A new wear facet terminology for mammalian dentitions

Julia A. Schultz, Ulrike Anders, Caroline Braune, Janka J. Brinkkötter,
Ivan Calandra, Sandra Engels, Eva Findeisen, Juan-Pablo Gailer, Jürgen Hummel,
Kai R. K. Jäger, Thomas M. Kaiser, Daniela C. Kalthoff, Wighart v. Koenigswald,
Ottmar Kullmer, Christina Landwehr, Markus Mau, Ulrike Menz, Irina Ruf,
Anne M. Schubert, Ellen Schulz-Kornas, Achim H. Schwermann,
Leonie C. Schwermann, Mirella Skiba, Patrick Steuer, Karl-Heinz Südekum,
Daniela E. Winkler, and Thomas Martin

Introduction

Teeth of vertebrates are under constant use and therefore show wear-induced traces on the surface. According to Williams (2005), the mechanism by which wear occurs is a mechanical and/or chemical process resulting in material loss. Wear facets, the smooth and polished contact areas between opposing teeth, form during force-fit chewing activity between antagonists due to attritional (tooth-tooth) and abrasional (tooth-substrate-tooth) contacts involving either some kind of resistant alimentary bolus or some other dental behavior with an empty mouth cavity (Maier & Schneck 1981). In mammals, the occlusion of dental surfaces produces characteristic facet patterns on the crown's surface. Orientation and inclination of a facet are determined by tooth morphology, while the texture of the surface (e.g., complexity and roughness) is the result of the food ingested (e.g., Schulz et al. 2010, Winkler et al. 2019, Schulz-Kornas et al. 2020, this volume). Complementary patterns of wear facets on the occlusal surface of opposing teeth change in shape and size during ontogeny and therefore can be used for age determination (e.g., Baumann 1949, Grau et al. 1970, Habermehl 1985, Anders et al. 2011a,b, Ruf et al. 2020, this volume).

Wear facet patterns begin to form as soon as the tooth crown erupts and antagonists occlude. Fortelius (1985) differentiated between primary and secondary occlusal surfaces. Facets on primary surfaces develop gradually on the enamel cover (i.e., enamel facets) and only later expose the dentin with increasing wear due to age. In those cases, the exposed dentin has no explicit function. Facets on a secondary surface are composed of enamel and dentin. Dentin exposure happens relatively fast and it forms depressions in close proximity to protruding enamel, and the combination of both has a specific function. Those facets remain constant for a relatively long period of time in the life of an animal (i.e., dentin facets interrupted and/or surrounded by enamel bands). Facets on secondary surfaces are specialized occlusal surfaces that are mostly developed in herbivorous taxa with a horizontal power stroke movement, regardless of the direction (Koenigswald 2020, this volume). In these specialized cases enamel and exposed dentin function as a unit, and neighboring facets merge and may cover large areas composed of both tissues (e.g., occlusal surface of elephant molars). In correspondence, some mammal groups developed specialized dentitions (e.g., hypsodonty, euhypsodonty, thickened enamel layer, enamel infoldings) to keep the function of dental structures including the facets stable over longer periods of time, thereby extending the lifespan of the individuals (heterochrony). However, the larger such composed areas become, the more difficult it is to identify individual facets. Extreme cases can be found in some rodents or modern equids where the flat occlusal surface forms basically one large rasp facet (Koenigswald 2018). In such cases it is very difficult to identify individual facets, making comparisons almost impossible. Here, the Modular Wear Facet Nomenclature may be applied to the functional parts of enamel bands only (see examples of *Apodemus* and *Bison* below).

In the past, the diversity of dental wear facet patterns of mammalian molars has led to the erection of diverse nomenclatory systems for comparative and descriptive purposes. The Modular Wear Facet Nomenclature for mammalian and mammal-like dentitions proposed by Schultz et al. (2018) is a general, descriptive and modular concept, offering the user flexibility, including the use of already established molar cusp terminologies. It primarily serves as a labelling system for wear facets, derived exclusively from the position in relation to major crown structures. It is therefore based on existing terms of primary tooth elements (e.g., cusps, crests, basins), because the conventionally accepted terms of cusps and crests are well established and widely used in the scientific literature and by many disciplines, like paleontology, biology, anthropology, archeology, human medicine and dentistry. The advantage of the modularity of the new nomenclature is that it is applicable to a wide variety of dentitions independent from specific taxonomic designations. It is an intuitive understanding that cusp and crest names determine the first element for naming the location of the facet on the tooth surface, and the second element depicts the facet's position in relation to the structure of the first element. This system is flexible; it therefore can be expanded with additional information if needed (e.g., phase of chewing cycle [1 for phase I; 2 for phase II] etc.). In this chapter we demonstrate the infinite applicability of the Modular Wear Facet Nomenclature to various mammalian cheek teeth and show the many options for comparative purposes (for illustration purposes 3D surface models of different mammalian dentitions were used and colored in 2D using Photoshop CS6).

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Institutional abbreviations

Gui Mam	Guimarota collection currently housed in the Institute of Geosciences, Section Paleontology, Rheinische Friedrich-Wilhelms-Universität Bonn, Germany
IGPB	Mammal collection of the Institute of Geosciences, Section Paleontology, Rheinische Friedrich-Wilhelms-Universität Bonn, Germany
NHM	Natural History Museum, London, UK
NMW	Mammal collection of the Naturhistorisches Museum, Vienna, Austria
NRM	Mammal collection of the Swedish Museum of Natural History, Stockholm, Sweden
SMF	Mammal collection of the Senckenberg Forschungsinstitut und Naturmuseum Frankfurt, Germany
UMZC	University Museum of Zoology, Cambridge, UK
ZFMK	Mammal collection of the Zoologisches Forschungsinstitut Alexander Koenig, Bonn, Germany
ZMB	Mammal collection of the Museum für Naturkunde Berlin, Germany

Anatomical abbreviations

AC/acd	anticone, anticonid
AL/ald	anteroloph, anterolophid
AS	anterostyle
CCA	centrocrista
CNG/cng	cingulum, cingulid
ecsd	ectostylid
en	entoconid
ENS	entostyle
ERS	enterostyle
hfd	hypoflexid
hld	hypoconulid
HY/hy	hypocone, hypoconid
L	lower
M/m	upper molar, lower molar
ME/me	metacone, metaconid
MSL/msld	mesoloph, mesolophid
MTCL	metaconule
MTL/mtld	metaloph, metalophid
P/p	upper premolar, lower premolar
PA/pa	paracone, paraconid
PAC/pacd	paracrista, paracristid
PCL	paraconule
POS	posterostyle
PPAC	postparacrista
PR/pr	protocone, protoconid
prcd	protocristid
PRL/prld	protoloph, protolophid
PSL/psld	posteroloph, posterolophid
TA	talon
U	upper

History of facet description and analysis

At the end of the 19th century, Cope (1883) and Osborn (1888), among others, developed the dental cusp nomenclature to describe features of teeth and to have a common language for discussion (for a detailed review see Ungar 2010). Butler (1952) and Mills (1955) were the first to document corresponding facet patterns on opposing upper and lower molars. Mills (1955) described these areas as follows: “These facets appear, macroscopically, as flat, highly polished areas on the cusps of the molar teeth. They can be seen more readily under low-power magnification, if the specimen is slowly turned about until the light strikes it at a favorable angle.” Butler (1973) restricted the term ‘facet’ to areas on which wear produces traces when teeth are nearly or actually in contact with their antagonists. He described facets as flat, light-reflecting areas with striations on the surface and he also proposed the functional interpretation that both facets and striations are indicative of relative movements, though never tested in in-vivo or in-vitro experiments. Fortelius (1985) followed Butler’s (1973) functional interpretation supporting the fact that facets are wear-dependent and have an orientation, which is dictated by the interactive wear process occurring between one or several facet pairs. During the last century, various attempts to refine the dental-cusp nomenclature were taken in order to better reflect mammalian dental evolution (e.g., Vandebroek 1967, Crompton & Jenkins 1968, Szalay 1969, Hershkovitz 1971, Butler 1978, Maier & Schneck 1981, Van Valen 1982). However, describing the occlusal surface in detail is a challenging task, because various factors influence the formation and a wide variation exists among different taxa. It was frequently discussed that ontogeny (Winkler & Kaiser 2011), ingested diet (Fortelius 1987), habitat (Kaiser & Schulz 2006, Schulz & Kaiser 2013), and even tooth position (Kullmer et al. 2009, Taylor et al. 2013, Gailer & Kaiser 2014) have an influence on the formation of the occlusal surface and its characteristic wear features.

