# ABNORMAL HISTOLOGY IN AN *IGUANODON* CAUDAL CENTRUM FROM THE LOWER CRETACEOUS OF THE ISLE OF WIGHT

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ABSTRACT. The abnormal histology of a ?pathological *Iguanodon* (Dinosauria; Ornithischia) caudal vertebral centrum is described and comparisons made with normal iguanodontid histology. The abnormal bone exhibits rapidly generated radial growth patterns; in the cancellous zone, areas of primary bone predominate and there is a distinctive contorted vascularity throughout. The similarities of the observed deformations to known mammalian pathologies such as local trauma, Paget's disease, haemangioma and vitamin deficiency are discussed. Further systematic surveys to ascertain details of dinosaur bone histology and variation are required.

IN thin section, dinosaur bones exhibit a range of osteological and histological detail which can be identified readily (Text-fig. 1). The outer edge of *Iguanodon* bones (the cortical zone or cortex) is nearly always vascular, often primary, parallel-fibred bone; the successive layers having built up on the periosteal (outer) surface as the bone grew. However, in some iguanodontid bones, the cortex is composed of primary, parallel-fibred bone which has formed osteons with woven bone in between. Where present, resting lines are visible in the cortex but disappear in the endosteal zone just below the cortex where the bone has been remodelled. In the endosteal zone, the primary bone has been absorbed by osteoblasts, creating resorption spaces. The osteoblasts then reversed their process and deposited secondary bone, starting on the rim of the resorption space and filling it with concentric layers of secondary (endosteal) bone forming distinctive Haversian rings. The collagen fibres are arranged concentrically in these rings and a characteristic extinction cross is observed under crossed polarized light. Osteocyte lacunae (the sites of dead osteoblasts) appear as short black lines, or dots, in thin section. This remodelling continued until the resorption spaces were left empty and the central, sponge-like cancellous zone was formed. In the secondary bone of the cancellous zone, collagen fibres run longitudinally along the remaining strands of bone (trabeculae). At high magnification, these mineralized collagen fibres are clearly visible.

Much of the study of fossil bone thin sections to date has been concerned with the ectothermy/endothermy debate (e.g. Ricqlès 1974*c*, 1976; Reid 1984*b*), but also random sections have been cut to compare with modern mammals and reptiles and to describe the detailed histology of dinosaurian bones (Enlow and Brown 1956, 1957, 1958; Enlow 1969; Ricqlès 1969, 1972, 1974*a*, 1974*b*; Reid 1984*a*). Exactly where each type of histology occurs within each bone, the variation between individual bones and variation between species has yet to be ascertained.

The specimens described herein were found on the beaches of the Isle of Wight, having been weathered out of the Wealden Group (Lower Cretaceous) at several locations. There was no indication that there was anything unusual about the *Iguanodon* centrum when it was collected as a 'rolled bone'; its external appearance was consistent with many others found under similar conditions. It was only when sectioned and examined petrographically that unusual features were evident.

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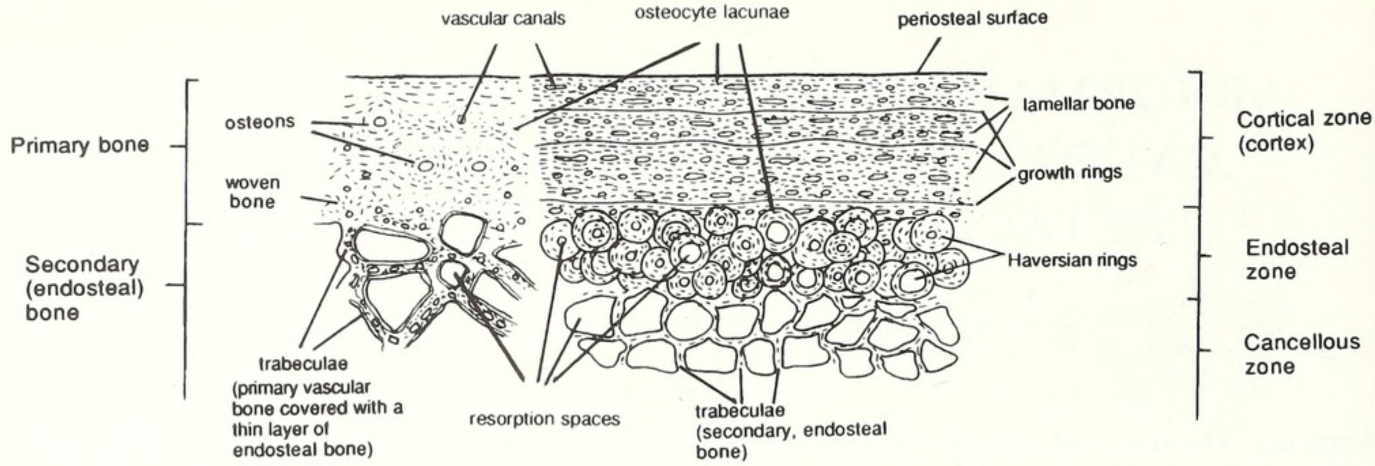
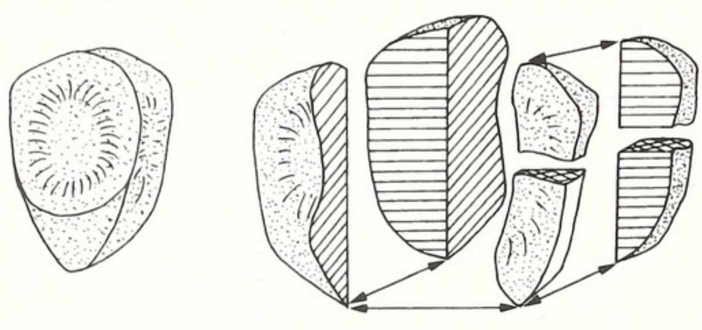



TEXT-FIG. 1. Sketch explaining general histological terminology of a transverse section through a normal fossil vertebrate bone. Not to scale.

