FOSSIL ELASMOBRANCH TEETH OF SOUTH AUSTRALIA AND THEIR STRATIGRAPHIC DISTRIBUTION

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SUMMARY

Several hundred fossil elasmobranch teeth, collected from Tertiary formations in South Australia, have been identified to species level in most cases. Twenty-five species have been recognized, including the new species *Carcharias maslinensis* Pledge, and three forms are identifiable only to genus level. The majority of species belong in the Infra-class Osteodonta, and some absentees are noted. Diagnoses for the various genera and species are given, and a guide to their salient features. When the occurrences are arranged stratigraphically, they fall into two main time spans, in Middle to Upper Eocene and Lower to Middle Miocene, when conditions were most suitable for preservation. It is concluded that the establishment of zones in Australia, based on assemblages of elasmobranch teeth, is not yet possible.

INTRODUCTION

The Elasmobranchii have a history reaching back to the Devonian Period, but many major groups became extinct before or during the Mesozoic. Although marine sequences of Cretaceous age are known in South Australia, no shark remains have been recorded from them yet. All the teeth described herein are from Tertiary deposits.

Apart from a brief note by McCoy (1875), Chapman (1913, 1914, 1917), Chapman and Pritchard (1904, 1907), and Chapman and Cudmore (1924) have been the only ones to write on the Tertiary fishes of Australia. Most of their material was from Victoria; only rarely were South Australian specimens mentioned.

The first work of any importance concerning fossil fishes was by Louis Agassiz, whose "Recherches sur les Poissons fossiles" was published at Neuchatel between 1834 and 1843. Other papers soon followed in Europe and America, and a few workers studied the fossil fishes of Indo-Pacific region. Very recently, L. S. Glikman (1964), of the Academy of Science of the U.S.S.R., published a volume wherein assemblages of sharks' teeth are used to define twelve zones in the Russian Paleogene. The present work was undertaken to determine whether similar zones could be established for the Australian Tertiaries.

MATERIAL

The paleontological collection of the Department of Geology, University of Adelaide, includes several hundred fossil elasmobranch teeth, mostly from local Tertiary formations. A large number of teeth in the collection of the Geological Survey of South Australia, and several small private collections, were also studied.

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DEPOSITORIES

Teeth held in the Department of Geology, University of Adelaide, are catalogued with the prefix "F".

Those in the collection of the Geological Survey are recorded in the Vertebrate Catalogue, and have numbers with the prefix "V", e.g. V35.

NOMENCLATURE

Many elasmobranch genus names were established by naturalists of the early 19th century, such as Rafinesque (1810), de Blainville (1816) and Cuvier (1817). Cuvier is best known, but many of the genera he established were synonyms. Agassiz propagated these synonyms in the literature, and it is only in recent years that the original names have come into more general usage for the fossil species. Some authors, such as Glikman (1964), have split these "classical" genera, but it is difficult to see their reasons for so doing.

As genera and species of fossil sharks are established only on the character of the teeth, it is obvious that both "splitting" and "lumping" may occur. Comparison with the teeth of living sharks can reduce this risk somewhat, according to the particular genus of shark, but not remove it. Many species are therefore only morpho-species, and may represent several different biospecies, or conversely one biospecies may be represented by several morpho-species. As far as possible, the teeth described herein are compared with species originally described from Europe or America, on the grounds that most species of larger sharks have very wide distributions, and the number of parameters by which sharks' teeth are identified are not sufficient to establish geographic species for similar forms from different parts of the world.

CLASSIFICATION

Several classifications of sharks have been proposed and these vary widely. Most have a strictly zoological approach, using characters, rarely, if ever, preserved in fossils. Nicholson and Lydekker (1889) used a major division based on the structure of the vertebrae, Tectospondyli and Asterospondyli, while Bertin and Arambourg (1958) had major divisions, Pleurotremata and Hypotremata, based on gill position, i.e. more or less on body form. Smaller divisions are based on morphological and physiological criteria in which tooth form is rarely included. Families and orders of fossil sharks' teeth are therefore based on living forms. However, the major division in fossil sharks is one of the basic tooth structure, and this has been utilised by Glikman (1964) in his classification of extinct and living elasmobranchs, which is marked by a distinction between orthodont and osteodont dentition.

Orthodont teeth (Text-fig. 1a) have a pulp cavity surrounded by orthodentine, and such teeth are found in the majority of living and fossil elasmobranchs, including one order of "true" sharks, the Carcharhinidae (whalers, topes, tigers and hammerhead sharks), also the dogfishes, rays and skates, and those primitive sharks: the hexanchids (notidanids) and heterodontids.

The Osteodonta have teeth (Text-fig. 1b) whose composition, including the root, is a vascular bone-like form of apatite called osteodentine. Only "true" sharks are included in the group: nurse and sand sharks, bulldog sharks, porbeagles, makos and blue pointers, threshers, and white pointers.

This division raises the question: which feature is of greater phylogenetic importance — a basic tooth structure, a basic vertebral structure, or overall body shape and anatomical layout?

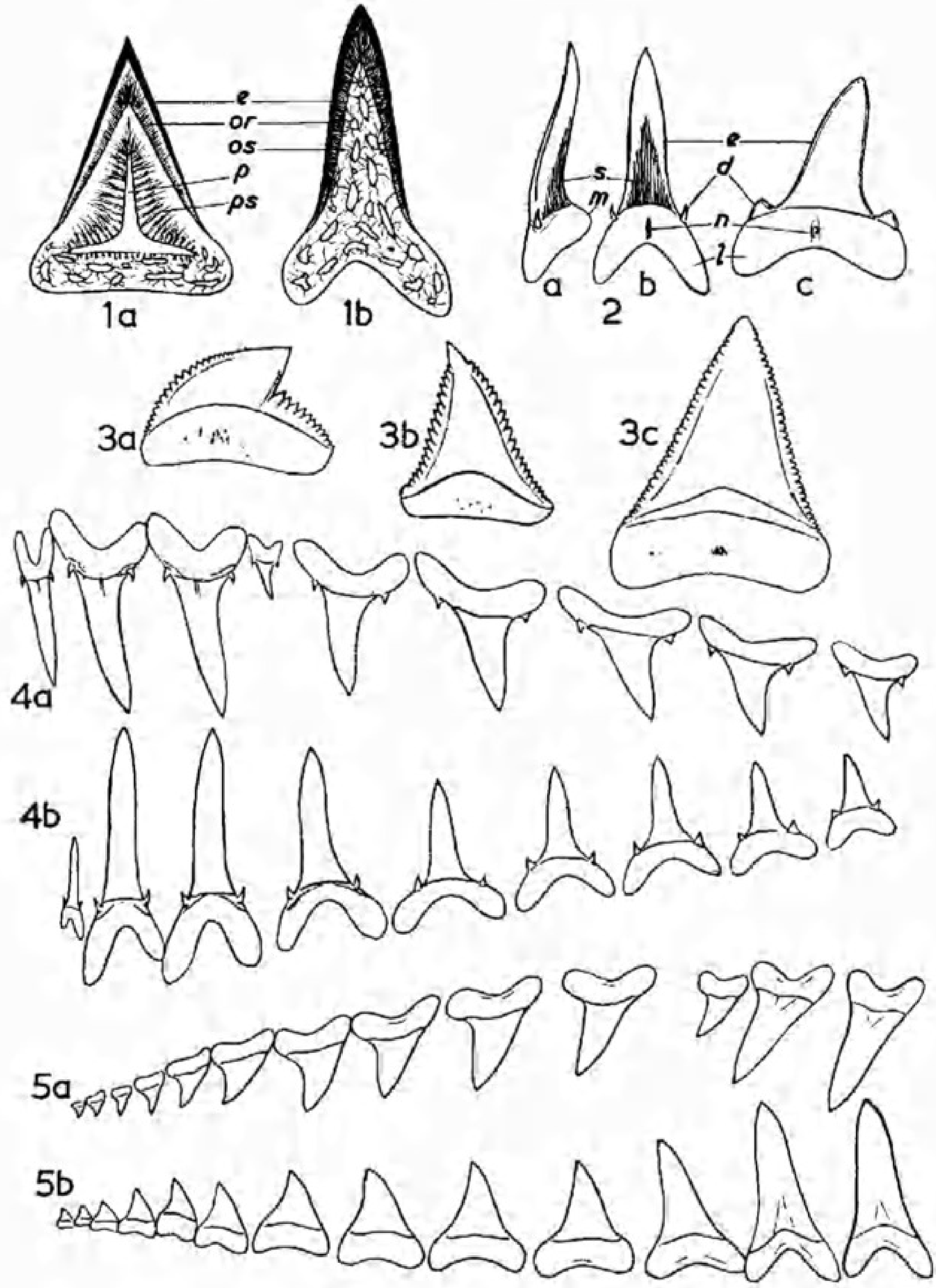


Fig. 1. a. Orthodont tooth (*Carcharhinus*). b. Osteodont tooth (*Carcharias*). *e*: Enamel (vitrodentine), *or*: orthodentine, *os*: osteodentine, *ps*: pseudodentine, *p*: pulp cavity (diagrammatic sections, after Bertin and Arambourg, 1958).

Fig. 2. a. Profile, *Carcharias macrotus*. b. Inner face, ditto. c. *Lamna apiculata*, inner face. *d*: lateral denticles, *e*: entire margin, *l*: root lobe, *m*: median boss, *n*: nutritive pit, *s*: striations.

Fig. 3. a. Serrated margins, e.g. *Galeocerdo*. b. Serrated margins, e.g. *Hemipristis*. c. Dentate margins, e.g. *Carcharodon*.

Fig. 4. *Carcharias arenarius* Ogilby. a. Upper jaw. b. Lower jaw. Anterior at left.

Fig. 5. *Isuropsis mako* (Whitley). a. Upper jaw. b. Lower jaw. Anterior at right.

However, the fossil record furnishes mainly the teeth, and the vertebrae found are difficult to ascribe to families. The use of the divisions Tectospondyli and Asterospondyli has been generally discontinued, and it is therefore felt that the use of basic tooth structure as a criterion for classification is defensible.

TOOTH MORPHOLOGY AND VARIABILITY

(Text-figs. 1-5)

Sharks' teeth consist of two main parts — the crown or biting surface, and the root. The crown may be solid (i.e. osteodont) or hollow (orthodont).

The crown consists of the main cusp or cutting blade, which may possess some accessory cusps. In osteodont sharks, these are paired lateral denticles or cusps; but in some orthodont sharks the teeth are asymmetrical, and accessory cusps occur only or mainly one the posterior side, e.g. *"Notidanus"* and *Galeocerdo*. The crown is often compressed into a blade, with the labial (outer) face being more planar than the lingual (inner) face.

The margins may be sharp cutting edges or quite blunt. Unless they are interrupted by dentes or serrae, they are termed "entire". Dentes are squarish "teeth" produced by invaginations of the edge, and serrae are saw-like points; intermediate shapes also occur.

Paired lateral denticles may take a variety of forms, even within the one species: sharp-pointed cones or barely discernible tubercles, straight or curved, broad sharp-edged compressed cones, or wedge-shaped blades. They may also bear serrae or dentes.

Ornamentation of the enamel is often present: plications of the enamel of the outer face, and longitudinal striations on the inner face.

