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# Preliminary elemental analysis of fossil insects from the Middle Jurassic of Daohugou, Inner Mongolia and its taphonomic implications

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**Fossil insects from the Middle Jurassic of Daohugou, Inner Mongolia were investigated using Scanning Electron Microscope (SEM) for the first time, and portions and distribution of some elements in compression and pyrited fossils were also revealed by X-ray Energy Dispersive Spectroscopy (EDS) attached to SEM. Most of compression fossil insects from the Daohugou Biota are preserved in organic remains (diagenetic products of the original organic components). A small part of compression fossils retain a comparatively high Fe concentration which probably resulted from the absorption of Fe by biopolymers during the decaying period. Pyritized insect fossils suggest that the "fossil envelop" model found in the Early Cretaceous Jehol Biota probably also occurs in the Daohugou Biota. Different preservation modes show various mechanisms of fossilization, and also suggest that several different microenvironments are present in Daohugou palaeolakes.**

Inner Mongolia, Middle Jurassic, Daohugou, fossil insects, taphonomy



Fossil insects have been studied for over 200 years, but their fossilization is still far from clear[1,2]. In recent 10 years, some considerable progress has been made in studying the insect taphonomy[3−13], and major studies refer to the preburial processes before the fossilization[3−6]. Analyses of the chemical composition of fossil insects focused mainly on those in amber[7,8] and some Cenozoic specimens[9−13], but much less on Mesozoic ones[4]. So far, the taphonomy of some early arthropods in some famous lagerstatten has been studied in detail[14−17], and these methods and results could also be applied to the study of Mesozoic fossil insects. Although abundant well-preserved fossil insects have been discovered from the Mesozoic of China, their taphonomy is completely unknown. Very recently, abundant plant and animal fossils have been reported from the Middle Jurassic of Daohugou, Ningcheng County, Chifeng City, Inner Mongolia, China[18−21]. The rich insect fauna from this locality provides some important clues to understanding the evolution of Mesozoic insects. These fossil insects are probably similar to those from the Jehol Biota in the taphonomic process, and both faunas are related to the volcanic activities. Therefore, fossil insects from Daohugou provide an approach to understanding the taphonomy of fossil insects from the Mesozoic of northeastern China.

## 1 Material and methods

The four orders, Diptera, Hemiptera, Orthoptera and Coleoptera, are common in fossil insect assemblages.

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Four Daohugou specimens within the above four groups are picked to represent three different modes of preservation. Specimen NIGP149368 is a compression of Procercopidae within Hemiptera, and its body is brown and its abdominal segments are clear. Specimen NIGP149369 is a compression of Prophalangopsidae within Orthoptera, and its body is grayish brown and strongly deformed. Based on our collections, most of Daohugou compressions (more than 99%) are preserved in this mode. Specimen NIGP149370 is a compression of Diptera without wings. Its body is brown and its abdominal segments are clear. Just a small part of Daohugou compressions (less than 1%) are preserved in this mode, which is similar to the first mode under the light microscope, except exhibiting yellowish. However, the elemental analysis demonstrates some distinct differences between these two modes (see below). Specimen NIGP149371 is a pyritized beetle retaining slightly three-dimensional structures. The beetle is yellowish brown, with appendages missing, tegmina broken and granules clear. The third mode, pyritization, is rare in the Daohugou Biota, and just occurs in several beetles. All examined specimens are preserved on the surface of gray or grayish-yellow thin-bedded tuffaceous siltstones. Conchostracans (*Euestheria*) are usually preserved on the same bedding plane. All specimens for this study are deposited in the Nanjing Institute of Geology and Palaeontology (NIGP), Chinese Academy of Sciences.

The SEM (scanning electron microscope) and EDS (X-ray energy dispersive spectrum) analyses were performed in the Key Laboratory of Marginal Sea Geology, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. Samples were cut to the appropriate size, and their undersurfaces were polished (topside of samples should not be polished in order to avoid configuration disturbing). Then these samples were cleaned with distilled water, and dried in the desiccator. Additionally, the samples were analyzed uncoated for subsequent analyses. Micro-surface information was obtained under the low vacuum mode (100 Pa in sample chamber) of the Quanta 400 SEM with the accelerating voltage 20 kV. The elemental analyses of points and areas were examined by the EDS produced by EDAX company (model: Genesis 2000). In order to obtain more exact data, the acquisition time for the SUTW-Sapphire EDS detector was between 90 and 120 s.