Historically, Butler (1952) was the first to number corresponding wear facet pairs of upper and lower molars (of perissodactyls). When Mills (1955) mapped wear facets of primate molars he did not use a numbering system at all, but instead he attributed each facet to the phase of mastication in which it was used. Crompton (1971) identified homologous facets in his comprehensive study on the evolution of the mammalian dentition and numbered them sequentially to their appearance during evolution. Gingerich (1974) followed this system and described how wear facets form on molars of the fossil primate *Plesiadapis*, but added a buccal phase (B) and a lingual phase (L) to each facet number specifying the phase of mastication. He described two orientations of parallel striations formed during the two power stroke phases (buccal and lingual phase) of the chewing cycle. The two movements were also recognized by Kay & Hiiemäe (1974) as “phase I” (i.e., buccal phase) and “phase II” (i.e., lingual phase) of the power stroke. Crompton (1971) defined in total six wear facets in the hyaenodontid *Didelphodus*, and Kay & Hiiemäe (1974) – working on primate molars – identified facets 7 to 10. In both studies the letters “a” and “b” were added to the numbers of the wear facets if two facets belong to one wear area, and were formed by the same antagonistic structure during the same movement. Kay (1977) identified 11 wear facets for cercopithecid molars. In the same publication, he described facet 7n (“n” for “new”); the homologous wear facet on molars of the propliopithecid primate *Aegyptopithecus* had been numbered 7 earlier by Kay & Hiiemäe (1974). More confusing, Kay (1977) also mentioned facet 10n, and an additional wear surface 9 with an anterior extension X. Several following studies added new abbreviations and letters. Maier (1980) basically

identified the same wear facets but did not add a and b. Adding to the confusion, facet X identified by Kay (1977) corresponds to facet 11 of Maier (1980) and facet 10n of Kay (1977) corresponds to facet 12 of Maier (1980). Maier & Schneck (1981) also identified an additional facet 13, only occurring in hominid molars (see Kullmer et al. 2020, this volume: 16, Tab. 2.1; Schultz et al. 2018: 35, tab. 1). Over the last 50 years numerous studies proposed tooth facet nomenclatures for various taxa including early mammaliaforms and stem mammals. However, in these taxa tooth structures are difficult to be put in homologous relation to that of crown mammals (e.g., tritylodonts [Crompton 1972], "symmetrodontans" [Crompton & Jenkins 1967], haramiyidans [Butler & MacIntyre 1994], non-mammalian mammaliaforms [Kermack et al. 1965, Crompton & Jenkins 1968, Gingerich 1973], "pseudotribosphenidans" [Chow & Rich 1982, Wang et al. 1998], etc.). In most of these studies the authors simply numbered the identified wear facets, suggesting a homology of structures which does not necessarily exist.

In summary, the past studies often proposed contradicting labeling systems for wear facets and used different numbers for the same facet (see Schultz et al. 2018: 35, tab. 1), which complicates comparisons and discussions of functional questions and bears the risk to lead to misunderstanding and misinterpretation. In some cases, different systems were used for the description of tooth morphologies and dental wear facets of mammals, depending on the specific morphology of the teeth, historical establishment or individual author affinities. Pinto-Llona (2013) for example reconstructed the paleodiet of Pleistocene cave bears from Spain using 2D macro- and microwear analyses. In her study she used the classical numbering system of Butler (1952) followed by the system of Kay (1977) in parenthesis in order to avoid inconsistencies. For studies like the one of Pinto-Llona (2013), the Modular Wear Facet Nomenclature may serve as a system for comparative and descriptive purposes, which aims to improve and foster a more transparent scientific communication.

How to apply the modular system

The Modular Wear Facet Nomenclature for mammalian and mammal-like dentitions incorporates conventionally accepted tooth terminology in connection with a modular organization. Cusps and crests are the initial elements for naming the location of the facet on the tooth. Since this system is flexible and works as a modular system it can be expanded with additional information if needed (e.g., phase of chewing cycle [1 for phase I, 2 for phase II], enamel [e], dentin [de]). In our approach, the first part of the facet name is an acronym of the cusp or crest the facet is associated with. In case of the protocone, this would be 'PR' (see Schultz et al. 2018: 36, tab. 2 for acronyms and page 12 this volume) following the conventional usage of capital letters for the upper dentition. Accordingly, for the protoconid, 'pr' would be used following the convention of using lowercase letters for the lower dentition. We distinguish five main directions depending on the location of the facet on the cusps or crests, that is 'm' for mesial, 'd' for distal, 'b' for buccal, 'l' for lingual, and 'h' for horizontal in case of flat apical wear. Those directions can be combined in order to precisely specify the location of the facet. For example 'mb' describes a facet that is mesiobuccally located on a cusp, if the facet is located more in buccal direction than in mesial, the letters can be exchanged to "bm" in order to clarify, i.e. buccomesially. In combination, for the protocone this results in 'PR-mb' as facet term, for the protoconid this results in 'pr-mb' as facet term. If a user wishes to describe the facet location in relation to a crest because the facet occupies a large area below a crest, the first module can be the acronym of the crest's name. This is also expandable to larger elements on the occlusal surface like lophs/lophids, fossettes/fossetids, styles/stylids or cingula/cingulids depending on the user's intentions. It further allows addressing dental wear surfaces on both enamel and dentin by adding a final module with '-e' or '-de'.

Formula: [structure on tooth surface]–[location of facet in relation to tooth structure]–[tissue (if important)]–[chewing phase (if important)]–etc.

Example: Facet 1 of Crompton (1971) of a moderately worn lower tribosphenic molar occupying nearly the entire area of the distal flank of the trigonid below the protocristid visible by the striated polished enamel surface, and being formed during phase I of the chewing cycle translates to: prcd-d-e-1

As an addition, here we propose a color code which is based on the standard 12-color circle, but for simplification and easy applicability we reduced it to eight colors (Fig. 1.1). In this circle for the upper dentition yellow is always assigned to mesial, purple to distal, red to buccal, and turquoise to lingual. Colors between the four main directions (clockwise: orange, pink, blue, green) indicate the directions lying between the main directions. For example, mesiolingual is green and distobuccal is pink. In order to color match opposing wear surfaces the color circle needs to be swapped for the lower dentition with mesial being purple and distal yellow (Fig. 1.1B). Accordingly, buccal is depicted by turquoise and lingual is red. Subsequently, mesiolingual is pink and distobuccal green etc. In our approach, horizontal facets are kept in white, to clearly distinguish them from inclined facets. Often horizontal facets are produced during abrasional processes (not necessarily in direct contact with an antagonist) resulting in blunted cusps. The same as for apical wear applies in the extreme cases of horizontal secondary occlusal surfaces with confluent facet areas composed of enamel and dentin areas mostly showing flat enamel cross-sections (i.e., enamel bands, for example Fig. 1.1C). If enamel bands appear inclined around cusps (Figs. 1.4A, 1.5B), parts of the enamel bands should be colored according to where the parts are located, thus treated as individual facets.

