Tooth puncture marks on a 30 million year old *Dinictis* skull

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Introduction

We seldom find evidence of direct interaction of animals in the fossil record. But a few years ago we discovered a beautifully preserved skull of the saber-toothed cat-like nimravid *Dinictis* (NDGS catalog number 59) with tooth-puncture marks, indicating that it had been killed by another animal. This unusual fossil was found weathering out of the Oligocene (about 32 million-year-old) Brule Formation at a fossil site that we refer to as the Fitterer Ranch locality near Dickinson in Stark County (NDGS locality number L21). This discovery was made during studies to learn more about the kinds of plants and animals that lived in western North Dakota during that time (Hoganson and Lammers, 1992; Murphy et al. 1993; Hoganson et al. 1998). Over 60 species of mammals were identified from fossils collected during those studies. Most of these animals were herbivores that roamed a mostly treeless plain in a temperate climate. The remains of some carnivores, although uncommon, were found, including the skull of *Dinictis*. Detailed preparation of the *Dinictis* skull revealed well preserved puncture marks which prompted our quest to determine the kind of animal that put this *Dinictis* to rest (Hoganson and Person, 2010).

The Fitterer Ranch locality was apparently first discovered by an American Museum of Natural History Frick Laboratory expedition to North Dakota led by Morris Skinner (fig. 1). Skinner collected Brule fossils from the Fitterer Ranch locality and other sites in North Dakota from 1944 to 1964. He did not describe the North Dakota Brule fossils and apparently did not collect *Dinictis* from Fitterer Ranch. Hoganson and Lammers (1992) were first to report *Dinictis* from Fitterer Ranch based on the skull specimen described here, but they did not identify the specimen to species. Murphy et al. (1993) and Hoganson et al. (1998) also did not identify this specimen to species. Hoganson and Person (2010) confidently assigned this specimen to *Dinictis felina* Leidy, 1854.

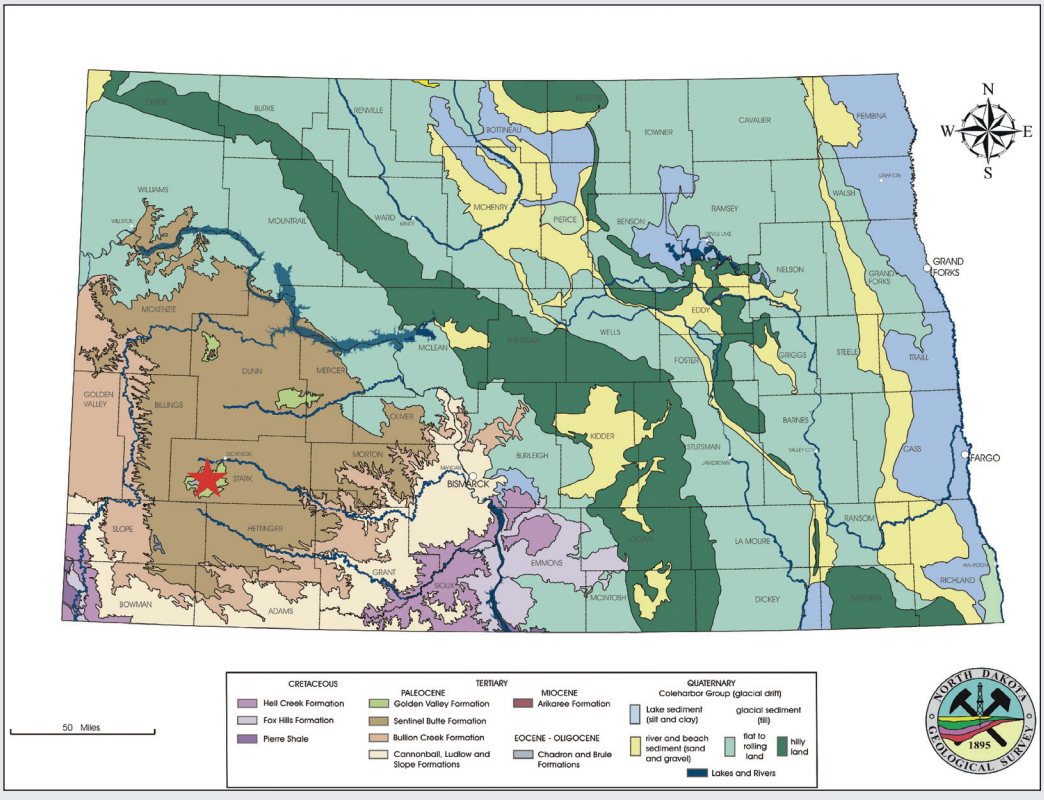

Figure 1. Generalized geologic map of North Dakota. Red star indicates location of Fitterer Ranch locality (NDGS L21).