## MATERIALS AND METHODS

The material studied comprises four *Iguanodon* (Dinosauria; Ornithischia) vertebral centra. The vertebrae are derived from separate animals but all originate from the seven caudal vertebrae nearest the sacrum (S. Hutt, pers. comm.). In three of the centra (MIWG 5454, MIWG 5385 and IWGMS: 1994: 14) the histology is apparently normal whilst the other (MIWG 7320) is different (abnormal). All the specimens are housed in the Museum of Isle of Wight Geology, Sandown Library, High Street, Sandown, Isle of Wight, PO36 8AF, (MIWG: old accession prefix to 1994 and IWGMS: new accession prefix from 1994 onwards).

Thin sections were prepared longitudinally, transversely and horizontally as shown in Text-figure 2. Detailed tracings of the overall bone patterns were compiled from projected thin sections and composite figures constructed (Text-figs 3–4).



TEXT-FIG. 2. Explosion diagram to show the orientation of the sections cut from the caudal centra. Not to scale.

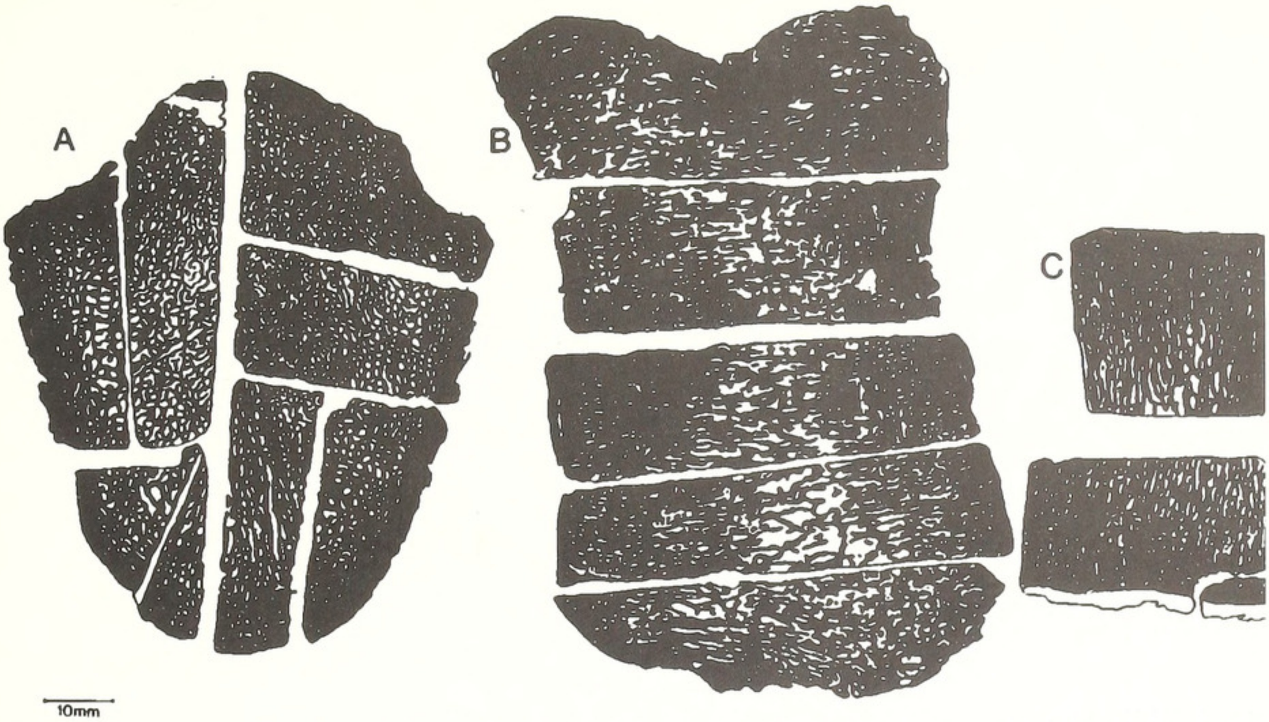
Examination of specimens MIWG 5454, MIWG 5385 and IWGMS: 1994: 14 shows closely similar overall bone patterns and histological detail. Therefore, for descriptive purposes, one centrum, IWGMS: 1994: 14, is used as an example of the normal structure, compared with the abnormal specimen (MIWG 7320).