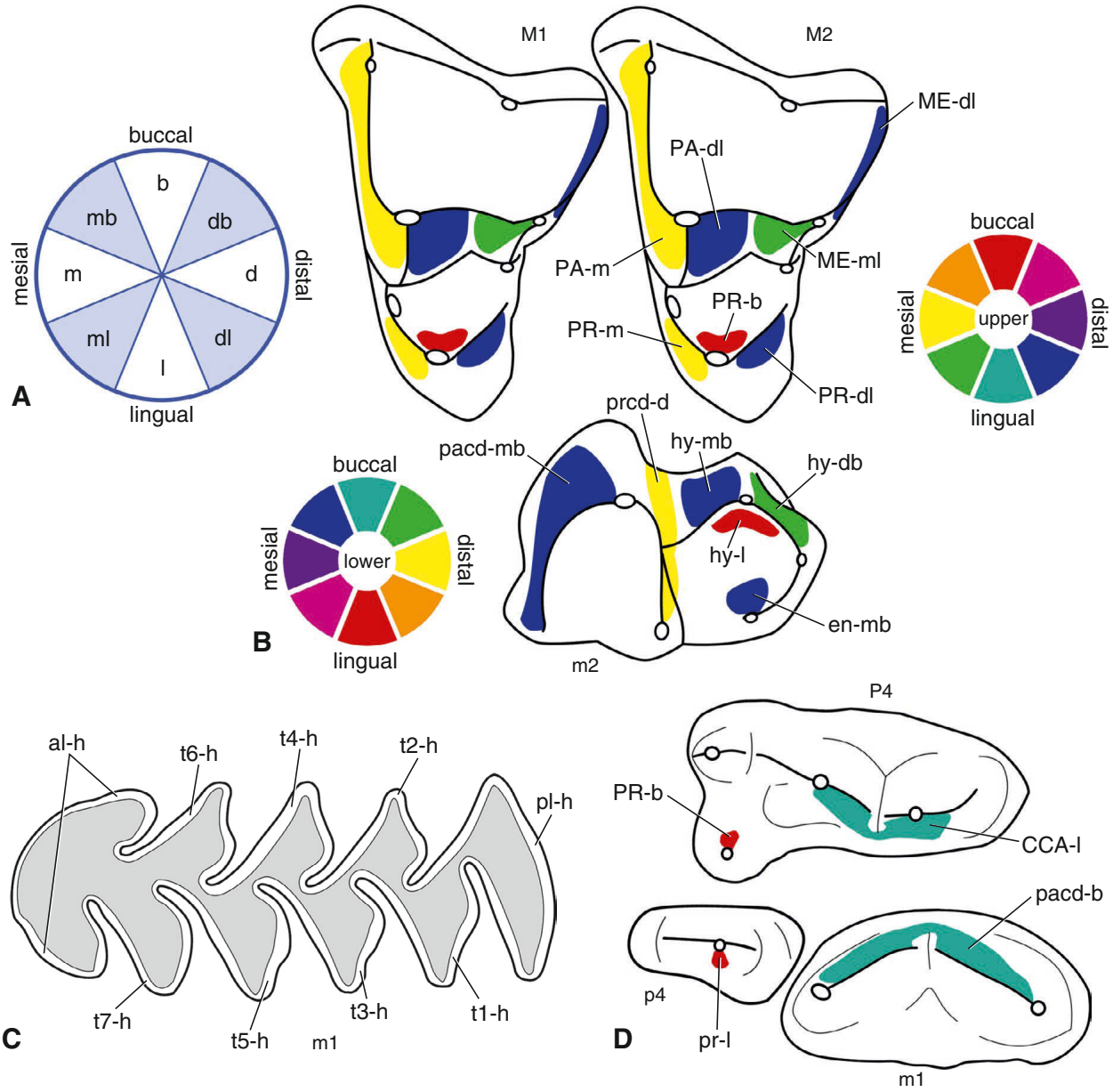

Fig. 1.1. Schematic instructions how to use the Modular Wear Facet Nomenclature. **A,** Main directions that indicate the position of the facet in relation to the structure on the tooth surface. The center of the circle is anchored to the structure of interest (e.g., cusp, basin, or crest). **B,** Example of facet labelling for two upper (M) and one lower molar (m) of the marsupial *Didelphis virginiana* (based on Crompton 1971). Proposed color-coding based on the standard twelve-color circle (here reduced to eight colors) for upper and lower teeth. The colors are swapped for the lower dentition to color match opposing wear surfaces of the upper. **C,** Lower molar of the cricetid rodent *Arvicola*, example for horizontal occlusal surface, with h being the acronym for 'horizontal'. **D,** Facet labelling on the carnassials (P4/m1) of the feliform carnivoran *Panthera leo*. Not to scale.

Examples

Non-mammalian Mammaliaformes

Morganucodon watsoni

UMZC.Eo.CR.1, Early Jurassic (Fig. 1.2A)

Cusp B of the upper first molar has one wear surface on the cingulum: distolingual (BCNG-dl). Cusp A also has one wear surface on the cingulum: mesiolingual (ACNG-ml). The crest connecting cusp C and cusp D has one large wear surface: distolingual (CD-dl). Cusp B of the second molar has one wear surface: distolingual (B-dl). The cingulum bordering cusp B on the lingual side has one wear surface: distolingual (BCNG-dl). Cusp A has two wear surfaces on the cingulum: mesiolingual (ACNG-ml) and distolingual (ACNG-dl). The cingulum bordering cusp C on the lingual side has one wear surface: mesiolingual (CCNG-ml). Cusp C has one wear surface: mesiolingual (C-ml). The crest connecting cusp C and cusp D has one large wear surface: distolingual (CD-dl)

Cusp b of the second lower molar has one wear surface: mesiobuccal (b-mb). Cusp a has two wear surfaces:

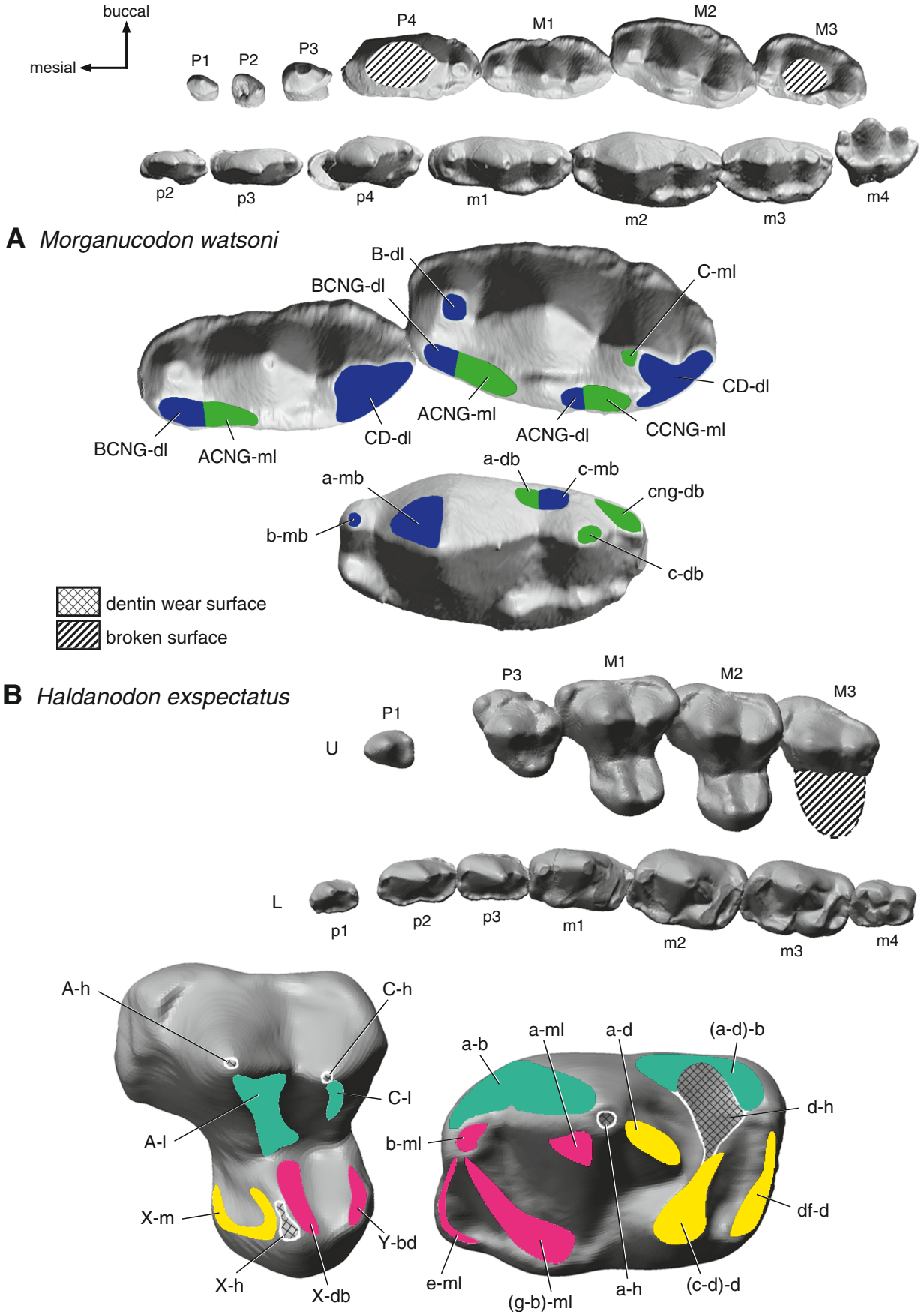

Fig. 1.2. Example for the application of the Modular Wear Facet Nomenclature in two mammaliaforms. **A,** premolars (P/p) and triconodont molars (M/m) of the morganucodontan *Morganucodon watsoni* (facet location and cusp terminology after Jäger et al. 2019, for chapter purposes slightly modified) and **B,** premolars and complex "pseudotribosphenic" molars of the docodontan *Haldanodon exspectatus* (terminology after Luo & Martin 2007). For close up views M2/m2 were chosen for colored facet locations, here and in the following figures if not labelled otherwise. Not to scale.

mesiobuccal (a-mb) and distobuccal (a-db). Cusp c has one wear surface: distobuccal (c-db). The cingulum bordering cusp c on the buccal side has one wear surface: distobuccal (cng-db)

Haldanodon exspectatus

Gui Mam 30/79 and Gui Mam 6/82,
Late Jurassic (Fig. 1.2B)

Cusp A of the M2 has two wear surfaces: lingual (A-l) and one flat apical dentin field (A-h). Cusp C has two wear surfaces: lingual (C-l), one flat apical dentin field (C-h). Cusp X has three wear surfaces: mesial (X-m), distobuccal (X-db) and one apical dentin field (X-h). Cusp Y has one wear surface: buccodistal (Y-bd).

Cusp b of the m2 has one wear surface: mesiolingual (b-ml). Cusp a has four wear surfaces: buccal (a-b), distal (a-d), mesiolingual (a-ml), and one flat apical dentin field (a-h). Cusp d has one wear surface: one large apical dentin field (d-h). Crest a-d has one wear surface: buccal ((a-d)-b). Cusp df has one wear surface: distal (df-d). Crest c-d has one wear surface: distal ((c-d)-d). Crest g-b has one wear surface: mesiolingual ((g-b)-ml). Cusp e has one wear surface: mesiolingual (e-ml). Terminology after Luo & Martin (2007).

Marsupialia

Virginia opossum (*Didelphis virginiana*)

Theoretical example in Fig. 1.1B, Recent

The paracone of the M2 has two wear surfaces: mesial (PA-m), distolingual (PA-dl). The metacone has two wear surfaces: mesiolingual (ME-ml), distolingual (ME-dl). The protocone has three wear surfaces: buccal (PR-b), distolingual (PR-dl), and mesial (PR-m).

The paracristid has one wear surface: mesial (pacd-m). The protocristid has one large wear surface: distal (prcd-d). The hypoconid has three wear surfaces: mesiobuccal (hy-mb), distobuccal (hy-db) and lingual (hy-l). The entoconid has two wear surfaces: mesiobuccal (en-mb) and mesial (en-m).

Afrosoricida

Greater hedgehog tenrec (*Setifer setosus*)

SMF 55333, Recent (Fig. 1.3A)

The paracone of the M2 has two wear surfaces: mesial (PA-m), distolingual (PA-dl). Alternatively, the paracrista has one wear surface: mesial (PAC-m). The postparacrista has one wear surface: distal (PPAC-d).

The paraconid m2 has one wear surface: mesiobuccal (pa-mb). The protocristid has one wear surface: distal (prcd-d). The entoconid (or hypoflexid) has one wear surface: an apical dentin field (en(or hfd)-h).

Sirenia

West Indian Manatee (*Trichechus manatus*)

ZFMK MAM 73223, Recent (Fig. 1.3B)

The paracone of the upper molar has one wear surface: distolingual (PA-dl). The paraconule has two wear surfaces: mesial (PCL-m) and one distal (PCL-d). The protocone has two wear surfaces: mesial (PR-m) and one distal (PR-d). The crest metaconule has one wear surface: mesial (MTCL-m). The hypocone has one wear surface: a flattened apical enamel field (HY-h).

The protoconid of the lower molar has one wear surface: distal (pr-d). The metaconid has one wear surface: distal (me-d). The hypoconid has two wear surfaces: mesial (hy-m) and distal (hy-d). The entoconid has two wear surfaces: mesial (en-m) and distal (en-d). The hypoconulid has one wear surface: a flattened apical enamel field (hld-h).

Scandentia

Common tree shrew (*Tupaia glis*)

IGPB M70, Recent (Fig. 1.4A)

The paracone of the M2 has three wear surfaces: mesial (PA-m), distolingual (PA-dl) and an apical dentin field (PA-h). The metacone has three wear surfaces: mesial (ME-m), distolingual (ME-dl) and an apical dentin field (ME-h). The protocone has one wear surface: buccal (PR-b).

The paracristid of the m2 has one wear surface: a mesiobuccal enamel facet (pacd-mb). The protocristid has one large wear surface: mesial (prcd-m). The protoconid has one apical wear surface: an apical dentin field (pr-h). The hypoconid has four wear surfaces: mesiobuccal (hy-mb), distal (hy-d), lingual (hy-l) and an apical dentin field (hy-h). The entoconid has one wear surface: an apical dentin field (en-h).