Stratigraphy

A complete section of the Brule Formation is exposed at the Fitterer Ranch locality (Murphy et al., 1993; Hoganson et al., 1998) (figs. 2 and 3). The Fitterer Ranch locality is registered as a North Dakota Natural Area because it is an important geological and paleontological site. The lower part of the Brule Formation consists of pinkish-brown to gray-green complexly interbedded claystones, mudstones, siltstones, freshwater limestones, tuffaceous beds, and crossbedded channel sandstones. The channel sandstones, such as the "Fitterer Bed" are difficult to trace for long distances and usually contain disarticulated mammalian remains. A useful tuffaceous marker bed in the lower Brule was termed the Antelope Creek tuff by Murphy et al. (1993) (fig. 4). The upper part of the Brule Formation at the Fitterer Ranch locality is less variable and consists primarily of alternating

Figure 2. Photo of Antelope Creek tuff (arrow) near the location where the *Dinictis felina* skull was found at the Fitterer Ranch locality. Jeff Person recording fossils from *Dinictis felina* site(left). Becky Gould pointing to Antelope Creek tuff(right).

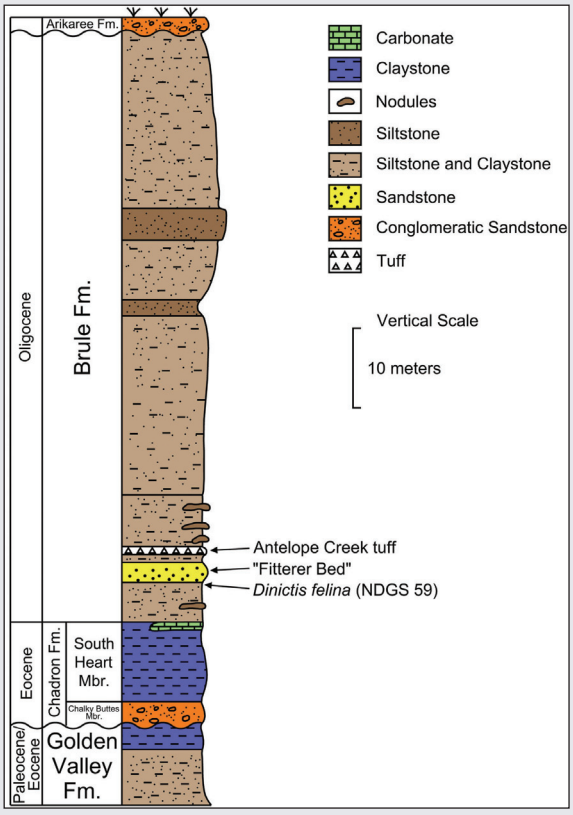

Figure 3. Stratigraphic section at the Fitterer Ranch locality.

siltstones, mudstones, and claystones that are ledge forming. The Brule Formation is about 213 ft (65 m) thick at this locality.

At the Fitterer Ranch locality, the Brule Formation is unconformably underlain by the grey-green claystone of the South Heart Member of the Eocene Chadron Formation and unconformably overlain by a conglomeratic sandstone of the Arikaree Formation.

Biochronology

Skinner (1951) was first to suggest that at least the lower part of the Brule Formation in North Dakota was Orellan in age. This was confirmed by Hoganson and Lammers (1992), Murphy et al. (1993), and Hoganson et al. (1998), mostly based on fossils from the Fitterer Ranch locality. Mammalian fossils are sparse in the upper part of the Brule Formation but a possible Whitneyan age is suggested by meager evidence (Hoganson et al., 1998). Magnetostratigraphic interpretation appears to corroborate an Orellan age for the lower Brule and a Whitneyan age for the upper Brule in North Dakota (Prothero et al., 1983).

