

# **Testing for the Effects and Consequences of Mid Paleogene Climate Change on Insect Herbivory**

Torsten Wappler<sup>1\*</sup>, Conrad C. Labandeira<sup>2,3</sup>, Jes Rust<sup>1</sup>, Herbert Frankenhäuser<sup>4</sup>, Volker Wilde<sup>5</sup>

**1** Steinmann Institute, University of Bonn, 53115 Bonn, Germany; **2** Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington, DC 20013, USA; **3** Department of Entomology and BEES Program, University of Maryland, College Park, MD 20742, USA; **4** Mainz Natural History Museum / State Collection for Natural History of Rhineland-Palatine, Mainz, Germany; **5** Senckenberg Forschungsinstitut und Naturmuseum, Paläobotanik, Frankfurt am Main, Germany.

\* Author for correspondence.

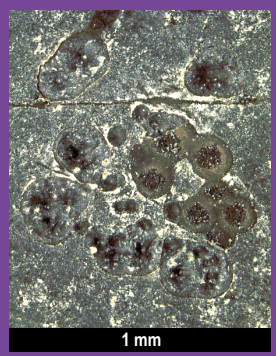
## **ELECTRONIC SUPPLEMENTARY MATERIAL**

### **FILE S3**

New damage types (DTs) recorded from Messel and Eckfeld and types that are new but common at both localities organized by functional feeding groups.

Galling

DT 144 Galling



Multiloculate; dark inner core, surrounding smooth surface and circular margins; often fused.

DT 145 Galling



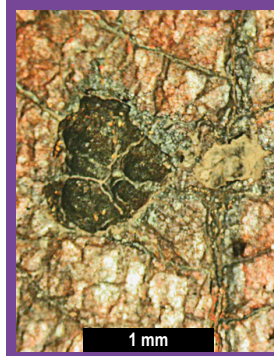
Spheroidal; large central chamber surrounded by thick wall and second tissue layer; outermost layer thin.

DT 146 Galling



Large, unilocular, hemispherical, with smooth surface and thickened base; on midrib.

DT 147 Galling



Small, irregular shape, thickened; with internal partitions representing continuation of tertiary venation.

# Galling

DT 149 Galling



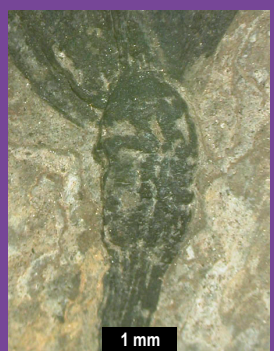
Cylindrical to ovoidal, interveinal; with prominently ribbed exterior and short, pedunculate base.

DT 150 Galling



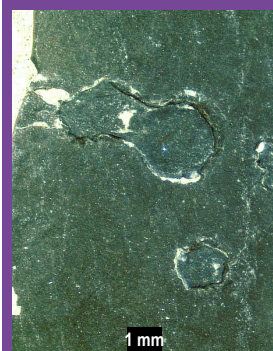
Elongate, attached to 2° veins; thick wall with transverse structure, smooth surface and acute tip.

DT 169 Galling



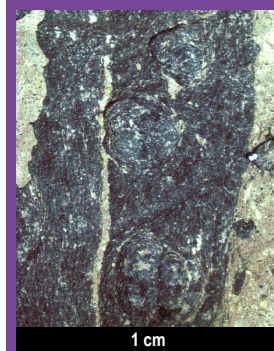
Large globose, fleshy gall with a slit-like aperture; occurring on petiole.

DT 186 Galling



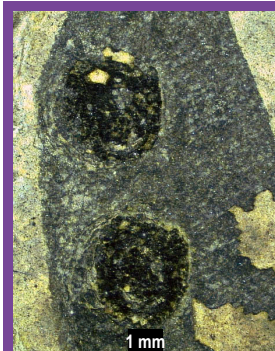
Deciduous, hemispheroidal galls up to 5 mm diameter with thickened outer layer and anchored to deep foliar tissues by a constricted but broad pedicel.