The root is of bone-like material, and is usually bifurcated into two more or less distinct lobes which can take a variety of forms, according to position in the jaw. At the middle of the inner side of the root there is often a "median boss" which bears a vertical groove containing the "nutritive foramen". This is mainly seen in osteodont teeth, but some carcharhinids also have a nutritive pore. Within any one species of shark, variation in tooth form is seen; it may be slight, involving only an increasing obliquity in the more distal teeth, or radical, as in the hexanchids, where the difference between teeth of upper and lower jaws is extreme. Some generalisations may be made, although exceptions can be found.

1. Teeth from the upper jaw are broader than their lower jaw equivalents.
2. Upper teeth show more inclination than the equivalent lower teeth, which are normally erect.
3. There is a gradual decrease in the length-breadth ratio of the crowns as one proceeds backwards in the jaw.
4. In sharks having "eye" teeth (which are considerably smaller than their immediate neighbours), the anterior teeth are considerably more elongate than those lateral teeth immediately following the eye teeth.
5. There may be an increase in the number of lateral cusps on teeth in the distal parts of the jaws; the cusps also become broader and relatively coarser.
6. Small symphysial teeth may occur at the symphysis of either jaw.

The living sharks, *Carcharias arenarius* and *Isuropsis mako* (Text-figs. 4, 5), found in South Australian waters, show many of these features. Others, such as *Galeocerdo* and *Carcharodon*, show little variation within the jaw, save inclination and crown proportions.

Measurements are taken along three approximately perpendicular directions. Generally, crown height only can be measured due to damage to the root, and this is taken in the plane of the outer face, from apex to base, in a line perpendicular to the base. Width is measured at the base of the crown, where it naturally separates from the root. Thickness is often difficult to measure because of the configuration of the tooth; it is taken in a line normal to the outer face, as close to the base as possible.

TAXONOMIC CHARACTERS

The characters that define genera of sharks' teeth are in some respects quite vague, yet in conjunction they serve to separate the groups fairly well.

Features used are:

1. Overall shape and proportions.
2. Presence or absence of serrated margins.
3. Presence or absence of lateral cusps.
4. Shape and number of lateral cusps, if present.
5. Shape of the roots.

Specific characters are the same as those listed above, with the addition of:

6. Presence or absence of striations on the lingual face.
7. Presence or absence of plicae in the enamel of the labial face.
8. Contortion or inclination of the crown.

In addition to just the presence or absence of these features, specific determinations also depend considerably on the degree to which a character is present. This can, and undoubtedly does, lead to some confusion in identification from inadequately illustrated descriptions.

SYSTEMATICS

The classification used herein is given below, and is adapted from those of Glikman (1964) and Bertin and Arambourg (1958).

Superclass Pisces
- Class Chondrichthyes
  - Subclass Elasmobranchii
    - Infraclass Orthodonta
      - Order Hexanchida
        - Family "Notidanidae" (Hexanchidae)
      - Order Heterodontida
        - Family Heterodontidae
      - Order Squatinida
        - Suborder Rajoidei
          - Families including Pristidae, Rajidae, Myliobatidae, Dasyatidae
        - Suborder Squatinoidei
        - Pristiophoroidei
        - Orectoloboidei
        - Squaloidei
      - Order Carcharhinida
        - Family Carcharhinidae
        - Sphyrnidae
    - Infraclass Osteodonta
      - Order Carchariida
        - Family Carchariidae (= Odontaspidae)
        - Isuridae

DESCRIPTION OF SPECIES

Infraclass Orthodonta

Family "Notidanidae"

Genus "Notidanus" Cuvier, 1817

Diagnosis. Teeth of upper jaw with prominent prime cusp and one or more small secondary cusps on distal side. Lower teeth very wide with numerous secondary cusps giving a saw-like form.

"Notidanus" Cuvier includes *Hexanchus* and *Heptranchias* Rafinesque, 1810, and *Notorhynchus* Ayres, 1855, as there is no apparent generic difference between the teeth of these living genera.

"Notidanus" serratissimus Agassiz

(Plate 1, Figs. 1-3)

Notidanus serratissimus Agassiz, 1843, p. 222, pl. 36, figs. 4, 5. Woodward, 1886, p. 216, pl. 6, figs. 23-26.

Diagnosis. Teeth small, five to ten cones with blunt apices; principal cone only slightly larger than immediate neighbour, but more robust. Anterior edge produced downwards and denticulated on lower half.

Observations. Woodward's figures 24 and 25 (1886) most closely agree with two teeth at hand, although one of these has eleven cones—more than prescribed by the diagnosis. In all other respects, including geologic age, they agree with the figured material.

Another specimen, however, from the Naracoorte Bore, exhibits a somewhat different form. The principal cusp is very broad and less acute, and about twice as high as the following cusps which are about the same height. It also has eleven cusps.

Four fragments (Pl. 1, Fig. 3) found in close proximity at Blanche Point are tentatively assigned to this species, although they show some variation in the coarseness and style of serration.

Occurrence. Blanche Point Marl, at Port Noarlunga and Blanche Point. Knight Formation equivalents, Naracoorte Bore, 426 ft.

Age. Middle and Upper Eocene.

Material Examined. Three teeth and several fragments.

Family PRISTIDAE

Genus Pristis Latham, 1794

Diagnosis. Rostrum of skull long smooth blade with rounded end and parallel sides. Rostral teeth triangular, compressed dorsoventrally, faintly striated lengthwise, occur regularly along rostrum.

Pristis cudmorei Chapman

(Plate 1, Fig. 6)

Pristis cudmorei Chapman, 1917, p. 139, pl. 9, fig. 7.

Diagnosis. Rostral teeth small, elongate, triangular, slightly inclined. Anterior margin sharp, finely denticulated to apex. Posterior edge thick and blunt. Both faces very finely and irregularly striated for half of height.

Observations. The three specimens at hand agree closely with Chapman's description of material of Upper Miocene age, but full equivalence of this neritic form is doubted because of the large time gap between the Victorian and South Australian occurrences.

Occurrence. Blanche Point Marl, Maslin Bay.

Age. Upper Eocene. Carter's Unit 2.

Material Examined. Three specimens.

Family MYLIOBATIDAE

Genus MYLIOBATIS Cuvier, 1817

Diagnosis. Dental pavement formed by regular interlocking of hexagonal tooth plates. Tooth plates with comb-like base—numerous transverse parallel blades on articulating surface. Median plates very broad, lateral plates regular hexagons.

Myliobatis spp.

(Plate 1, Figs. 4, 5)

Observations. Two pieces from the Blanche Point Marl, and six pieces of different species from Naracoorte are the only South Australian specimens seen by the author. A fragment of caudal spine (Pl. 1, fig. 5) is also referred to this genus, but none of the material has been identified to species level.

Occurrence. Blanche Point Marl, Maslin Bay; Naracoorte E. & W.S. Bore No. 5, 426 ft., Knight Group equivalents.

Age. Middle and Upper Eocene.

Material Examined. Spine fragment from Blanche Point, 6 tooth plate fragments from Naracoorte bore, 2 from Blanche Point.

Family CARCHARHINIDAE

Genus CARCHARHINUS Blainville, 1816

Diagnosis. Teeth small, stout; lower teeth narrow, erect; upper teeth broader, inclined. No lateral denticles. Base widely expanded. Cutting margins often finely serrated. Root nearly straight, with central notch.

Carcharhinus cf. **collatus** Eastman, 1904

(Plate 1, Fig. 7)

Carcharias collata Eastman, 1904, p. 85, pl. 32, fig. 3.
Chapman and Cudmore, 1924, p. 118, pl. 9, figs. 13-16.

Diagnosis. Robust *Carcharhinus* teeth with cutting edges finely serrated on basal prolongations, very finely on cusp, entire apex. Inner face strongly convex. Enamel of outer face extends much lower than on inner face. Root elongated, large, symmetrical.

Observations. The four specimens at hand agree with the figure of *C. collatus* given by Chapman and Cudmore (1924), and also with Eastman's figures of his types from the Miocene deposits in Chesapeake Bay, Maryland, although one specimen is more oblique, and another more robust.

Occurrence. The teeth all came from 255 ft. depth in the Marion No. 2 Bore, Sturt River Valley, Adelaide Plains. This depth is in or near the Munno Para Clay member of the Port Willunga Beds, as defined by Lindsay and Shepherd (1966).

Age. Lower to Middle Miocene: Batesfordian-Balcombian.

Material Examined. Four specimens.

Carcharhinus (Prionodon) aculeatus (Davis)

(Plate 1, Fig. 8)

Galeocerdo aculeatus Davis, 1888, p. 8, pl. I, figs. 1-3.
Carcharias (*Prionodon*) *aculeatus* Woodward, 1889, p. 440.
Chapman and Cudmore, 1924, p. 119, pl. 9, figs. 19, 20.

Diagnosis. *Carcharhinus* teeth with whole cutting margin serrated, rather coarsely on lateral prolongations, finely on cusp, coarsest in notch; apex almost entire.

Observations. This species is represented by a solitary tooth from the River Murray Cliffs. It is similar to specimens of *C. collatus* at hand, but the serrations are considerably coarser and the tooth is slightly larger. The cusp shows a distinct inclination and the anterior notch is shallow. The tooth compares favourably with the figures of Chapman and Cudmore (1924).

Occurrence. River Murray Cliffs, locality uncertain, preservation suggests Cadell Marl Lens. Davis' material came from the Oamaru area (?L. Miocene) and from the L. Pliocene "Awatere Series".

Age. Lower Miocene.

Material Examined. One specimen.

Genus Hemipristis Agassiz, 1843

Diagnosis. Principal teeth large, triangular, compressed; cutting edges coarsely serrated almost to apex. Lower anterior teeth slender, subulate, inwardly curved, only a few minute serrae at base.

Hemipristis serra Agassiz

(Plate 1, Fig. 9)

Hemipristis serra Agassiz, 1843, p. 237, pl. 27, figs. 18-30.
Woodward, 1889, p. 449.
Chapman and Cudmore, 1924, p. 115, pl. 9, fig. 12.

Diagnosis. Marginal serrations in broad upper teeth large, extending almost to apex. Margins of anterior lower teeth very sharp distally. Inner face of root with deeply cleft median boss.

Observations. This species, while common in the Tertiaries of Europe, America and Indonesia, is quite rare in Australia, and only two specimens are known to the author, one found by Cudmore (Chapman and Cudmore, 1924) and the other very recently by Mr. R. J. F. Jenkins. The latter specimen is slightly smaller, but broader than that figured by Chapman and Cudmore. The marginal serrations are coarse, very sharp, and stop about 5 mm below the apex. The crown is inflated, but the external face is depressed at the base; the margins are twisted, convex outwards. Most of the root is missing.

Occurrence. Cliff, left bank of River Murray, one mile below Pelican Point, near Morgan, South Australia. Cadell Marl Lens in the Morgan Limestone.

Age. Lower Miocene - Batesfordian.

Material Examined. One specimen (F17288).

Genus Carcharoides Ameghino, 1901

Diagnosis. Teeth similar to *Lamna*, but with denticulated margin as in *Carcharodon*. Lateral denticles compressed, dentate. Orthodont.

Carcharoides cf. totuserratus Ameghino

(Plate 1, Fig. 11)

Carcharoides totuserratus Ameghino, 1906, p. 183 (footnote), fig. 50.
Chapman and Cudmore, 1924, p. 121.

Diagnosis. Teeth large; inclined crowns. Large pointed lateral cusps, all margins denticulated.

Description of Specimen. Crown elongate triangular, acute, slightly oblique. Margin irregularly dentate, dentes wide and separated by shallow grooves. Outer face almost flat, smooth, inner face convex, smooth.

