

ROOT RESORPTION ASSOCIATED
WITH SLOW AND RAPID MAXILLARY EXPANSION

A SCANNING ELECTRON MICROSCOPE STUDY

IAN ALEXANDER McNEILL B.D.S. (Syd.)

A REPORT SUBMITTED IN PARTIAL
FULFILMENT OF THE DEGREE OF
MASTER OF DENTAL SCIENCE

DEPARTMENT OF PREVENTIVE DENTISTRY
FACULTY OF DENTISTRY
THE UNIVERSITY OF SYDNEY
1981

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DEDICATION

I wish to dedicate this thesis to my dear wife Jann, without whose encouragement and "never say die" attitude, I couldn't have managed.

"Life's too short"

ACKNOWLEDGEMENTS

I wish to thank Associate Professor K. Godfrey for allotting me a place in this course and for his advice and encouragement during the past two years.

My appreciation goes to the management of Australian Iron and Steel, Port Kembla and especially, Mr. Eric Bradley, Metallurgist in charge of the electron microscope section. The superb photomicrographs are a testimony to his competence and patience throughout this study and to the many "after hours" sessions he spent looking at teeth.

Sincere thanks go to Associate Professor K.S. Lester, Westmead Dental School, for his help in interpreting the histological detail.

To my tutors, especially Dr. Paul Benbow, who gave me great inspiration both as an undergraduate and now as a graduate student.

To Dr. Chris Daley for his help with the light microscope and Dr. Graham Craig for his advice on the electron microscope.

To Mrs. Joan Thwaite and Mr. Rod Joynes of the Dentistry Library, University of Sydney for their help with research material.

To Mr. Robert Johnson and Mr. Robert Van Luyn of the Audio Visual Department, Faculty of Dentistry, University of Sydney, for handling the enormous photographic task I gave them.

To Mrs. M. Tilley, for her excellent typing of this thesis.

To the Royal Australian Army Dental Corps for giving me employment when the "going was tough."

Finally my grateful thanks to Mr. Ray Crux, ex Regional Director, Illawarra Health Region, Health Commission of N.S.W. for recommending me for this course.

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CHAPTER 1

INTRODUCTION

Expansion of the palate and dental arch has been a debatable topic since Angell (1860) first described the procedure. Controversy has reigned over the advantages and disadvantages of this treatment. The aim of this study was not to enter into the debate on the possible medical and dental benefits of maxillary expansion or palatal splitting but rather to compare and contrast rapid maxillary expansion and slow expansion by examining extracted teeth that had been subjected to the forces of both slow and rapid maxillary expansion, for areas of root resorption.

The scanning electron microscope would be used, as this device is capable of showing the microstructure of resorbing dentine and cementum in fine detail.

The appliance used for slow expansion was the Quad Helix as devised by Ricketts (1979), whereas the appliance for rapid expansion was the Hyrax screw (Dentaurum). Root resorption as a result of orthodontic forces has been described in the orthodontic literature for a considerable time. Bates in 1956 described the traumatization of the periodontal membrane and subsequent resorption of the tooth root.

Ketcham in 1927 and again in 1929 was also concerned about root resorption and came to the rather startling discovery

that of 500 orthodontic patients whose teeth were examined radiographically 21% showed distinct evidence of root resorption of permanent teeth.

The earliest approach to the histological investigation of tooth movement was through experiments of different kinds with laboratory animals. The light microscope had its limitations and could often only show advanced root resorption. With the advent of the S.E.M. it was possible to detail the beginning of root resorption following orthodontic treatment.

Thus the basis for this thesis was simply to see if it was better in terms of tooth root destruction to use rapid or slow expansion.

In the words of Rinderer (1966) "In many orthodontic treatment methods one has to accept resorption on the surface of the roots and as such it should be neither dramatised nor overlooked."

CHAPTER 2

EVOLUTION OF RAPID MAXILLARY EXPANSION

Many early clinicians indulged in sweeping statements on the benefits of maxillary expansion. Many of these statements were purely substantive and not proven by scientific fact.

2.1 Those in favour!

Angell (1860) is believed to be the first to use rapid maxillary expansion. Without the aid of radiographs, he surmised he had split the palate when he saw a diastema appear between the central incisors. Some 33 years later Goddard (1893) described the fitting of a jack screw appliance to the teeth of a fifteen year old patient.

"By measuring from the buccal surfaces of the first bicuspids, it was seen that the arch was spread exactly one quarter of an inch. The appliance was attached to the first bicuspid and first molar on each side but does not come in contact with any of the six anterior teeth." He noted that the centrals measured from distal to distal surfaces had separated at least 1/16th of an inch. He explained that as the appliance did not touch the centrals, this separation could only be explained by the supposition that the two halves of the maxilla had separated. He also examined the before and

after dental casts and pointed out that a depression existed in the post expansion cast, between the central incisors, indicating that a separation had taken place along the palatal suture.

In this paper Dr. Goddard was criticised by Dr. H.R. Haley because it was felt that Goddard's method only served in tipping the teeth and did not move teeth bodily.

Ottolengui (1904) after some 15 years experience with maxillary expansion stated that his method (using a vulcanite plate and wooden wedges) was a superior method in that the teeth were moved bodily and not tipped buccally as in other methods. His presentation was criticised by the eminent teacher Dr. Angle who claimed that the plate method was "old fashioned, unclean, and impaired the singing voice."

Landsburger (1910) was almost lyrical in his appraisal of rapid maxillary expansion. He suggested that every case of regulation of the upper teeth should begin with expansion of the maxilla.

2.2. Those against!

About this time there were many who did not believe that the suture could be split and many others who believed that rapid expansion did more harm than good.

Angle (1910) at this time held that too great a force was used

in rapid maxillary expansion and that this rapid movement of the teeth was not physiological.

Those who believed that the suture could not be opened included A.H. Ketcham (1910) who tried to open the suture of a '5 year old child and failed. Dewey (1914), Kemple (1914) and Federspiel (1913) all expressed disbelief in the opening of the mid palatal suture.

C.H. Hawley (1912) a noted orthodontist, constructed his own expansion device and even used such a device on a member of his own family. Hawley presented a series of cases examined both radiographically and on study casts.

"I can see no evidence that the suture had been opened. It therefore is evident that the appearance of a space between the central incisors, either when force has been applied to them, or when they are left free, is not necessarily evidence that the maxillary suture has been opened. What seems to be happening is the stretching of thin plates of the palate between the reinforced portion along the suture and the thick alveolar structure surrounding the teeth."

We now know that the median palatine suture can be opened and that the reason for the above writers failure was that insufficient force was used or the appliance was unsuitable.

After 1915, the interest in rapid maxillary expansion waned. Perhaps this was due to the very strong influence of the teachings of Angle, because in America nothing concerning rapid expansion of the palate appeared in the literature for some 40 years.

2.3 The Renaissance of Palate Splitting

According to Thorne (1956) (who made exhaustive search into rapid maxillary expansion) interest continued somewhat sporadically in Europe after its lapse in the U.S.A. However, this interest was almost completely centred on the rhinological benefits of rapid maxillary expansion as against its orthodontic benefits.

Rinderer (1966) and McCracken (1963) both felt that Derichsweiler (1953) who once again started work on the expansion of the palatal suture, was responsible for the revival of interest in this procedure. This work, which was largely carried out on animal experiments in Germany, soon spread to the United States.

Haas (1965) who has published more work on rapid maxillary expansion than any person alive, claims that Korkhaus (1953) was responsible for reintroducing the procedure to the U.S.A. His remarkable cephalometric records of cases treated by palatal expansion aroused the interest of Haas himself, back in 1956.

Whoever revived the technique doesn't really matter; expansion of the arch and splitting of the mid palatal suture are today an integral part of orthodontic treatment.

Haas in 1958 wrote a thesis on palate splitting and thus began a life-times' work on the topic.

2.4 The Modern Day Exponents

Krebs (1958) and again in 1964 did some monumental studies on the technique. By using metallic implants he was able to show beyond any doubt that the sutures had been separated. By taking radiographs and observing his sample of 23 patients for some 7 years he produced some worthwhile conclusions;

1. An increase of about 8mm in the width of the dental arch was observed, it was slightly greater between the canines than between the first molars. The width of the maxilla as represented by the distance between the implants lingual to the canines increased by 5.7mm, whilst at the implants in the zygomatic processes there was an increment of 3.8mm. The nasal cavity was widened by 2.8mm.
2. A large amount of expansion in the dental arch was associated with a large amount of expansion in the

maxillary base, more frequently in boys than in girls.

3. The most marked effect of the rapid expansion therapy was recorded before and during the pubertal growth spurt. Thereafter the reaction in the mid-palatal suture was apparently slower.
4. When the retention was discontinued there was usually a reduction in the dental arch width, which often continued for up to 4.5 years, but in no case was there complete relapse.

It is interesting to note that nearly twenty years later, Isaacson, Worms and Spiedel (1976) were to say that implants were today the best way to precisely determine tooth movements relative to the alveolar bone.

Korkhaus (1953) described permanent maxillary expansion of "ten millimetres or more, in some cases, enlarging by that, the palate and even the apical base, including the intra nasal space." He stated "In many cases free nasal respiration can be achieved only by extensive widening of the maxilla and palate."

Thorne (1956) published a paper that was to further add to our knowledge of rapid maxillary expansion. Thorne was keenly interested in the historical background to rapid maxillary expansion and set about to prove the efficacy of the method for himself.

Using study casts and occlusal radiographs on a sample of forty children he announced the following conclusions:

1. During the progress of the treatment, a diastema appears, which closes spontaneously in a few weeks. The diastema varied between 0-5.2mm with an average of 3mm.
2. Bite opening varied in the incisor region between 0.5 and 8mm and occurred in about half of the cases.
3. Some degree of facial tilting of premolars and molars occurred in some three quarters of the cases treated.
4. By measuring the widening between the crowns (on models) of the six year old molars, Thorne found the average increase in width to be 6.7mm. The greatest increase in width was 11.5mm.
5. The mandibular teeth did not follow the expansion in the upper arch. The average value for widening of 6 to 6 was 0.7mm and is thus rather insignificant.
6. The apical base (as measured by a precise system, with radiographs) increased in width by between 1.3mm and 6.5mm with an average of 3.1mm.

7. The nasal cavity width increased less and varied from 0.4 to 5.7mm with an average of 1.7mm.

By using a stereograph, Gerlach (1956) was able to reproduce the basal bone and thus measure it. He showed that by moving the teeth facially, a bone rebuilding process was created with an increase in base bone development. He stressed the fact that tooth tipping, should be avoided and that although many patients breathed more easily through their nose, not every mouth breathing habit could be cured by rapid expansion of the palate.

Haas (1963) has written intensively on the subject in the 60's and 70's and 80's and agrees with Gerlach when he said he by no means sees rapid maxillary expansion as a "cureall".

Howes (1960) told us that arch width was usually the problem with children in the mixed dentition stage, not arch length. He showed that arch length was a circumferential measurement (1st molar to 1st molar) and the terms arch length and arch width were often confused.

He saw the reason for collapse during earlier attempts at palate splitting as being the placement of teeth in positions where little basal bone was present for their support. He advocated the expansion of the arch in the mixed dentition

stage provided an increase in arch width was to be gained.

Stockfisch (1969) suggested that we over expand 2-4mm when splitting the palatal suture. After reviewing some 150 patients from 5-15 years after completion of the procedure he found that "The maximum stable expansion of the maxillary base that was achieved was 10mm and the minimum expansion was 6mm. The degree of relapse was approximately 4mm within 3-5 years.

Lebret (1965) studied the changing configuration of the palate after using rapid maxillary expansion and other expansion methods.

Posen, Bayne and Cleall (1963) used split acrylic plates as the expansion device on *Macacarhesus* monkeys in the mixed dentition stage. After sacrificing them at varying intervals after expansion, they concluded that

- (a) The Palatal suture was in fact split and that the upper arch was widened by this therapy.
- (b) After a few months bone deposition returned the suture to normal.

Starnbach and Cleall (1964) again using the fixed split acrylic plate with expansion screw reported on yet another experiment using Rhesus-macaca monkeys. This paper considered the effect on the teeth and the adjacent suture, the zygomatico-temporal

suture and the nasal suture. They concluded that:

1. Tooth movement was predominantly bodily rather than tipping.
2. The longer the animals were retained after expansion, the less marked was the cellular activity.
3. As a result of rapid maxillary expansion one could expect concomitant changes (i.e., cellular activity) in the surrounding tissue.

Starnbach in conjunction with Bayne, Cleall and Subtelny (1966) again investigated dental movement and associated changes in sutures due to splitting of the palate. Again Macaca-rhesus monkeys were used as the experimental animal. On examination, clinically and radiographically it appeared that the posterior teeth had been tipped buccally. However, histological evidence showed that the teeth had in fact been moved bodily which agreed with his experiment in 1964. Once again it showed that alterations occurred at the various sutures of the maxilla along with the palate splitting.

Wertz (1968) studying variations in nasal airflow coinciding with rapid maxillary expansion concluded "opening of the mid-palatal suture for the sole purpose of increasing nasal permeability cannot be justified unless the obstruction

is shown in the lower anterior portion of the nasal cavity and accompanied by a bilateral maxillary arch width deficiency."

Other workers to make worthwhile contributions during the 60's were Rinderer (1966) and Davies and Kronman (1969).

The literature of the 70's saw familiar names beginning to reappear.

Wertz (1970), a devotee of the technique, studied sixty patients from his own private practice who had been successfully treated by rapid expansion of the maxilla for bi-maxillary narrowness. As a supplement two dried skulls were subjected to the same mechanical therapy in order to gain further information regarding skeletal changes during the procedure.

Using study models, frontal and lateral cephalograms, occlusal radiographs and intra-oral photographs, Wertz arrived at some interesting conclusions:

1. Although the buccal teeth showed some degree of tilting, this was thought to be due to the lateral arcing effect of the bone segments themselves.
2. Studied in profile, downward displacement of the maxilla was rather routine, but forward displacement to any degree was limited to isolated cases.

3. Occlusally the mid palatal suture seemed to open in a non-parallel fashion - somewhat resembling the opening of scissors by imagining the scissor points to be at the anterior nasal spine.

Wertz in his article of 1968 said that the suture did not open completely. In this study he revised his theory and said that the suture did in fact open in its entirety.

4. This therapy must result in a pyramid-shaped parting of the halves of the maxilla, with the base of the pyramid located inferiorly and the apex in the area of the fronto-maxillary suture.

It was also interesting to note that Wertz tested the dry skulls - one adult and one mixed dentition skull, results agreed with clinical findings. However, although the adult skull offered no resistance to actual opening of the mid palatal suture, the rigidity of the maxillary articulations prevented maximum repositioning of the maxillary halves.

Sain (1963) was not convinced that the mid palatal suture was easy to open in adults. He stated "The oldest person I tried palatal expansion on, was in her thirties. She had a unilateral crossbite. The centrals never did open and

I guess we never opened the palatal suture in her case. However, the crossbite corrected in two or three weeks and she tolerated it very well."

Kudlick (1964), following on the experiment of Wertz, used similar skulls to test the displacement of bones of the craniofacial complex under the influence of midpalatal expansion. Four skulls were tested to compare before and after expansion effects on the bones in the fronto-maxillary complex, the orbital cavity, the zygomatic arch, the mid palatal suture area and the pterygo - palatine - maxillary complex.

He found:

- (i) Except for the sphenoid bone, all craniofacial bones directly articulating with the maxilla, were displaced.
- (ii) The cranial base angle remained constant.
- (iii) Displacement of the maxillary halves was asymmetrical.
- (iv) The sphenoid bone rather than the zygomatic arch was the main buttress against maxillary expansion. We must note here that this statement is contradictory to the work of Wertz (1970) who declared that the zygomatic arch was the main buttress and moreover he maintained that it was fortunate that this safety factor was built in, otherwise it was

possible for the frontal processes of the maxilla to be moved into the orbital cavity.

- (v) Although the amount of resistance to expansion in each dry human skull varied, basic patterns of displacement were evident.

Perlow (1977) was concerned with the side effects of palate splitting when he wrote "Admittedly splitting the palate is relatively simple to perform and as a rule, free from serious complications. Nevertheless, it cannot be said to be 100% free in all cases. Recently Graber has voiced his concern and cites Rinderer and Hotz, who have known or experienced serious untoward results in criticising the method of treatment."

Perlow agreed with Wertz (1970) and Kudlick (1974) by pointing out that palate splitting is not a localised affair but actually involved seven other bones. He also warned that at the current stage, America is litigation conscious and thus each treatment rendered has to be almost 100% effective otherwise the clinician may finish up in court.

On a brighter note, Ten Cate, Freeman and Dickinson (1977) undertook a worthwhile study using albino rats.

By placing an expansion spring across the right and left

parietal bones, and activating them for various amounts of time it was possible to study histologically the effect on the sutures. They were of no doubt that with the cessation of sutural expansion, regeneration of the suture occurs. That is to say, no scar tissue filled the gap but that there was complete reconstitution of the injured tissue with consequent full restoration of the original architecture.

Wertz and Dreskin (1977) attempted to create guidelines or treatment goals for practitioners contemplating mid palatal suture opening. They examined 56 cases from private practices and used lateral and frontal roentgenograms to analyse them.