## DESCRIPTION

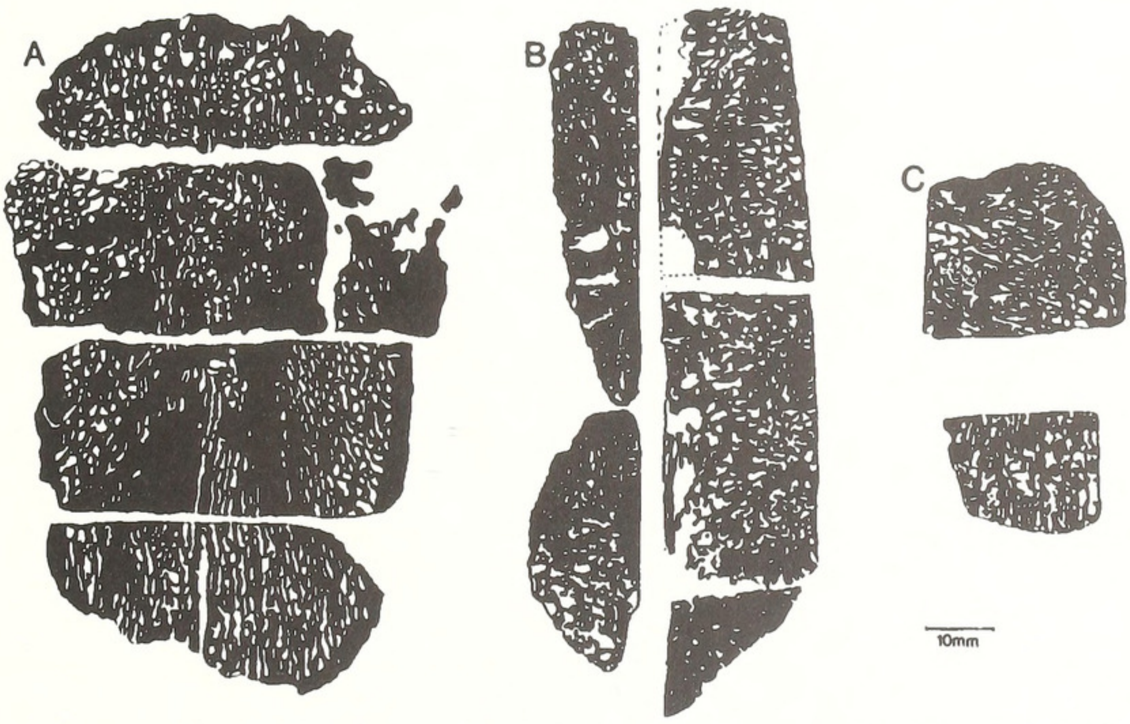
### *Transverse sections*

*Overall bone pattern*. Sections from the normal centra show the central cancellous zone to be composed of a regular arrangement of trabeculae surrounding voids roughly equal in size (Text-fig. 3A). Some voids in the ventral half of the centrum are elongated radially and one or two radially orientated nutrient canals are also present. As the cortex is approached, the voids become smaller.

The section from the abnormal centrum is very different. Although some post-mortem crushing has occurred, much of the internal structure is still intact and clearly visible (Text-fig. 4A). In the