Observations. The sole specimen at hand consists only of the enamel shell of the crown, and no root or lateral denticles are present. It is somewhat smaller than Ameghino's type, and less oblique, and shows a flaring of the base that is difficult to visualize in *C. totuserratus.* It is also similar to *C. tenuidens* Chapman; Chapman records both forms from Janjukian deposits at Waurn Ponds, Victoria; Ameghino's material, from the Patagonian Series, is now regarded as being of Lower Miocene age.

Occurrence. Road cutting near Strathalbyn cemetery, Mannum Formation equivalents.

Age. Lower Miocene.

Material Examined. One specimen.

Genus Galeocerdo Müller and Henle, 1838

Diagnosis. Teeth serrated on both edges. Apex sharply inclined, deep notch posteriorly, coarse serrations below notch.

Galeocerdo cf. aduncus Agassiz

(Plate 1, Fig. 10)

Galeocerdo aduncus Agassiz, 1843, p. 231, pl. 26, figs. 24-28.
Woodward, 1889, p. 444.
Chapman and Cudmore, 1924, p. 117.
Leriche, 1957, p. 38, pl. 45, figs. 18-21.

Diagnosis. Anterior margin arched; apex short, broad, sharply inclined, very similar to existing *Galeocerdo cuvieri* but smaller.

Observations. There is only one South Australian specimen of this species at hand. At first glance it seems referable to *G. latidens* because of its relatively great width and low crown. However, the anterior margin is distinctly arched, and finely denticulate. On reference to a jaw of the living *G. cuvieri,* it would appear that the tooth came from a posterior position, where the crown is relatively low.

Another tooth (Plate 1, Fig. 10b), of presumed Miocene age, and from an uncertain locality, is at hand. It differs from the above in having an elongated apex reaching almost to the posterior extremity of the tooth. The anterior edge shows a sharp bend about halfway along its length, and the two halves are straight. As such, it does not fit any species known to the author, but no attempt has been made to erect a new species on it at this stage.

Occurrence. Exact locality unknown, but from the River Murray cliffs, probably at Morgan.

Age. Lower Miocene.

Material Examined. Two teeth.

Family TRIAKIDAE

Genus Mustelus Linck, 1790

Diagnosis. Teeth small, similar, rhomboidal occlusal surface, arranged in oblique rows to form wide curved dental pavement on jaws; many in function at same time.

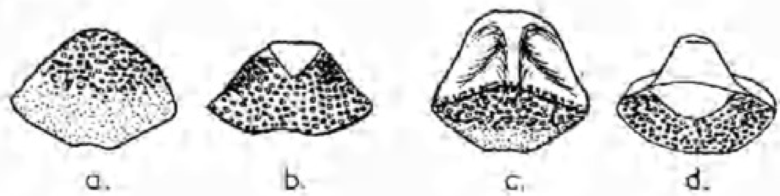


Fig. 6

Fig. 6. Comparison of *Mustelus antarcticus* and ?*Mustelus* sp.
a. *M. antarcticus*, occlusal surface, Recent.
b. ?*Mustelus* sp., ditto (F17287), U. Eocene.
c. *M. antarcticus*, postero-occlusal aspect showing length.
d. ?*Mustelus* sp., ditto. (x 5 approx.)

cf. Mustelus sp.

(Text-fig. 6)

Description. A single, small, subrhomboidal tooth was found by Mr. R. J. F. Jenkins at Blanche Point. It is similar in form to a tooth from the living gummy shark *Mustelus antarcticus* Gunther, but differs in that the posterior corner of the rhomb is truncated, while the anterior truncation is wider.

The gently arched occlusal surface of the tooth is granulate, but there is a distinct smooth triangular area at the posterior corner (in the living *M. antarcticus* the whole surface is granulate, more coarsely on the posterior half). The tooth is not as deep as *M. antarcticus*, and its articulating process is obscured or missing.

Observations. This is the first report of any tooth of this form from Australian Tertiaries, although the Triakidae have a history reaching back to the Cretaceous, and *Mustelus* itself has been recorded from Oligocene deposits (Arambourg and Bertin, 1958, p. 2036).

If the present determination is correct, the genus will thus have its stratigraphic range extended back to the Upper Eocene.

Occurrence. Blanche Point Marl, Maslin Bay.

Age. Upper Eocene, Aldingan Stage, Carter's Unit 2.

Material Examined. One specimen, plus example from living gummy shark.

Infraclass Osteodonta

Family CARCHARIIDAE (= ODONTASPIDAE)

Genus Carcharias Rafinesque, 1810

(syn. Odontaspis Agassiz, 1843)

Diagnosis. Teeth with high, narrow, compressed crown; with one or two pairs of lateral denticles, generally sharp pointed. Anterior teeth very high crowned, large and slender, with much produced bifurcated root. Similar to Cretaceous *Scapanorhynchus* and some forms of *Lamna*. Cutting edges entire, beginning several millimetres above base of crown.

Carcharias macrotus (Agassiz)

(Plate 3, Figs. 1-8)

Lamna elegans Agassiz, 1843, p. 289, pl. 35, figs. 1-7, pl. 37a, figs. 58, 59.
Otodus macrotus Agassiz, 1843, p. 273, pl. 32, figs. 29-31
Odontaspis elegans Woodward, 1889, p. 361.
O. macrota Woodward, 1899, p. 9, pl. 1, figs. 19, 20.
O. macrota striata White, 1931, p. 58, figs. 45-74.

Diagnosis. High narrow crown, slightly curved; outer face smooth, slightly convex; inner face convex but medially flattened, longitudinally striated, striae rather irregular. Single pair of lateral denticles. Prominent median boss with nutritive pore. Root lobes long, generally pointed.

Observations. Teeth of this species show a variety of forms, depending on position in the jaw, and also, to some extent, on age. The denticles show a number of different forms, from fine curved cones to broad compressed cones, to chisel-like blades. Striations vary in continuity and degree, from strongly incised grooves to barely discernible narrow facets. Many specimens lack the root and/or lateral cusps, making identification rather uncertain. Several bio-species may be represented. According to White (1931, p. 62) the forms "*Odontapsis elegans*" (Ag) and *O. macrota* are the same species, "*O. elegans*" being juvenile to *O. macrota*.

Two other forms have been separated in the South Australian material. One is represented by six teeth (V49) from the Naracoorte bore assemblage (Plate 3, Fig. 7). They differ from most specimens in having a quite robust habit with short narrow crowns and strong, thick, widely bifurcated roots. All show the typical *C. macrotus* striations. Three of them are from the upper jaw, having shorter, inclined crowns. All bear short lateral cusps, and two of the lower teeth also have a second, minute, inner pair.

The other aberrant form (Plate 3, Fig. 8) is represented by three teeth (V53) from the Peel's Bore assemblage, which differ in size, preservation and root form from the numerous specimens of *C. macrotus* also present. All three bear strong striations, and lack lateral cusps. One is a compressed symphysial tooth, and the other two have roots with widely divergent, flattened, round-ended lobes.

Not enough is known of these two forms to put them in other species.

Occurrence. Basal member of the Tortachilla Limestone, upwards to the lower part of the Port Willunga Beds—Maslin and Aldinga Bays. Peel's Bore near Robe (390 ft.), and an aberrant form from the E. & W.S. Bore No. 5, at Naracoorte (426 ft.). Also from the Strathalbyn cemetery road cutting, Morgan type section, and Dry Creek Sands (Tennant's Bore, Salisbury).

Age. Common in Middle and Upper Eocene, and sporadically to Pliocene, in South Australia.

Material Examined. Approximately 50 specimens from Maslin and Aldinga Bays in A.U. catalogue; about 100 from Peel's Bore and other places, held in the Geological Survey collection, including the aberrant forms (V49 and V53).

Carcharias contortidens (Agassiz)

(Plate 3, Fig. 11)

Lamna (Odontaspis) contortidens Agassiz, 1843, p. 294, pl. 37a, figs. 17-23.
Odontaspis contortidens Woodward, 1889, p. 366.
Chapman and Cudmore, 1924, p. 122.

Diagnosis. Teeth slender; delicate longitudinal striae on inner face. Sigmoidal curvature of anterior teeth and median boss of root more pronounced than in *C. macrotus*.

Observations. A large number of teeth from Peel's Bore were separated from *C. macrotus* by their greater slenderness and sinuosity. The striations are often finer and more numerous than in *C. macrotus* and extend nearer to the apex. Miocene specimens from the Marion No. 2 Bore are similar to, but considerably smaller than those from Peel's Bore.

Occurrence. Peel's Bore (390 ft.), near Robe; Marion No. 2 Bore (255 ft.), Sturt River Valley; Blanche Point Marl, Aldinga Bay; and Dry Creek Sands in the Abattoirs Bore.

Age. Middle to Upper Eocene, Miocene, Pliocene.

Material Examined. About 50 specimens, mainly from Peel's Bore (V14, V17).

Carcharias maslinensis sp. nov.

(Plate 2, Figs. 1-8)

Diagnosis. Teeth with very slender crown, circular cross-section at base. Anterior teeth with very sinuous elongate crowns, twisted. Anterior cutting edge more prominent. Regular, deeply-incised, longitudinal striations on inner face, almost to apex. Pair of minute, conical lateral denticles, well separated from crown. Root of anterior teeth with strong median boss. Lateral and distal teeth straighter, erect, having roots with widely divergent flattened lobes.

Description of Types

Holotype (F17260) (Pl. 2, Figs. 1, 2). A typical anterior tooth of *Carcharias*, but distinguished by extreme slenderness, prominent sinuosity and axial twist. It is almost circular in section at the base, where the cutting edges are nonexistent, but becomes semicircular towards the apex, with the outer face being almost flat. Anterior cutting edge begins about two millimetres above base and is quite sharp; posterior cutting edge begins about 5 mm above base but is less prominent and rather blunt. The outer face is smooth except for a small sub-median plica, the inner face is strongly convex and longitudinally striated to within 3 mm of the apex. Striae are fine, regular, almost parallel, bifurcating towards the apex. A very small, curved-conical lateral cusp is preserved on the anterior side of the crown, some distance below the base.

The root is strongly bifid with narrow lobes at about 40°, separated by a prominent median boss with a deep nutritive pit at the apex.

Dimensions. Total height 20·8 mm; crown height (along outer face) 16·8 mm; inward displacement of apex c. 10 mm; base width 4·5 mm; base thickness 4·0 mm.

Paratypes

(a) *Anterior teeth* (V35) (Pl. 2, fig.3). Similar to holotype, but most have lost the lateral cusps.

(b) *Lateral teeth* (V18) (Pl. 2, figs. 4a, 4b). A number of teeth found in the same Naracoorte bore assemblage are deemed to represent the lateral and posterior teeth of *C. maslinensis* sp. nov. because they are similar to the anterior teeth in slenderness, striation, and lateral cusps. They differ in being erect, with equal margins, a relatively short crown, and widely-bifurcating, flat-lobed roots. Two groups can be separated; one, having relatively wide main cusps, presumably represents teeth from the upper jaw, the other, lower jaw teeth. This conclusion is based on observations on the variation of teeth in the jaws of the living *Carcharias arenarius* Ogilby, which observations also explain the differences in root form and the shortness of the crown in the lateral teeth.

Judging by the gradation in size and form of both lateral and anterior teeth and the preservation, it is considered that they might represent one individual.

Occurrence. E. & W.S. Bore No. 5, Naracoorte (426 ft.).