The idea was to monitor the patient from beginning of treatment until the retention stage. By this means any skeletal or dental change that would have normally occurred, without any treatment is thus not mistakenly attributed to the orthodontic procedure.

Some significant results were achieved:

1. Maxillary expansion was achieved in all of 56 cases treated, but the older patients experienced little in orthopedic change. This observation was made by other workers including Sain (1963) and Wertz (1970).

2. The maxilla always moves downwards and moves varying degrees from slightly backward to sometimes significantly forward during suture opening.
3. Maxillary skeletal width can be expanded with no relapse in younger patients. Older patients, however, often lose much of the increase gained by expansion of the maxilla.

Lastly, a most significant point

4. In younger patients the mandible permanently rotates open less than 1 degree.

Linder-Aronson and Lingren (1979) studied the skeletal and dental effects of rapid maxillary expansion on a sample of 7 boys and 16 girls. By taking measurements on study models and lateral cephalograms and observing the patients for an average of 6.9 years, they found that the mean expansion between the upper molars was 7.9mm, with a range of 3.1 to 16.0mm.

After five years observation it was found that the final increase in width was 45% of that initially achieved after expansion. This finding agrees with the work of Stockfisch (1969). Also particularly interesting is that the mean final increase in the intercanine width was small and only 23%

of the original expansion. This demonstrates that rapid maxillary expansion gives very little extra space in the arch and thus cannot be used as an alternative to extraction.

They also found that both overjet and overbite were almost unchanged some seven years after the start of treatment. This of course is in agreement with Wertz and Dreskin (1977).

Timms (1980) studied the effects of rapid maxillary expansion further back in the arch, i.e., the effect on the palatine and pterygoid bones. He realised that to measure bones posterior to the dental arch was nigh impossible radiographically.

He thus palpated the pterygoid hamuli in the mouth, marked them with a pencil and took his measurements directly from these. Timms postulated that any increase in interhamular width would indicate basal movement. The intermaxillary arch width increases were recorded by measuring from the lingual surface of the upper molar to the lingual surface of the opposite upper molar.

Timms admits that this was a "modest research project" but it did "throw some new light on the effects of rapid maxillary expansion on the basal bone posterior to the application of force."

The increase in interhamular width varied from 3.0 to 7.0mm whereas the increase in intermolar width varied from 6.5 to 9.5mm. As might be expected, the greater the intermolar width, the greater the interhamular width. However, due to many factors the coefficient of correlation when applied to the two measurements was statistically weak. The study did prove that there was movement of the basal bone posterior to the application of force and that this movement was greater than had been formerly realised.

2.5 The Indications For Rapid Maxillary Expansion

It would seem fitting to end this history with a paper by Haas (1980).

In this article the author outlines his indication for rapid palatal expansion. They are:-

1. Cases of real and relative maxillary deficiency.
2. Cases of nasal stenosis.
3. All types of Cl lll cases. These would include of course, the pseudo Cl.lll, the dental Cl. lll and the surgical Cl. lll.

4. The mature cleft palate patient. The procedure is not of particular advantage in the young cleft palate patient since it is very easy to expand the lateral masses by less complex methods.
5. Antero-posterior maxillary deficiency cases.
6. Selected arch length problems in a mature, good morphogenetic skeletal pattern.

Haas maintains, that with judicious use of the rapid maxillary expansion appliance upper buccal teeth are absolutely stable, after having been expanded 9-12mm. This statement, of course, disagrees with the work of Linder-Aronson (1979) and Stockfisch (1969).

It can now be concluded beyond doubt that it is possible to split the palatal suture and retain the arch in a stable manner. However, there are some small "grey areas" in this method and these should be elucidated before this treatment method becomes the tool of all and sundry.

CHAPTER 3

EVOLUTION OF THE QUAD-HELIX APPLIANCE

Most of the early expansion appliances were in fact modified Vulcanite dentures.

3.1 The Genesis

W.H. Coffin (1881) introduced a plate used by his father before him. The Coffin plate, as it became generally known found instant favour, although it was in direct conflict with the advocates of the jack screw. This latter form of expansion was firmly established at this time. This period probably marked the beginning of the argument: screw force (intermittent) versus looped wire force (continuous) - a "bone of contention" that exists to this very day.

The Coffin plate consisted of a divided vulcanite plate, the two halves being connected by a piece of piano wire bent to the shape of the letter W. It was held in place by either caps or clasps on the molars, and by means of the spring in the wire, exerted lateral pressure or expansive force.

A variation on the Coffin spring was the appliance devised by George Crozat (1919) in the early 1900's. The appliance can have both labial and lingual actions and, although removable, is entirely tooth born.

A little later Pollock (1930) described his appliance which was basically a W arch with a labial bow attached to two molar bands. Pollock referred to the appliance as a fixed-removable appliance.

"Fixed because it is cemented to place by a temporary cement, insofar as the anchor bands are concerned removable, because it may be quickly removed by the operator and the lingual base wire adjusted." Dukes (1969) has described the appliance in detail, due to certain reluctance on the part of Pollock to adequately promote his creation.

According to Ricketts, Gugino, Hilgers and Schulhof (1979) the W arch was further modified in 1947. A button of acrylic was placed on the palate and this was used by Nance for holding arches.

3.2 Rickett's modifications

It would appear that Ricketts (1979) studied the evolution from the Coffin spring and W arch. He at first introduced helical loops on either side of the posterior end of a W arch. It was anticipated that this would widen the range and introduce more flexibility. Later Ricketts added two anterior coils to ensure even more flexibility.

3.3 Activation in the Mouth

Thus in 1973 the Quad-Helix appliance, as it was so named, was born. Ricketts no doubt saw the possibility of activation in the mouth, thus avoiding the "fixed-removable" concept of Pollock. Chaconas and de Alba Levy (1979) criticised the intra-oral method of activation stating that each bend produced a progressive decrease in the force originally placed in the appliance.

Birnie and McNamara (1980) state that the intra-oral method of activation is of 'dubious value' "It is physically extremely difficult to carry out because of the bucco-palatal rigidity created by cementing the appliance to the upper first molar teeth."

The writer agrees that it is very difficult to assess the forces placed in the appliance using the intra-oral method of activation. It is much easier for both operator and patient to remove the appliance, reactivate to the known desired amount of expansion and recement. The appliance then acts continuously over a set period of time until the activation has ceased.

Chaconas and Caputo (1975) found that the force magnitude created by the appliance is sufficient to produce tooth movement, but generally is not enough to create an orthopedic effect on adults when the mid-palatal suture is closed.

In children, however, the appliance is capable of orthopedically widening the maxilla by opening the mid-palatal suture.

Bell and Le Compte (1981) using the quad-helix on ten subjects - five in the mixed dentition, five in the deciduous dentition found the following:-

1. The functional posterior cross-bite that existed in each patient was successfully corrected on an average in 30 days.
2. Mid - palatal suture separation was produced in each patient as evidenced by occlusal radiographs.
3. Maxillary intermolar and intercanine transverse measurements showed significant increases in all patients with mean values of + 5.3mm and + 4.1mm, respectively. These measurements decreased by -1.5mm and -1.9mm, respectively, after a three month post-retention adjustment period.

Interestingly, Bell and Le Compte (1981) removed the appliance in order to re-activate it. However, they do not state their reasons.

3.4 Advantages of the Appliance

Sandham (1979) says of the usefulness of the quad-helix:

"It is particularly useful in children with repaired clefts of the palate, where arch collapse has taken place. The appliance is just as effective as rapid expansion screws, but from a technical point of view much more simple to construct."

According to Ricketts (1979) :-

1. The quad-helix widens the palatal suture in pace with the new formation of bone. He maintains that the result is more stable than rapid maxillary expansion as with the latter, the new bone formed is of the young type, i.e., very loose and unstable.
2. It is easy to construct.
3. Ricketts also states that it could be effectual in certain cases for correction of mild Cl.II malocclusion. This could be accomplished as the quad-helix has the effect of rotating the banded molars around their palatal roots, thus initiating Cl. II correction.
4. Sandham (1979) has added finger springs to the appliance to push anteriors labially or lingually.

5. Birnie and McNamara (1980) have shown that the appliance is capable of proclining anterior teeth. To effect this they have added two more helices (6 in all) behind the upper anteriors.
6. Chaconas and de Alba Levy list even more advantages:-
 - (i) It can act as a habit-breaking device for patients who are chronic thumb suckers.
 - (ii) It is relatively comfortable for the patient; it rarely affects normal speech.
 - (iii) It does not cause the unpleasant pressures associated with rapid jack screw palate splitting devices.
7. Birnie and McNamara (1980) indicate that the appliance can be used to contract the maxillary intermolar width.
8. Bell and Le Compte (1981) add one more - Removal of adjustment responsibility from the patient and parents.

3.5 Disadvantages

1. With excessive expansion the teeth do tip outwards. Ricketts (1979) states that this is not so much of a problem as "downward and outward positioning of the upper buccal teeth is seemingly followed by an attempt on Nature's part to upright the roots." He later alters this statement by saying, "The problem is that uprighting is not predictable and not always dependable."

2. The movements are often not excessive enough and are not retained long enough.
3. The appliance often restricts space needed for the tongue. If the appliance is too far downward and backward in the mouth, the tongue will tend to be disturbed and become creased during its function.

3.6 Design and Construction

The quad-helix is available as a preformed unit or can easily be bent from .036" (0,9mm) Eligiloy (Rocky Mountain Products). Five sizes are available in the quad-helix preformed blanks and the most suitable size is selected. The appliance is bent so as to adapt closely to the palate - within 2-3mm of the tissue so as to be well clear of the tongue. Sandham (1979) suggests keeping the two anterior coils as far apart as possible, especially if you wish to use intra-oral activation. Birnie and McNamara (1980) have set specifications for the design of the appliance"-

1. The anterior bridge should be straight and lie along a line joining the distal surfaces of the upper canines.
2. The helices should be wound so that they lie on the palatal surface of the appliance, thus holding the spring away from the palatal mucosa.
3. The posterior helices should be sloped so that they lie

parallel to the palatal vault and should be sufficiently distal to the molar bands to prevent softening during soldering.

4. The lateral arms should extend forward to control the teeth which are to be moved.

Construction:

1. Select bands.
2. Weld on lingual cleat or soldering clip. The writer has found that the cleat (i) Aids in repositioning band back into the impression and (ii) Acts as a rest or stop for the wire whilst soldering.
3. Take impressions with bands in situ.
4. Reposition band in impression and pour model.
5. Bend quad-helix (or use preformed appliance) and solder to band.
6. Clean and polish.
7. Activate the appliance. (Sandham (1979) (B) says to expand the appliance about 8mm keeping the outer buccal arms parallel. Birnie and McNamara (1980) suggest 20mm between the posterior helices. Bell and Le Compte (1981) simply expand the appliance to one half

a molar tooth bi-laterally. The writer finds this to be a most satisfactory means of gaining the correct activation. (See Chapter 5 for forces values from various activations).

8. The quad-helix is now cemented in place, making sure the bands are well seated.

Birnie and McNamara (1980) suggest that, "in order to allow for the small amount of rebound which occurs, the case should be overtreated until the palatal cusps of the upper arch overlie the buccal cusps of the lower arch.

Bell and Le Compte (1981) didn't expand as drastically. They discontinued the force once the lingual cusp of the upper molar contacted the occlusal slope of the buccal cusp of the lower molar. In the writer's experience, this amount of overcorrections seems to work satisfactorily.

3.7 Indications

Ricketts (1979) summarises the following indications for the quad-helix appliance:

1. All cross bites in which the upper arch needs to be widened.
2. Cases needing mild expansion in the mixed or permanent dentition, which frequently exhibit lack of space for

the upper laterals and in which the long range growth forecast is favourable.

3. Cases of Class II in which the upper arch needs to be widened effectively and the upper molars rotated distally.
4. Class III conditions in which the upper arch needs to be widened and advanced with Class III elastics.
5. Thumb sucking or tongue thrusting cases with their various modifications.
6. Cleft palate conditions whether unilateral or bilateral.

3.8 Footnote

Since the preparation of this literature review Rocky Mountain Products have introduced on to the Australian market, a removable Quad-helix appliance. The device is packaged as for the existing range of Quad-helices but has obvious advantages over the former. Firstly, there is no necessity to take impressions - the appliance can be fitted in the mouth at one sitting. This is accomplished by means of rectangular tubes which are welded on to the lingual side of the band. The Quad-helix is then slotted in and adjusted. The introduction of this modification would also tend to justify the overall advantages of extra-oral activation, making it a true "fixed-removable" appliance.

CHAPTER 4

THE QUAD-HELIX AND ELGILOY WIRE

4.1 Introductions

As there is only one real Champagne - that made from the grapes of the specific district of France, so too there is only one real Quad-helix - that made from Elgiloy wire. It would seem fitting, therefore, that a small chapter of this thesis be devoted entirely to the properties and uses of this special wire.

None could sum up the benefits of a wire such as Elgiloy better than Kohl (1964) when he said -

"For the correct use of orthodontic appliances, one must have a thorough knowledge of the materials from which these appliances are made. The mechanical and physical properties of these materials change greatly under varying conditions of manipulation. The light continuous pressures produced by these appliances stimulate osseous development in the direction desired. Thus they have a dynamic nature, producing sufficient pressure to stimulate movement, but not enough to cause necrosis of the bony tissue. The appliance must act within maximum and minimum limits; therefore, its capabilities for applying force should be known."

4.2 Development

Elgiloy was developed and patented by the Elgin watch company for use in watch mainsprings. It is similar in appearance to stainless steel wire, but is actually a cobalt-base alloy.

4.3 Composition

Cobalt	-	40%
Chromium	-	20%
Nickel	-	15%
Molybdenum	-	7%
Manganese	-	2%
Carbon	-	0.15%
Beryllium	-	0.04%
Iron	-	Balance

U.S. Patent No. 2524661

The Rocky Mountain Company (1981) developed Elgiloy for use in orthodontics.

4.4 Advantageous Properties

Set Resistance - Retains power longer than stainless steel.

Fatigue Resistance - More cycles than stainless steel without breakage.

Greater Spring Efficiency - Up to 20% more power than spring steels without increase in dimensions.

Corrosion Resistance - Out performs chrome stainless steel by 17%

Non-Magnetic - through all temperature ranges.

4.5 Engineering Data

Ultimate Strength	340,000 p.s.i.
Yield Strength	310,000 p.s.i.
Modules of Elasticity	28,500 p.s.i.
Torsional Modulus	11,200,000 p.s.i.
Hardness (Rockwell C)	51-55
Annealing Temperature	2250 ^o F

(Elgiloy can be annealed. However once annealed, there is no way of gaining resiliency by the heat-treatment method.)

Heat-Treatment Temperature	900 ^o F
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Rocky Mountain maintain that the spring qualities of Elgiloy can be increased by heat-treating.

4.6 Some Studies with Cobalt-Chromium Alloys

Denver (1958) in a study of cobalt-chromium wire assessed the effects of heat-treatment at 900^o F for 3 minutes and found -

- (i) a 70% reduction in ductility.
- (ii) a 60% improvement in the ability of cobalt-chromium wire to resist permanent deformation following heat-treatment.

Fillimore and Tomlinson (1976) conducted a study "to quantify the effects that several heat-treatment temperatures have upon the ability of a particular temper of cobalt-chromium wire to resist permanent deformation." They concluded that heat treatment of 1200°F gives the maximum resistance to permanent deformation of .016" x .022" cobalt-chromium wire. Increases in resistance to permanent deformation of approximately 95% and 174% may be expected from heat-treatment of .016" x .022" chrom-cobalt wire at 900° and 1200° respectively.

A word of warning, however, from Fillimore and Tomlinson, who claim that the Rocky Mountain heat-treatment unit, using electric current may not always give uniform or accurate results. They state that an electric current produces uneven heating of the wire and thus variable results. The authors concluded, that the most consistent and uniform method of heat-treatment was by means of the dental furnace.

4.5 Range of Tempers

Elgiloy is supplied in four tempers to provide flexibility and these four tempers react differently to heat treatment. Each wire is colour coded and each has different characteristics. Yellow Elgiloy possesses ideal qualities for bending a Quad-helix as it is relatively ductile and possesses high spring. It can be used as manufactured or it can be heat treated for maximum resiliency and spring performance.

CHAPTER 5THE FORCES INVOLVED - RAPID EXPANSION (HEAVY FORCES)

-V-

SLOW EXPANSION (LIGHT FORCES)5.1 Rapid Expansion

In 1964, Isaacson and Murphy studied by the implant method the effects of rapid maxillary expansion on five patients who had undergone surgery to repair complete clefts of the pre-maxilla and secondary palate. Among other things, they found that the forces involved, did not always cause symmetrical expansion of the upper arch. The important message, however, that emerged from this study (and emphasised by Isaacson) was that there was a need for more information regarding the forces produced by rapid expansion of the maxilla using a screw device.

Thus later, Isaacson, Wood and Ingram (1964) investigated the magnitude of force required to split a palatal suture.

Fired by the knowledge of their previous study, (a) that forces involved must be great, as not only is the palatal suture expanded, but so too are other basal facial sutures, and (b) as stated previously, the expansion screw force was not necessarily the same on each side of the arch, Isaacson et al completed what is now regarded as a classical study.