## 2 Results

The concentration of both elements C and Ca in fossils NIGP149368 and NIGP149369 is distinctly higher than in matrix, while that of other elements is lower than in matrix (Table 1). The backscattered electron map of specimen NIGP149368 indicates that element C is not equably distributed in the fossil: the darker in the BSE map, the higher the carbon content (Figure 1(c)). Elemental maps for C and Ca match the profile of the fossil. Furthermore, the lighter areas in the C elemental map agree with the darker areas in the BSE map (Figure 1(c)—(e)). The concentration of C and Fe in fossil NIGP149370 is respectively twice than in matrix, while that of other elements is lower than in matrix (Table 1). Moreover, the Fe elemental map matches the profile of the fossil very well (Figure 1(g)). Fossil NIGP149371 comprises pyrites, and thus its content of both elements Fe and S is higher than in matrix. Partly oxidized pyrites make the fossil reddish in colour. SEM analysis reveals that pyritic crystals are mainly distributed on or around

**Table 1** Relative abundance for elements in six spots shown in Figure 1[a)]

| | | C | O | Mg | Al | Si | K | Ca | Fe |
|---|---|---|---|---|---|---|---|---|---|
| NIGP149368 (fossil) | wt% | 28.75 | 35.08 | 0.27 | 4.26 | 23.30 | 4.60 | 3.48 | – |
| | at% | 41.28 | 37.82 | 0.19 | 2.72 | 14.31 | 2.03 | 1.50 | – |
| NIGP149368 (matrix) | wt% | – | 43.38 | 0.42 | 8.59 | 37.77 | 9.83 | – | – |
| | at% | – | 58.38 | 0.40 | 6.86 | 28.95 | 5.41 | – | – |
| NIGP149369 (fossil) | wt% | 46.58 | 25.54 | 0.15 | 3.46 | 13.75 | 5.94 | 3.02 | 0.75 |
| | at% | 60.94 | 25.08 | 0.10 | 2.01 | 7.69 | 2.39 | 1.18 | 0.21 |
| NIGP149369 (matrix) | wt% | 6.51 | 46.24 | 0.29 | 6.33 | 34.07 | 4.59 | – | 1.50 |
| | at% | 10.72 | 57.15 | 0.24 | 4.64 | 23.99 | 2.32 | – | 0.53 |
| NIGP149370 (fossil) | wt% | 14.64 | 44.29 | 0.73 | 6.36 | 25.33 | 3.42 | 0.89 | 4.34 |
| | at% | 22.82 | 51.82 | 0.56 | 4.41 | 16.88 | 1.64 | 0.41 | 1.46 |
| NIGP149370 (matrix) | wt% | 7.66 | 42.40 | 1.00 | 8.36 | 31.70 | 4.94 | 1.11 | 2.84 |
| | at% | 12.83 | 53.30 | 0.83 | 6.23 | 22.70 | 2.54 | 0.56 | 1.02 |

a) "–" represents non-detected; wt% and at% represent the percentage of atom weight and atom quantity, respectively.

