.0003	1.86179	0.0103	0.17945	0.0009	1076	-26	1068	4	1064	5
91500	0.35677	0.07469	0.0003	1.84117	0.0098	0.17875	0.0008	1061	40	1060	4	1060	4
91500	0.35047	0.07472	0.0003	1.84764	0.0102	0.17932	0.0008	1061	8	1063	4	1063	4
GJ	0.02746	0.06014	0.0003	0.82106	0.0064	0.09897	0.0007	609	11	609	4	608	4
GJ	0.03256	0.06003	0.0005	0.81061	0.0086	0.09791	0.0009	606	17	603	5	602	5
NIST	0.78823	0.89823	0.0225	0.14755	20.068	0.00119	0.1572			140		8	