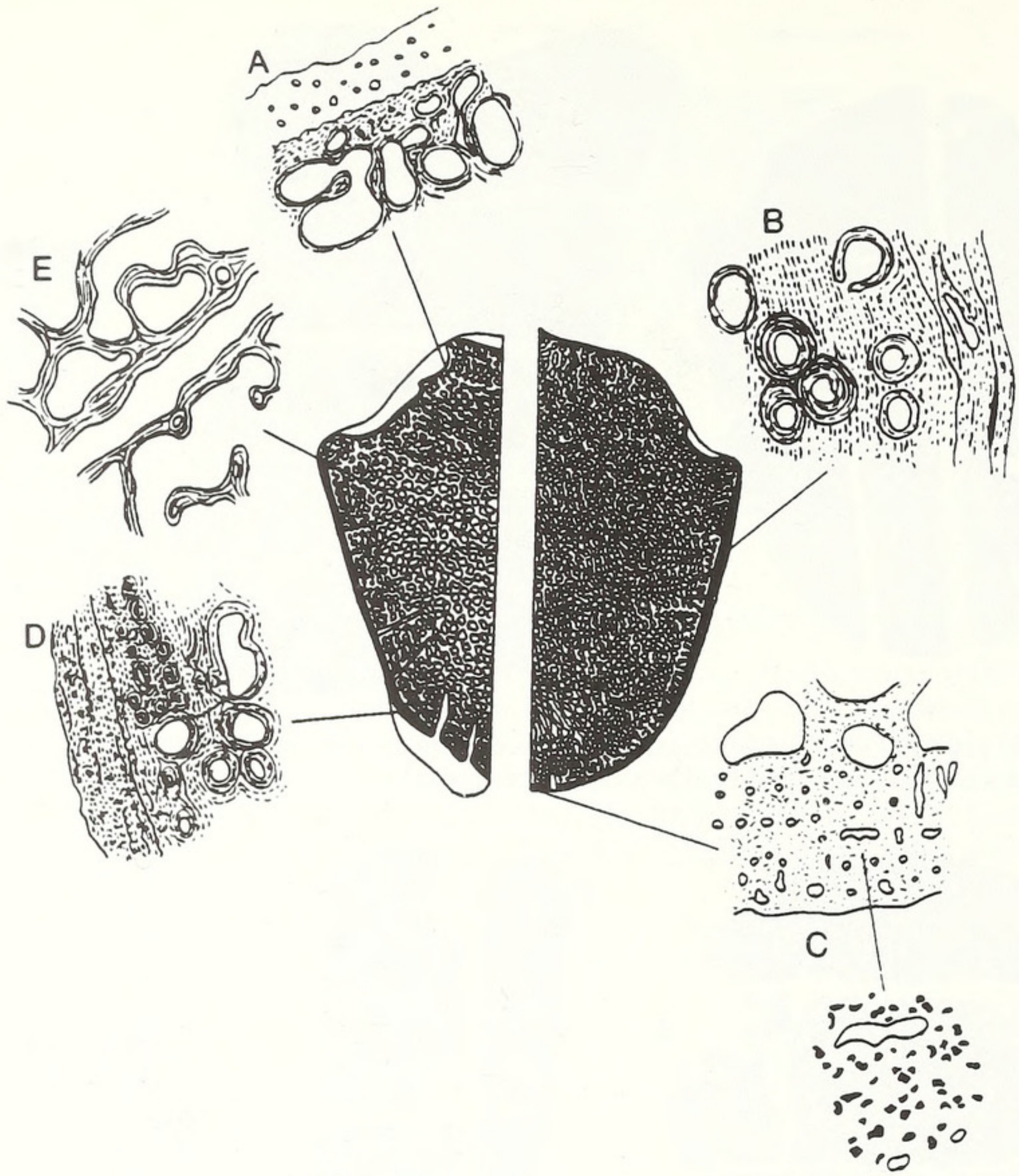

TEXT-FIG. 3. Bone patterns displayed by a normal *Iguanodon* caudal vertebral centrum (IWGMS: 1994: 14). A, transverse section; B, longitudinal section; C, horizontal section. Scale bar represents 10 mm.




TEXT-FIG. 4. Bone patterns displayed by an abnormal *Iguanodon* caudal vertebral centrum (MIWG 7320). A, transverse section; B, longitudinal section; C, horizontal section. Scale bar represents 10 mm.

dorsal half of the centrum, the voids show a similar pattern to the other three centra, although without the same degree of regularity, but in the ventral half, all the voids are radially disposed and are markedly elongated. Six radial nutrient canals are also visible in the specimen.

*Histology*. At the dorsal end of the normal centra, the cortex is composed of fine cancellous bone abutting calcified cartilage (Text-fig. 5A). The trabeculae have a core of primary woven bone

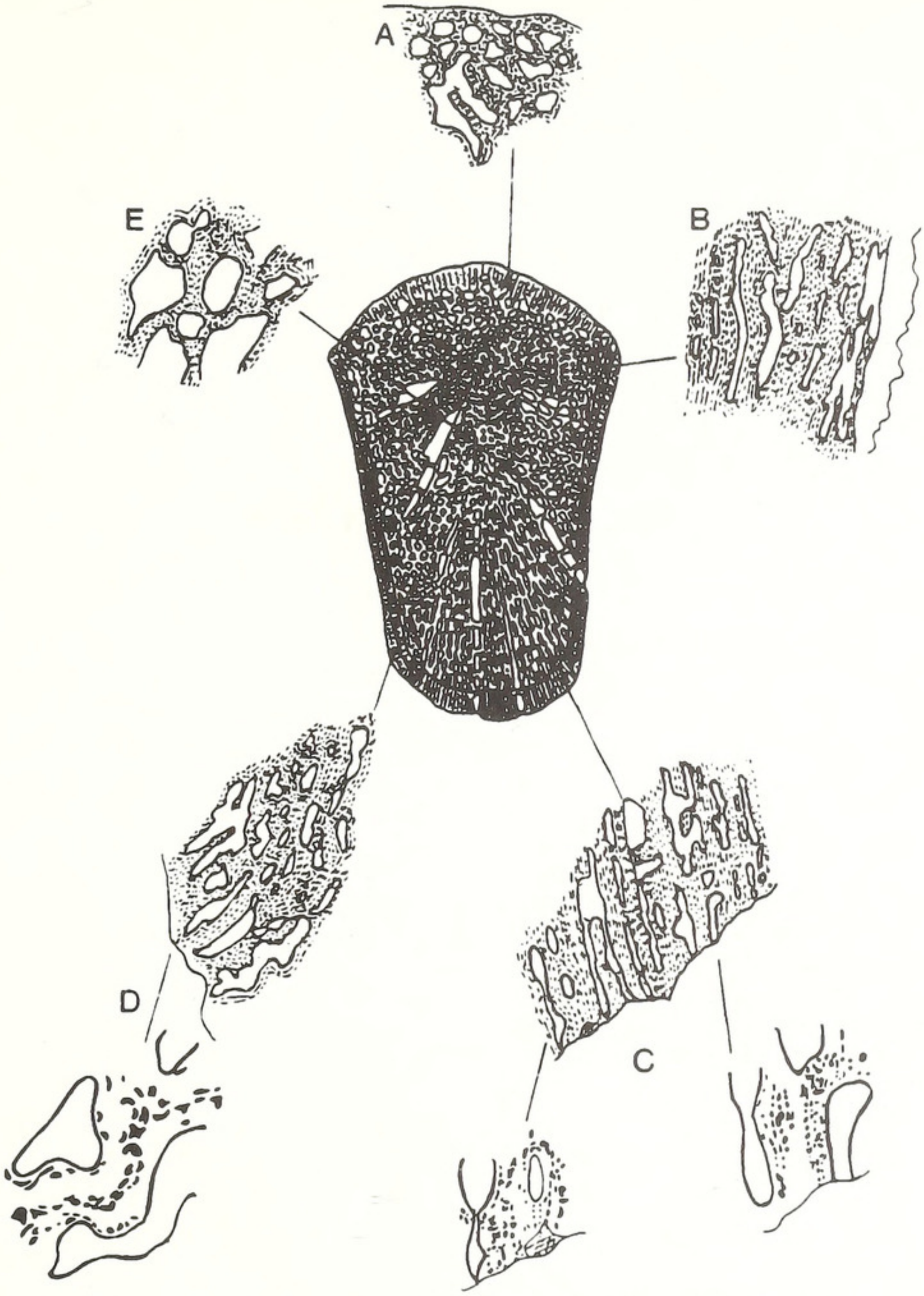



TEXT-FIG. 5. Sketch of a transverse section of a normal *Iguanodon* caudal centrum (IWGMS: 1994: 14), showing histological detail. See text for discussion. Not to scale.