Rodentia

Yellow-necked fieldmouse (*Apodemus flavicollis*)

IGPB 1077, Recent (Fig. 1.4B)

The protocone of the M2 has two connected wear surfaces forming an enamel band: lingual (PR-l) and buccal (PR-b). Buccally and lingually the combined wear surface is connected with the paracone and the enterostyle. The anticone has two wear surfaces forming an enamel band: distolingual (AC-dl) and lingual (AC-l). Paracone and metacone have one wear surface forming an enamel band: lingual (PA-l + ME-l). The hypocone has two connected wear surfaces forming an enamel band: a large buccal one (HY-b) and a smaller lingual one (HY-l). The posterostyle has one wear surface: buccal (POS-b); it is connected with the lingual wear surface of the hypocone. The enterostyle has one wear surface: buccal (ERS-b); it is connected to the lingual wear surface of the protocone. The anterostyle has two wear surfaces: lingual (AS-l) and buccal (AS-b).

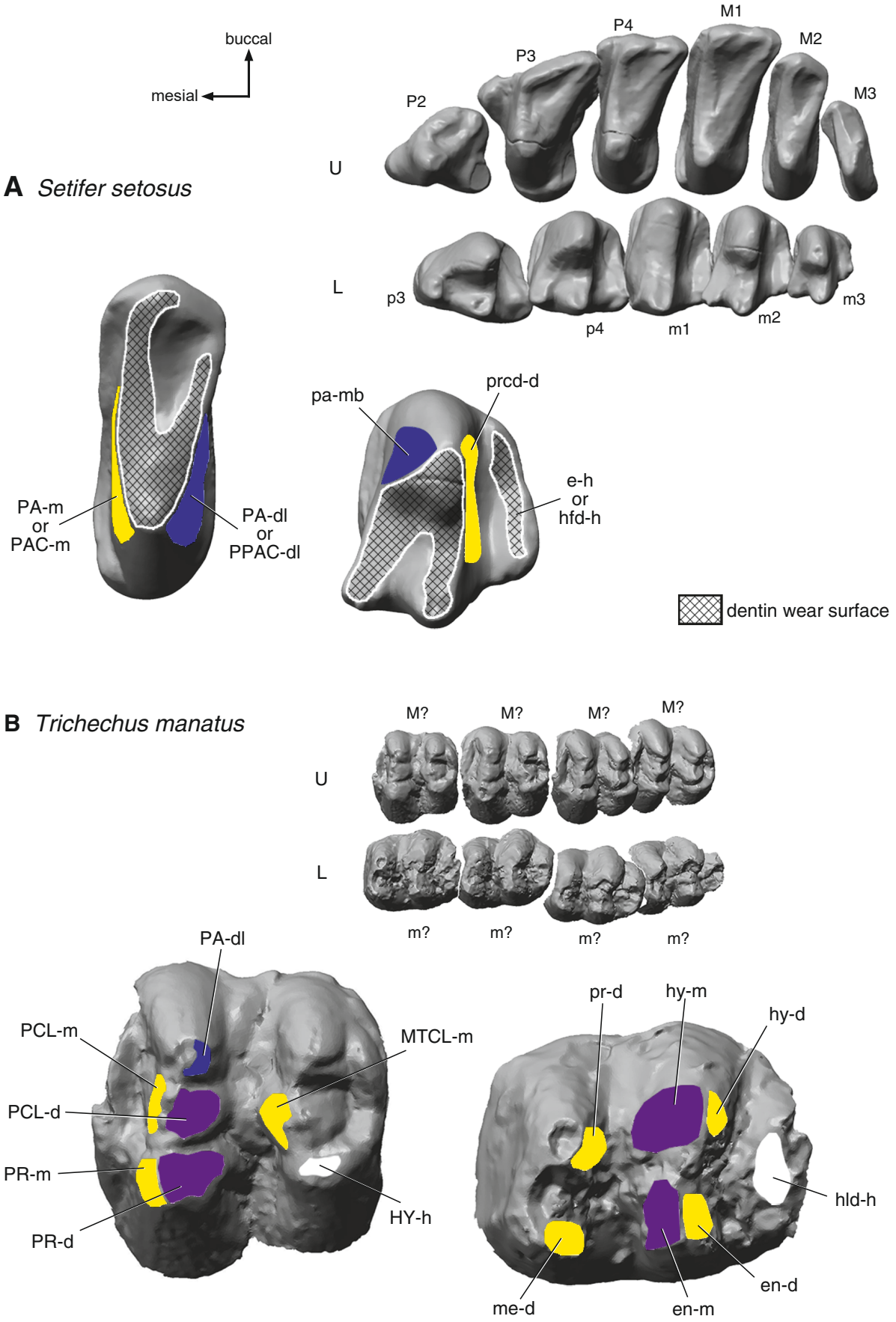

Fig. 1.3. Example for the application of the Modular Wear Facet Nomenclature in two afrotherians. **A,** zalambdodont premolars (P/p) and molars (M/m) of the afrosoricid *Setifer setosus* and **B,** bunodont molars of the manatee *Trichechus manatus*. Because of the horizontal tooth replacement mode in Sirenia it is not possible to determine the exact tooth positions, here indicated by a question mark. Not to scale. Terminology after Thenius (1989).