In October 1964, Isaacson and Ingram, using a specially adapted expansion screw device, were able to estimate, electrically, the actual forces incorporated during treatment. It was apparent from the study that a single activation of the expansion screw produced from about 3-10lbs. of force. In an effort to keep the expansion forces down below 10lbs. Isaacson suggested that instead of utilising full activation twice a day, the patient be instructed to use only half activation twice a day. This proved to be impossible due to the design of the appliance. Thus the patient was subjected to the full load every time.

It is rather frightening to read Isaacson's results. Upon initial activation the applied force lessened or decayed after a few minutes. This force, however, was still present on following days and became known as the residual force. This residual force plus the force produced by normal activation reached a figure of 22.5lbs. on a 15 1/2 year old female. Isaacson in the discussion of this study, raised the obvious question, "Is it necessary to use 10 lbs. of force and over, to successfully expand the maxilla. He goes on to suggest that lower loads may be just as capable of producing equally successful clinical results.

Zimring and Isaacson (1965) researched Part III in the study - Forces present during retention. This investigation was conducted on four patients, three male and one female. It was found that residual loads were still present at the termination of appliance activation in all four patients.

The loads gradually disappeared within 6 weeks - the greatest decrease in load occurring during the first week of retention and in succeeding small increments from week to week thereafter.

A rather atypical occurrence was observed by these authors. In one patient, the activation of the appliance was gradually scaled down due to accumulating residual loads. Even when activating the appliance once every second day, the load still increased. Finally the appliance had to be removed because of associated depressing side effects such as dizziness, pressure at bridge of nose and under the nose. At the time of removal an estimated 34.8 pounds of pressure was present.

5.2 Slow Expansion

"The objective was to develop 500 gms of force for orthopedic movement when desired" Ricketts et al (1979).

Very little has been published about forces produced by the quad-helix appliance. Chaconas and Caputo (1975) state that an initial 8 mm of expansion before cementing the bands created approximately 14 ounces of force. Further, they remarked on the gentle effect of the appliance, "The quad-helix appliance proved to be the least effective orthopedic device. Although the effects of palatal separation, were seen with increased activation, the appliance primarily affected the posterior teeth."

Using 1.00 mm hard stainless steel Birnie and McNamara (1980) more effectively tested the quad-helix for its expansion forces. They found that by expanding the posterior helices by 10mm on each side, the force required to compress the springs to their original dimension was 360 ± 20 gm. The figure agrees favourably with the result achieved by Chaconas and Caputo.

It must be remembered that if Elgiloy wire was expanded to the same extent a greater force could be anticipated due to its greater spring efficiency (see Chapter 4).

Storey (1973) (A) studied the relative responses to slow and rapid expansion in the premaxillary suture of rats and rabbits. His results indicated that sutural integrity was maintained in the animals subjected to slow expansion (i.e., 0.5 to 1.00 mm per week) and that the relapse potential of the expanded premaxillary segment was less.

Cotton (1978) hypothesised that palatal expansion without excess dental expansion could be accomplished by means of a constant low magnitude force system. Using three monkeys (*Macaca Mulatta*), he applied low magnitude continuous force (1 to 2 pounds) in a transverse direction to the palatal vault and posterior teeth. Using implants and plaster casts he assessed linear and angular changes of the maxilla versus those of the posterior teeth. The maxillary arches of all animals were expanded until the posterior teeth were nearly in a complete crossbite and treatment duration varied from 37 to 74 days.

The major finding was that mid-palatal suture opening did occur in the monkey using very light forces.

Cotton's conclusions bear testament to his use of a light force -

"1. The magnitude of mid-palatal suture separation incident to 1-2 pounds of continuous force in the rhesus monkey was comparable to that in rapidly expanded non-human primates as well as in clinical patients.

2. Early postexpansion skeletal stability may be a result of slow maxillary expansion.

3. After slow expansion a short fixed retention period appears desirable in order to maintain all of the maximum achieved mid-palatal separation.

4. Autonomous post-expansion lingual tipping of molars in this study contributes to the evidence that the attached soft tissue and/or surrounding peri-oral musculature are aetiological factors in tooth movement after maxillary expansion.

Cotton's final conclusion agrees wholeheartedly with Isaacson and Ingram (1964) in suggesting the use of light forces.

5. Results of this study would suggest a rationale of maxillary expansion that included delivery of lighter force levels and/or slower activation schedules than are currently used.

Following this important work by Cotton, Hicks (1978) published his findings which set about to prove the reliability of Cotton's study, but this time in a strictly clinical situation.

Hicks conducted his study on five children - three boys and two girls, whose ages ranged from 10 - 15 years. By placing tantalum implants in these children after the method of Krebs (1964) and Bjork (1966) he was able to measure on radiographs the linear and angular responses to slow maxillary expansion. He used dental casts to measure dental responses. Using a split acrylic appliance and a spring expander he was able to maintain a constant force level of two pounds, across the palate.

The expansion phase of the study ranged from 8 to 13 weeks and Hicks was able to show quantitatively and conclusively that the maxillary segments had separated in every patient.

Hicks did find that facial tipping of the maxillary teeth did occur initially during expansion, but this tipping did not increase substantially relative to linear increases in the latter phase of expansion.

Although having written a substantial article, Hicks also recommends that further study is necessary to evaluate variables, such as, age, appliance design and, moreover, expansion force.

The writer agrees totally and ponders the question - In most cases there is no need for rushed treatment in expanding the dental arch. Why the hurry?

CHAPTER 6

THE MICRO-STRUCTURE OF CEMENTUM

Like all other connective tissue the cementum is composed of cells (the spiderlike cementocyte) and intercellular substances. Light microscope studies have previously divided cementum into two types - cellular and acellular. This nomenclature is still used when describing cementum viewed under the scanning electron microscope. Orban (1976) reminds us that the term acellular is unfortunate, "As a living tissue, cells are an integral part of cementum at all times. However, some layers of cementum do not incorporate cells, whereas other layers do contain cells in their lacunae."

As a general rule, acellular cementum is found in the coronal half of the root. However, alternating layers of acellular and cellular cementum may be found in the apical half of the root. Cementum is thinnest at the cemento-enamel junction (20-50 microns) and thickest towards the apex (1500-200 microns).

Mjor and Pindborg (1973) described in detail the structural entities of cementum.

They describe Sharpeys fibres, which are produced by the fibroblasts in the periodontal membrane, as radially

oriented structures penetrating the cementum. The fibres are an extension of the periodontal fibre and connect the tooth to the bone.

Matrix fibres are present which have been produced by cementoblasts and fasten the Sharpey's fibre to the cementum.

Incremental lines are present which tend to indicate a rhythmic pattern of mineralisation - the rest periods (as seen in enamel and dentine).

Cementoblasts are to be found at the cementum surface. These cells produce the matrix fibres and the ground substance and have the typical appearance of protein-producing cells.

In the cellular cementum are to be seen lacunae and canaliculi, practically identical to osteocyte lacunae, reminding us once again that there is little difference between cementum and bone. Characteristically, however, the lacunae are located further apart and are more irregularly distributed than in bone. The lacunae of cementum contain cementocytes and the canaliculi will contain cellular processes. Generally the cementocytes have relatively little cytoplasm and few organelles which is a sign of low activity. Otherwise, the cementocytes show the same cytological picture as the cementoblasts.

Toda et al (1974) studied and classified the cementum lacunae

in human teeth, using the scanning electron microscopes.
into three types:

Type I was where the lacuna wall consisted of bundles of fibres of various sizes. In Type II the lacuna wall showed a rough surfaced or granular appearance, and in Type III the wall showed mild undulation but was smooth as a whole. Type I was seen most frequently - in more than 80% of the teeth studied.

Selvig (1966) was one of the first to study cementum from permanent teeth under the scanning electron microscope. He tried to determine if acellular and cellular human cementum were structurally different or similar to alveolar bone. He also set out to study the patterns of Sharpey's fibres.

After collecting extracted teeth from persons of various age groups, he concluded that in the ultrastructure of acellular cementum, cellular cementum and alveolar bone, differences were found in orientation, width and degree of calcification of the matrix fibres. However, when he examined the hydroxyapatite crystals of cementum and alveolar bone, situated on the surface, he found them to be thin plate-like structures with the same dimensions as those of cementum. These hydroxyapatite crystals at the surface of cellular cementum, acellular cementum and alveolar bone had dimensions no larger than $400 \times 200 \times 20 \text{ \AA}$.

Regarding the Sharpey's fibres he found that those fibres in

acellular cementum were closely packed and in general, completely calcified. In cellular cementum the Sharpey's fibres were separated by other fibres and were more easily seen.

Furseth (1969) studied the structure of cellular cementum of young human permanent teeth. This author was more concerned with the actual fine structure of the cellular components, rather than the matrix fibre elements. His findings proved for Mjor and Pinborg (1973) that the cementoblasts exhibited "the cytological characteristics of cells actively synthesising proteins with abundant endoplasmic reticulum, a well developed Golgi apparatus and numerous mitochondria." His observations on this occasion agreed with a previous work (1967) on human deciduous teeth, in which he showed that cementocytes contained fewer organelles than cementoblasts, thus indicating that they are less active than cementoblasts.

However, he does stress the point that just because they appear structurally less active, it does not mean that they are incapable of producing collagen.

CHAPTER 7

THE MICROSTRUCTURE OF DENTINE

7.1 General

Dentine is composed of a matrix of collagen fibres in a randomly arranged network. Upon calcification, the hydroxyapatite crystals overshadow or mask each individual fibre. Odontoblasts line the periphery of the pulpal chamber and each gives out a cytoplasmic process which is housed in a dentinal tubule. There are approximately 65,000 tubules per sq. mm near the pulp and about 15,000 per sq. mm at the periphery. The tubules also become narrower as they reach the periphery of dentine.

7.2 Detail

The "periodontoblastic space" is the term given to the area between the wall of the tubule and the odontoblastic process. It is important in that it contains tissue fluid and a few organic components such as collagen fibres. Thus the contents of the tubule represent the soft tissue of the dentine.

The peritubular dentine forms the wall of the dentinal tubule and the regions external to this have been termed inter-tubular dentine. Electron microscope studies have shown that the peritubular dentine is more highly calcified than the intertubular dentine, whose matrix contains abundant amounts of collagen (Boyde and Lester (1967) (b), Selvig (1968) and

Tojo et al (1975)).

Boyde and Lester (1967) (A) were able to examine under the scanning electron microscope fractured dentinal surface of the teeth of certain mammalian species. What was significant about this work, was that they were able to give a good description of the inner walls of a dentinal-tubule - a sight which was beyond the wildest dreams of the light microscopist.

The interface between peritubular and intertubular dentine, stands out in ground sections. In early studies using the light microscope, this interface was termed the sheath of Neumann, but since the introduction of the electron microscope no such anomaly has been able to be demonstrated.

Interglobular dentine refers to the fact that dentine is sometimes mineralised in small globular areas which finally grow together to form uniformly calcified dentine. If this fusion does not take place, unmineralised or hypomineralised areas remain between the globules - thus interglobular dentine.

Of particular significance to this study is an anomaly seen in ground sections - the Tomes granular layer. This feature was first seen in the light microscope and its presence has not been doubted by far reaching electron microscopy. This layer of dentine adjacent to the cementum is found only in the root and is believed to be made up of tiny areas of interglobular dentine.

7.3 Short History of S.E.M. Studies

One of the first to investigate dentine under the S.E.M. was Johansen (1964) who was able to measure the size of an individual apatite crystal in dentine. By stereoscopic observation he saw these crystals as "plates on edge" with their longest dimension being 1,000 Å and thickness varying from 20 - 35 Å. Such a finding was hitherto unheard of with only the scant resources of the light microscope available.

Boyde and Lester (1967 A) and 1967 B) were pioneers in the ultrastructural studies of dental hard tissues.

Mjor (1972) pointed out that the "assessment of the normal relationship between the inorganic and the organic fractions simultaneously is difficult, but it is possible, for example, with the use of the electron microscope techniques." (Vide beginning of this Chapter.) He showed quite conclusively with the aid of microradiographs that the peritubular dentine was more highly mineralised than intertubular dentine.

Tojo et al (1975) examined the dentinal surface, fractured at right angles to the dentinal tubules. They demineralised the area with 1/20 N Formic acid for 20 seconds. They distinguished three structures within the dentinal tubule - a membranous tubular structure, a thick walled tubular structure and a solid structure. They surmised that these structures belonged to the odontoblastic process - thus

revealing it to be more complex than was first seen with the light microscope.

Boyde and Sela (1978) were able to demonstrate the presence of calcifying globules or calcospherites in the dentinogenesis of permanent tooth germs of young rhesus monkeys.

CHAPTER 8

HISTOLOGICAL AND OTHER STUDIES OF DENTAL HARD TISSUE RESORPTION

8.1 Introduction

The fact that roots of teeth resorbed after some trauma was first reported in the literature by Bates (1856). Numerous reports followed this publication - all concentrating on the supposition that root resorption was a pathological process.

Ketcham (1927), Rudolph (1936) and Becks (1939) studied the effects of orthodontic tooth movement on root resorption and although arriving at widely varying conclusions did all agree that root resorption could occur in certain individuals in the absence of any trauma, infection or orthodontic force. We must also remember that the early investigators relied almost solely on radiographic evidence, which at most times only showed advanced root resorption.

8.2 History

Henry and Weinmann (1951) using the light microscope made a quantitative analysis of the resorption pattern of cementum of permanent teeth in terms of number, size, distribution and types of resorption areas. By studying histologically fifteen human dentitions from persons brought for autopsy, they reached some interesting conclusions:-

1. They reported root resorption in 90.5% of the teeth examined and certain of those teeth had many episodes or resorption.
2. It is "normal" but not physiologic for the root surface of a tooth to incur resorption to some degree during its life. This point was later hotly disputed by Reitan (1975).
3. Resorption occurs more readily upon surfaces which are facing towards the direction of physiological movement.
4. The size of a resorption area is a good indication of the severity of the trauma to which the tooth has been subjected.

Massler and Malone (1954) using radiographs compared the dentition of randomly selected people with the dentition of orthodontically treated patients. They found a marked increase in the severity of the resorptive processes in orthodontically treated teeth, while the number of teeth involved increased from 81% to 92%. We must once again raise the question as to whether radiographs are an accurate or worthwhile method of measuring root resorption.

8.3 Quantitative Analysis

With the increasing availability of the electron microscope in the early 60's a more quantitative approach to the cause

and effect of root resorption was possible.

Sognnaes (1963) said: "The dental hard tissues are subject to bone like resorption processes in the presence of osteoclast like multi-nucleated giant cells situated in characteristic Howship's lacunae along resorbing surfaces of cementum, dentine and even enamel." This author goes further to say that the origin of the multinucleated osteoclasts (more aptly named odontoclasts) cannot be traced back to the fusion of single nucleus cells within the tissue undergoing resorption. Neither enamel, dentine nor cementum have such cells (undifferentiated mesenchymal cells). We saw in previous chapters that cementum has an interstitial cell - the cementocyte, but primary cementum is completely acellular.

8.4 Theories on the Resorption Process

Sognnaes believed that the process of resorption was due to the consistent presence of a highly vascularised tissue in immediate contact with the resorption site. This tissue is rich in giant cells capable of becoming odontoclasts.

Bien (1967) felt that root resorption was caused less by the magnitude of the forces than by the rate of application of these forces. Using the phrase "teeth are fluid cushioned." he hypothesised that root resorption was finally due to tiny bubbles of CO_2 which were liberated at the root apex. A drop in pH is assumed to occur and acid dissolution of the

root follows. He based his findings on animal experiments, histological data and a study of fluid dynamics. Bien was not alone in his hypothesis, for previously Goldhaber (1965) had listed CO_2 as a bone resorbing factor.

Dellinger (1967) using four *Macaca speciosa* monkeys, studied tooth intrusion. He noted that the degree of root resorption was directly proportional to force used (agreeing with Henry and Weinmann (1951)) and there was an optimal force possible, which could intrude teeth and at the same time minimise root resorption.

8.5 Modern Day Workers

Boyde and Lester (1967 A) investigated the resorbing surfaces of exfoliated or extracted human deciduous teeth. The authors used both the scanning electron microscope and the transmission microscope to study enamel, dentine and cementum. "The great depth of focus of the scanning electron microscope gives it (thus so far unique) ability to form coherent images of such very deeply embayed surfaces as those presented by Howship's lacunae."

The stereo pair images of carbon replicas obtained with the transmission electron microscope showed a considerably better resolution (c.a. 20-30⁰A) than the scanning micrographs (200-500⁰A).

In inorganic dentine they saw resorption, evidenced by the presence of deep Howship's lacunae with clearly defined edges. Where two or more lacunae met beneath the surface, a large irregular particle of dentine would be released. The peritubular dentine was seen to project above the level of the surrounding intertubular dentine. A zone immediately surrounding the peritubular dentine was found to be eroded deeper (like a moat) into the surrounding intertubular dentine. Completely sclerosed dentinal-tubules were quite prominent on the resorbing surface. Perhaps the most significant point to emerge from this study was that peritubular dentine was more resistant to osteoclastic resorption than the surrounding intertubular dentine. Since it is an accepted fact that resorption is basically a demineralisation effect the authors could not decide how a highly mineralised area such as peritubular dentine was not demineralised first.