covered by a layer of secondary lamellar bone. A similar area in the abnormal specimen shows the cortex to be composed of fine cancellous bone, composed entirely of primary woven bone with very little secondary lamellar bone (Pl. 1, fig. 1; Text-fig. 6A). The outer edge of the cortex is missing, but the histology of the bone shows none of the regularity displayed by the other three specimens.

Most of the remaining cortex from the normal vertebrae is composed of parallel-fibred vascular primary bone with primary osteons and resting lines (Pl. 1, fig. 2; Text-fig. 5B, D) and one specimen (IWGMS: 1994: 14) also exhibits areas of plexiform bone (*sensu* Ricqlès 1974*c*). Secondary Haversian rings replace primary bone in the endosteal zone, eventually passing into the cancellous zone where the trabeculae are composed of secondary, lamellar bone with occasional cores of primary bone. The voids which contained blood vessels are arranged in concentric layers. However, the cortex at the extreme ventral end has no resting lines and is entirely primary woven bone (Text-fig. 5C), the resorption spaces grading from small to large on passing into the cancellous zone.

The cortex in the mid region of the abnormal specimen is very vascular (Pl. 1, fig. 3; Text-fig. 6B) and has no resting lines. There is no transition (endosteal) zone; the large resorption spaces of the cancellous zone invade the cortex. The trabeculae are composed of primary cortical bone which still contains primary vascular canals; very little, if any, secondary lamellar bone coats the trabeculae.




TEXT-FIG. 6. Sketch of a transverse section of an abnormal *Iguanodon* caudal centrum (MIWG 7320), showing histological detail. See text for discussion. Not to scale.

At the ventral end, the cortex is composed of woven and parallel-fibred bone and is very vascular with radially orientated blood vessels (Pl. 1, fig. 4; Text-fig. 6C–D). Again, there is no transition zone between the cortex and cancellous zone, the large resorption spaces invading the cortex. The periosteal surface is missing but there is no indication of circumferentially arranged vascular canals. This radially orientated cortical pattern covers the whole of the hemispherical ventral end of the centrum.

The trabeculae in the cancellous zones of the normal vertebrae are composed predominantly of secondary lamellar bone, sometimes bearing a thin core of primary woven bone (Text-fig. 5E). Some post-mortem crushing has occurred in the cancellous zone of the abnormal specimen, but in a central, uncrushed area, the trabeculae are composed mainly of primary vascular woven bone surrounded by a thin layer of secondary lamellar bone (Pl. 1, fig. 5; Text-fig. 6E). In other areas trabeculae are composed entirely of secondary bone.

*Longitudinal sections*

*Overall pattern.* In longitudinal section, the normal bones have similar overall bone trabeculae patterns (Text-fig. 3B). The voids in the central part of the cancellous zone are markedly elongate in an anterior-posterior direction. Flanking these larger voids, the trabeculae are arranged in a grid-like pattern (Pl. 1, fig. 6; Text-fig. 7A), particularly in the waist of the centrum where the voids become almost square. In contrast, longitudinal sections of the abnormal specimen show no such pattern (Text-fig. 4B), the voids being irregular without order. Some post-mortem crushing has occurred in the central area, but enough non-brecciated bone remains for any regular structure to have been visible, if it were present.

*Histology.* Within the normal specimens, the trabeculae in the cancellous zone are composed of thin cores of primary woven bone surrounded by layers of secondary lamellar bone (Pl. 1, fig. 6; Text-fig. 7A). In contrast, the trabeculae in the cancellous zone of the abnormal specimen have thick centres of primary woven bone, often containing the cortical vascular canals, surrounded by thin layers of secondary lamellar bone (Text-fig. 8A). Furthermore, in the centre there are thick trabeculae composed of primary parallel-fibred and woven bone (Pl. 1, fig. 7; Text-fig. 8B).

In this longitudinal orientation, all the cortices of the normal specimens are composed of fine cancellous bone which abuts and includes calcified cartilage (Text-fig. 7C–D). In contrast, the cortex at the ventral end of the centrum of the abnormal specimen is radially orientated vascular woven bone (Text-fig. 8C), similar to that observed in the transverse section. The cortical bone in the waist of the centrum is composed of partially compacted cancellous bone (Pl. 1, fig. 8; Text-fig. 8D) which becomes compacted cancellous bone towards the dorsal end (Pl. 1, fig. 9; Text-fig. 8E).

*Horizontal sections*

The overall patterns of the trabeculae in horizontal sections of the normal specimens are consistent with those in the transverse and longitudinal sections (Text-fig. 3C) whilst the corresponding sections from the abnormal specimen show continued irregularity (Text-fig. 4C). The histology of all four specimens is exactly comparable with that shown in the transverse and longitudinal sections.