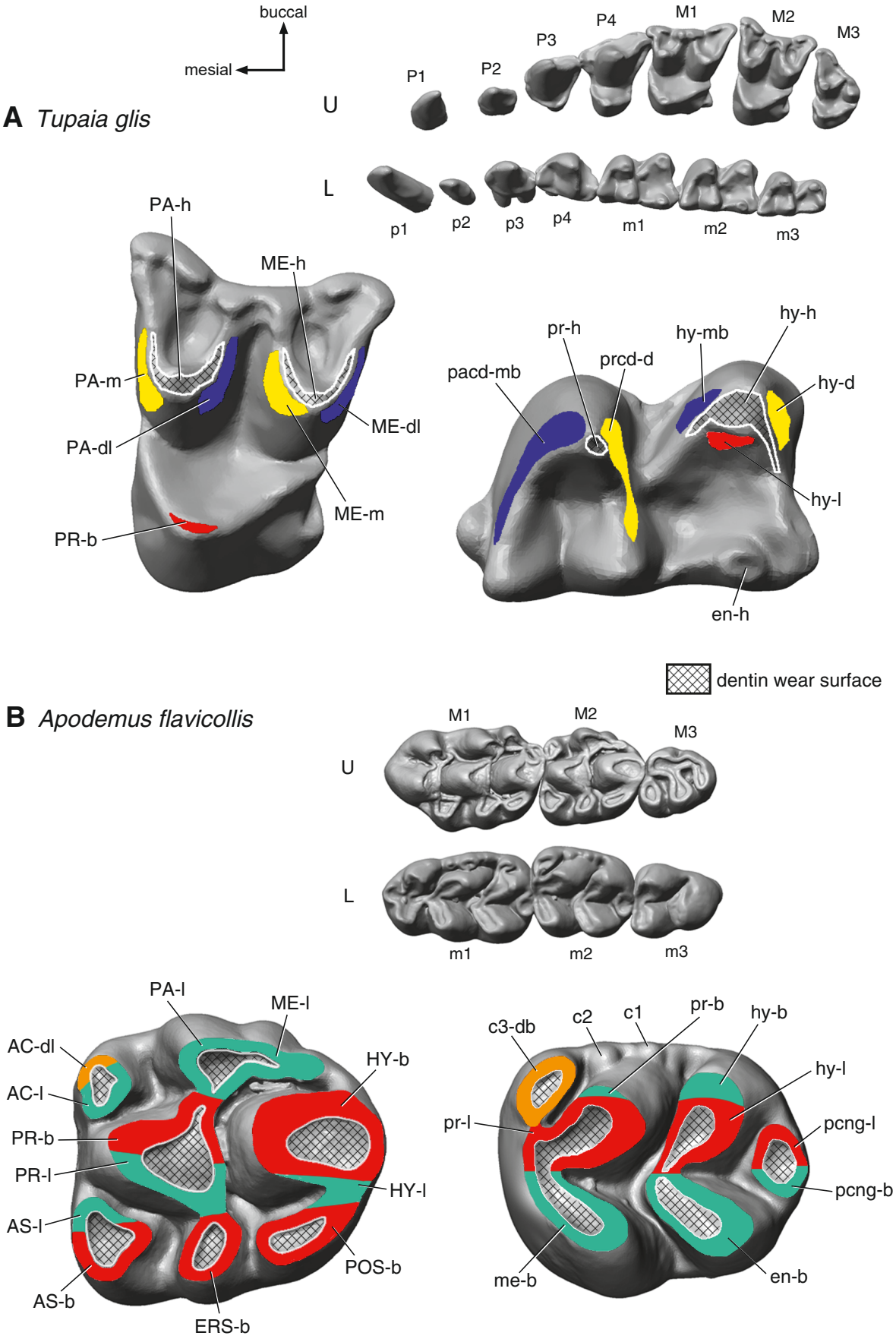

Fig. 1.4. Example for the application of the Modular Wear Facet Nomenclature in *Tupaia* and *Apodemus*. **A,** premolars (P/p) and molars (M/m) of the common tree shrew *Tupaia glis* and **B,** brachyodont molars of the muroid rodent *Apodemus flavicollis*. Not to scale.

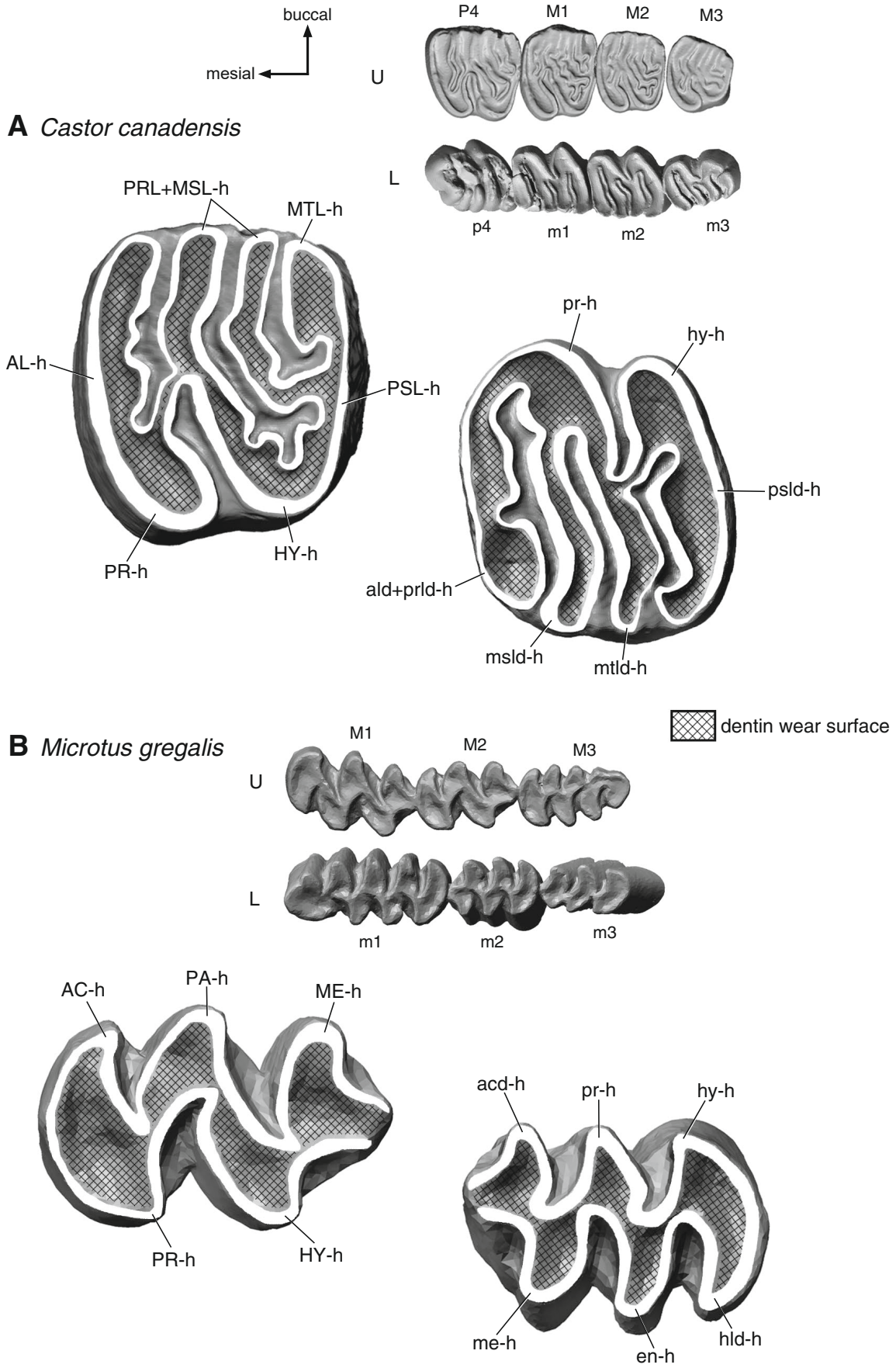

Fig. 1.5. Example for the application of the Modular Wear Facet Nomenclature in two rodents with high crowned teeth. **A,** hypsodont premolars (P/p) and molars (M/m) of the North American beaver *Castor canadensis* and **B,** euhypsodont molars of the vole *Microtus gregalis*. Not to scale.

The cusp c3 of the m2 has one wear surface: distobuccal (c3-db). The protoconid has two connected wear surfaces forming an enamel band: buccal (pr-b) and lingual (pr-l). The metaconid has one large wear surface: buccal (me-b). The wear surfaces of cusp c3, protoconid, and metaconid are connected. The hypoconid has two connected wear surfaces forming an enamel band: buccal (hy-b), lingual (hy-l). The entoconid has one wear surface: buccal (en-b). The wear surfaces of hypoconid and entoconid are connected. The posterior cingulum has two connected wear surfaces forming an enamel band: lingual (pcng-l), buccal (pcng-b).

North American beaver (*Castor canadensis*)

Upper jaw specimen IGPB MaÜ2, lower jaw specimen IGPB M3346, Recent (Fig. 1.5A)

The occlusal surface of the upper cheek teeth is flat and shows only faint relief, forming one confluent horizontal wear surface. There are no isolated facets developed, but the whole enamel part on the occlusal surface forming lophs is equally worn. Therefore the wear surface can be described as following: AL-h, PRL+MSL-h, MTL-h, PSL-h, PR-h, HY-h.

The lower teeth show the same pattern like the upper cheek dentition, a flat confluent wear surface with all components worn. Similar to the upper dentition the occlusal surface of the m2 can be described with ald+prld-h, msld-h, mtld-h, psld-h, pr-h, hy-h.