The characteristic general features of resorption bays in the cementum was that their edges were very sharp. The joining together of several Howship's lacunae often gave rise to considerable undermining. The resorbing front was seen to be interrupted by a series of minute projections which the authors tentatively identified as sclerosed cementocyte canaliuli: However, where the resorption front had entered the dentine, these projections could be attributed to surface manifestations of completely sclerosed terminal branches of dentinal tubules.

Tayer, Gianelly and Ruben (1968) set out to study the histogenesis of cells involved with orthodontic tooth movement. In an experiment on a dog they were eventually to agree with Sognnaes (1963) - that a proliferative response of cells accompanied tooth movement and that this cell increase was aimed at production of resorption cells.

Stenvick (1969) subjected twenty five human teeth to experimental intrusion prior to extraction for orthodontic reasons. Typical Howships lacunae were observed in all but five of the teeth. In fifteen of the affected teeth odontoclasts were to be seen in the Howship's lacunae although the frequency of the lacunae greatly outnumbered the resorptive cells. In nine of the teeth, resorption and repair seemed to be taking place at the same time.

8.5 Piezo-electricity and Root Resorption?

De Angelis (1970) in a study of the response of alveolar bone to orthodontic force, surmised that since dentine had been shown to have piezo-electric properties (Shamos and Levine (1976)), cementum being a similar material must also have such properties. They concluded that root resorption may be attributable to a force magnitude or duration sufficient to initiate cementoclasia by stimulation of piezo-electricity within cementum.

8.7 Root Resorption and Subsequent Repair

Timms and Moss (1971) concerned with the "paucity of literature" on histological findings in rapid palatal expansion conducted a study on eight patients. Each patient (five boys and three girls) had been treated with rapid maxillary expansion. Following expansion the teeth (either upper second premolars or upper first molars) were removed surgically after periods ranging from six months to twenty three months. The histological findings were significant, in that there was root damage (resorption) to every tooth. In all areas where resorption had occurred, the cementum and dentine had been repaired with osteoid tissue. This included even teeth extracted after two years wherein there was evidence of recent root resorption.

8.8 Amount of Force and Duration of Force as Factors

Buck and Church (1972) repeated what Timms and Moss had said - a lot of animal experiments had been carried out, but the literature was lacking in histological findings on human tooth movement. Ten girls and two boys who would subsequently require removal of premolars for orthodontic treatment were used in this study. An appliance was used to tip the experimental teeth buccally with a force of 70 ± 7 gms. The teeth were extracted from different groups at fourteen days, twenty one days and twenty eight days respectively. There was no evidence of root resorption on teeth extracted

after fourteen days, but at twenty eight days, root resorption was relatively extensive. As only very light forces were used, this could account for lack of early root resorption.

Reitan (1972) who has been the most prolific writer on the histological background of tooth movement since 1951 discussed the mechanisms of apical root resorption. He used seventy two human premolar teeth obtained from thirty two patients. Before extraction he subjected the teeth to tipping, extrusion and intrusion after using a varying amount of force. An unexpected finding was that five teeth out of thirty that had been subjected to extrusion forces showed evidence of resorption lacunae around the apex. The author considers this to be the exception rather than the rule. Root resorption occurred in a majority of cases but resorption lacunae were superficial and small, provided moderate forces were used and this resorbed surface will be reconstructed with cellular cementum.

Kvam (1972) by attaching an appliance capable of exerting a force of 50 gms. in a lateral direction to forty teeth, was able to study tissue changes after they were extracted. The teeth were removed after 5, 10, 15, 20, 25, 30, 35, 45 and 76 days of activation and studied under the S.E.M. Kvam contained his study to the marginal and middle region of the root. Initially some small resorption lacunae were present but in specimens treated for longer than thirty

five days all root surfaces showed extensive resorption. At first the marginal root portion was particularly affected and subsequently also the mid-portion became affected. After 25, 35, 45 and 76 days the resorption lacunae involved the dentine but they were not particularly deep. Kvam also agreed with Boyd and Lester (1967 A) when he noted the presence of smaller diameter tubules in the dentinal surface which he took to be side branches of larger dentinal tubules.

8.9 Resorption Prone Individuals

Kvam also pointed out that the S.E.M. was capable of spotting very small resorption lacunae on control teeth that had never been subjected to orthodontic forces. He agreed with Henry and Weimann (1951) when he deduced that these resorption lacunae were due to forces from physiological movement. It is for this very reason that Reitan prefers to use the light microscope when making a quantitative assessment of resorption defects. Following this discovery Kvam is in agreement with Ketcham (1929) and Massler and Malone (1954) when he states that some individuals are more prone to root resorption than others.

8.10 Begg Technique as a Cause of Root Resorption?

Wainwright (1973) studied facio-lingual or "round tripping" movements of teeth by supplying a force to move teeth backwards and forwards. He designed his experiment around four

Macaque speciosa monkeys at a stage of development comparable to late adolescence in the human. Wainwright appears to criticise the Begg technique when he suggests that a technique that utilises uncontrolled tipping followed by axial uprighting is not good for the tooth. He found that equal amounts of resorption occurred on both buccal and lingual surface and with the aid of injected Procion dye, he was able to show that resorption continued after the force was released from the tooth. Perhaps a criticism of Wainwright's work would be that he conducted his experiment on monkey premolars which are multi rooted.

Storey (1973 B) in a paper, summarising his work on tooth movement during the past twenty five years, suggested "that the same factors which induce bone resorption are operating, but in a somewhat haphazard fashion, perhaps related to blood supply or a discontinuity of collagen fibres across the periodontal space." He also gained the impression that dentine takes a lot longer than bone to resorb.

Rygh (1977) published a paper entitled "Orthodontic Root Resorption studied by Electron Microscopy." This was a sequel to work he had completed in 1972 and 1973 and was a monumental work in which the maxillary first molar was moved buccally in 67 Wistar rats. An appliance was activated to provide a constant force of 5, 10 or 25 gms. The experiment periods were 30 mins, 2, 6, 12, 24, 48 and 60 hours and 5, 14 and 28 days.

Also human material was used consisting of 11 premolar teeth that were moved buccally by means of a fixed appliance for periods between two and fifty days. Forces used in the experiment were 70, 100, 120 and 240 gms. and these teeth were subsequently removed surgically along with the surrounding tissue.

He concluded -

1. Once the barriers of collagen and cementoid disappear after hyalinisation, the cementum is left "raw" and open to resorptive processes to take over.
2. When a resorption lacuna has been formed it represents a "break through" to start the resorptive process. The study clearly indicated that cementum on the edge of the lacuna is resorbed from the rear, even when the cementum had a normal periodontal surface.

He agreed with Reitan (1972) that if the application of force is absent or is below a certain level, then repair will commence in resorption lacunae.

Also like Reitan, Rygh, studies the tooth firstly with the light microscope. His findings are very pertinent to this study. All free homogenous areas in the rat periodontium were evident in as little time as 6 - 12 hours. Extensive hyalinisation was evident in 2-3 days.

He saw large multinuclear cells near the cementum surface, some distance from the hyalinized zone, particularly in specimens of longer experimental period. When sectioning the root it was found that these multinuclear large cells were part of a group of cells that were actually resorbing dentine and cementum.

Under the electron microscope the odontoclasts showed numerous mitochondria and vacuoles. The part of these cells adjacent to the cementum revealed a complicated system of folds and deep penetrating clefts corresponding to the ruffled border of osteoclasts.

8.11 Identification of the Resorption Causing Cell?

Yaacob (1981) made a histopathological study of eighteen erupted and eight unerupted teeth, which showed signs of idiopathic external resorption. He found the brush or ruffled border of the osteoclast difficult to find thus agreeing with Ham (1969) but disagreeing with Rygh (1977). Yaacobs finds showed that the osteoclasts are actively involved in root resorption - this being accepted theory, but that the accompanying mononuclear cells took no active part in resorption.

8.12 The Origin of the Clastic Cell

He theorises on the origin of the osteoclast:-

1. They arise from precursor cells, adjacent to the surface of the bone, which may or may not group to form the multinucleated cells we see in Howship's lacunae. This is not the theory of Sognnaes (1963)
2. They evolve from wandering cells (macrophages, histiocytes or a monocyte) that move to the bone surface and thus coalesce to form multinucleated cells.

8.13 Footnote

It must be accepted that a clastic cell is present which erodes the tooth root surface. Whether this cell be called osteoclast or odontoclast matters little. What does concern the writer is what triggers the cell to appear. Is it a pure pressure-tension reaction? Are the cells attracted due to a piezo-electric effect? This "triggering mechanism" demands more study.

CHAPTER 9

PRESENT STUDY

INTRODUCTION

On reviewing the literature on rapid and slow expansion there appeared to be a number of questions left unanswered. Certainly it has been written many times that the stronger the force - the more damage we can expect to the tooth root. However, could we as clinicians expect to find less resorption using a supposedly less forceful device such as a quad-helix appliance.

It must be remembered, that whilst the dental changes with these two methods are comparable (i.e. arch expansion) the overall changes are significantly different. Slow expansion exhibits a greater tooth movement, whereas rapid expansion show a greater orthopedic effect. Thus, using different biomechanical principles, we might anticipate different tissue responses.

EXPERIMENT 1.

Aims

To assess and compare, using electron photomicrographs, the extent and pattern of root resorption of extracted teeth. These teeth would be collected from patients who had therapy from :

- (i) The Quad-Helix Appliance.
- (ii) The Hyrax Screw Appliance.

Patient Sample

The Author was able to collect teeth from ten patients during the period June, 1980 to September, 1981. All of the patients in the slow expansion group were either treated by or their treatment was supervised by the author.

Those patients treated with rapid maxillary expansion were selected from within the clinics of the United Dental Hospital or from orthodontists in private practice. The sample size of this group was small as an attempt was made to standardise the experiment by studying only those teeth that had been moved with the Hyrax (Dentaurum) expansion appliance. Furthermore, many orthodontists find it unnecessary to remove teeth after rapid maxillary expansion, and so it was not expected to obtain a large study sample.

A total of forty teeth were examined microscopically for areas of resorption, i.e., twenty upper teeth, subject to expansion forces and twenty lower teeth, being the natural antagonists of the upper teeth.

Patients were selected for treatment when -

- (a) There was an excess of dental material in the mouth, thus necessitating removal of four tooth units. These were the teeth used for the study.

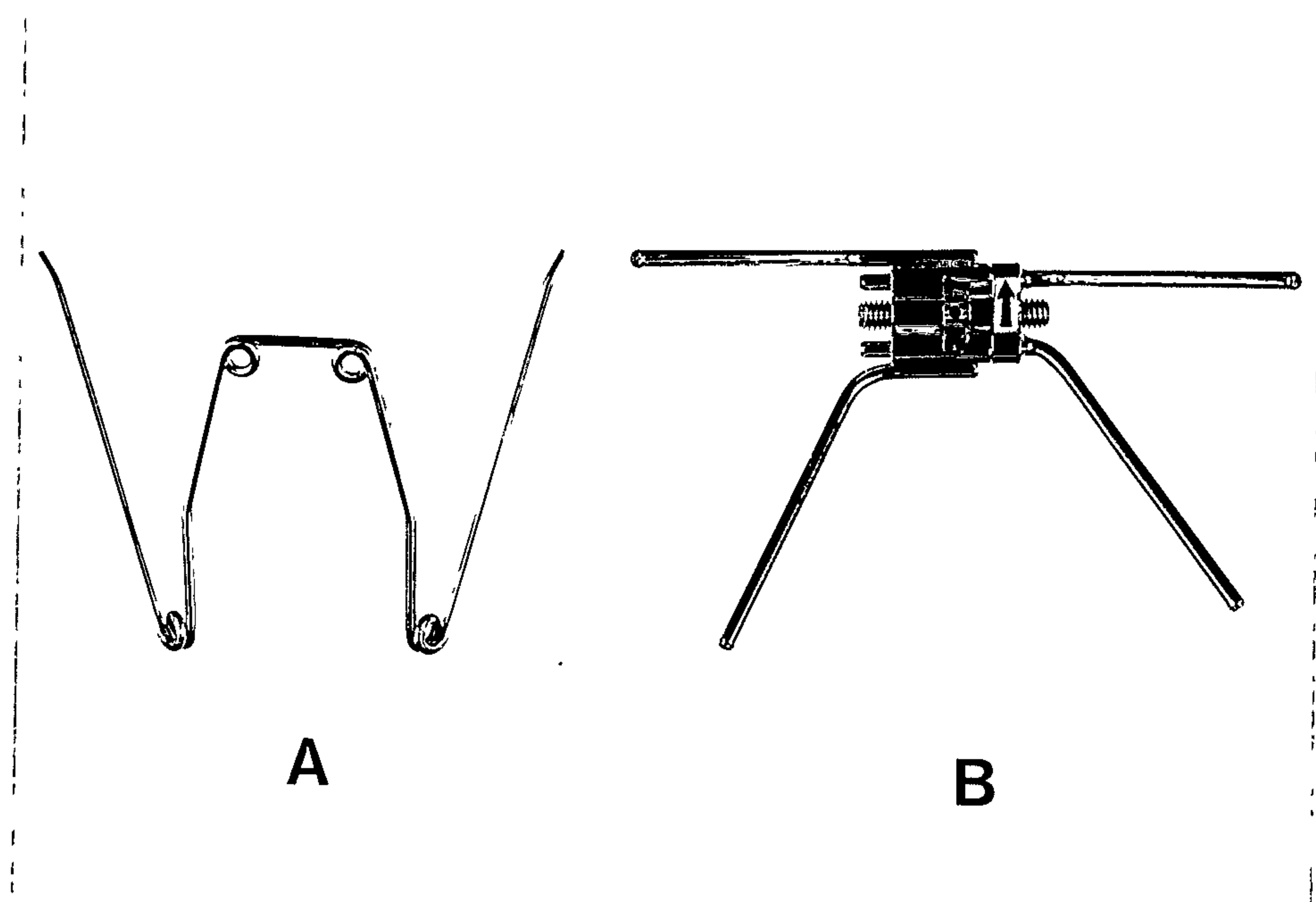


Fig. I The appliances used in this study
(A) Quad Helix (B) Hyrax appliance.

- (b) There was present a unilateral or bi-lateral cross bite, which required correction before any further orthodontic therapy was undertaken.

Patients were divided into two groups: Group I - the slow expansion or Quad Helix Group and Group II - the rapid expansion or Hyrax Group.

GROUP I - THE QUAD-HELIX GROUP

<u>Patient</u>	<u>Sex</u>	<u>Age at start of treatment</u>	<u>Treatment time</u>	<u>Teeth removed</u>
S.D.	F	15.3	3mo	All 4's
S.M.	F	12.3	3mo	" "
L. McL.	F	14.2	3mo	" "
S. McP.	F	13.8	3mo	" "
C.A.	M	14.4	3mo	" "
L.T.	F	11.10	3mo	" "

GROUP II - THE HYRAX GROUP

<u>Patient</u>	<u>Sex</u>	<u>Age at start of treatment</u>	<u>Treatment time (wks)</u>	<u>Retention Period</u>	<u>Teeth removed</u>
M.B.	M	12.4	2	2mo	$\frac{6}{6}$ $\frac{6}{6}$
M.S.	F	13.3	3	3mo	$\frac{4}{4}$ $\frac{4}{4}$
S.T.	M	12.4	2	4mo	$\frac{4}{4}$ $\frac{4}{4}$
R.F.	M	16.11	3	2mo	$\frac{4}{4}$ $\frac{4}{4}$

APPLIANCES

GROUP I

All quad-helix appliances were bent from 0.9mm yellow Elgiloy wire, following as closely as possible the specifications laid down by Birnie and McNamara (1980). The completed appliance was then soldered to selected bands, there being no heat treatment. The arms of the device were expanded one half a tooth on each side and then cemented to the upper first molars with zinc oxy-phosphate cement. The patient was instructed to return for observation in six weeks at which time the appliance was removed from the mouth, reactivated and recemented. Treatment was stopped when the lingual cusp of the upper molar contacted the occlusal slope of the buccal cusp of the lower molar. This was considered to be the least amount of expansion desirable. In some patients a complete buccal cross bite ensued but the treatment goal was achieved for all at the second observation appointment, i.e. 12 weeks.

GROUP II

Bands were selected and, after impression taking and model pouring, the appliance was constructed. The expansion screw was placed centrally and as high as practicable in the vault of the palate. Parents were instructed in the method of turning the screw in the mouth, i.e., from in front, clockwise.

They were also instructed to turn the screw once in the morning and once at night. This resulted in a daily expansion of 0.4mm with a total expansion of approximately 7mm for each screw.

Expansion was considered adequate in all cases in 2-3 weeks. The appliance was then used as a retainer (by wiring the screw) and further activation was not possible. Retention periods varied greatly among the group due to a variety of factors.