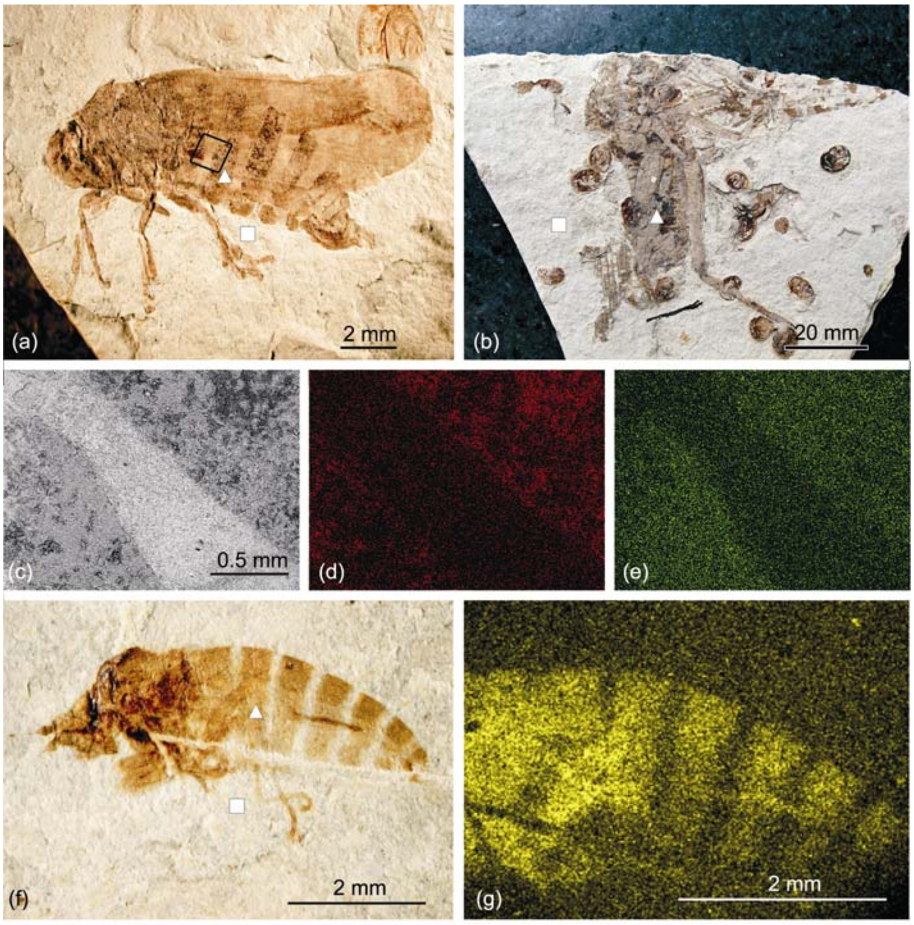


**Figure 1** (a) Light photomicrograph of a procercopid (Hemiptera) (No: NIGP149368; Middle Jurassic, Daohugou, Inner Mongolia); (b) light photomicrograph of a prophalangopsid (Orthoptera) (No. NIGP149369; Middle Jurassic, Daohugou, Inner Mongolia); (c)—(e) BSE photomicrograph, C elemental map, Ca elemental map for specimen NIGP149368 (area shown by black square in (a) respectively; (f) light photomicrograph of a dipteran (No. NIGP149370; Middle Jurassic, Daohugou, Inner Mongolia); (g) Fe elemental map for specimen NIGP149370. Triangles showing the spots in fossils for EDS analysis, and squares showing the spots in matrix for EDS analysis.

the tegmina, and distinctly decrease in the matrix far from the tegmina. Pyrites are composed of irregular crystals, of which each comprises some minute microcrystallines of 0.5—1 μm in diameter (Figure 2).

## 3 Discussion

Insect cuticles are mainly composed of chitin, which may survive for a long time under anoxic conditions[2]. Hence, the parts of insect with thick cuticles are more easily fossilized, exemplified by fossil cockroach tegmina and beetle elytra widespread all over the world. All fossil chitin, however, are discovered from Cenozoic insects. The oldest chitin is known from an Late Oligocene (25 Ma) weevil at Enspel, Germany[13], and the chitin in much older insects has been chemically degraded[22]. During diagenesis, degraded biopolymers could be transformed into more stable biopolymers by the random intermolecular polymerisation and polycondensation[9]. Furthermore, chemical experiments also revealed that labile lipids could be incorporated into a resistant aliphatic macromolecule via *in situ* polymerization[22−24]. Some Palaeozoic and Mesozoic arthropods (including insects) are composed of biopolymers[22]. A much higher concentration of element C in insects of specimens NIGP149370, NIGP149368 and NIGP149369 than in matrix suggests that these compression fossils comprise biopolymers. So far, some types of biopolymers have been discovered from fossil insects, and different biopolymers occur in different groups[9,11]. Therefore, the original biomolecules (such as chitin) in Daohugou insects most probably have been transformed into more resistant biopolymers, of which the exact compositions remain to be determined.