Narrow-headed vole (*Microtus gregalis*)

IGPB 1004, Recent (Fig. 1.5B)

The occlusal surface of the upper cheek teeth consists of a confluent, flat plane. Due to the flat occlusal surface, typical isolated facets are not developed. The enamel band, forming triangles, surrounds one large dentin field. The wear surface can be described as: AC-h, PR-h, PA-h, HY-h, ME-h.

Similar to the upper dentition the lower dentition as well shows a flat occlusal surface. Here are also no isolated facets developed, and the whole surface is one confluent wear surface. Therefore the facets can be described as followed: acd-h, me-h, pr-h, en-h, hy-h, hld-h.

Soricomorpha

European mole (*Talpa europaea*)

ZFMK 93.76, Recent (Fig. 1.6A)

The paracone of the M2 has three wear surfaces: mesial (PA-m), distolingual (PA-dl), and an apical dentin field (PA-h). The metacone has three wear surfaces: mesial (ME-m), distolingual (ME-dl), and an apical dentin field (ME-h). The protocone has three wear surfaces: buccal (PR-b), lingual (PR-l), and an apical dentin field (PR-h).

The paraconid of the m2 has one wear surface: an apical dentin field (pa-h). The protoconid has two wear surfaces: mesiobuccal (pr-mb), and an apical dentin field (pr-h). The protocristid has one large wear surface: distal (prcd-d). The hypoconid has four wear surfaces: mesiobuccal (hy-mb), distal (hy-d), lingual (hy-l), and an apical dentin field (hy-h). The entoconid has two wear surfaces: buccal (en-b) and an apical dentin field (en-h). The metaconid has one wear surface: an apical dentin field (me-h).

Carnivora

Wolf (*Canis lupus*)

NRM 2011 5027, Recent (Fig. 1.6B)

The paracone of the M2 has two wear surfaces: mesial (PA-m) and distolingual (PA-dl). The protocone has one wear surface: distobuccal (PR-db). The cingulum has one wear surface: mesiobuccal (CNG-mb).

The paracristid of the m1 (large cutting edge) has one wear surface: mesiobuccal (pacd-mb). The metaconid has one wear surface: distal (me-d). The entoconid has one wear surface: mesiobuccal (en-mb). The hypoconid has two wear surfaces: mesiolingual (hy-ml) and distolingual (hy-dl).

Lion (*Panthera leo*)

NRM A595061, Recent (Fig. 1.1D)

The protocone of the P4 has one wear surface: buccal (PR-b). The crest connecting paracone and metacone (i.e., centrocrista) has one large connected wear surface: lingual (CCA-l).

The crest connecting the protoconid and paraconid (i.e., paracristid) of the m1 has one large wear surface: buccal (pacd-b).

Polar bear (*Ursus maritimus*)

NMW 7140, Recent (Fig. 1.7A)

The paracone of the M2 has one wear surface: lingual (PA-l). The protocone has two wear surfaces: mesiobuccal (PR-mb) and distobuccal (PR-db). The hypocone has two wear surfaces: mesial (HY-b) and distal (HY-d). The metacone has two wear surfaces: mesial (ME-m) and mesiolingual (ME-ml). The talon has one wear surface: buccal (TA-b).

The protoconid of the m2 has three wear surfaces: mesiolingual (pr-ml), distolingual (pr-dl), and buccal (pr-b). The metaconid has two wear surfaces: mesiobuccal (me-mb) and distal (me-d). The hypoconid has three wear surfaces: mesial (hy-m), distobuccal (hy-db), and lingual (hy-l). The entoconid has one wear surface: mesiobuccal (en-mb).

Artiodactyla

European bison (*Bison bonasus*)

NHM-92-3-15-1, Recent (Fig. 1.7B)

The paracone of the M2 has four wear surfaces, all connected forming enamel bands: mesiobuccal (PA-mb), mesiolingual (PA-ml), distobuccal (PA-db), and distolingual (PA-dl). The protocone also has four wear surfaces form-

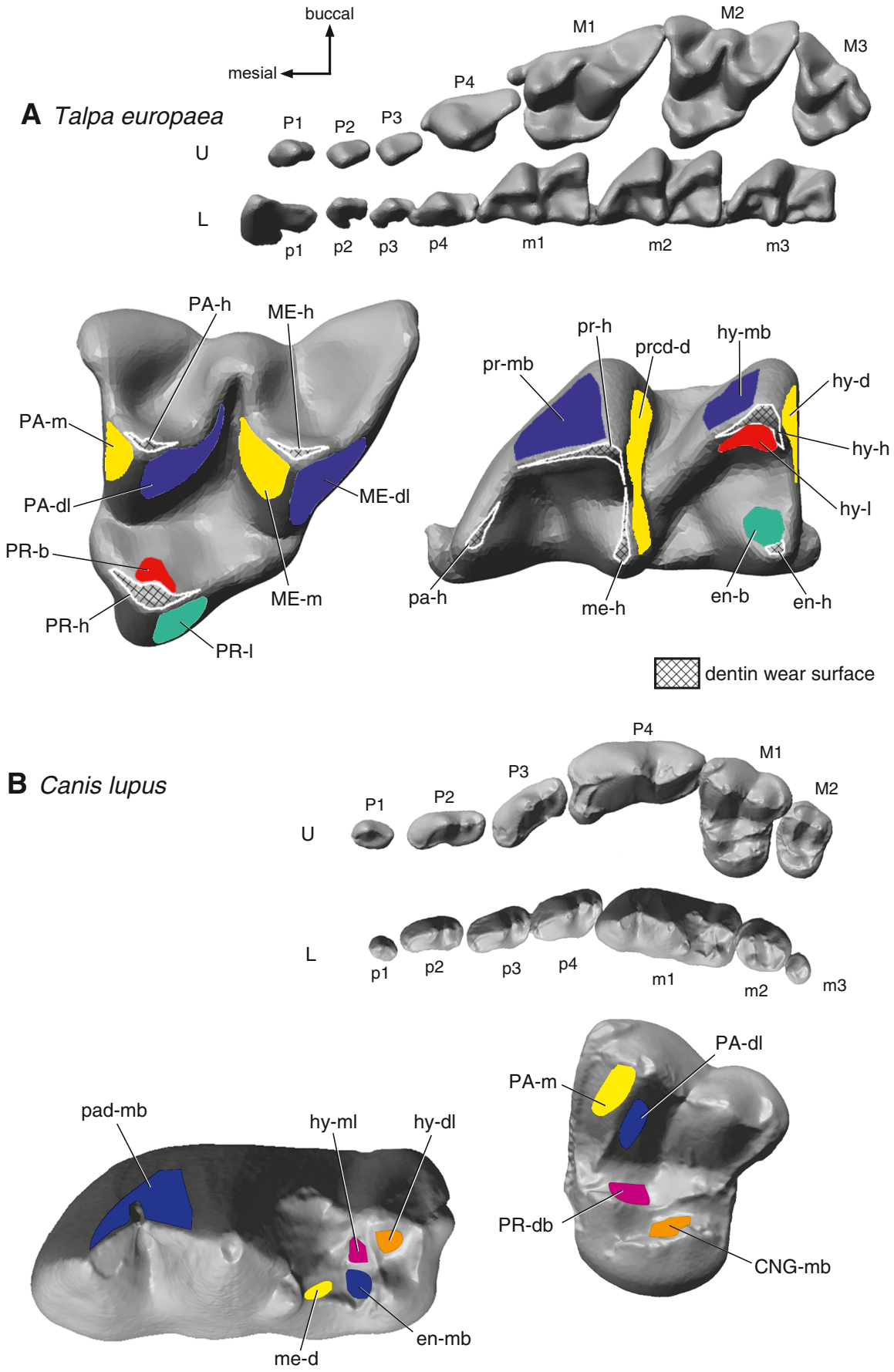

Fig. 1.6. Example for the application of the Modular Wear Facet Nomenclature in *Talpa* and *Canis*. **A,** premolars (P/p) and molars (M/m) of the soricomorph lipotyphlan *Talpa europaea* and **B,** of the carnivoran *Canis lupus*. Close up pair M1/m1 for the wolf example. Not to scale.