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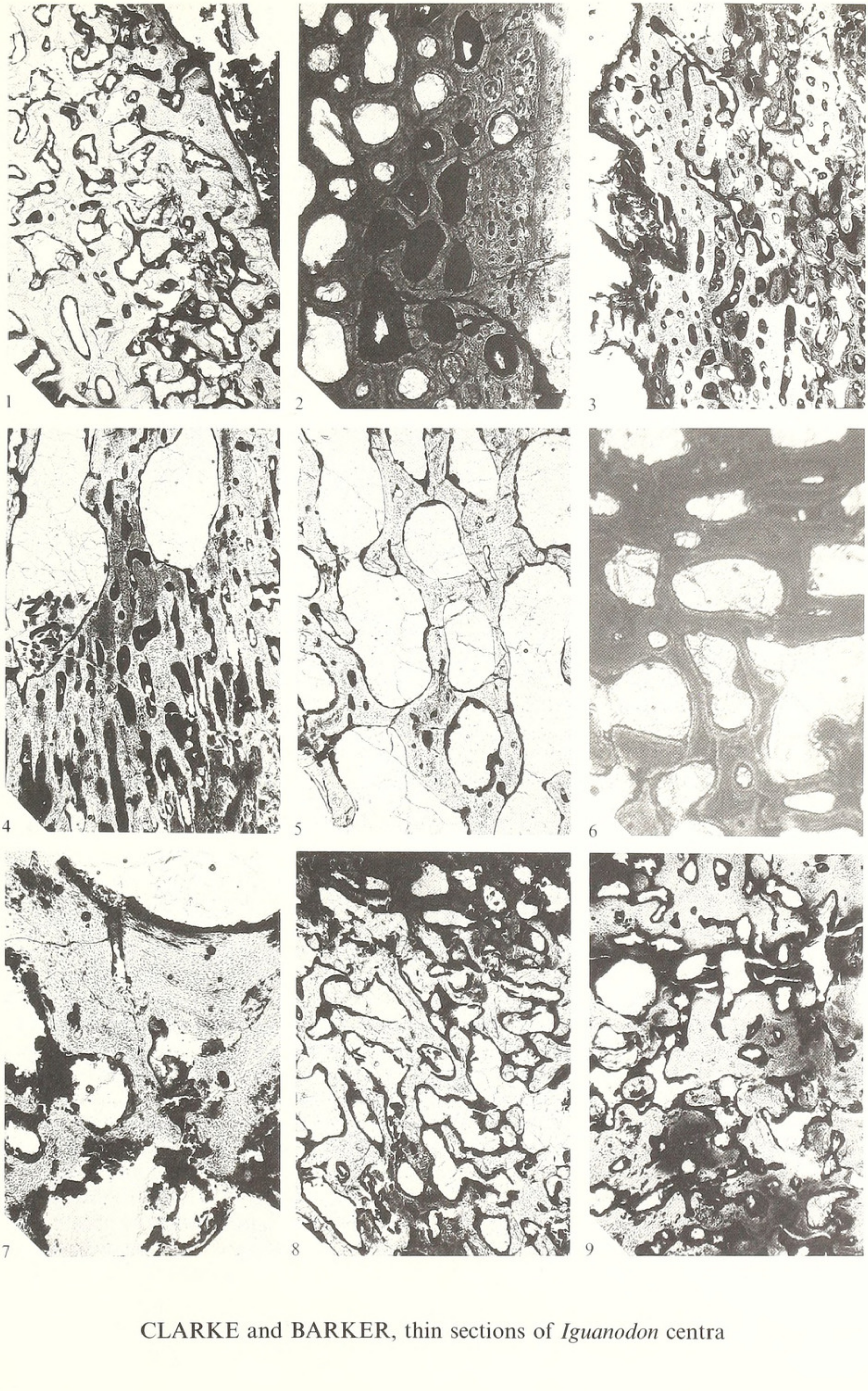
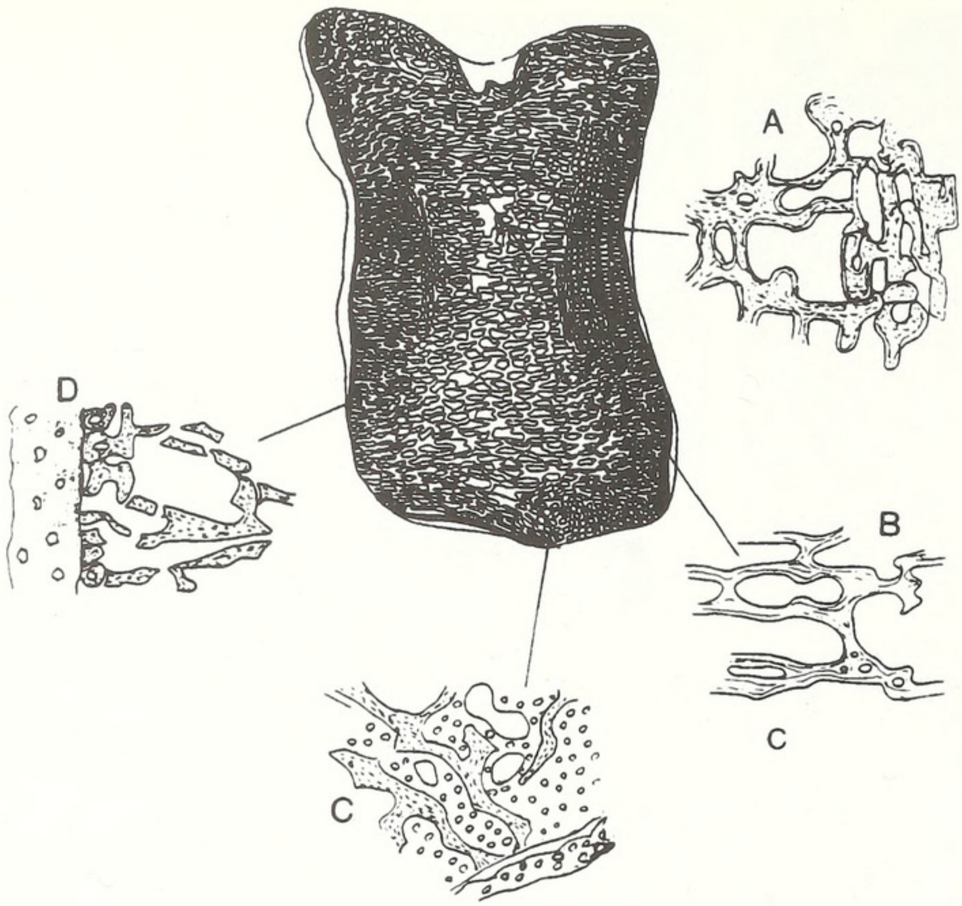
EXPLANATION OF PLATE 1