DT 188 Galling



Large, compound, foliar, smooth-surfaced galls; spheroidal-lobate in shape with up to 8 individual locules; occurring on leaf midblade area between midrib

DT 189 Galling



Large compound galls subdivided by tertiary venation into distinct dark-hued single-chamber subunits; enveloped by an outer indurated layer of confluent tissue.

DT 190 Galling



Circular to somewhat ellipsoidal to even narrowly ellipsoidal scales with a central, concentric dark region and lighter-hued concentric rings towards the margin; often

DT 194 Galling



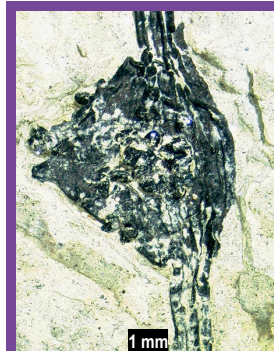
Basal attachment scar of a large, probably deciduous pedunculate gall, occurring in thickened foliar tissue, characterized by radiatory ridges forming a central tubular

DT 197 Galling



Ovoidal, elliptical, to somewhat irregularly margined bister galls with a variable broad, thickened margin of transverse lineations and a lighter hued, finer-textured

DT 199 Galling



Petiolar or twig galls ovoidal to spheroidal in shape beaving a distinctive pointed, lipped ostiole, a central chamber containing dark, rounded, maccuated

DT 204 Galling



A linear series of up to 15 circular to elongate galls occurring adjacent to one another and bounded laterally by parallel major veins, each with a dark, thick

DT 205 Galling



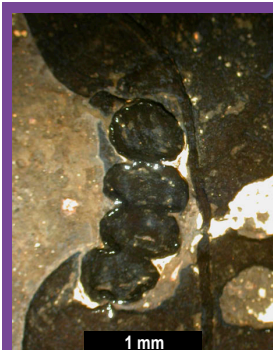
Distinctive, deciduous, short, pedunculate, spinose gall of an overall elliptical shape and a central chamber with particulate material; approximately 15 short

DT 206 Galling



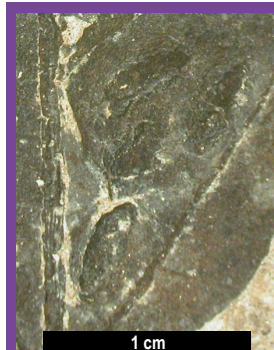
Several small, circular, single chambered galls aligned end-to-end in a linear sequence parallel to the primary plant-host venation.

DT 209 Galling



A linear series of 3 to 4 equisized circular to broadly ellipsoidal opaque galls, each with a dark outer cover and a single, cupacious chamber, occurring on

DT 213 Galling



Deciduous, elongate elliptical sessilely to leaf blade with a smooth-surfaced outer indurated layer and a single ellipsoidal inner

Hole Feeding

DT 148

Hole Feeding



Circular holes with a broad flange of reaction tissue, often extending to enveloping polylobate area.

DT 212

Hole Feeding



A dumbbell-shaped mandible bite mark on either side of a midrib or other primary vein, with bite enlarged toward leaf margin and joined over the vein, forming a

Margin Feeding

DT 142

Margin Feeding



Cusped margin feeding with a very broad rim of transverse lineations.

Hole Feeding

Margin Feeding

DT 143

Margin Feeding



Three or more serial, cusped margin excisions, separated by small leaf-margin segments.

DT 198

Margin Feeding



Highly trenched, narrow margin feeding with extensive necrotic flaps or adjoined necrotic tissue and projecting veinal stringers, frequently extending to the midrib

DT 200

Margin Feeding



Cusped to nearly-trenched margin feeding with an opaque, thickened rim of reaction tissue organized into inverted cusps and projecting flaps.

Mining

Mining

DT 170

Mining



Circular to ellipsoidal (rectangular) mined areas, left veins of the leaf have been left intact over the mined areas, apparently consumption of parenchyma by

DT 171

Mining



Small meandering, frass-filled mine with rimmed, circular, terminal chamber of tiny coprolites.

DT 173

Mining



Long serpentine mine; enlarged oviposition site; frass trail intestinform, of rounded angulate loops; terminal chamber large.