Depositories of Types. Holotype: Dept. of Geology, University of Adelaide, F17260. Paratypes: Geological Survey of South Australia, V18, V35.

Observations. The teeth differ from *Lamna attenuata* Davis, which Chapman reported (1918) from the Lower Aldingan Beds, by possessing striations on the inner face, and a twisted sigmoidal shape of the crown. Chapman and Pritchard (1904) describe *Odontaspis attenuata* (Davis) as having a striated inner face, but none of the material seen in the Victorian National Museum agrees with the specimens of *C. maslinensis.* The lateral teeth of *C. maslinensis* are similar to very small specimens of *C. macrotus.*

TABLE 1.
DIMENSIONS OF TYPES

Anteriors			Upper Laterals			Lower Laterals		
height	width	thickness	height	width	thickness	height	width	thickness
holotype			*paratypes*			*paratypes*		
16·8	4·5	4·0	8·3	4·8	2·4	7·7	3·9	2·3
			7·2	4·1	2·0	7·9	3·0	2·5
paratypes								
16·1	4·9	4·1	6·1	3·5	2·0	7·0	2·4	2·2
12·1	3·5	2·5	6·8	3·4	2·0	5·8	3·0	1·7
12·1	3·6	2·9	7·0	3·7	2·2	7·3	2·8	2·1
13·0	3·4	2·5	6·5	2·8	2·1	5·8	2·1	1·7
9·9	3·1	2·3	5·0	2·7	1·8	7·5	3·0	2·3
12·6	3·0	2·5	5·1	2·9	1·7	7·2	3·0	2·0
8·4	2·8	2·4	5·4	3·3	1·5			
			6·0	2·9	1·6			
			3·6	2·2	1·7			
			7·6	4·5	2·3			

C. maslinensis is commonly found in the Eocene deposits of South Australia, and appears to have undergone some evolutionary change, as specimens from the Blanche Point Marl and Port Willunga Beds (lower part) are stouter than those from the older Tortachilla Limestone and Knight Formation. It is a common constituent of the assemblage of crowns in the basal grit member of the Tortachilla Limestone, but most identified specimens are of anterior teeth, for it is difficult to distinguish the lateral teeth on crowns alone. Three poorly preserved specimens from the Strathalbyn assemblage could conceivably be reworked from underlying Eocene strata during the Miocene transgression.

Occurrence. Peel's Bore, 390 ft., Co. Robe, Hd. Ross, Sec. 19; E. & W.S. Bore No. 5, Naracoorte, 426 ft.; a farm bore near Lucindale, 200 ft; a farm bore near Kingston, 715 ft.; basal grit of Tortachilla Limestone at Maslin Bay, basal part of Muloowurtie Formation, Yorke Peninsula, Blanche Point Marl; lower part of Port Willunga Beds; and Strathalbyn (cemetery road cutting) Mannum Formation equivalent.

Age. As recorded so far, *C. maslinensis* ranges from Middle to Upper Eocene, and possibly to Lower Miocene, unless reworked.

Material Examined. About 50 specimens from south-eastern bores, including the types F17260, V35, and V18. Another 50 crown enamels from the Tortachilla Limestone, and several teeth from other levels.

Carcharias cf. cuspidatus (Agassiz)

(Plate 3, Figs. 9, 12, 13)

Lamna cuspidata Agassiz, 1843, p. 290, pl. 37a, figs. 43-50.
Odontaspis cuspidata Woodward, 1889, p. 125.
White, 1931, p. 52, figs. 13-44.

Diagnosis. Teeth very similar to *C. macrotus* except for absence of striae on inner face. Sometimes more robust than corresponding teeth of *C. macrotus*, but smaller. One pair of small, pointed, lateral cusps. Nutritive foramen in deep cleft.

Observations. A large number of teeth, many from Peel's Bore, fit in this diagnosis, but most are wanting roots and/or lateral cusps. Those which are complete come within the range of variation for the species as illustrated in White's figures, but altogether they make up a rather heterogeneous collection which may represent several species. It has not been possible to separate them into more satisfactory groups.

Occurrence. Peel's Bore, 390 ft. (Knight Formation); basal part of Tortachilla Limestone, Blanche Point Marl, Port Willunga Beds in the Willunga Basin; and Strathalbyn (Mannum Formation equivalent).

Age. Middle Eocene to Lower Miocene, in South Australia.

Material Examined. Almost 100 specimens, including about 50 from Peel's Bore, and many crown enamels from the Tortachilla Limestone, and Strathalbyn.

Carcharias cf. rutoti (Winkler)

(Plate 3, Fig. 14)

Otodus rutoti Winkler, 1876, p. 6, pl. 1, figs. 3, 4.
Odontaspis rutoti Woodward, 1889, p. 361.
Chapman and Cudmore, 1924, p. 125, pl. 10, fig. 27.
White, 1931, p. 49, figs. 4-12.

Diagnosis. Teeth small; robust but not very high, with faces smooth, but there may be vertical plications on outer face. At least two pairs of sharp lateral cusps—outer ones insignificant. Root with prominent median boss. Outer base-line of crown re-entrant.

Observations. Small specimens similar to *C. rutoti* have been recovered from the Blanche Point Marl, where the apparently easily detached lateral cusps are preserved. No specimens have been seen having three pairs of lateral cusps as in Winkler's description, but from White's figures, such occurrences are uncommon—only one of his nine figures shows three pairs of cusps. One specimen ascribable to the species was found in the Peel's Bore assemblage.

On the specimens available, the main cusp is more or less inclined, fairly broad, and relatively thin. The denticles are conical, sometimes compressed, and sometimes incurved towards the main cusp.

Chapman and Pritchard (1904) recorded similar teeth from Victoria as "*Lamna bronni*", which is a Cretaceous form, and it has been suggested that *C. rutoti* is the correct determination.

Occurrence. Blanche Point Marl, Blanche Point, Maslin Bay. Knight Formation, Peel's Bore (390 ft.).

Age. Middle and Upper Eocene.

Material Examined. Two teeth from Blanche Point, one from Peel's Bore.

Carcharias dubius (Agassiz)

(Plate 3, Fig. 10)

Lamna dubia Agassiz, 1843, p. 295, pl. 37a, figs. 24-26.
Odontaspis dubia Glikman, 1964, pl. 25, figs. 12, 13, 16, 17, 19; pl. 27, figs. 18-23.

Diagnosis. Teeth very similar to *C. contortidens*, but lack striations on inner face. Crown rounded, subcylindrical at base, not flattened towards apex. Single pair of lateral cusps: cylindrical, elongate, very acute. Root and lateral cusps rarely preserved.

Observations. A number of teeth having similar characters to this form were found in the Peel's Bore Assemblage. The crowns are elongate and acuminate, with little or no cutting edge on the lower part. Width is only slightly greater than thickness. Root large, prominent median boss, lobes at about 90°. The teeth show signs of being polished, but not of excessive wear. They are similar to those figured by Glikman (1964) except that the root is not as broad.

Occurrence. Peel's Bore (390 ft.), County Robe, Hd. Ross, Sec. 19.

Age. Middle Eocene.

Material Examined. Five teeth from Peel's Bore.

Carcharias sp. indet.

Observations. Five entirely unworn teeth, having some resemblance to *C. dubius* and *C. cuspidatus*, but differing in detail, were found in the Naracoorte Bore Assemblage.

The teeth are small, having narrow erect crowns and a pair of large conical lateral cusps. They differ from *C. dubius* in having sharp cutting edges, also on the denticles, and widely divergent root lobes. The median boss is prominent. One tooth is from an anterior central position, while another is posterior and is developing a second pair of denticles.

Occurrence. E. & W.S. Bore No. 5, Naracoorte (426 ft), Knight Formation equivalent.

Age. Middle Eocene.

Material Examined. Five teeth from the Naracoorte Bore.

Carcharias cf. **ensiculatus** (Davis)

(Plate 3, Fig. 15)

Lamna ensiculata Davis, 1888, p. 18, pl. 3, figs. 6, 7.

Diagnosis. Teeth small, strong, erect. Crown enamel divides just above base, at point marked by constriction, and extends over upper part of root lobes. Faint indication of lateral cusps.

Observations. This form is represented here by a single specimen which well illustrates the peculiar flaring and bifurcation of the lower part of the enamel. No lateral cusps can be seen. The root is strong and deeply bifurcated at about 90°; the inner side is flattened and bears a prominent nutritive pit. However, the root is not as large as in the figures of Davis. His material came from the "Oamaru Formation" (Oligocene) of New Zealand, which is considerably younger than this specimen.

Occurrence. E. & W.S. Bore No. 5, Naracoorte (426 ft.).

Age. Middle Eocene.

Material Examined: One specimen.

Genus Carchariolamna Hora, 1939

Diagnosis. Teeth having form of *Lamna* and bearing close resemblance to *Carcharoides*, but being distinguished by osteodont structure, less developed lateral cusps, finely denticulated margin, and blunt apex.

Carchariolamna cf. heroni Hora

(Plate 3, Fig. 16)

Carchariolamna heroni Hora, 1939, p. 203-205, pl. 13, figs. 1-4.

Diagnosis. Teeth similar to *Carcharias* or narrow specimens of *Lamna* sp., erect, broad base, apex blunt; margins finely denticulate, from apex almost to base. Lateral denticles small, blunt, incipient. Root broad.

Observations. The specimen at hand consists only of the crown of a tooth. It agrees with Hora's description and figures, except that the apex is more acuminate, and no flaring is seen at the base. The margin is well preserved, and differs from that of *Carcharoides* in the fineness of the dentes.

Occurrence. Marion No. 2 Bore, 225 ft., Sturt River Valley. Another tooth of this form was found by Howchin in a quarry at Mt. Gambier.

Age. Lower to Middle Miocene (Batesfordian-Balcombian).

Material Examined. Two specimens.

Family ISURIDAE

Genus Lamna Cuvier, 1817

Diagnosis. Teeth as for *Carcharias* Rafinesque, but principal cusps broader, and lateral cusps larger and stouter. Cutting edges do not extend to base of crown.

Lamna obliqua (Agassiz)

(Plate 4, Fig. 1)

Otodus obliquus Agassiz, 1843, p. 267, pl. 31, 36, figs. 22-27
Lamna obliqua Woodward, 1889, p. 404.
White, 1931, p. 46, fig. 3.

Diagnosis. Teeth robust, large; crown moderately compressed, acuminate, one pair of broad lateral cusps, sometimes a second smaller pair in distal teeth. Both faces smooth. Rarely, cutting edges faintly denticulated. Prominent median boss, nutritive foramen not in groove.

Observations. This species is rare in Australian Tertiaries, and only two specimens have been available. The larger specimen is a distal tooth having a short crown and two pairs of stout lateral cusps. The root is stout and widely bifurcated with pointed lobes. The other specimen, from Peel's Bore, is small, more oblique, with one pair of small denticles.

Occurrence. The larger specimen is part of an old collection and is labelled "Miocene,? Deepwell, Murray Scrub". However, the preservation is similar to that of teeth from the Knight Formation of the Murray Basin. The smaller specimen is from Peel's Bore, near Robe.

Age. Middle or Upper Eocene.

Material Examined. Two specimens.

Lamna cf. apiculata (Agassiz)
(Plate 4, Fig. 2)

Otodus apiculatus Agassiz, 1843, p. 275, pl. 37, figs. 32-35.
Lamna apiculata Chapman, 1918, p. 13, pl. 5, figs. 17-20. pl. 6, fig. 4.
Chapman and Cudmore, 1924, p. 126, pl. 10, figs. 28, 29.