EXPERIMENTAL METHOD

After extraction all teeth were placed in a 10% buffered solution of neutral formosaline. Once required for scanning electron microscope examination, the specimens were rendered anorganic. This was achieved by immersing the specimens in a cold 5% solution of sodium hypochlorite for 24 hours at room temperature. The teeth were then thoroughly rinsed in distilled water and dehydrated in a series of ascending grades of alcohol. The last stage was to place the specimens in a dessicator and to dry them thoroughly at room temperature. In most studies of teeth using the scanning electron microscope cracking occurs. This annoying phenomenon is regarded by most workers as an unavoidable artefact. However, it was the author's experience to see that it is possible to avoid most cracking in the preparation of teeth if the last vestige of water is removed from the tooth. This is only possible by (a) slow drying and (b) meticulous preparation.

After drying, the teeth were mounted on aluminium specimen stubs with a silver glue paste. (Colloidal silver in methyl-iso butyl ketone). It was then necessary to place the specimens in a sputter coating unit, where, in a vacuum of Argon gas, 50nm of gold was coated on to the specimen.

The material was then ready for examination under the scanning electron microscope. The author was fortunate to have the use of two machines. The first machine used was the Cambridge Stereoscan 150 Mk II, (located at Australian Iron and Steel, Port Kembla), equipped with energy dispersive and wavelength dispersive X-ray microanalysis facilities. Images were obtained with a high resolution backscattered electron detector (scintillator type) using derivative processing of the video signal. Generally speaking, the author found that the use of backscattered electrons, rather than secondary electrons provided a better image for dental examinations. An accelerating voltage of 20 Kv was used for all the recordings on this machine.

Photographs were taken both with Polaroid film and Kodak 4" x 5" Professional Copy film. Polaroid was used as a check for focus and film clarity and the Kodak 4" x 5" was used for permanent records. Low magnification photographs (x3) of an entire tooth was possible with the Cambridge 150 Mk.II. The author was thankful for this attribute as many previous studies have shown only the root minus the crown and thus some authenticity is lost.

Variable factors recorded below each specimen were, the scale, the accelerating voltage, the specimen number, the negative number and the mode - in this instance, backscattered electrons.

The other machine used by the author was the I.S.I. Super III A (International Scientific Company) at the Electron Microscope Unit at the University of Sydney. Accelerating voltage was kept at 15Kv and backscattered electrons were again used as the imaging source. It was not possible to obtain as low a magnification as the Cambridge machine offered. However, the high magnification photographs presented with some fine resolution.

RESULTS

All teeth were examined at first under the light microscope. Without exception, all orthodontically treated teeth showed evidence of root resorption. Resorptive bays were noted on the proximal and other surfaces of these teeth but only the bays on the pressure side of the root were examined in detail. Of the twenty lower control teeth examined, fourteen showed evidence of the presence of resorptive lacunae.

This accounts for 70% of the sample which is not as high as the figure obtained by Henry and Weinmann (1951) of 90.5%. Perhaps this was due to the average age of the present sample of 13.6 years, as compared to the Henry and Weinmann sample in which the youngest person was 16 years of age.

GROUP I

Although no strict pattern of resorption evolved, there was more of a tendency for resorption bays to occur at the coronal third of the root and the apical third on the pressure side. Patient C.A. typifies the Quad-Helix group. See Figs. 2-10. Resorption bays were present just below the cemento-enamel junction and at the root apex. Both these bays were shallow and their sides were not as steep as those of Group II. Group I resorption bay sides may be described as "saucer like" whereas Group II resorption bay sides are "cliff like". At no time was the dentine penetrated by Group I bays. It was apparent that repair and resorption were co-existent and that the undermining effect of Group II resorption bays was absent in all lesions.

The resorptive bay at the cemento-enamel junction in this patient showed very little detail. There was no evidence of Howship's lacunae or of cellular cementum repair. The same phenomenon occurred later in this study for patient T.McP (Fig.13). The author feels that this was a resting resorbing surface. A thorough examination of each bay failed to show penetration of the dentine. It was evident from Fig. 5 that repair and resorption were taking place at the same time. The presence of active, young cementocytes as evidenced by the large lacunae and surface canaliculi bore testimony to the fact that repair was taking place (see Fig.7). Higher magnification photos of this area of patient C.A. showed young freshly laid down collagen fibres.

Patient L.McL was seen to have very shallow resorption bays. Reference to the photographs of this specimen will show resorption bays in the cervical third of the root and at the root apex. Repair seemed to be ahead of resorption as cementocytes laid down immature cementum. The evidence of many cementocyte lacunae in the resorption bays indicated a vigorous repair response. Every bay examined showed a similar response and once again there was no dentinal involvement.

Patients T.McP, S.D., S.M. and S.T. all showed similar responses.

GROUP II

Both upper 1st molar teeth from patient M.B. showed extensive resorption bays on the buccal aspect of the buccal roots above the bifurcation and on the buccal aspect of the palatal root just below the trifurcation. This finding is in agreement with Rinderer (1966) but disagrees with Timms and Moss (1971). The latter found that the most marked resorption occurred on the mesio-buccal and disto-buccal aspects of the roots. An explanation of this variance may lie with the type of appliance used. However as only two molar teeth were examined in this present study, no statistical significance could be assumed. Patient M.B. also had deep resorptive lesions on the apex of all three roots.

Patient M.S. showed considerable areas of resorption at both the coronal third and apical areas of the buccal aspect of the buccal root. The buccal aspect of the palatal root also featured deep resorption bays. All areas were deep. The coronal areas and the area on the palatal root extended through to dentine. (see Fig.26). The resorption bay examined at the buccal root apex showed a repair front, evidence by many cementocyte lacunae and collagen fibres. The coronal bays also showed that repair and resorption were co-existent. The higher magnification (x5000) photo shows that a mineralised collagen front on dentine is present and thus Nature is attempting to repair the defect.

Patients S.T. and R.F. showed a similar pattern of resorption to the above.

Patient S.T. showed a long, elongated resorption bay in the coronal third of the root. There was a lesser, shallower bay at the root apex. The resorptive Howship's lacunae had exposed the very tiny peripheral openings of the dentinal tubules. (see Fig.32.) Resorptive bays were also present to a lesser extent at the mesial and distal surfaces of the root. There was a repair front (fig.33) evidenced by cementocyte lacunae, but this front appeared to be in a state of rest. Active resorption predominated over-repair in most lesions of this tooth.

EXPERIMENT 2

AIM

To reveal the presence and distribution of clastic cells in tooth root specimens that had been subjected to therapy from:-

- (i) The quad-helix appliance
- (ii) The Hyrax screw appliance

METHOD

A complete premolar tooth from patient S.T. (Hyrax group) and one from patient L.McL (quad-helix group) were placed in 12% Formic acid for two weeks at room temperature. The inorganic component of the teeth was removed in this period and the crown was able to be detached from the root. The roots were embedded in a paraffin block and sectioned at right angles to the long axis of the root with a Leitz rotary microtome. Serial sections were cut in the areas of expected root resorption i.e. buccal surface, coronal third of root. Sections were placed on gelatinized slides which were later deparaffinised and stained with Haematoxylin and Eosin.

Slides thus made were able to be examined under a Leitz Dialux 20 photomicroscope. Selected slides were recorded on Kodak Ektachrome 160 EPT transparency film and prints were later made.

RESULTS

Both groups displayed the presence of large clastic cells in and around eroded areas of cementum. Due to the multi-nucleated nature of these cells the author was safe in

assuming them to be odontoclasts. The root surface of patient S.T. appeared to have more odontoclasts abounding, but no real comparisons could be drawn due to small sample size.

A repair front was seen in the sample from patient L.McL and the role of the cementocyte in the production of new or repair cementum was shown.

DISCUSSION

This present study showed that expansive forces caused resorptive lesions in all teeth. There was a definite tendency for resorptive lesions to be less deep in those teeth subjected to lighter orthodontic forces. (The author was able to identify teeth from Groups I and II without previously having been told the origin of the tooth).

Teeth from Group I tended to have more areas of repair within their resorptive bays, whereas the reverse must be said of teeth from Group II.

No definite pattern of resorption could be attributed to either group except to say that resorptive areas were predominantly seen on the buccal surface. The resorption bays of Group II teeth were more destructive as evidenced by their ragged outline and their undermining capability.

The fact that resorption occurred at both the coronal buccal third and the palatal apex of the roots indicates a tipping movement occurring in both groups.

Since the total duration of appliance wear varied little for both groups it must be assumed that force magnitude and not longevity of treatment was the factor in repair.

RESORPTIVE AREAS

GROUP I

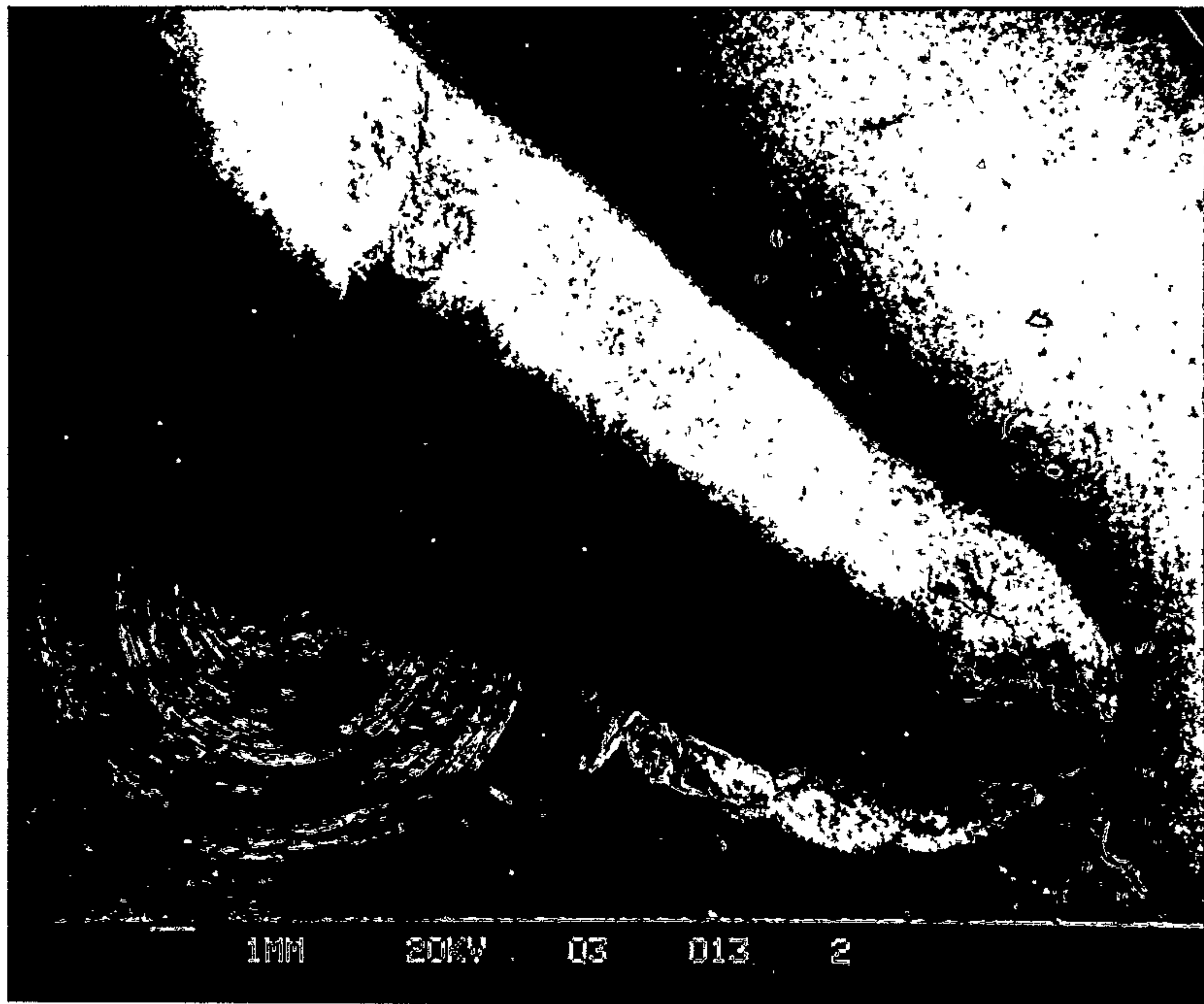


Fig. 2 Single rooted upper premolar - patient C.A. -
Group I. Resorption bays are typically seen at
the cemento-enamel junction and root apex on the
buccal surface. The middle third of the root
is free of Howship's lacunae. x 4

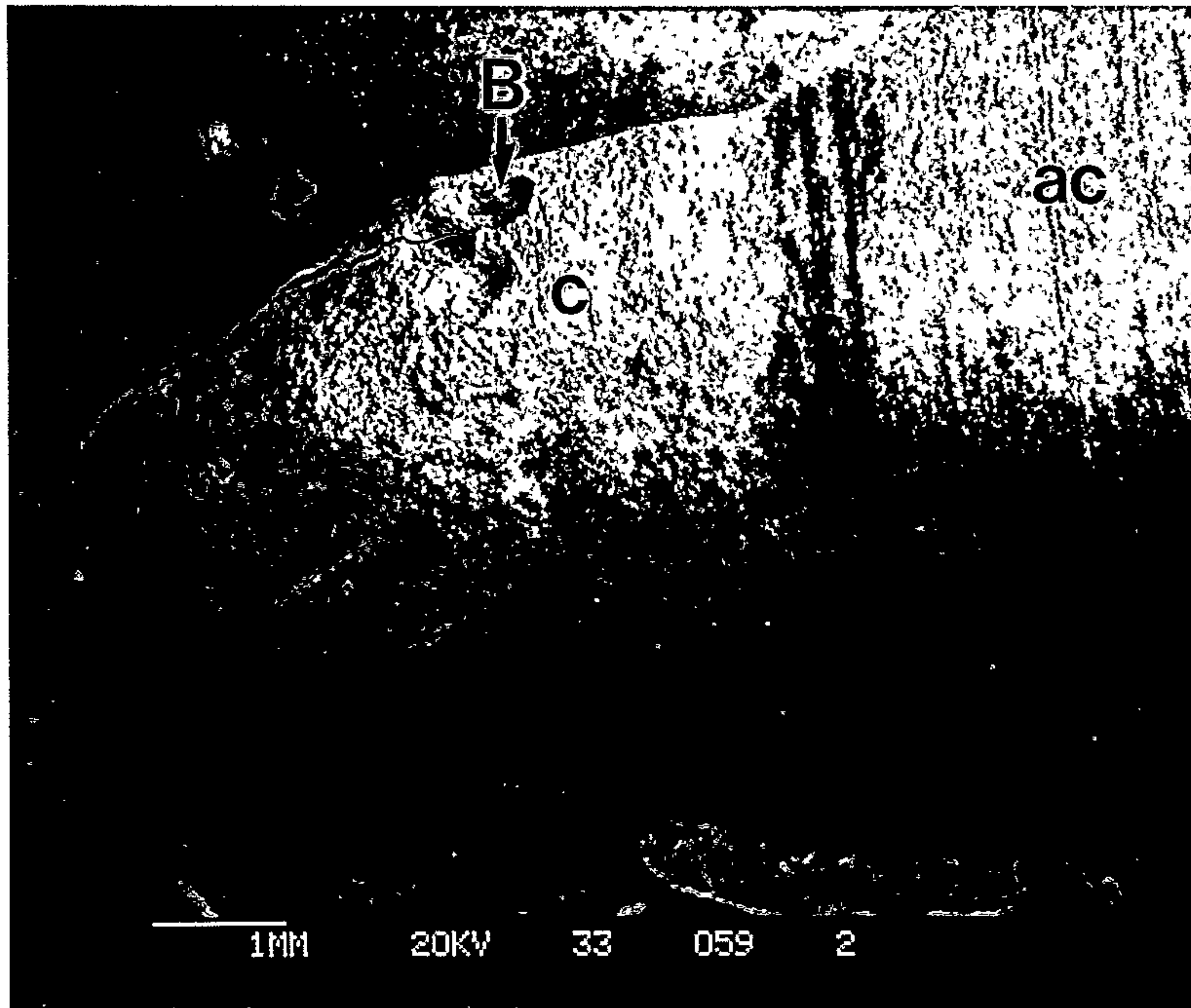


Fig. 3 Patient C.A. Higher magnification
root apex area showing resorption bay
(B) acellular cementum (ac) and
cellular cementum (c)