DT 176

Mining



Small (<10 mm) mine with a short, linear to curved early phase, and a much expanded ovoidal to circular terminal phase. (117)

DT 182

Mining



Multiple (up to 8) sinusoidal mines (cu 1.5 mm diameter and at least 30 mm long) originating from a single oviposition event and following a parallel, co-ordinated

DT 185

Mining



Curvilinear to broadly serpentine leaf mine with an exceptionally thickened margin and an apparently devoid of identifiable internal contents such as coprolites, and

DT 187

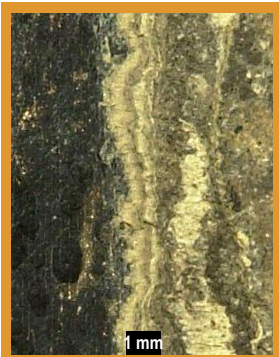
Mining



Medium-sized (ca. 15 mm x 10 mm) ovoidal blotch mines with a pronounced outer sinusoidal margin containing submillimeter sized ellipsoidal coprolites

DT 193

Mining



Delicate, graule leaf mine at edge of a parallel-veined leaf characterized by comparatively wide affected area (ca. 2 mm) with a distinct reaction rim and a very

DT 195

Mining



Circular to broadly ellipsoidal to elongate mine-like circular excavations of inner tissue dominated by an inner cluster of 10-20 elongate parallel-sided

DT 208

Mining



Mine consisting of an initial elongate region containing the oviposition site and first few small larval instars followed by a significantly narrower, curvilinear

DT 210

Mining



Small, initially hariline wide mine, enlarging in width to ca. 1.0 mm, containing circular to ellipsoidal frass placed along the medial axis at regular intervals in the last

Piercing & Sucking

DT 157

Piercing & Sucking

DT 168

Piercing & Sucking

DT 183

Piercing & Sucking

DT 191

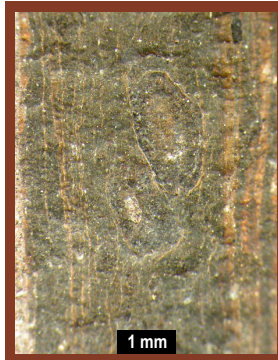
Piercing & Sucking



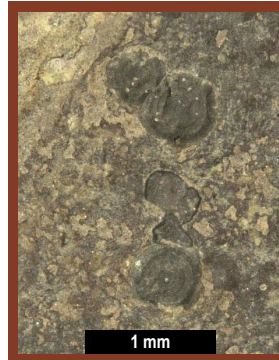
Circular scale marks with radial striae along margin and central disrupted region.



Small (1mm diam.) covering scales including earlier waxy instars; numerous concentric lineations.



Broad ellipsoidal to circular (0.3-0.5 mm wide x 0.6-0.9 mm long) raised regions nestled between two boundary adjacent, parallel veins; with distinct outer, inner boundary.



Circular to variably rounded scales with numerous, often perfectly concentric very fine rings (up to 60), defined by 4-12 thicker, dark concentric bands, ca. 10-20 micrometers thick.

# Piercing & Sucking

Skeletonization

DT 192

Skeletonization

Surface Feeding

DT 196

Surface Feeding

DT 201

Surface Feeding



Broad, curvilinear skeletonized area in costal leaf region between two adjacent, major, secondary veins exhibiting totally consumed leaf cells surrounded by resistant, sclerotized cells.



Approximately symmetrically removed surface tissues adjacent to both sides of a midrib or other primary vein, defined by a curvilinear marginward reaction.



Removal of tissues along the surface of a primary vein, resulting in a concatenated series of elongate to very elongate scrapings with circular endings.

# Skeletonization

DT 202

Surface Feeding

DT 203

Surface Feeding

DT 207

Surface Feeding



Removal of surface tissue along one side of a leaf bounded by a straight midrib axially and variously succate or curvilinear margin toward the leaf margin.



Elongate pattern of surface tissue removal across mid-ranked parallel veins with a prominent reaction rim of dark wedge-like or wispy extensions into the inner margin.



Linear swaths of removed surface tissues, ca. 0.5-1.5 mm wide, combined in radiating criss-crossing branching or veinule-following rectangular patterns.