Figs 1–9. Thin sections of *Iguanodon* centra. 1, MIWG 7320; near the cortex at the dorsal end of the abnormal centrum; the trabeculae are composed of primary woven bone with little, if any, secondary lamellar bone; periosteal surface at upper right at 30° to the vertical. 2, IWGMS: 1994: 14; cortex from the side of the normal centrum composed of parallel-fibred vascular primary bone with primary osteons and resting lines; note the graduation of small to large resorption spaces away from the cortex; periosteal surface to the right. 3, MIWG 7320; cortex from the side of the abnormal centrum composed of very vascular primary woven bone; note the large resorption spaces invading the cortex; periosteal surface to the right. 4, MIWG 7320; cortex at the ventral end of the abnormal centrum composed of primary woven and parallel-fibred bone; note the high density of vascular canals orientated in a radial pattern and the large resorption spaces invading the cortex; periosteal surface at the bottom. 5, MIWG 7320; trabeculae in the cancellous zone of the abnormal centrum composed of primary vascular woven bone surrounded by a thin coating of secondary lamellar bone. 6. IWGMS: 1994: 14; grid-like pattern formed in the waist of the normal centrum; the trabeculae are composed of a thin core of primary bone surrounded by layers of secondary lamellar bone; dorsal end to the left. 7, MIWG 7320; trabeculae in the centre of the abnormal centrum composed of thick sections of primary woven and parallel-fibred bone. 8, MIWG 7320; cortical bone in the waist of the abnormal centrum composed of partially compacted cancellous bone; periosteal surface at the top. 9, MIWG 7320; cortical bone from the dorsal end of the central dished area of the abnormal centrum composed of compacted cancellous bone; periosteal surface at the top. All ×13, except fig. 6, ×20.