x 12

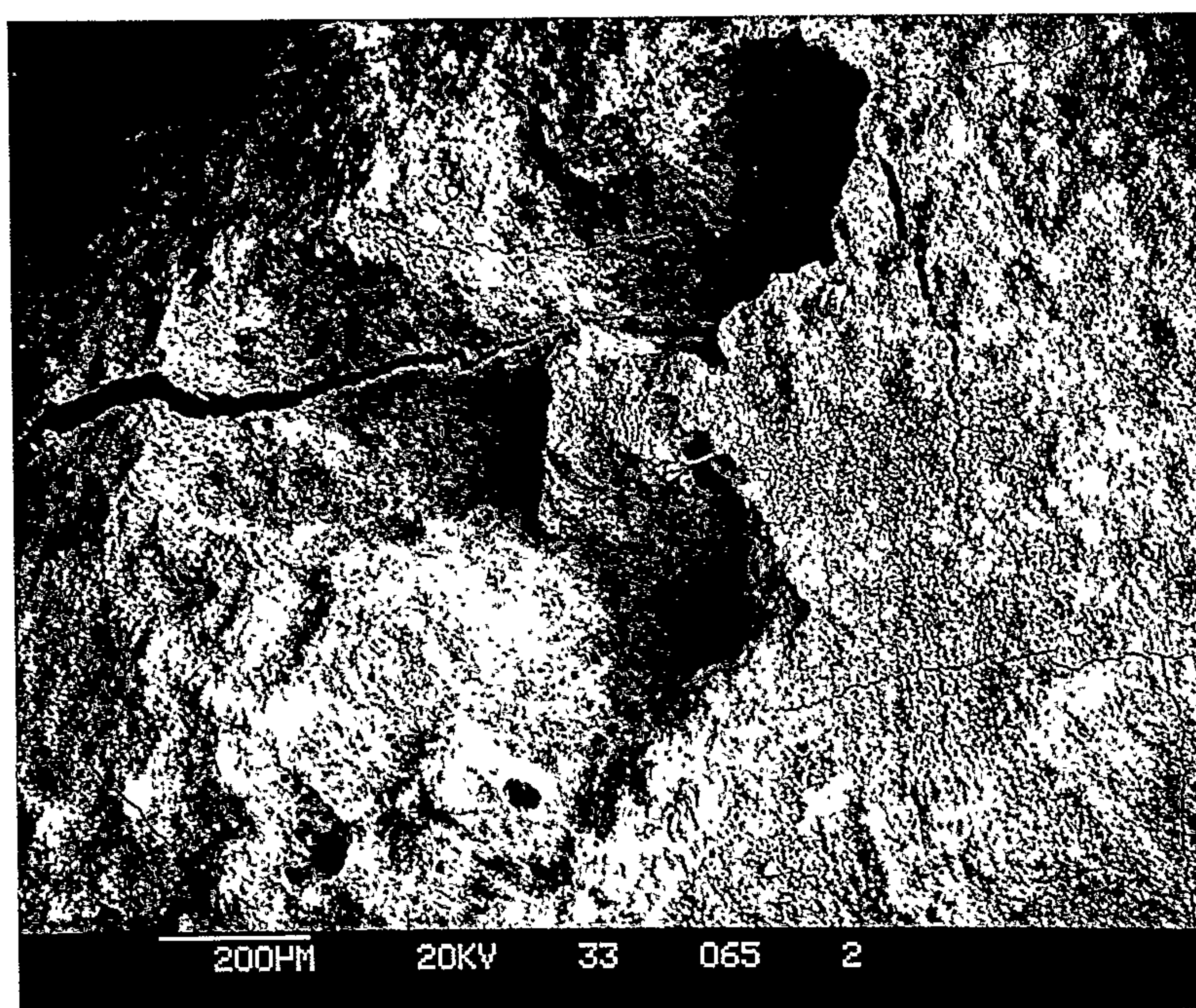


Fig. 4 Patient C.A. Tiny openings in floor of bay (from Fig.3) are cementocyte lacunae, indicating the presence of cellular cementum.

x 65

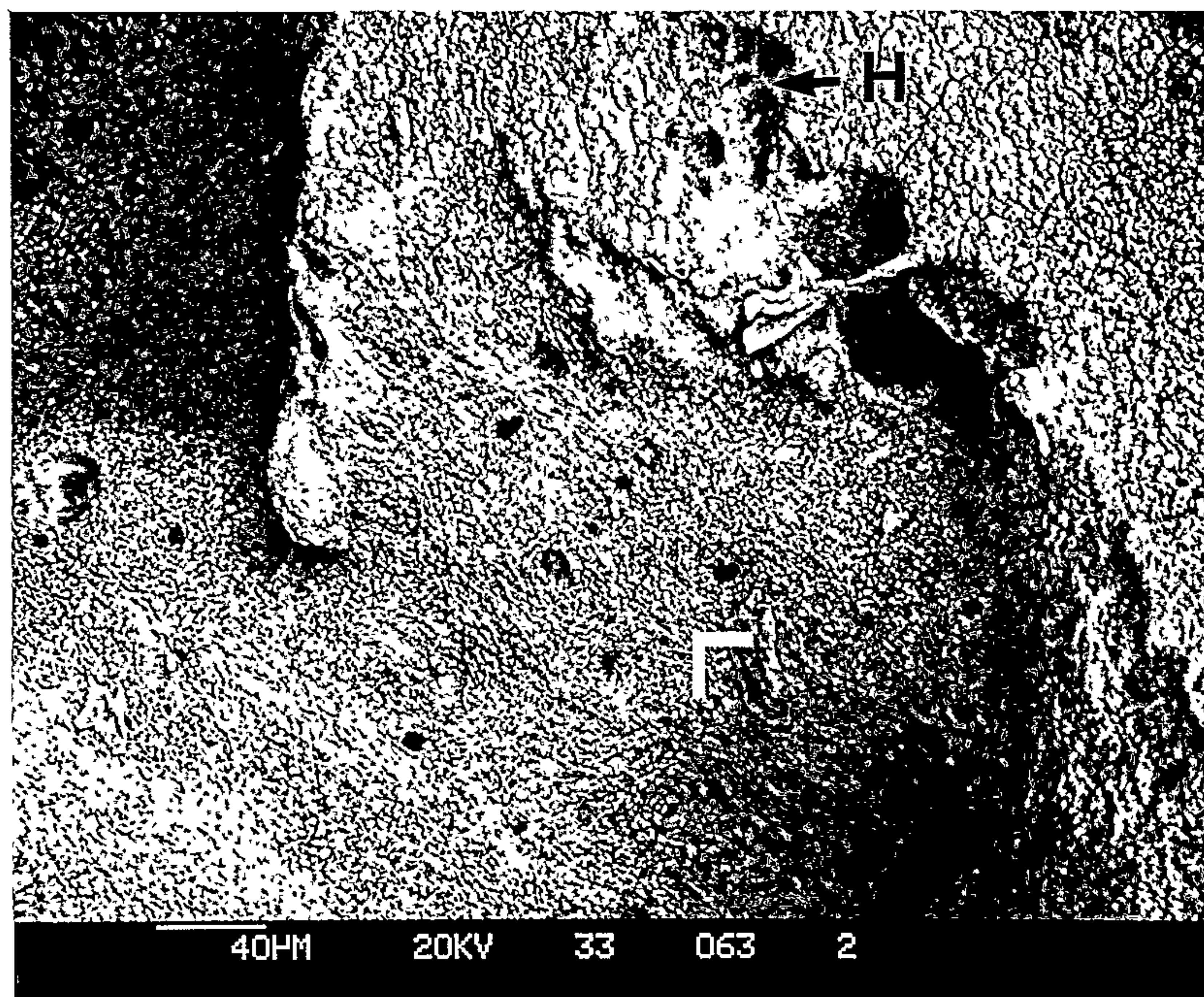


Fig. 5 Patient C.A. Detailed area - side of resorption bay - cellular/acellular cementum interface. Area A Fig.4. This photo shows the presence of Howship's lacunae at H. and mineralised front of collagen at the floor of the bay (arrowed). The many cementocyte lacunae indicate an active repair response. Repair is definitely predominating over resorption in this instance.

x 250.

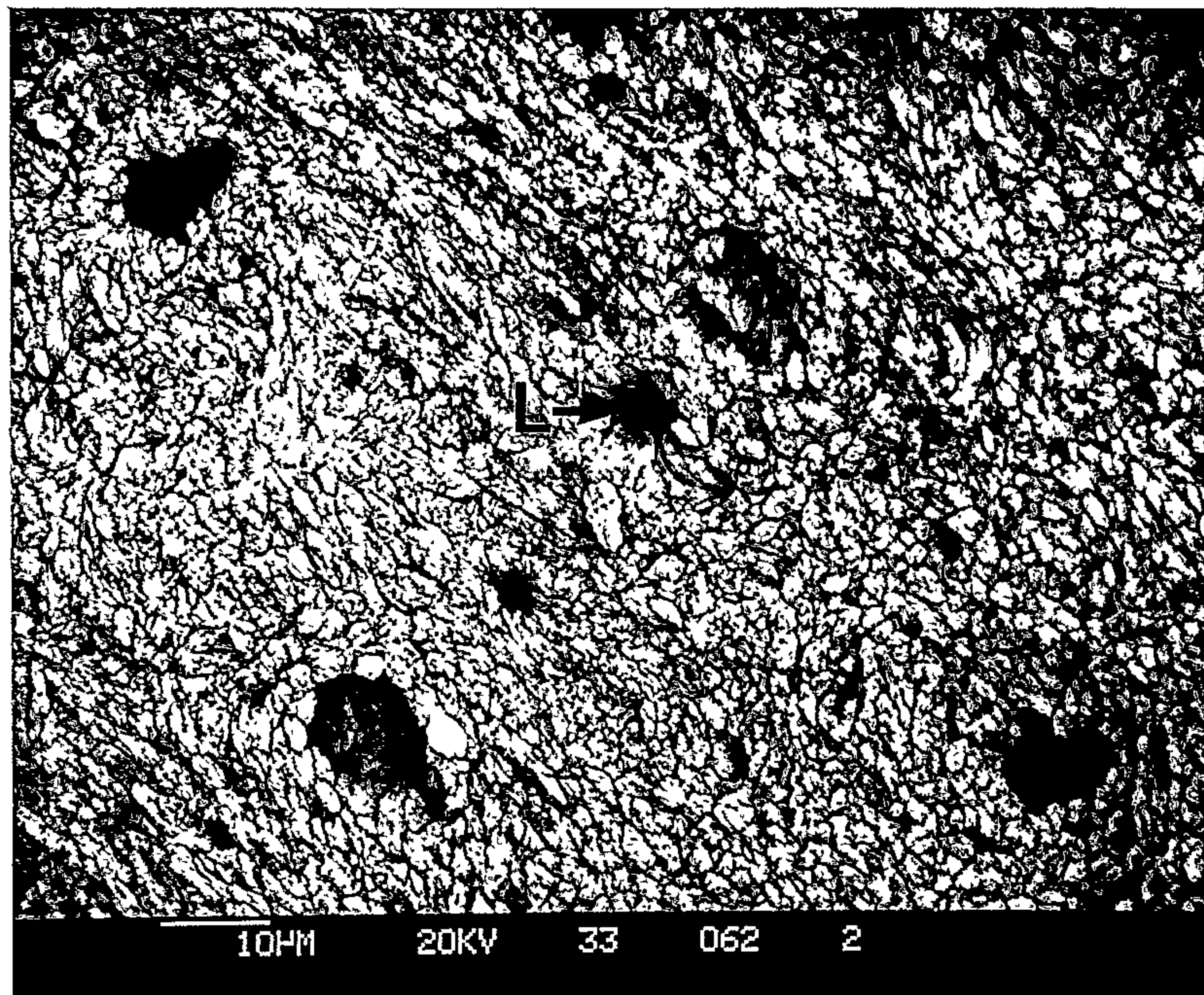


Fig. 6 Patient C.A. Higher magnification of repair
front arrowed above (Fig.5)
Cementocyte lacuna (L)

x1000

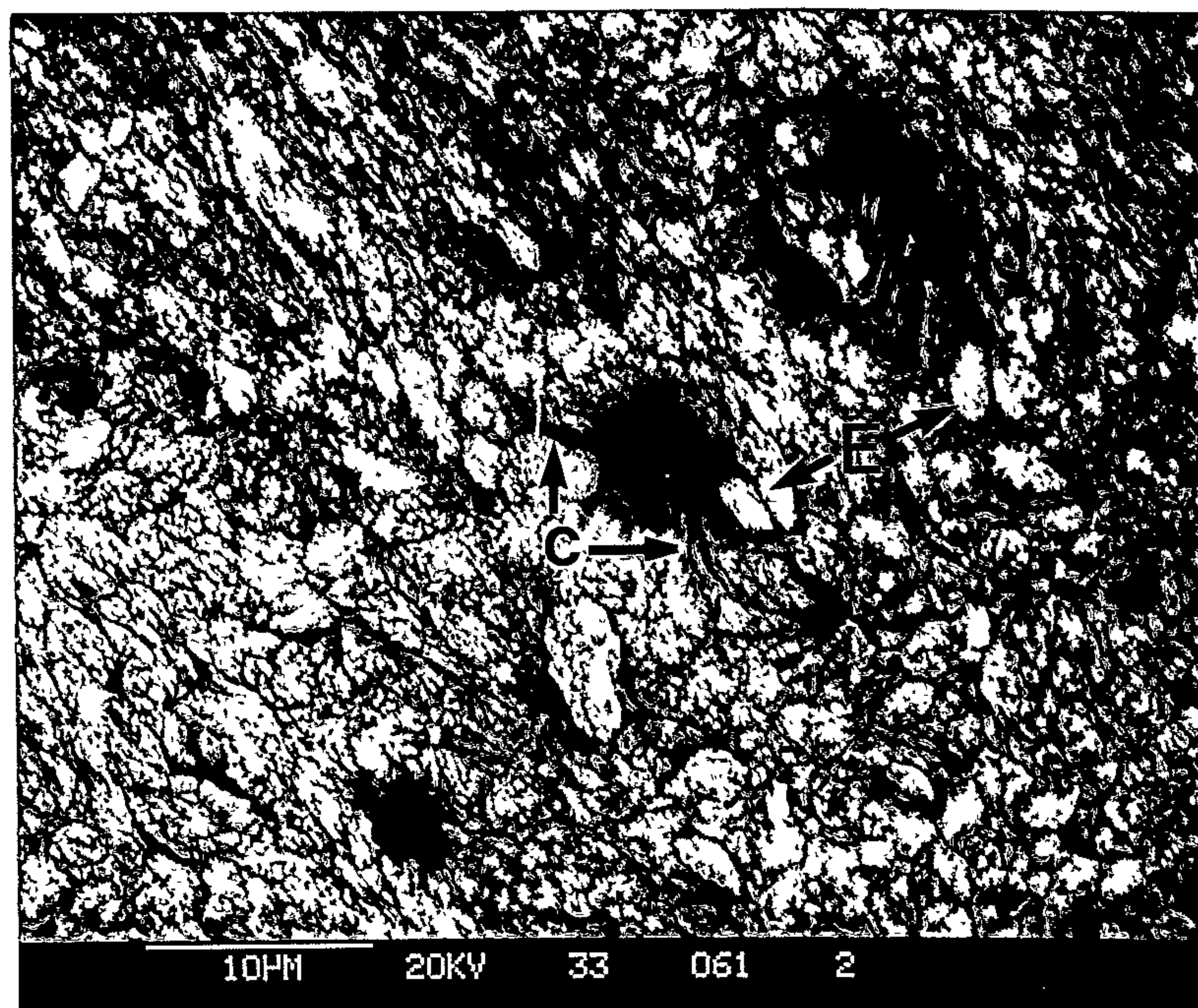


Fig. 7 Patient C.A. Higher magnification area L (Fig.6). Canaliculi (c) are evident at the opening of this cementocyte lacuna - indicating the previous site of a cell.(F) denotes the mineralising ends of collagen fibres.

x 2000

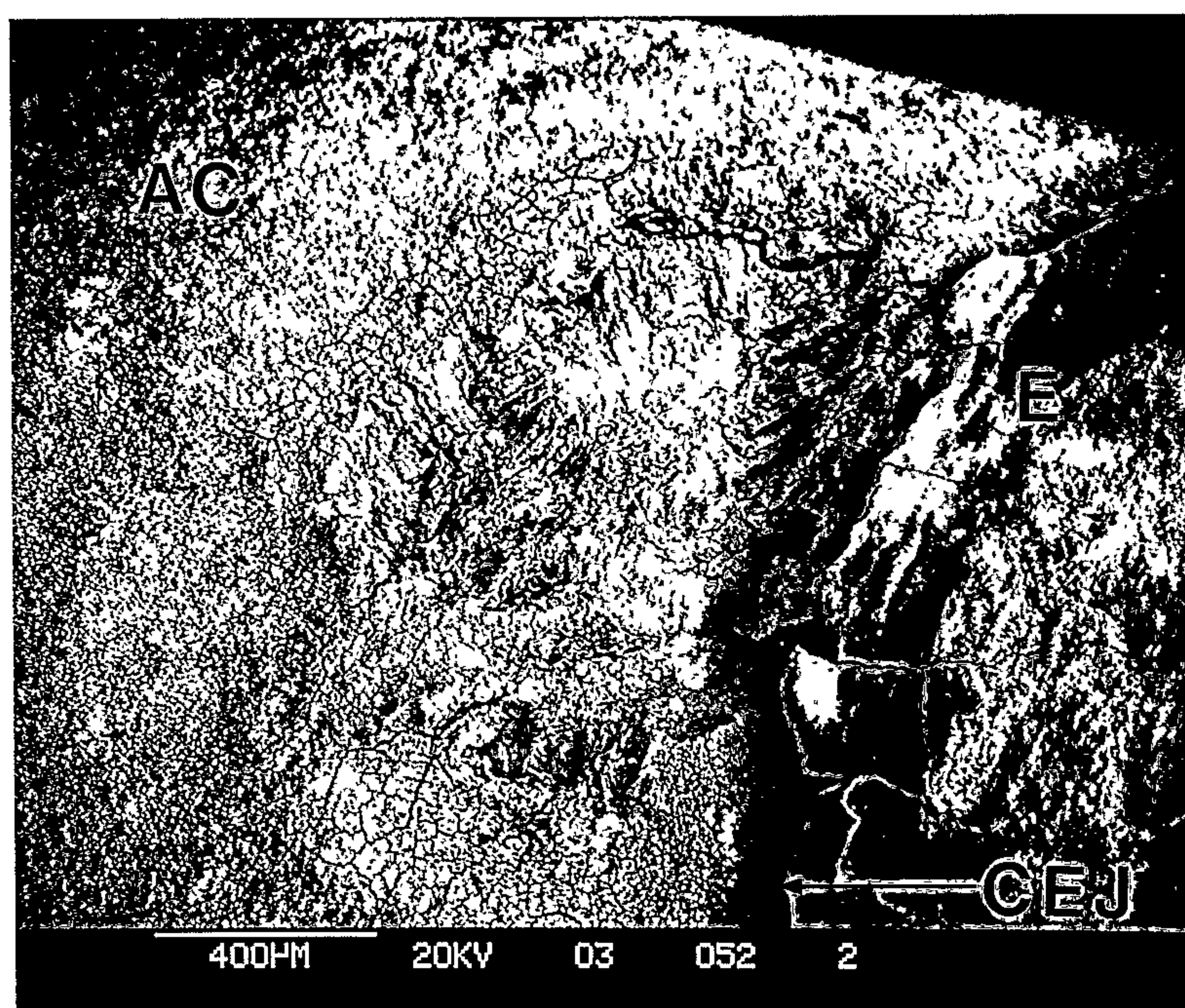


Fig. 8 Patient C.A. Resorption bay at C.E. junction
(see Fig.2). Walls are generally not as steep
as those of Group II.