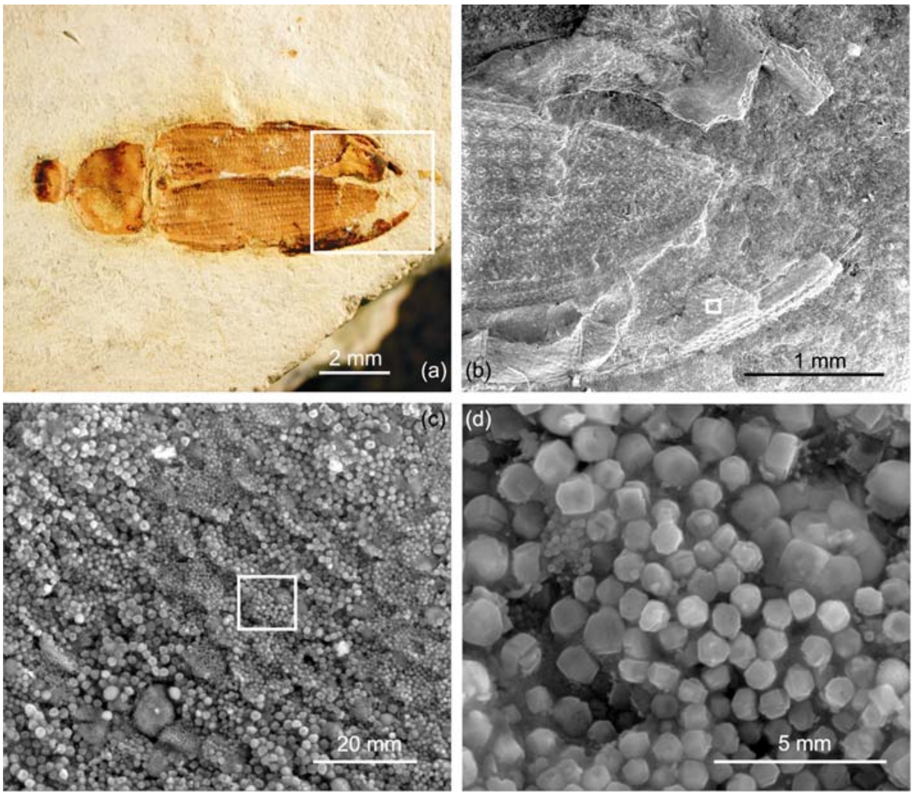


**Figure 2** (a) Light photomicrograph of fossil beetle (No. NIGP149371; Middle Jurassic, Daohugou, Inner Mongolia); (b), (c), (d) SEM magnifications of areas showed by white squares in (a), (b), (c) respectively.

Various types of fossilization occur in insects under different microenvironments. Therefore, diverse fossil insects from the same bed or different strata probably have different fossilization modes[2]. Clay minerals played a key role in the preservation of soft tissues in some famous lagerstatten[4,25]. However, only elements C and Ca possess a high concentration in insects of specimens NIGP149368 and NIGP149369, suggesting that clay minerals are not important for the preservation of Daohugou insects. The high concentration of Ca in fossil insects probably resulted from calcium carbonate minerals, which are normally associated with fossil insects[4]. These minerals could not normally replicate the structure of insects, but may infill voids left following the decay of soft-tissues and promote rapid lithification[4]. The distinct difference between NIGP149370 and other two specimens is that the former preserves a high concentration of Fe, which is also higher than that in matrix. Petrovich suggested that the preservation in the Burgess Shale could be attributed to decay inhibition as a result of adsorption of $Fe^{2+}$ ions (products of Fe(III) reduction) onto structural biopolymers[26]. Similarly, the high concentration of Fe in fossil NIGP149370 probably resulted from the absorption of Fe by biopolymers.

Pyritization is among the most common fossilization modes, and usually occurs in animal soft-tissues and plant remains[15,25]. It has been found in some Cenozoic insects[1]. However, only a few previous studies focused on taphonomic implications of Mesozoic pyritized insects. Leng and Yang found some *in situ* pyrite framboids and microcrystallines of plant and feather fossils in the Jehol Biota, and proposed that the "fossil envelop" microenvironment during the early fossilization process is a prerequisite to the formation of pyrites[27]. The pyritized insect suggests that the similar microenvironment and fossilization mechanism found in the Early Cretaceous Jehol Biota probably also occurs in the Daohugou Biota. Generally, pyritization only preserve the outlines of fossil insects, because pyrite crystals are coarse and form too late in the taphonomic process to replicate the finest details[16,17]. The physical properties of pyrites can be used to define a series of geochemical and depositional parameters[4,16,27]. However, some information concerning the palaeoenvironment remains to be analyzed because of the lack of enough well-preserved pyritized insects.

In conclusion, fossil insects from the Middle Jurassic of Daohugou have different preservation modes, which show various mechanisms of fossilization, and also suggest that several different microenvironments are present in Daohugou palaeolakes. However, some questions should be highlighted to require further research. How do different modes of preservation correspond to different microenvironments? How do microenvironments affect the taphonomic processes of fossil insects?

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