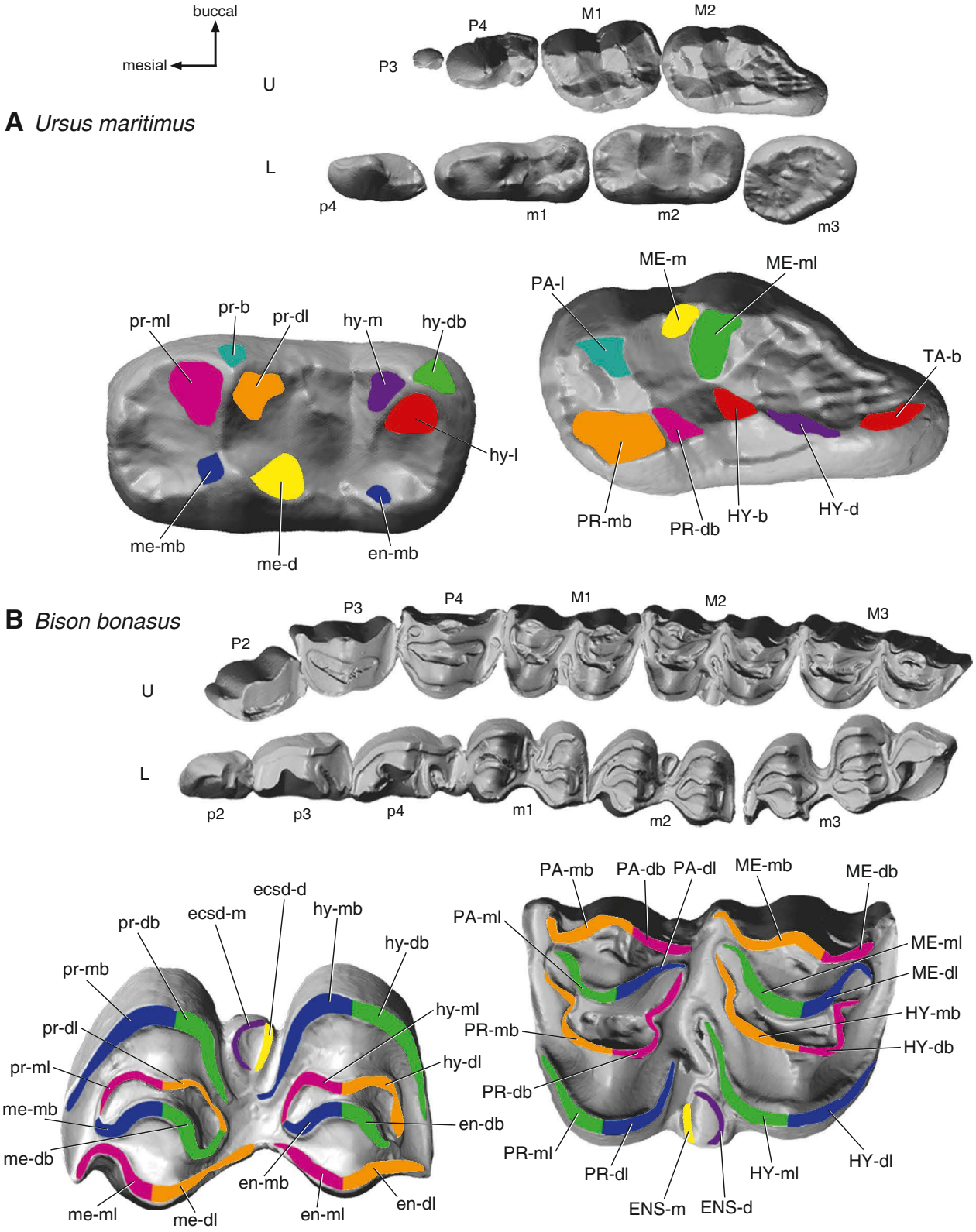

Fig. 1.7. Example for the application of the Modular Wear Facet Nomenclature in *Ursus* and *Bison*. **A,** premolars (P/p) and molars (M/m) of the arctoid carnivoran *Ursus maritimus* and **B,** of the bovid artiodactyl *Bison bonasus*. Not to scale.

ing enamel bands: mesiobuccal (PR-mb), mesiolingual (PR-ml), distobuccal (PR-db), and distolingual (PR-dl). The hypocone also has four wear surfaces forming enamel bands: mesiobuccal (HY-mb), mesiolingual (HY-ml), distobuccal (HY-db), and distolingual (HY-dl). The metacone also has four surfaces forming enamel bands: mesiobuccal (ME-mb), mesiolingual (ME-ml), distobuccal (ME-db), and distolingual (ME-dl). The entostyle has two wear surfaces: mesial (ENS-m) and distal (ENS-d).

The protoconid of the m2 has four wear surfaces, all connected forming continuous enamel bands: mesiobuccal (pr-mb), mesiolingual (pr-ml), distobuccal (pr-db), and

distolingual (pr-dl). The metaconid has also four surfaces forming a continuous enamel band: mesiobuccal (me-mb), mesiolingual (me-ml), distobuccal (me-db), and distolingual (me-dl). The hypoconid also has four wear surfaces forming an enamel band: mesiobuccal (hy-mb), mesiolingual (hy-ml), distobuccal (hy-db), and distolingual (hy-dl). The entoconid also has four wear surfaces forming an enamel band: mesiobuccal (en-mb), mesiolingual (en-ml), distobuccal (en-db), and distolingual (en-dl). The ectostylid has two wear surfaces: mesial (ecsd-m) and distal (ecsd-d).

Conclusion

With the examples shown above, we demonstrate that the Modular Wear Facet Nomenclature is broadly applicable to a wide variety of mammalian and mammaliaform cheek teeth. It can easily be expanded to the facets on incisors and canines and serves primarily as a description to convey topographic location of facets in relation to primary structures on the occlusal surface with previously established homology, such as cusps and crests. The homology of wear facets is inevitably determined by the structures they occur on (e.g. cusps, basin surfaces, crests, lophs etc.) and thus the system (and the implicit homology of wear facets) can be further changed and re-adapted if the homology hypotheses of the primary structures should change. As shown above, the modular system allows high flexibility and can be expanded with further information if necessary (e.g., phase of chewing cycle I [1] or II [2], or tissue type like enamel ['e'] or dentin, ['de']). If the homology is uncertain, taxon related terms can be used (e.g., cusp numbering system in rodents) for the first module depicting the structure a facet is located on. The simple modular structure makes this nomenclature applicable to a wide array of occlusal surfaces. A common nomenclature is the basis for communication, allowing comparisons between studies and across taxa, and thereby permitting functional inferences. Even more so, a common nomenclature facilitates the interpretation of evolutionary changes in tooth crown morphology.

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