(E) enamel

(C.E.J.) Cemento-enamel junction

(A.C.) acellular cementum

x 50

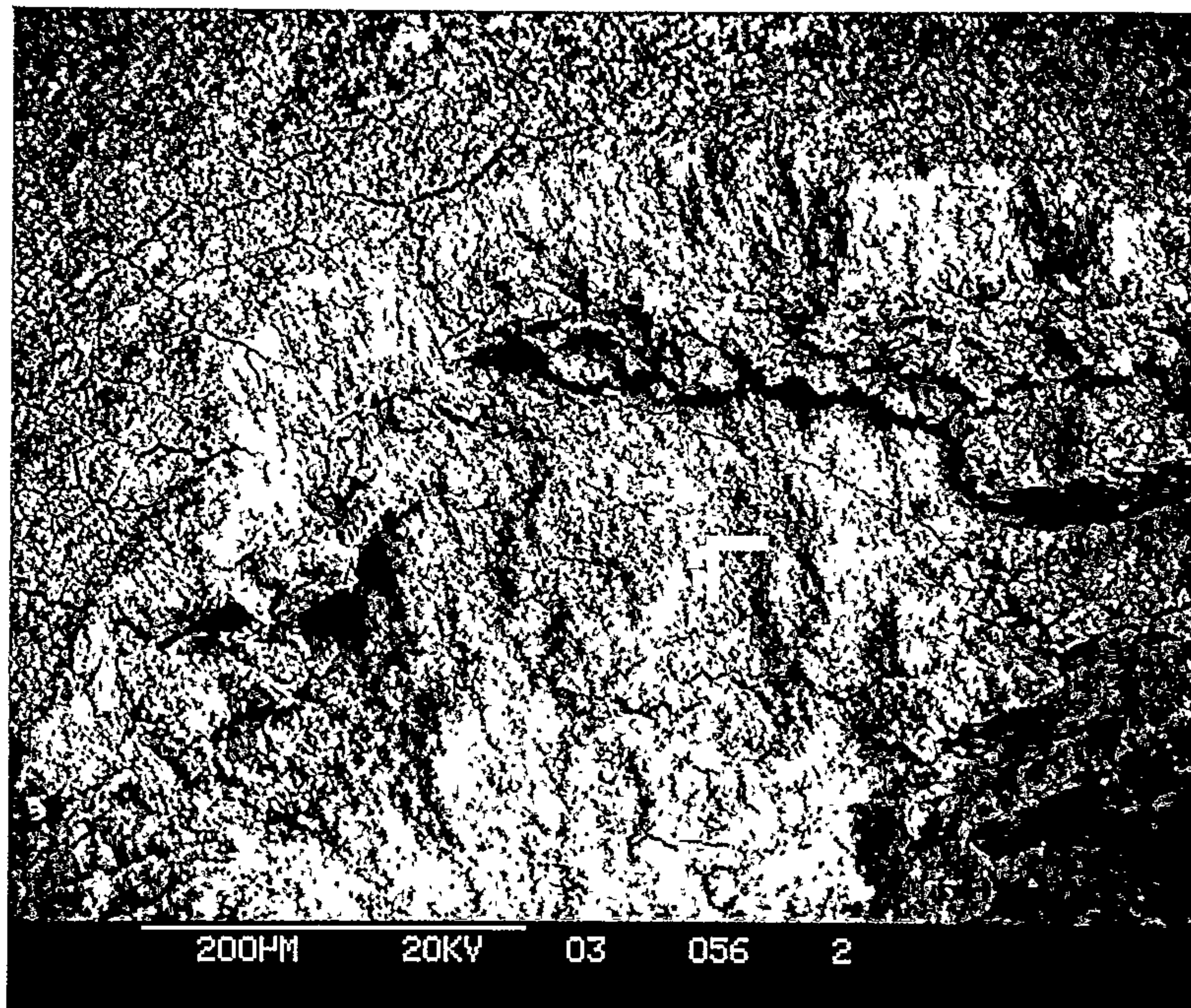


Fig. 9 Patient C.A. Higher magnification of sides and floor of resorption bay from above. This lesion is very shallow and shows only the presence of acellular cementum.

x 175

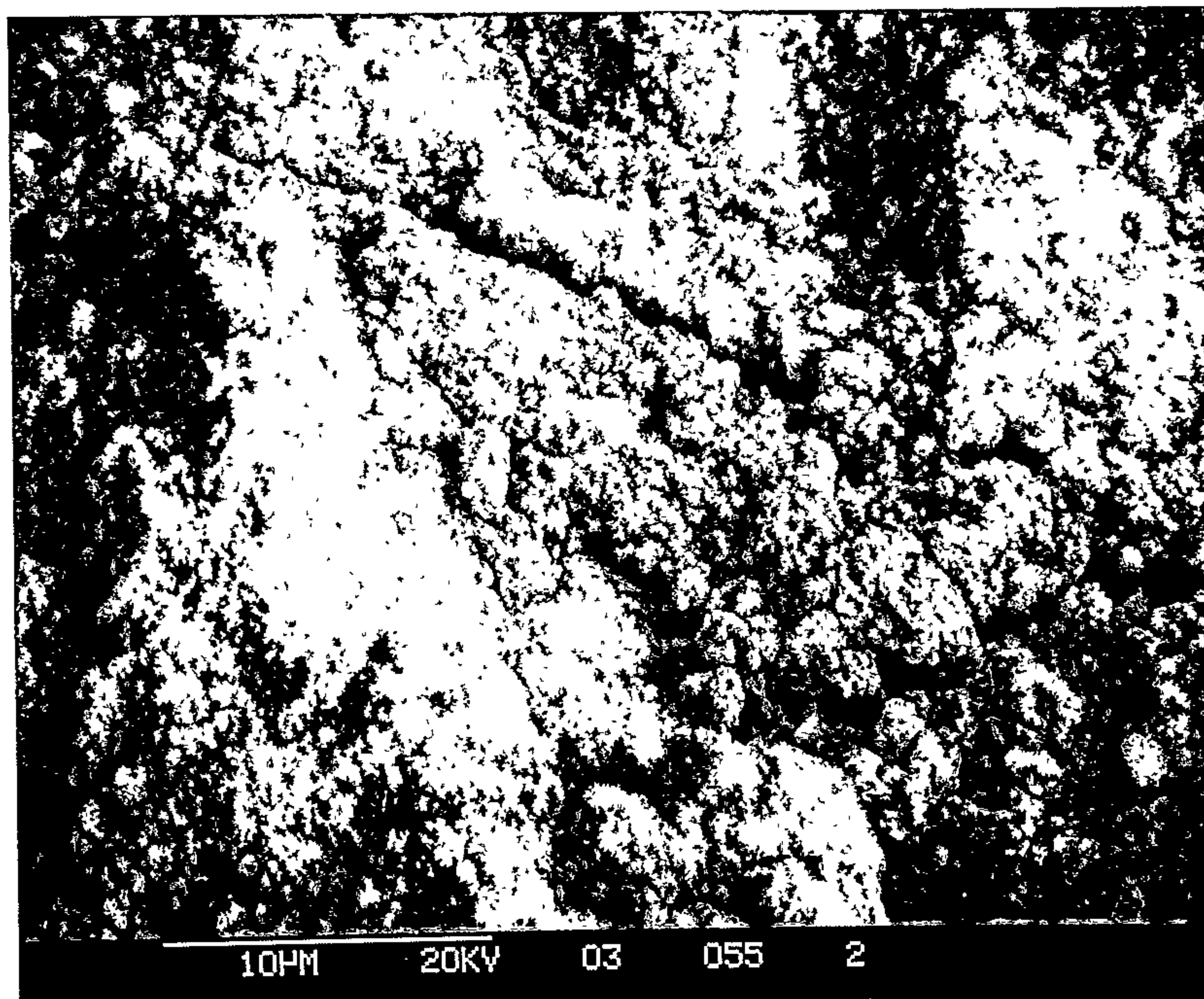


Fig. 10 Patient C.A. Floor of lesion (arrowed in Fig. 9). This is probably a resting resorbing surface.

x 3000



Fig. 11 Patient T.McP. - Group I. Root shows resorptive bays at cervical areas and root apex areas.
C.E.J. Cemento-enamel junction.

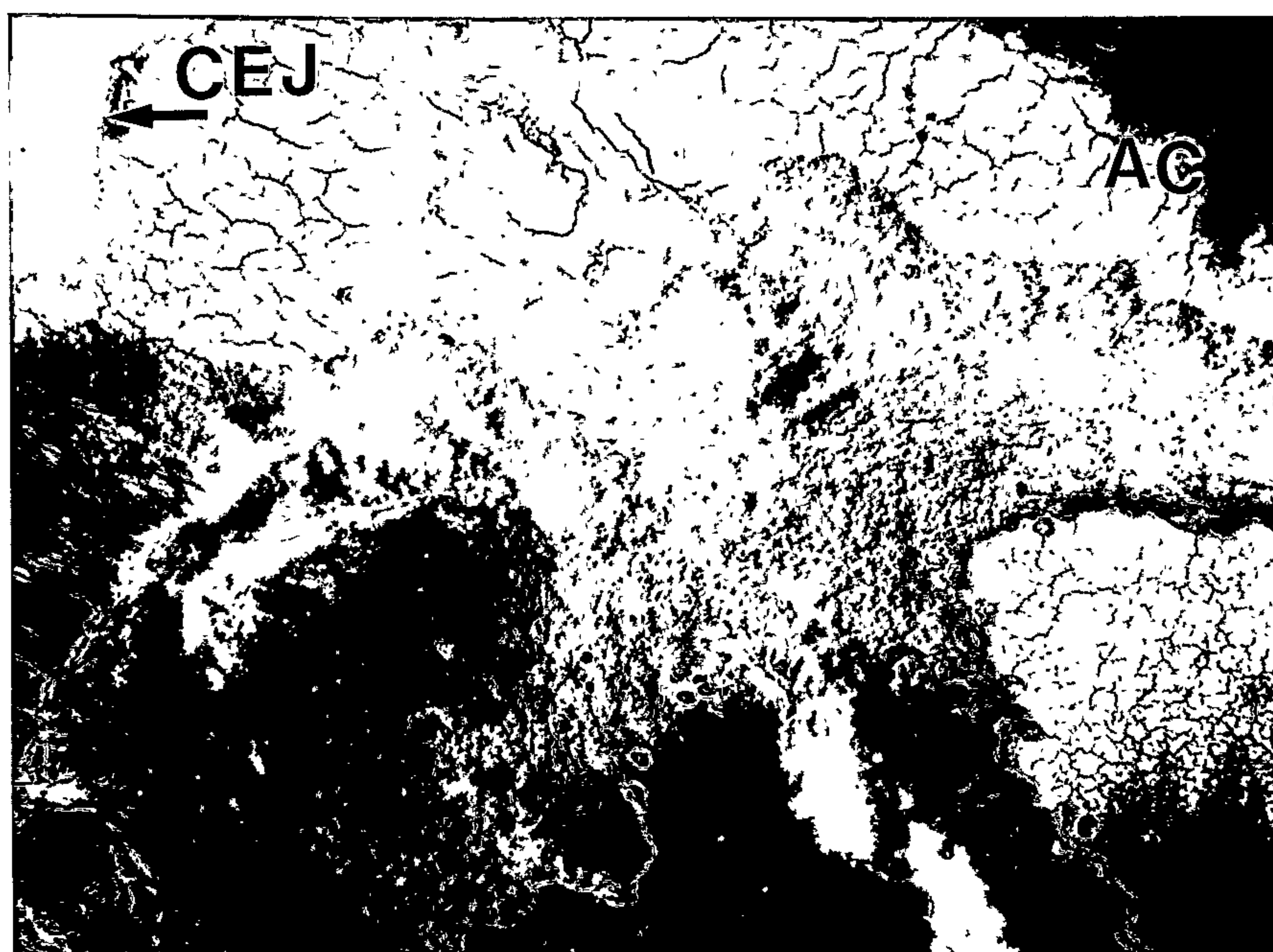


Fig. 12 Patient T.McP. Higher magnification of this Y-shaped lesion (from Fig. 11) shows its shallow nature and saucer shaped sides.

C.E.J. Cemento-enamel junction

A.C. acellular cementum

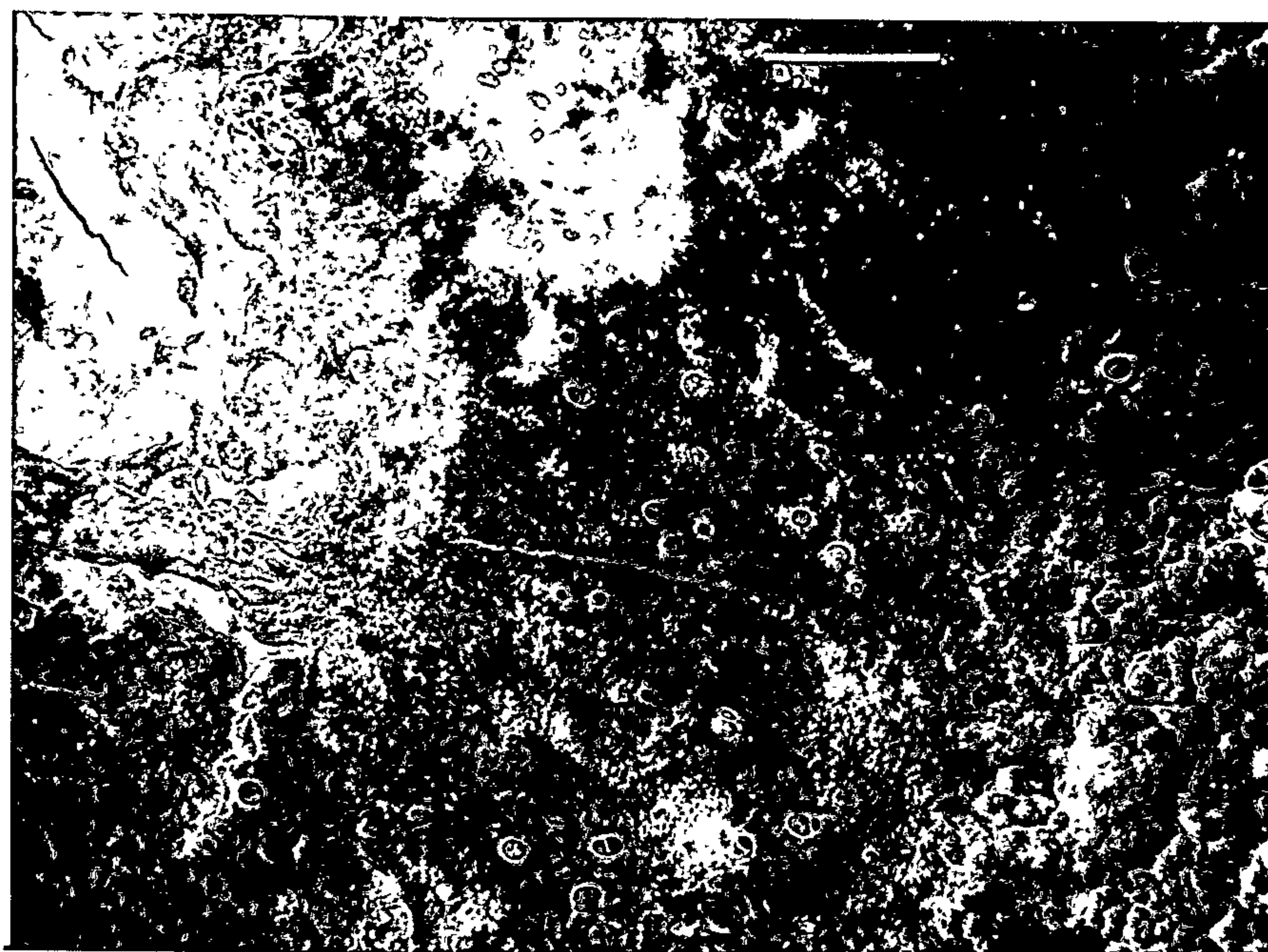


Fig. 13 Patient T.McP. Floor of the lesion (Fig.12).