The *Dinictis felina* skull under consideration here was found in a Brule Formation clayey siltstone 18.2 feet (5.55 m) above the South Heart Member of the Chadron Formation and 10.3 feet (3.15 m) below the Antelope Creek tuff. Fossils found with the *Dinictis* skull, including the horse *Mesohippus bairdi* (fig. 5) and the rabbit *Palaeolagus burkei* (fig. 6) indicate a latest Orellan (Or4) interval zone, that is, 32.5 to 32.0 million years ago (table 1). The remains

Figure 4. NDGS paleontologist Becky Gould removing *Mesohippus bairdi* partial skeleton from *Dinictis* site. Arrow showing location of Antelope Creek tuff.

of other animals were also found with *Dinictis* including the tortoise *Stylemys*, the dog *Hesperocyon gregarious*, the deer *Leptomeryx evansi*, the mice *Eumys elegans* and *Paradjiduamo?*, land snails, and seeds from the maiden hair tree *Celtis*.

Discussion

Three distinct and well-defined tooth puncture marks are present on the right temporal and parietal bones of this *Dinictis felina* skull (fig. 7). Another possible bite mark occurs on the left parietal, although this mark is less obvious because of missing and fractured bone. Two tooth scratch marks are present on the left maxilla, near the orbit and suture with the frontal. There are no indications of healing around