Diagnosis. Moderate size, triangular, relatively thin, more or less oblique; outer face with some small vertical plicae at base; pair of short, blunt, biconvex lateral cusps. Root strong; widely divergent, pointed lobes. Detached crowns very similar to *Isurus hastalis,* but have greater median thickness.

Observations. Only a few of the specimens at hand still retain the lateral cusps; identification of others is uncertain. Many specimens are small, and may represent a different species, as they occur in only one horizon—the basal part of the Tortachilla Limestone. The form occurs sporadically through the Tertiary.

Occurrence. Basal member of Tortachilla Limestone, Maslin Bay; Blanche Point Marl at Aldinga Bay, Port Noarlunga and Moana; Strathalbyn; Morgan Limestone type section (Cadell Marl Lens); Morgan township; base of Loxton Sands, Waikerie.

Age. Upper Eocene to Pliocene.
Material Examined. Fourteen specimens.

Lamna cf. crassidens Agassiz
(Plate 4, Fig. 4)

Lamna crassidens Agassiz, 1843, p. 292, pl. 35, figs. 8-21.
Odontaspis (?) *crassidens* Woodward, 1889, p. 373.
Lamna crassidens Chapman and Cudmore, 1924, p. 128.

Diagnosis. Teeth robust, large, rather spatulate outline; outer face gently convex; inner face strongly convex, medially depressed. Root strong, long widely divergent lobes. Crowns very similar to *Isurus desorii.*

Observation. A single tooth fits this description. The crown is erect, and spatulate, with the inner face strongly convex but medially depressed. It is placed in *Lamna* because the cutting edges do not extend to the base, and it is too robust to be put in *Carcharias.* There is no sign of lateral cusps. The root has widely divergent lobes.

Occurrence. River Murray cliffs, probably near Morgan.
Age. "Lower Murravian" i.e. Lower Miocene.
Material Examined. One specimen.

Lamna vincenti (Winkler)
(Plate 4, Fig. 3)

Lamna compressa Agassiz (pars), Agassiz, 1843, p. 290, pl. 37a, figs. 41-42.
Lamna vincenti (Winkler), Woodward, 1899, p. 10. pl. 1, figs. 21, 22.
Leriche, 1905, p. 125-127, pl. 6, figs. 36-51.
Leriche, 1936, p. 390, pl. 26, figs. 14, 15.

Diagnosis. Teeth strongly compressed, crown expanded at base, inner face smooth; upper teeth oblique, lowers erect; one pair of lateral cusps, moderate size, well separated from crown, divergent; small outer pair of cusps in more distal teeth.

Observations. Two undoubted specimens of this species were found in the Blanche Point Marl by Mr. R. J. F. Jenkins, and several incomplete teeth may also be referable to the species. It is distinguished from the form *C.* cf. *rutoti,* which is also present, by the compressed crown and straight outer base-line.

Occurrence. Blanche Point Marl, Blanche Point.
Age. Upper Eocene, Carter's Unit 2.
Material Examined. Two complete teeth and several crowns.

Genus Isurus Rafinesque, 1810

Diagnosis. Teeth generally large; crown compressed, triangular, acute, erect or slightly oblique; margins entire, extend right to base; no lateral cusps. Root thick; short, rounded lobes.

Isurus cf. **hastalis** (Agassiz)
(Plate 4, Fig. 5)

Oxyrhina hastalis Agassiz, 1843, p. 227, pl. 34, figs. 3-13, 15-17.
Woodward, 1889, p. 385.
Isurus hastalis Ishiwara, 1921, p. 62, pl. 10, figs. 1-32.
Chapman and Cudmore, 1924, p. 129, pl. 10, fig. 30.
Oxyrhina hastalis Leriche, 1957, p. 27, pl. 2, figs. 1-8.

Diagnosis. Teeth large, broad, compressed; outer face flat or concave, sometimes with plicae; root short, almost straight, blunt-ended. Anterior teeth very large, triangular, thin erect; upper laterial teeth inclined. Lower teeth thicker, more erect.

Observations. This species has been the subject of much "splitting" and "lumping". Agassiz's species *Oxyrhina hastalis, O. trigonodon,* and *O. plicatilis* are now commonly included in the synonymy, and Ishiwara (1921), for instance, has included a number of Jordan's Californian species. As a result, *Isurus hastalis* consists of a number of forms, and allocation to the species is sometimes uncertain. Reference to the teeth of the living *Isuropsis mako* (Whitley) (= *Isurus glaucus* (Müller and Henle)) shows that such a wide range of forms is to be expected.

Few undoubted specimens of *I. hastalis* are at hand from South Australia, although they are abundant in the Victorian Miocene. The teeth show a similar range in form to those figured by Ishiwara (1921), but they are often considerably smaller. They also have a long time range, and may therefore represent several species. Some specimens assigned here may be incomplete teeth of *Lamna apiculata.*

Occurrence. Blanche Point Marl, and lower Port Willunga Beds in Aldinga Bay (uncertain identification); Strathalbyn cemetery road cutting; Cadell Marl Lens, Morgan type section; Morgan township; Mannum; Mt. Gambier.

Age. (?) Upper Eocene to Middle Miocene.

Material Examined. Eight good specimens and numerous enamel fragments from Strathalbyn.

Isurus desorii (Agassiz)
(Plate 4, Fig. 7)

Oxyrhina desorii Agassiz, 1843, p. 202, pl. 37, figs. 8-13.
Woodward, 1889, p. 382.
Isurus desorii Chapman and Cudmore, 1924, p. 132, pl. 10, fig. 32.
Oxyrhina desori Leriche, 1957, p. 26, pl. 44, figs. 18-23.

Diagnosis. Teeth with crowns narrower than *I. hastalis,* broader than *I. retroflexus,* sigmoidal curvature in upper anterior teeth. Outer face nearly flat, inner very convex, but medially depressed.

Observations. The few specimens available are generally in a poor state of preservation, consisting of detached crowns only. There are few really distinctive characters, but the teeth fit roughly between the limits set. However, there appears to be a tendency for the forms *hastalis, desorii* and *retriflexus* to intergrade, and these determinations must therefore be regarded cautiously.

Occurrence. The better preserved teeth are of uncertain origin, but appear to have been collected from the Murray Cliffs—possibly from the Cadell Marl Lens near Morgan. Others, consisting of enamel only, were collected from the road cutting near the Strathalbyn cemetery, i.e. Mannum Formation equivalent. A tooth ascribable to *I. desorii* was also found in the Peel's Bore Assemblage.

Age. Middle Eocene (?), Lower Miocene.

Material Examined. Eight specimens.

Isurus retroflexus (Agassiz)

(Plate 4, Figs. 8, 9)

Oxyrhina retroflexa Agassiz, 1843, p. 281, pl. 33, fig. 10.
Woodward, 1889, p. 389.
Isurus retroflexus Chapman and Cudmore, 1924, p. 130, pl. 10, fig. 31.
Oxyrhina retroflexa Leriche, 1957, p. 30, pl. 45, figs. 9-11.

Diagnosis. *Isurus* teeth, rather short, robust, narrower than *I. desorii*. Anterior crowns strongly incurved. Inner face very convex, not depressed; outer face slightly convex in lower teeth, flat in upper teeth. Lateral teeth curved backwards to angle of jaws.

Observations. Teeth of this form are very similar to those of *I. desorii*, but are marked by greater incurvature, and by convex outer faces. One specimen of an upper anterior tooth is almost complete, and shows a basal expansion of the crown enamel onto the root.

Occurrence. One specimen, a lower anterior, was found in limestone at Myponga in a posthole at the Myponga cheese factory. The others are from less well defined localities: Aldinga Cliffs, Murray Cliffs, according to their labels.

Age. Upper Eocene (?)–Oligocene, Lower Miocene.

Material Examined. Seven specimens.

? **Isurus** sp.

(Plate 4, Fig. 10)

Description. A number of similar teeth, represented only by the enamel of their crowns, have been found in two different formations.

The crowns are elongate, narrow, relatively thin, and slightly inclined. The apex is blunt. The margins are entire, reaching right to the base, but are blunt; although worn, they show little sign of having been sharp. The outer face is slightly convex, medially depressed at the base, and extends below the normal base-line in a wide "tongue". The inner face is more convex, smooth.

The slenderness and the character of the outer face make its allocation to *Isurus* rather uncertain.

Occurrence. Basal grit member of the Tortachilla Limestone, Maslin Bay; and Strathalbyn cemetery road cutting—Mannum Formation equivalent.

Age. Upper Eocene, and Lower Miocene.

Material Examined. Fifteen specimens.

Genus CARCHARODON A. Smith (in Müller and Henle, 1838)

Diagnosis. Teeth large to very large, triangular, serrate or dentate margin; outer face flat, inner face convex; sometimes with serrate lateral cusps.

Carcharodon megalodon (Charlesworth)

(Plate 4, Fig. 12)

Carcharias megalodon Charlesworth, 1837, p. 225, fig. 24.
Carcharodon megalodon Agassiz, 1843, p. 247, pl. 29.
McCoy, 1875. Dec. 2, pl. 11, fig. 4, p. 9.
Woodward, 1889, p. 415.
Ishiwara, 1921, p. 65, pl. 10, fig. 33, pl. 11, figs. 1-8, pl. 12, figs. 1, 2.
Chapman and Cudmore, 1924, p. 133.
Leriche, 1957, p. 32, pl. 3, figs. 1-18.

Diagnosis. Very large, broad triangular, robust; outer face flat; apex slightly everted; no distinct lateral cusps. Margin with rounded dentes.

Observations. This is one of the best known of fossil sharks' teeth, mainly because of its large size. The sharks growing these teeth have been estimated to have reached 30 metres in length, with a jaw gape of two metres. Although found in large numbers in some parts of the world, only relatively few teeth have been found in South Australia. An upper right lateral tooth, in the Department of Geology collection, has a crown about 45 mm high, and shows marked inclination towards the posterior. A fragment of enamel from the Strathalbyn locality may also belong to *C. megalodon*. The teeth are marked by a spatulate outline, the margins being convex towards the apex, and concave towards the base.

Occurrence. The specimens at hand come from Barber's Quarry, Mount Gambier, and also from Strathalbyn. Others have been found at Pt. MacDonnell, Lake Bonney (S.E.), Morgan, and Blanchetown, and elsewhere in the Murray Basin.

Age. Lower to Middle Miocene.

Material Examined. Seven specimens, including five in the South Australian Museum.

Carcharodon auriculatus (Blainville)

(Plate 4, Fig. 11)

Squalus auriculatus de Blainville, 1818, p. 384.
Carcharodon auriculatus Agassiz, 1843, p. 254, pl. 28, figs. 17-19.
C. angustidens Agassiz, 1843, p. 255, pl. 28, figs. 20-25, pl. 30, figs. 2, 3.
McCoy, 1875, Dec. 2, pl. 11, figs. 2, 3, p. 8.
C. auriculatus Woodward, 1889, p. 411.
Chapman and Cudmore, 1924, p. 134.
C. angustidens Leriche, 1957, p. 32, pl. 3, fig. 14.

Diagnosis. Teeth robust, smaller and narrower than *C. megalodon*; single pair of serrated lateral cusps, especially large in lateral teeth, which have very narrow, rather oblique crowns.