CLARKE and BARKER, thin sections of *Iguanodon* centra



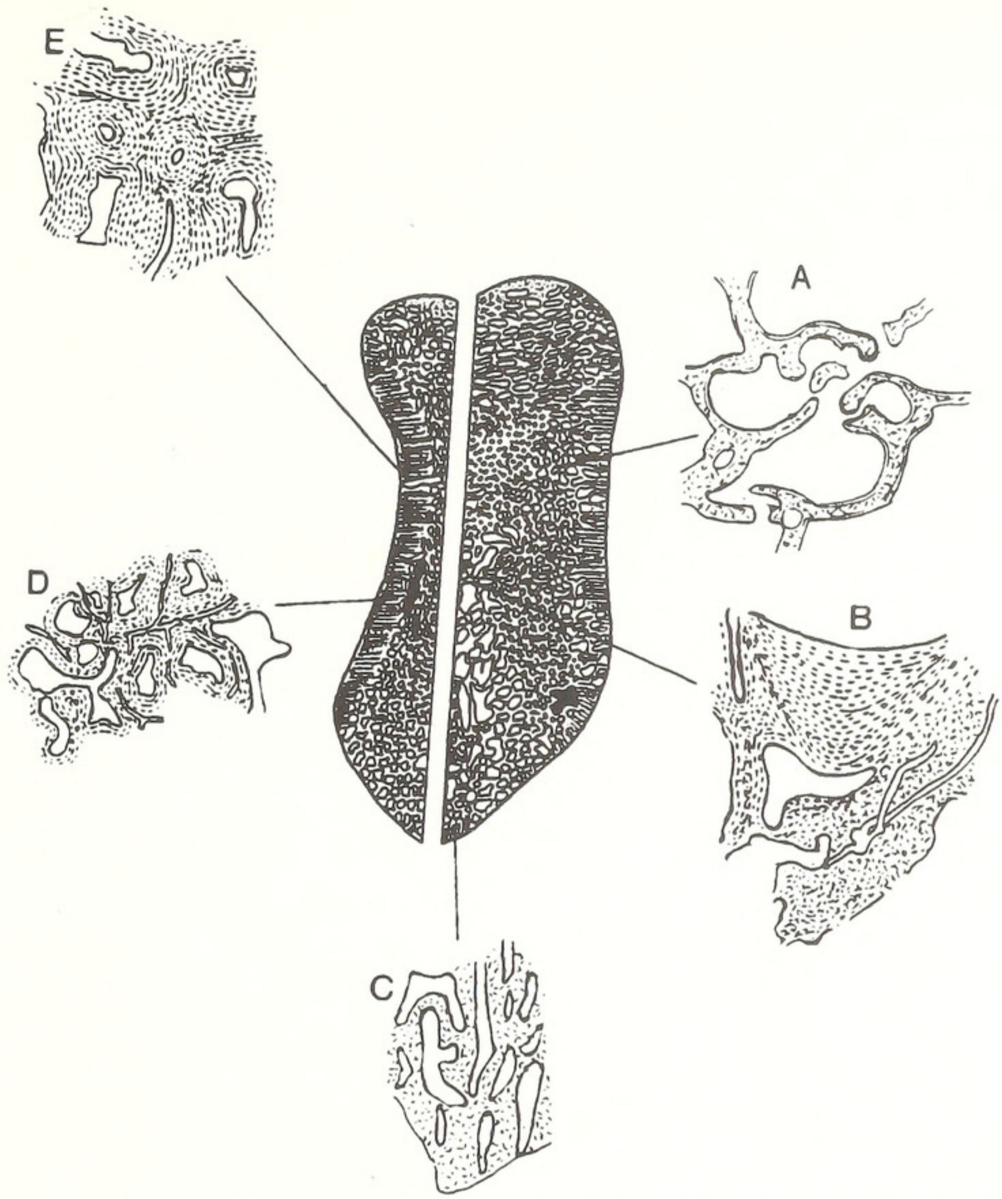

TEXT-FIG. 7. Sketch of a longitudinal section of a normal *Iguanodon* caudal centrum (IWGMS: 1994: 14), showing histological detail. See text for discussion. Not to scale.

## DISCUSSION

*General.* A sketch of the general histological detail (and its associated terminology) normally observed in thin sections of dinosaur bones is given in Text-figure 1. In the authors' experience, the abnormal bone (MIWG 7320) shows unusual histological detail. Cortical bone at the sides of normal centra is usually parallel-fibred, sometimes with resting lines, with a reasonable density of concentrically arranged vascular canals; while the cortex at the ventral end is sometimes primary woven bone, containing primary osteons. The vascularity of the cortex in MIWG 7320 is unusually high and, together with the presence of woven bone, suggests a high growth rate (Enlow 1969). The radial cortical pattern in the ventral end of the centrum is also highly unusual and again the presence of woven bone, together with the direction of linearity, further suggest abnormally high growth rates (D. Cooper, pers. comm.).

Inside the cortex of iguanodontid vertebral centra, secondary Haversian rings are rare and there is usually a transition zone where primary bone is resorbed and secondary bone deposited. This gradual change is characterized by small resorption holes which become progressively bigger towards the centre of the centrum. In MIWG 7320, large resorption spaces directly invade the cortex; there is no transition zone where small resorption holes occur.

In the normal iguanodontid centra, the trabeculae in the cancellous zone usually contain a high percentage of secondary, endosteal bone, remodelling having continued until only a thin core (if any) of primary bone remains. Sometimes primary vascular canals are retained in the outer areas of the cancellous zone, but in the centre of the centrum most have been removed by remodelling. in MIWG 7320, the trabeculae throughout most of the cancellous zone are unaltered primary vascular bone surrounded by a thin coating of endosteal bone; there are only small areas in which




TEXT-FIG. 8. Sketch of a longitudinal section of an abnormal *Iguanodon* caudal centrum (MIWG 7320), showing histological detail. See text for discussion. Not to scale.

the trabeculae are composed of secondary endosteal bone. The thick patches of primary bone in the centre of MIWG 7320 are highly unusual; trabeculae in this region are usually thin.

*Aetiology of pathological bone*. It is unfortunate that only a single skeletal element was available for study. However, the comparative histologies described above indicate clearly that bone growth and modification in the MIWG 7320 centrum was unusual.

All features in MIWG 7320 suggest that bone deposition and resorption were abnormally rapid whilst remodelling and deposition of secondary bone was very slow or absent. Most previous pathological studies have been centred on mammals (principally human) so any comparisons must be qualified, however, possible aetiologies are:

(a) Localized trauma during early ontogeny could have caused low grade osteoperiostitis or traumatic arthropathy.

(b) Disease – the bone histology is reminiscent of osteoporosis in mammals, described as 'decreased bone formation, increased bone resorption or a combination of both' (Cappell 1964). However, the high rate of growth of primary bone is more akin to Paget's disease (Osteitis deformans), which is also known to attack only single bone elements. Histological illustrations of

Paget's disease show a remarkable resemblance to the dorsal end of the abnormal specimen (Cappell 1964, pl. 10, fig. 17.28). Another possible cause could be vitamin-related if the condition was pervasive throughout the organism.

(c) Genetic causes – there is, as yet, no means of relating genetic abnormalities to bone histology in dinosaurs. We have observed no evidence to suggest any genetic cause for this condition, although some form of endocrine abnormality remains a possibility again if pervasive throughout the organism.

(d) Haemangioma – the bone was X-rayed and interpreted by a consultant histopathologist and cytopathologist. There is evidence of high turnover of tissue but the overall sectional area percentage of bone does not exceed normal limits and suggests that this is not a true haemangioma (L. Harvey, pers. comm.). Furthermore, although the patterns in the trabeculae bear a similarity to radial sun-burst histologies in some haemangiomas, the radiographs did not reveal the diagnostic striations present in true haemangiomas (Rothschild and Martin 1993).

The specimen described above, shows enough variation from the normal to be considered abnormal, even pathological; the growth structures indicating that something was stimulating the growing mechanisms to an abnormal degree.

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