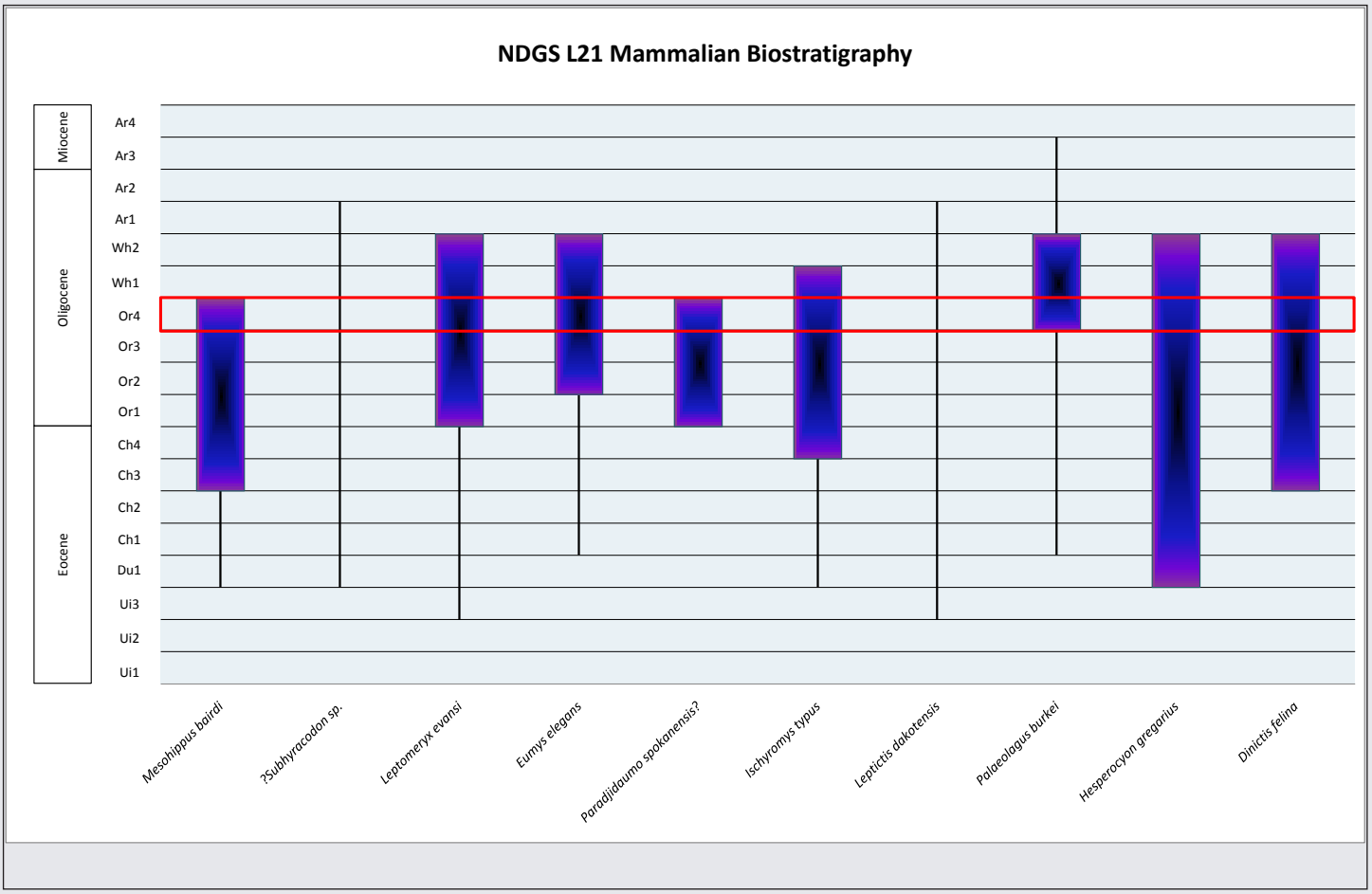

Table 1. Age of the *Dinictis felina* site at the Fitterer Ranch locality (NDGS L21). This chart shows the biostratigraphic ranges of known mammalian taxa from the site and mammal intervals. Lines are ranges of genera and boxes are ranges of species. The red box illustrates the sub-age where species coexist and is therefore the interpreted age of the site.

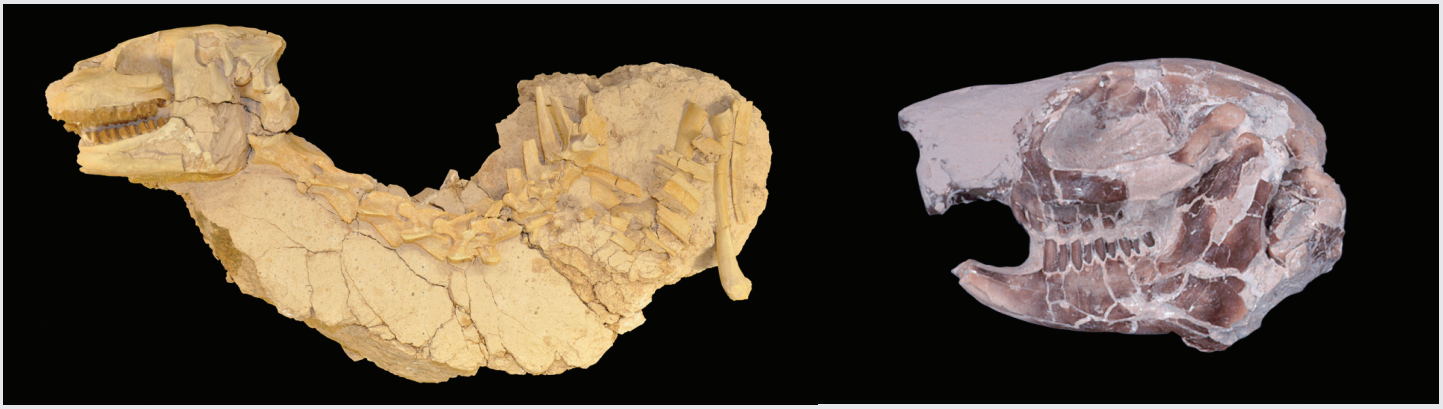

Figure 5. Photo of *Mesohippus bairdi* skeleton. Length 20 inches (51 cm) This specimen is a sub-adult, but adults could reach 2 ft. (60 cm) tall at the shoulder, and up to 4 ft. (1.2 m) long.

Figure 6. Photo of *Palaeolagus burkei* skull. Length 2 inches (51 mm) These rabbits probably looked similar in appearance to modern rabbits and grew to lengths of 10 inches (25 cm).

the tooth puncture marks. Also the left zygomatic arch is broken and distorted. We believe the tooth puncture marks, scratches, and broken zygomatic arch reflect an act of predation because it is likely that a scavenger would have concentrated on fleshy areas of the carcass, not the skull. There is no indication that the punctures were healing, suggesting that the blow to the skull was fatal.

The posterior bite mark is on the right parietal near the sagittal crest and occipital. This mark is longer than it is wide and is perpendicular to the other two marks visible on this side of the skull. It is 0.55 inches (14.0 mm) long (anterior/posterior) and 0.3 inches (7.3 mm) wide (labial/lingual). Unlike the other two marks, this mark is "sunken" producing a depression in the bone, but the bone was not pierced. The ventral portion of the mark has a small asymmetrical concavity giving the mark the shape of a footprint suggesting multiple bites, slipping of the penetrating tooth or shaking of the skull.

The middle bite mark is located on the right parietal and is the largest of the three. This puncture is 0.4 inches (10.0 mm) long (anterior/posterior) and 0.6 inches (15.9 mm) wide (labial/lingual). There are small pieces of crushed bone along the anterior and ventral edges of the mark which are broken concentrically, otherwise the puncture is oval.