Observations. The specimen at hand is almost complete, lacking only the apex of the crown. The crown is erect, and narrow in its upper part, but flares suddenly about 1 cm above the base. The inner face is convex but medially depressed. The lateral cusps are compound, i.e. their outer edges have two or more major points, all of which are serrated. The serrae are quite pointed, whereas the specimens of *C. megalodon* at hand have rounded dentes. The root is strong, with widely divergent, flattened lobes.

Occurrence. Port Willunga Beds, Aldinga Bay. Others have been found at Mount Gambier and Tailem Bend.

Age. Oligocene to Lower Miocene.

Material Examined. Seven specimens, including six in the South Australian Museum.

Carcharodon carcharias (Linnaeus)
(Plate 4, Fig. 13)

Squalus carcharias Linnaeus, 1758, p. 235.
Carcharodon rondeletii Müller and Henle, 1841, p. 70.
Woodward, 1889, p. 420.
Carcharodon carcharias Ishiwara, 1921, p. 68, pl. 17, fig. 5.
Chapman and Cudmore, 1924, p. 135.

Diagnosis. Carcharodon teeth, but relatively small, reaching 40 mm height; broad triangular, thin, straight margins, no lateral cusps.

Observations. The specimen at hand consists of the main part of the crown. The margins flare only slightly at the base, and are irregularly denticulated with well-separated rounded dentes. The outer face is slightly convex, but medially depressed. This species is still found in South Australian waters, and has world-wide distribution.

Occurrence. Dry Creek Sands, Abattoirs Bore, Hd. Yatala.

Age. Upper Miocene, Recent.

Material Examined. One specimen, plus jaw of living shark.

Carcharodon sp. **indet.**
(Plate 4, Fig. 14)

Observations. A small tooth, obviously belonging to *Carcharodon* sp., has been found in the Blanche Point Marl. The apex and much of the root are missing, and the total height of the remainder is about 15 mm. The crown is quite thick (6 mm), and almost complete, except for apex and extremities of the base, and is inclined to the posterior. Only one of the cutting edges is preserved intact, and shows moderate-sized round-ended dentes. The tooth evidently comes from the posterior part of the jaw. Of the root only the central portion remains, preserving a median boss with a shallow groove.

Occurrence. Blanche Point Marl, Blanche Point.

Age. Upper Eocene—Carter's Unit 2.

Material Examined. One tooth. Jenkins' collection.

STRATIGRAPHIC DISTRIBUTION

It is seen that, although sediments covering most of the Tertiary are present in South Australia, the known distribution of fossil sharks' teeth within them is discontinuous. This is mainly a collecting bias, due to favourable lithology for preservation and subsequent discovery, although assemblages from bores come from discrete levels.

A number of assemblages from units in which fossil sharks' teeth are relatively plentiful are listed below. They are treated in stratigraphic order.

a. *Knight Formation* (lower part): Peel's Bore, Co. Robe, Hd. Ross, Sec. 19, 390 ft., E. & W.S. Bore No. 5, Naracoorte, 426 ft.

Age. Middle Eocene.

Species. "Notidanus" serratissimus, Myliobatis spp., *Galeocerdo* sp. indet., *Carcharias macrotus, C. contortidens, C. maslinensis* sp. nov., *C. cuspidatus, C. rutoti, C. dubius, C. ensiculatus, Lamna obliqua, Isurus* cf. *desorii.*

b. *Tortachilla Limestone* (basal grit), Maslin Bay.

Age. Aldingan (Upper Eocene), Carter's Unit 1.

Species. *Carcharias macrotus, C. cuspidatus, C. maslinensis* sp. nov., *Lamna* cf. *apiculata, Isurus* (?) *hastilis, Isurus* (?) sp.

These are all preserved as only the enamel shells of the crowns.

c. *Blanche Point Marl.* Blanche Point and other places.

Age. Aldingan, Carter's Unit 2.

Species. *"Notidanus" serratissimus, Pristis* cf. *cudmorei, Myliobatis* sp., *Carcharias macrotus, C. contortidens, C.* cf. *cuspidatus, C.* cf. *rutoti, C. maslinensis, Lamna apiculata, L. vincenti, Isurus* cf. *hastalis, Carcharodon* sp. indet.

d. *Strathalbyn,* cemetery road cutting (Hd. Bremer, Sec. 2548).

Formation. Sublittoral equivalents of Mannum Formation.

Age. Lower Miocene.

Species. *"Notidanus"* sp. indet. (fragmental), *Carcharoides* cf. *totuserratus, Carcharias macrotus, C.* cf. *cuspidatus, C.* (?) *maslinensis, Lamna apiculata, Isurus hastalis, I. desorii, Isurus* (?) sp. (same as in Tortachilla Limestone), *Carcharodon megalodon.*

e. *Marion No. 2 Bore,* Sturt River Valley, Hd. Adelaide (depth 255 ft.).

Formation. In or near Munno Para Clay member, Port Willunga Beds.

Age. Batesfordian-Balcombian (Lower Miocene), Carter's Units 9-10.

Species. *"Notidanus"* sp. indet. (fragment), *Carcharhinus* cf. *collatus, Carchariolamna* cf. *heroni, Carcharias contortidens, C. cuspidatus.*

f. *Cadell Marl Lens,* Morgan Limestone (type section, 4 miles downstream from Morgan).

Age. Lower Middle Miocene. Carter's Unit 10.

Species. *Carcharhinus aculeatus, Galeocerdo aduncus, Hemipristis serra, Carcharias macrotus, C.* cf. *cuspidatus, Lamna apiculata, L. crassidens, Isurus hastalis, I. desrii, I. retroflexus, Carcharodon megalodon.*

g. *Dry Creek Sands,* as in Abattoirs Bore, Tennant's Bore.

Age. Upper Pliocene (Yatalan).

Species. *Myliobatis moorabbinensis,* Carcharhinus (Prionodon) aculeatus,* Carcharias* cf. *macrotus, C. contortidens,* Lamna* sp., *Carcharodon carcharias.*

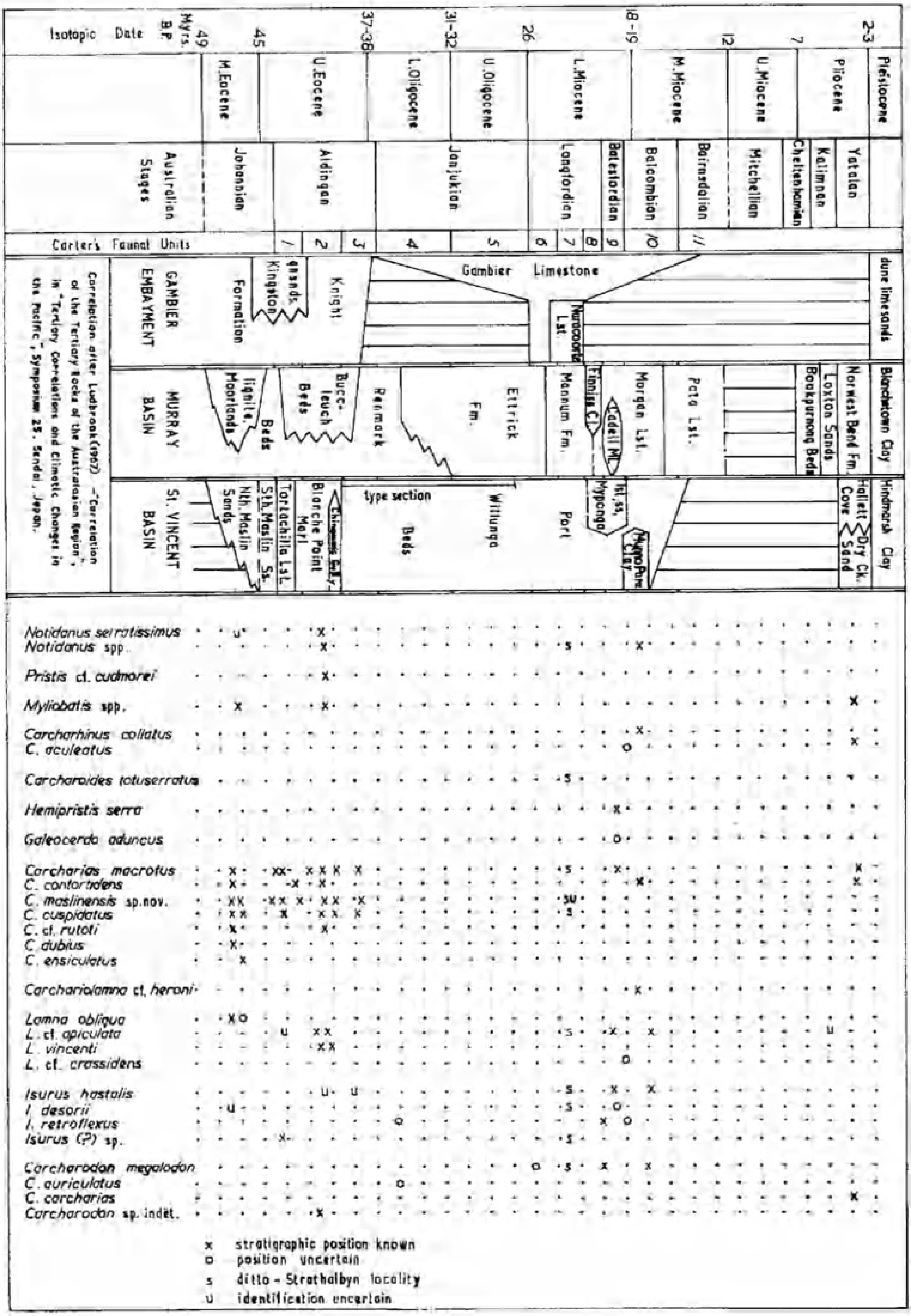
As the accompanying Table 2 shows, some species are restricted to relatively short-time ranges. This is partly an artificial zonation, caused by differential preservation and paucity of specimens. Some species have short time ranges on a world scale, and the specimens at hand fall into them; others have long time ranges and may be represented by only a few specimens. In several cases, teeth apparently fall outside the accepted time ranges for the species with which they are compared.

The following species are apparently restricted to the Middle Eocene in South Australia: *Carcharias dubius, C. ensiculatus, Lamna obliqua.*

Apparently restricted to Upper Eocene: *Pristis* cf. *cudmorei, Lamna vincenti.*

Found in both Middle and Upper Eocene: *"Notidanus" serratissimus, Carcharias maslinensis, C.* cf. *rutoti.*

* These species were reported by Crespin and Cotton (in Miles, 1952) from the Abattoirs Bore, but the material has not been seen by the author.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Australian Stages
Johannian Aldingan Janjukian Longfordian Batesfordian Balcombian Bairnsdalian Mitchellian Cheltenhamian Kalimnan Yatalan
Carter's Faunal Units
Correlation after Ludbrook (1967) "Correlation of the Tertiary Rocks of the Australasian Region", in "Tertiary Correlations and Climatic Changes in the Pacific", Symposium 25, Sendai, Japan.
GAMBIER EMBAYMENT
MURRAY BASIN
ST. VINCENT BASIN
Gambier Limestone
dune limesands
Notidanus serratissimus
Notidanus spp.
Pristis cf. cudmorei
Myliobatis spp.
Carcharhinus collatus
C. aculeatus
Carcharoides totuserratus
Hemipristis serra
Galeocerdo aduncus
Carcharias macrotus
C. contortidens
C. maslinensis sp.nov.
C. cuspidatus
C. cf. rutoti
C. dubius
C. ensiculatus
Carchariolamna cf. heroni
Lamna obliqua
L. cf. apiculata
L. vincenti
L. cf. crassidens
Isurus hastalis
I. desorii
I. retroflexus
Isurus (?) sp.
Carcharodon megalodon
C. auriculatus
C. carcharias
Carcharodon sp. indet.
x stratigraphic position known
o position uncertain
s ditto - Strathalbyn locality
u identification uncertain

Found only in Oligocene: *Carcharodon auriculatus.*

Apparently restricted to Lower and Middle Miocene: *Carcharhinus collatus, Carcharoides totuserratus, Hemipristis serra, Galeocerdo aduncus, Carchariolamna* cf. *heroni, Lamna* cf. *crassidens, Carcharodon megalodon.*

Apparently restricted to Pliocene (and later): *Carcharodon carcharias.*

Miocene to Pliocene: *Carcharhinus aculeatus.*

The other species occur during both Eocene and Miocene, and some range into the Pliocene. They raise the presently insoluble problem of whether such forms indeed represent single species.