The anterior bite mark is located near the right parietal/temporal suture and is the smallest of the three marks. The puncture is 0.4 inches (10.0 mm) long (anterior/posterior) and 0.5 inches (13.5 mm) wide (labial/lingual). There is a small piece of crushed bone along the ventral edge of the mark which is broken concentrically, otherwise the puncture is oval.

To determine the animal that caused these bite marks, we compared the puncture marks on our specimen to others reported in the literature, to a skull of *Nimravus* also exhibiting a cranial puncture in the collection of the South Dakota School of Mines & Technology, and by comparing the morphology and geometry of the punctures on our skull to teeth of potential Brule Formation predators. Animals that we considered potential predator candidates were crocodilian, *Dinictis*, *Hoplophoneus*, *Archaeotherium*, *Daphoenus*, and *Hyaenodon*, all of which have been reported from the Brule Formation in Stark County, North Dakota.

Crocodilians have the capacity to inflict damage such as this. However, since they are ambush predators from water it is unlikely that a crocodilian would produce bites on the top of a skull. In addition, the punctures on the *Dinictis* skull are laterally compressed whereas crocodilian teeth are more conical. It is also unlikely that *Dinictis* or *Hoplophoneus* produced the puncture

Figure 7. View of bite marks on right parietal of NDGS 59. Bars show distance between bite marks. Note one mark would have been located inside orbit and would not have penetrated bone.

Figure 8. Photo of *Hyaenodon* skull. Length 10 inches (25 cm)

marks because their upper canines are too laterally compressed compared to the oval shape of the punctures. Their upper canines were also probably too fragile to be able to penetrate the skull. Their lower canines were too small to create the punctures. The upper and lower canines of *Daphoenus* are also too small to have caused the punctures. The upper and lower canines of *Archaeotherium* are too large to have caused the punctures and the spacing between the canines is also much too wide compared to spacing between the punctures.

We suggest that *Hyaenodon* killed this *Dinictis* because the geometry of the tooth punctures is similar to the slightly labially/lingually compressed shape of the upper canines of *Hyaenodon* (fig. 8). Also, the distance between punctures is consistent with the spacing between the upper canines of *Hyaenodon*. This is particularly true if multiple bites occurred, as we suggest. The punctures were not made by the lower canines of *Hyaenodon* because they are splayed out labially and would have produced a different shaped puncture. Both *Hyaenodon horridus* and *Hyaenodon crucians* have been recovered from the Brule Formation in North Dakota, but because the range of spacing between the upper canines (table 2) is more consistent with *Hyaenodon horridus*, we suggest that *H. horridus* is the more likely predator.

Conclusion

We envision that *Hyaenodon horridus* attacked this *Dinictis felina* from the rear on its left side (figs. 9 and 10). It dispatched the *Dinictis* by multiple bites to the skull. After at least two bites, its upper front canines created two incipient bite marks on the parietal near the sagittal crest and two crushing and deep penetrating punctures on the right parietal. During the attack, the lower jaw of *Hyaenodon* crushed the left zygomatic arch and its lower premolars created scratches on the left maxilla and another bite mark on the left parietal.

***Dinictis* the rock star**

Our North Dakota *Dinictis* specimen became part of a National Geographic television documentary. The documentary was part of National Geographic's Prehistoric Predators series that aired during the fall of 2009 on the National Geographic channel. This episode was about *Hyaenodon*, called "Razor Jaws" in the documentary, in reference to its sharp, flesh-tearing teeth. We are filmed making skull and tooth measurements of *Dinictis* and *Hyaenodon*, and discuss how we determined that *Hyaenodon* was the predator that killed *Dinictis*.

Figure 9. Authors interpretation of how bite marks were produced on the skull of *Dinictis felina* (white) by *Hyaenodon horridus* (tan). Illustration by Becky Gould.

Acknowledgements

We would like to thank the following for their contributions to the project. The Fitterer family, Dr. James Martin, Ms. Sally Shelton, Ms. Becky Gould, and the South Dakota School of Mines and Technology.

	distance between upper canines	left canine antero/post	left canine lab/ling	right canine antero/post	right canine lab/ling
Dinictis (NDGS 60)	33.6 mm	12.4 mm	*	12.8 mm	*
Hyaenodon (SDSM 493)	35.4 mm	13.1 mm	8.9 mm	*	*
Hyaenodon (SDSM 3017)	40.2 mm	15.1 mm	10.8 mm	14.2 mm	10.9 mm
Daphoenus (SDSM 24100)	21.5 mm	13.5 mm	8.9 mm	*	*
Daphoenus (SDSM exhibit)	24.5 mm	11.8 mm	8.4 mm	10.9 mm	8.2 mm
Hoplophoneus (SDSM 2544)	33.7 mm	15.7 mm	8.4 mm	14.5 mm	8.4 mm
Archaeotherium (NDGS exhibit)	72 mm (approx.)	21.4 mm	16.6 mm	*	*

Table 2. Measurements of various skulls studied.

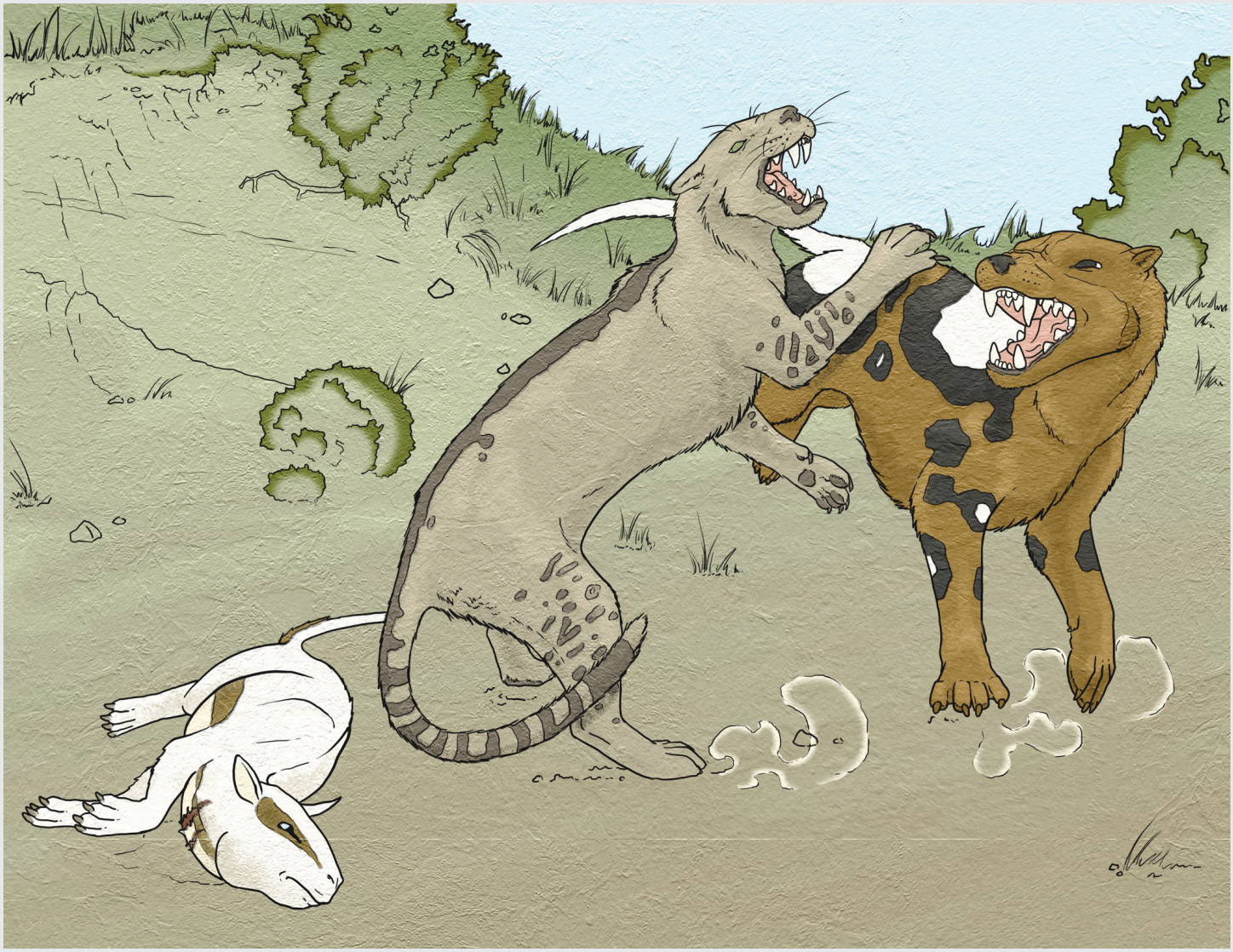

Figure 10. Colored scene of *Dinictis* (middle) and *Hyaenodon* (right) fighting over the carcass of *Merycoidodon* (left) (Hoganson and Gould, 2011).

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