In comparison with the list of species given by Chapman and Cudmore (1924), some notable absentees are seen for South Australia. *Heterodontus,* represented in Victoria by four species, has not been recorded, and there are fewer myliobatids. There are also fewer Carcharhinid sharks represented, and such species as *Galeocerdo latidens* and *Sphyrna prisca* have not been recognized. These omissions are apparently the result of unfavourable sedimentary environments combined with inadequate collecting in the requisite stratigraphic levels.

The time is not yet ripe to establish zones based on sharks' teeth assemblages as Glikman has done, although a large collection from any one locality would indicate the appropriate Cainozoic epoch. Although many sharks are pelagic, it is doubtful whether their teeth could be accurately used for wider than regional correlation.

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EXPLANATION OF PLATES

(All figures of inner faces except where stated)

PLATE 1

Infra Class Orthodonta (all 2 x natural size).

Fig. 1. "*Notidanus*" *serratissimus* Ag., Blanche Point Marl (F17262).
Fig. 2. "*N.*" cf. *serratissimus* Ag., Naracoorte No. 5 Bore, 426 ft. (V34).
Fig. 3. "*Notidanus*"? *serratissimus* Ag., Blanche Point Marl (F17284 and Jenkins collection).
Fig. 4. *Myliobatis* spp., toothplates, articulating surfaces, Naracoorte No. 5 Bore (V44).
Fig. 5. *Myliobatis* sp., caudal spine, Blanche Point Marl (V56).
Fig. 6. *Pristis* cf. *cudmorei* Chap., rostral teeth, Blanche Point Marl (F17285, F17318).
Fig. 7. *Carcharhinus* cf. *collatus* (Eastman), Marion No. 2 Bore, Sturt River Valley (F17279, F17312-F17314).
Fig. 8. *C. aculeatus* (Davis), River Murray Cliffs, probably Morgan (F17270).
Fig. 9. *Hemipristis serra* Ag., Cadell Marl Lens, 4 miles S. of Morgan (F17288).
Fig. 10. a. *Galeocerdo aduncus* Ag., Morgan (F17275). b. *Galeocerdo* sp., locality unknown, possibly near Morgan (F17271).
Fig. 11. *Carcharoides* cf. *totuserratus* Ameghino, Strathalbyn (F17281).

Plate 2

Carcharias maslinensis sp. nov. (all 2 x natural size)

Figs. 1-4. E. & W.S. bore No. 5, Naracoorte (426 ft.), Knight formation.
Fig. 1. Holotype, inner face (F17260).
Fig. 2. Holotype, posterior profile.
Fig. 3. Paratypes--anteriors (V35).
Fig. 4. Paratypes (V18): a. upper laterals; b. lower laterals.
Fig. 5. Maslin Bay, basal Tortachilla Limestone—crown enamels only: a. upper laterals (F17295-F17300); b. lower laterals (F17301-F17307); c. anteriors (F17289-F17294).
Figs. 6, 7. Anterior teeth, Blanche Point Marl (Carter's Unit 2), Maslin Bay (Brooke and Jenkins collections).
Fig. 8. Anterior tooth, lower Port Willunga Beds (Carter's Unit 3), Aldinga Bay (F17267).

Plate 3

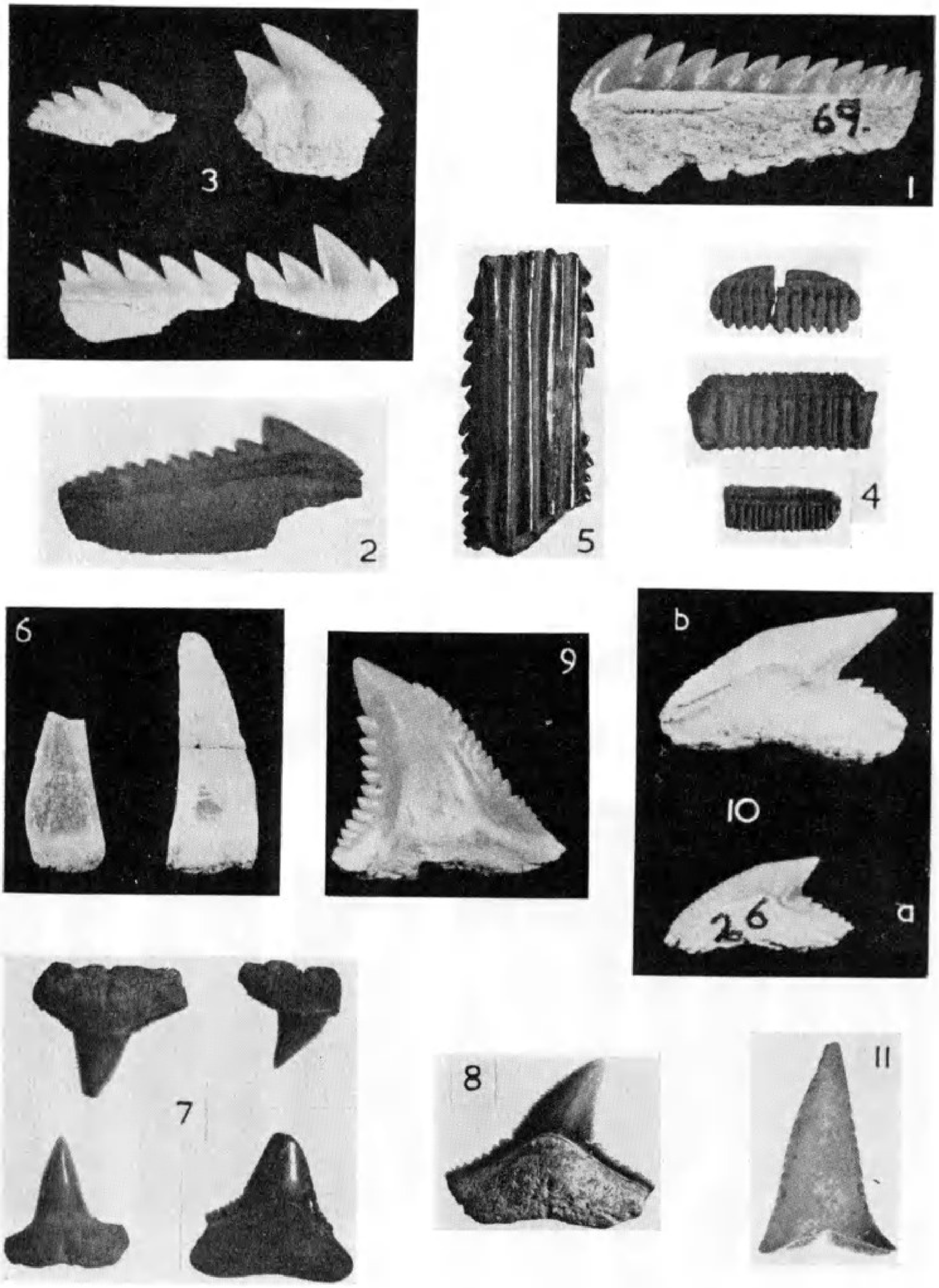
(Natural size except where stated)

Figs. 1, 2, 3. *Carcharias macrotus* (Ag.), large specimens, upper and lower anteriors, Blanche Point Marl, Maslin Bay (F17308-F17311, and Jenkins collection).
Figs. 4, 5, 6. *C. macrotus* (Ag.), Peel's Bore (390 ft.) near Robe; Knight Formation (V16, 19).
Fig. 7. *C.* cf. *macrotus* (Ag.), Naracoorte Bore No. 5 (426 ft.) (V49).
Fig. 8. *C.* cf. *macrotus* (Ag.), Peel's Bore (390 ft.) (V53).
Fig. 9. *Carcharias* sp. indet., Naracoorte Bore No. 5 (V32).
Fig. 10. *C. dubius* (Ag.), Peel's Bore, near Robe (V27).
Fig. 11. *C. contortidens* (Ag.), Peel's Bore (V14).
Fig. 12. *C.* cf. *cuspidatus* (Ag.), (?) Blanche Point Marl (F17264).
Fig. 13. *C.* cf. *cuspidatus* (Ag.), Blanche Point Marl, Maslin Bay (Jenkins collection).
Fig. 14. *C.* cf. *rutoti* (Winkler), Blanche Point Marl, Maslin Bay (F17263 and F17265).
Fig. 15. *C. ensiculatus* (Davis), Naracoorte Bore No. 5, x 2 (V36): a. inner face; b. outer face.
Fig. 16. *Carchariolamna* cf. *heroni* Hora, Marion No. 2 Bore, Sturt River Valley, x 2 (F17280).

Plate 4

Family Isuridae (all natural size).

Fig. 1. *Lamna obliqua* (Ag.), "Deep Well, Murray Scrub", probably from Eocene Knight Formation equivalents (F17269).
Fig. 2. *L. apiculata* (Ag.), Blanche Point Marl, Maslin Bay and Witton Bluff, Pt. Noarlunga F17261, F17266, and Jenkins collection).
Fig. 3. *L. vincenti* (Winkler), Blanche Point Marl, Maslin Bay (F17286 and Jenkins collection).
Fig. 4. *L.* cf. *crassidens* Ag., Murray Cliffs, probably near Morgan (F17272).
Fig. 5. *Isurus hastalis* (Ag.), Murray Cliffs, probably Cadell Marl Lens near Morgan (F17273).
Fig. 6. *I.* cf. *hastalis* (Ag.), basal Port Willunga Beds, Aldinga Bay (F17268).
Fig. 7. *I. desorii* (Ag.), Strathalbyn, crown enamels only (F17282, F17315).
Fig. 8. *I. retroflexus* (Ag.), upper right lateral tooth, Port Willunga Beds, Reddin's Bore, Gawler River (270 ft.). (Photo by courtesy of J. M. Reddin.)
Fig. 9. *I. retroflexus* (Ag.), anterior teeth, Murray Cliffs, ?near Morgan (F17274): a. inner face; b. profile.
Fig. 10. *Isurus* (?) sp., basal Tortachilla Limestone, Maslin Bay (F17283, F17316, F17317).
Fig. 11. *Carcharodon auriculatus* Ag., Port Willunga Beds, Aldinga Bay (F17276).
Fig. 12. *C. megalodon* Charlesworth, Barbers Quarry, Mt. Gambier (F17277).
Fig. 13. *C. carcharias* (Linn.), Dry Creek Sands, Abattoirs Bore, Pooraka (F17278).
Fig. 14. *Carcharodon* sp. indet., outer face, Blanche Point Marl, Witton Bluff, Port Noarlunga (Jenkins collection).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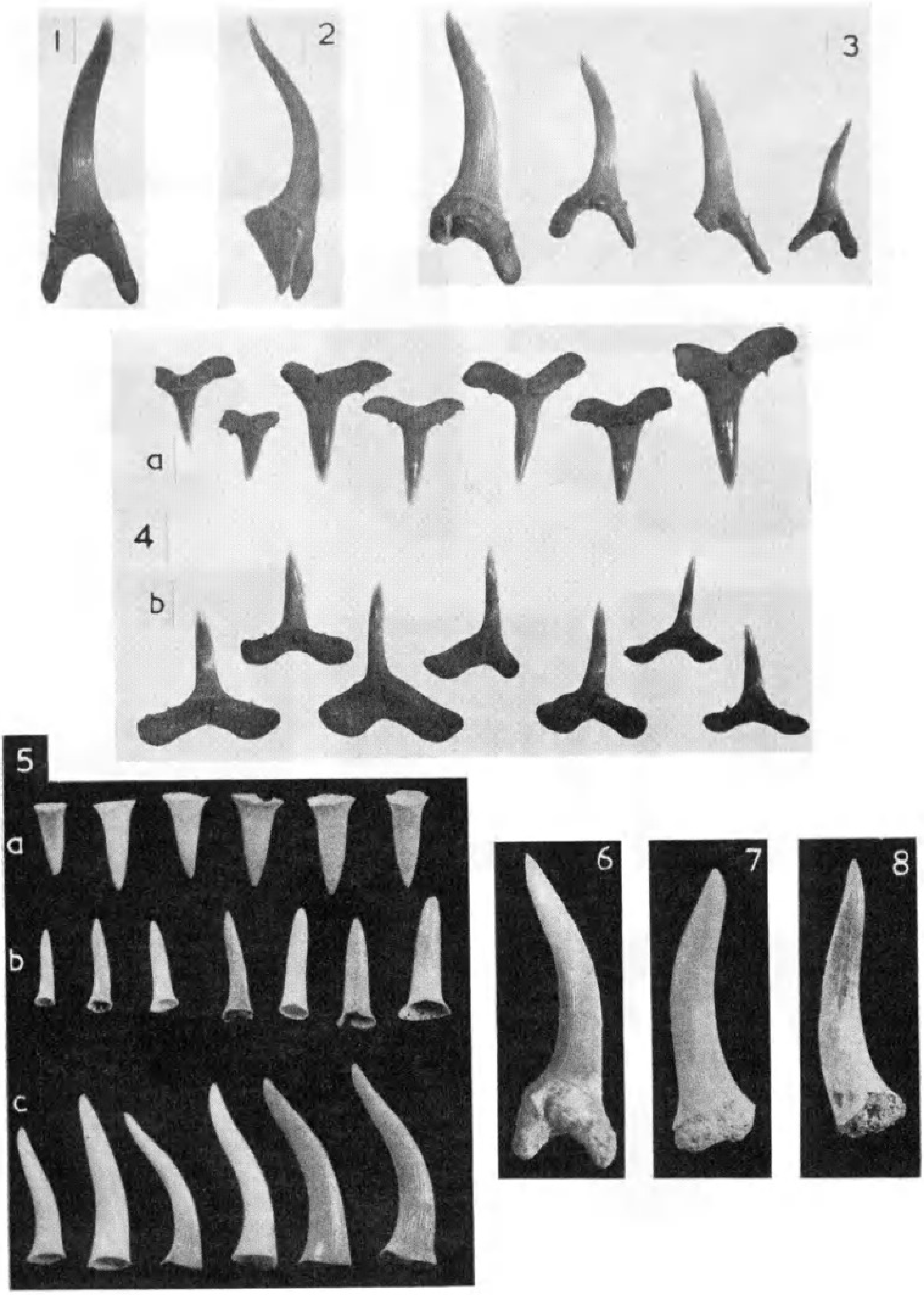
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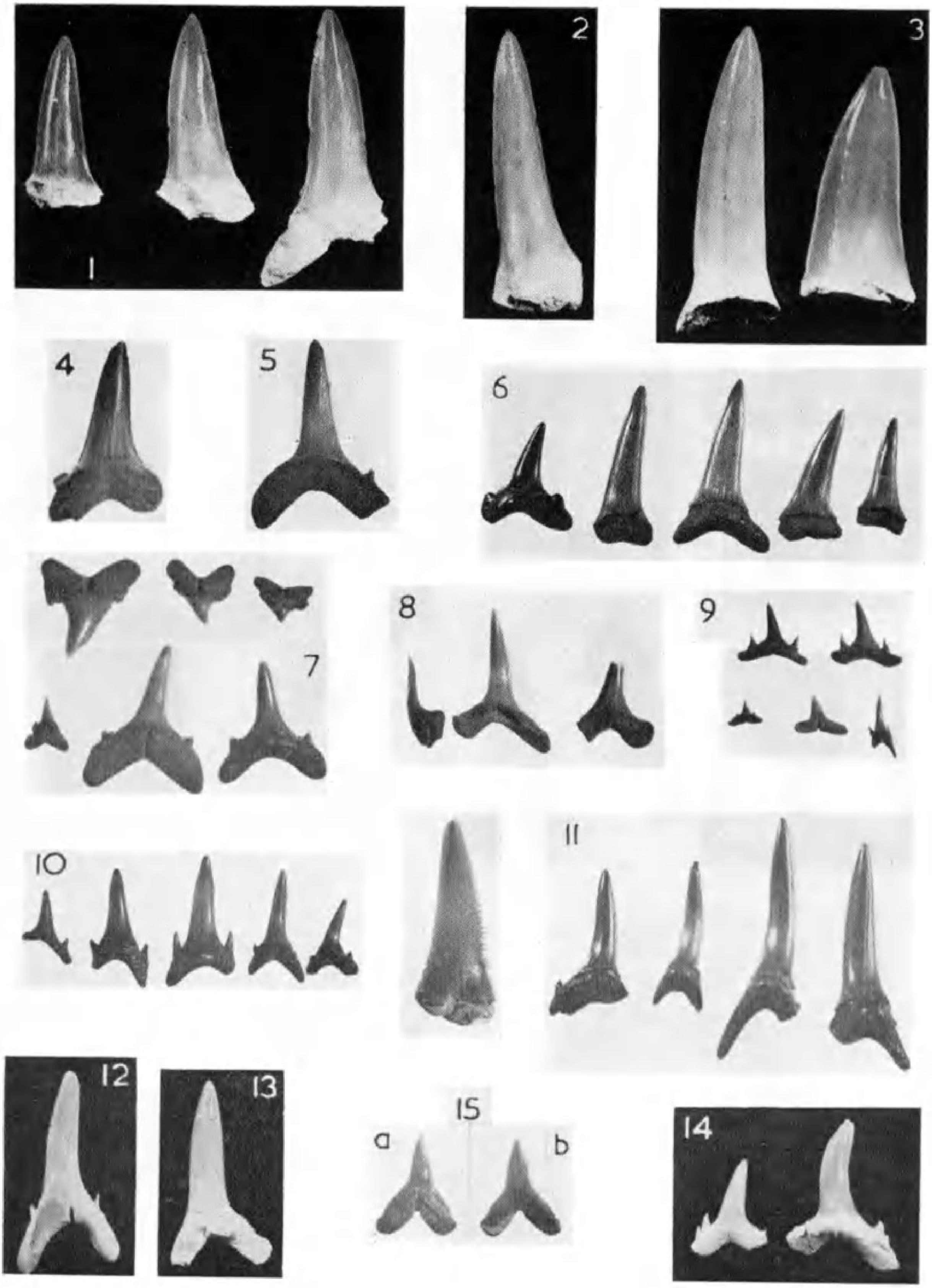
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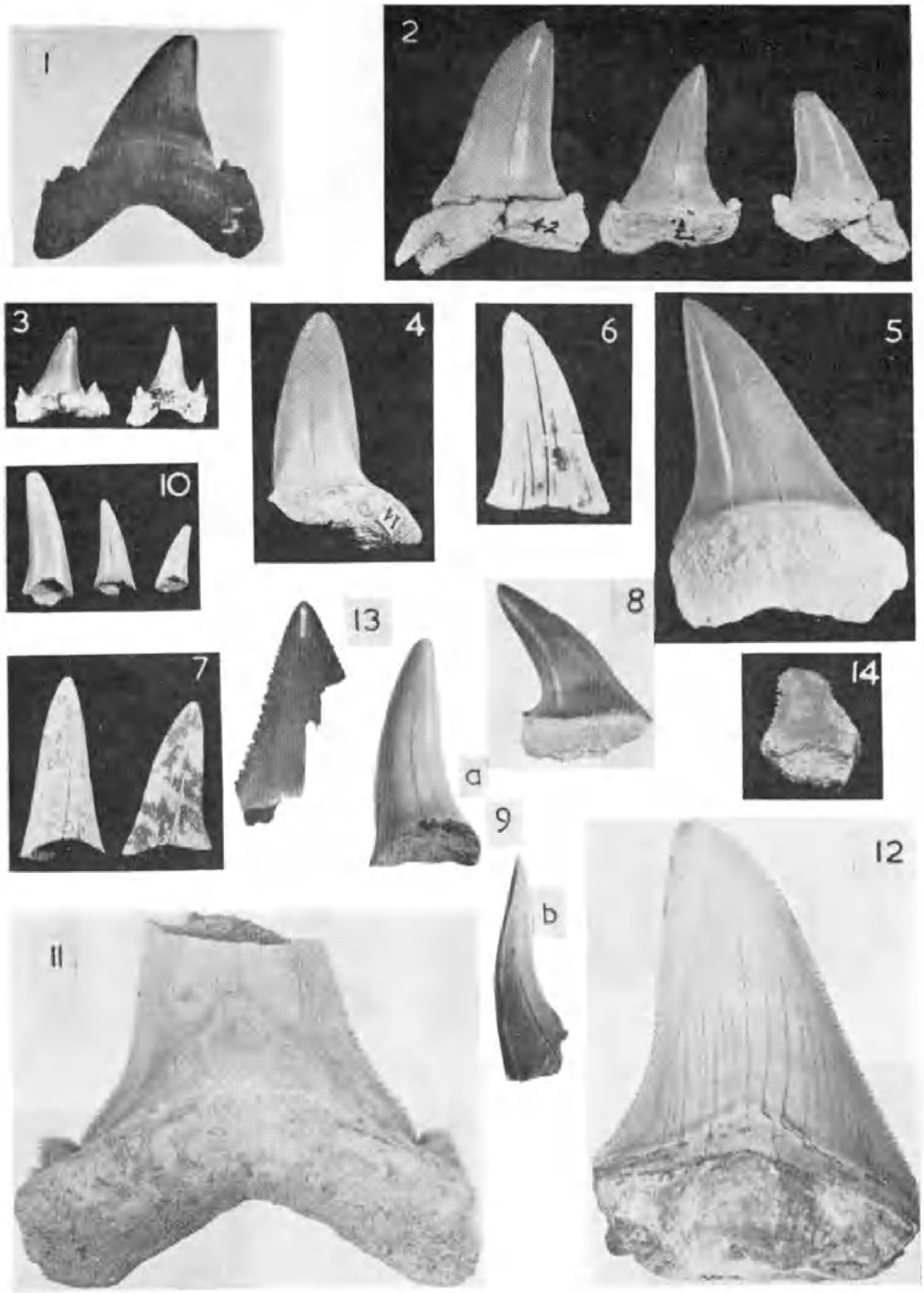
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