There are few features. This is a very shallow lesion in frank acellular cementum and is considered to be a resting resorbing surface. Note the presence of the characteristic acellular cemental bump at B.

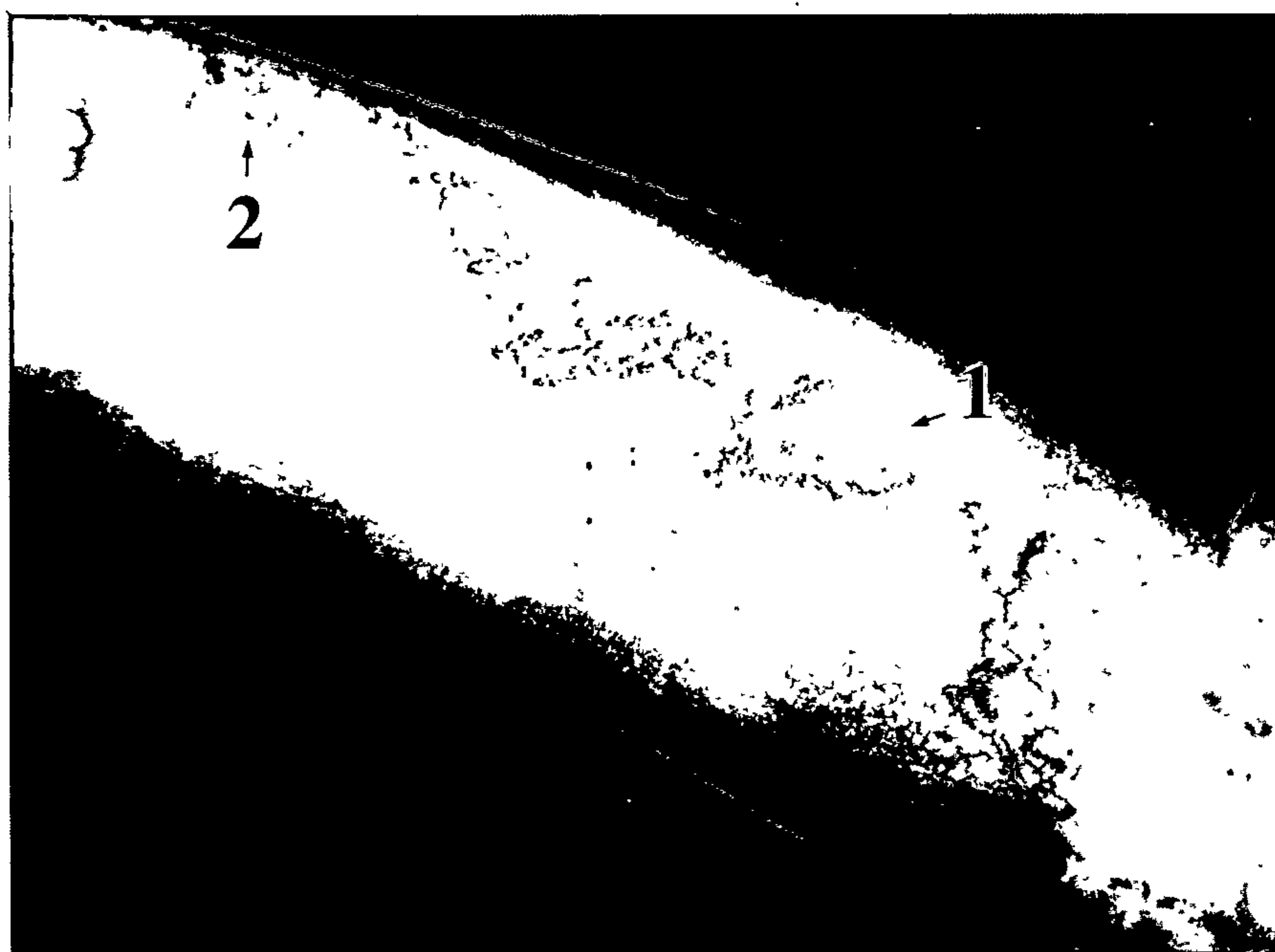


Fig.14 Patient L.McL. - Group I. Resorptive lesions
in the coronal third and root apex area.

C.E.J. Cemento-enamel junction

x 6



Fig.15 Patient L. McL. Higher magnification area |
 Fig.14. At R. is a resting resorbing area
 in a confluence of Howships lacunae. Above
 this is an early remineralising surface E,
 where the Howships lacunae are almost obliterate-
 rated by a granular surface deposit.
 M is thought to be extraneous matter

x 600



Fig. 16. Patient L.McL. Higher magnification shows obliteration of Howship's lacunae by early remineralisation.

x 2800



Fig.17. Patient L.McL. This photo shows that a lesion on this tooth (area 2 Fig.14) has nearly been repaired with cellular cementum. Note presence of many cementocyte lacunae at C and randomly arranged collagen fibres. i.e. mineralising front of cellular cementum as compared to the external surface of the root - acellular cementum at ac.

x 250

RESORPTIVE AREAS

GROUP II

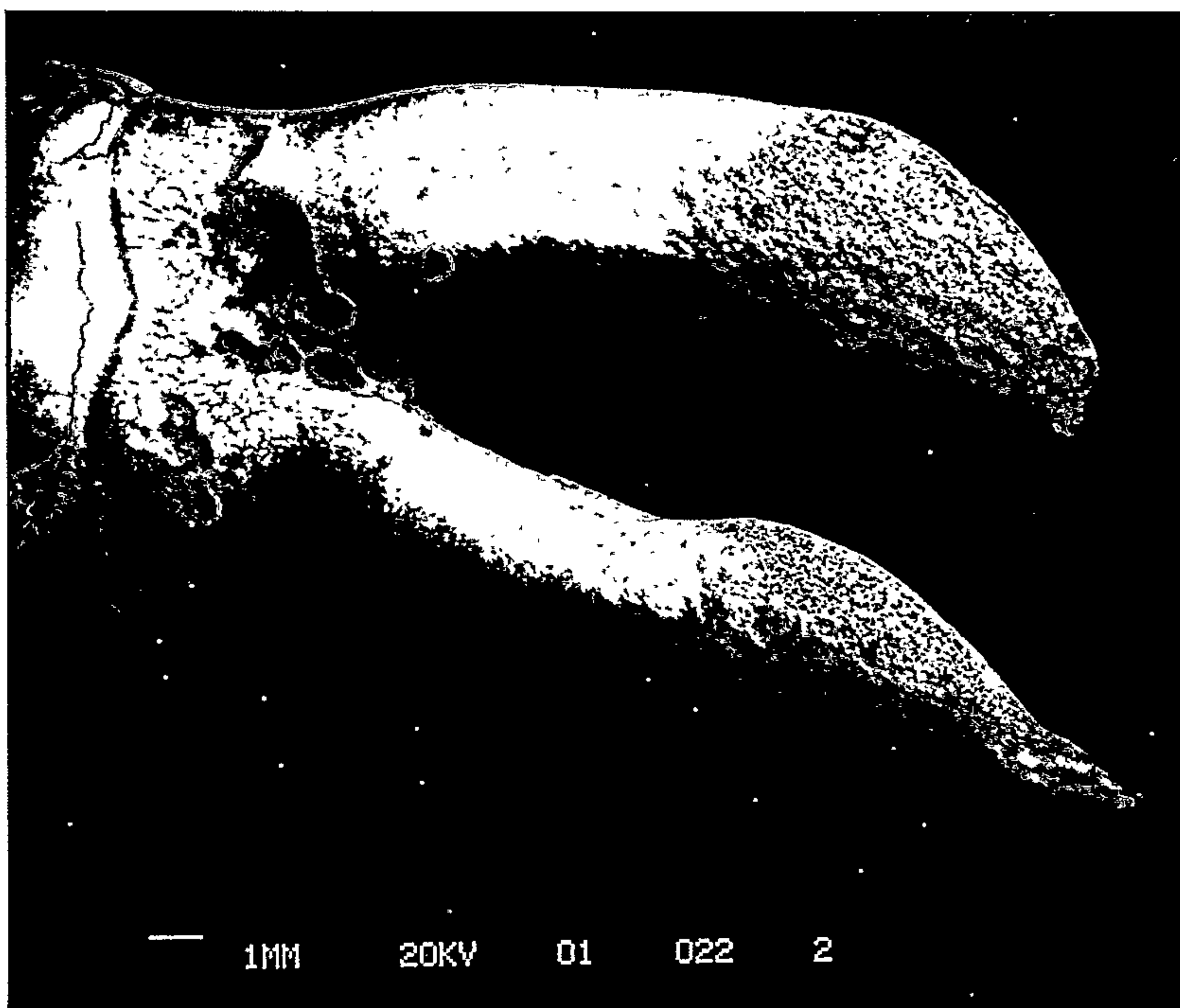


Fig. 18 Patient M.B. Upper left 1st permanent molar. Note large resorptive areas on buccal surface of both buccal roots and at bifurcation. Both apices have resorptive bays penetrating through to dentine.

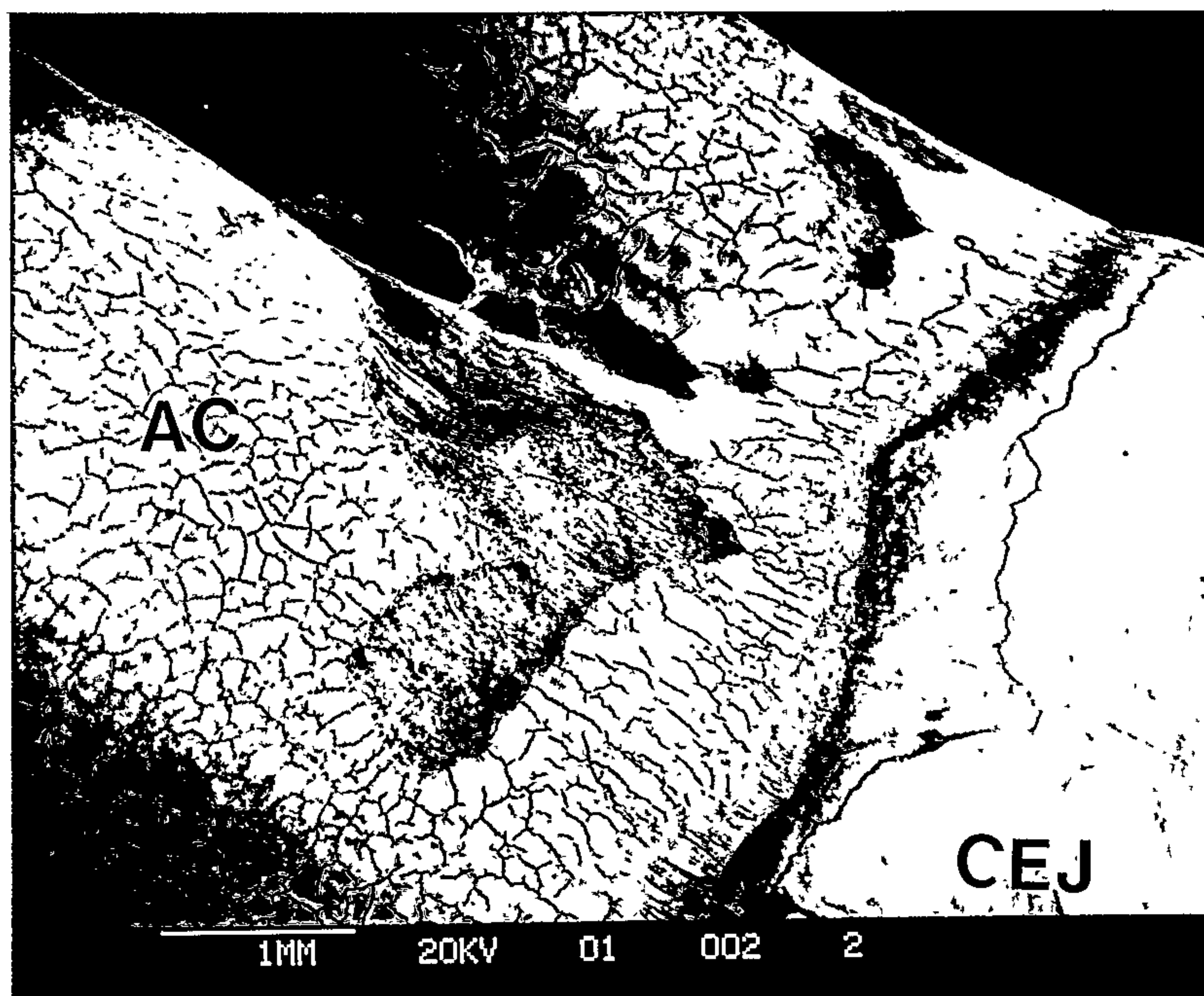


Fig. 19. Patient M.B. Higher magnification of deep resorptive bay showing "cliff-like" side and undermining.

C.E.J. Cemento-enamel junction

A.C. Acellular cementum.

x 18.

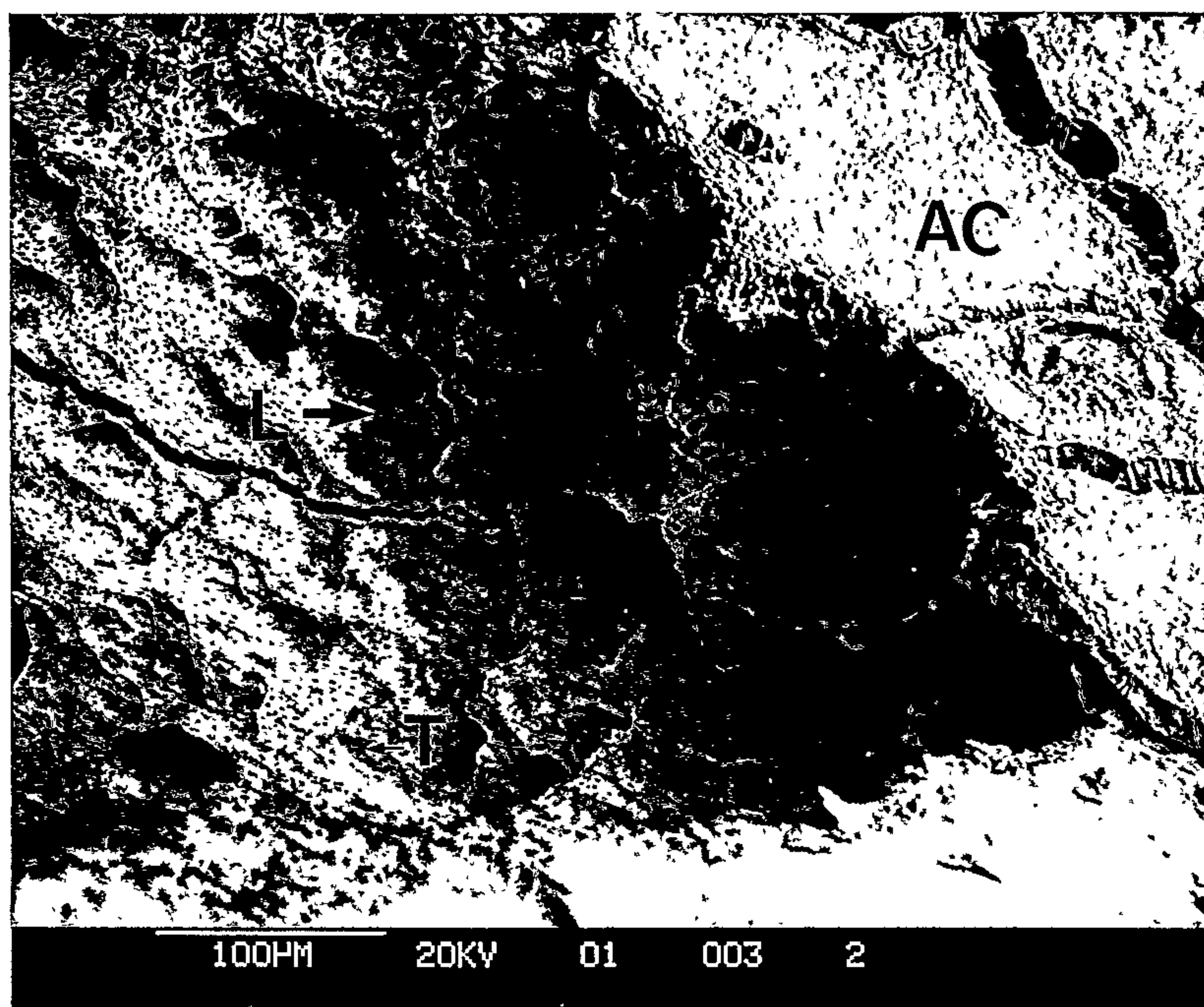


Fig.20 Patient M.B. Howship's lacunae (L) expose the terminal ends of the dentinal tubules. (T).

AC Acellular cementum.

x 200

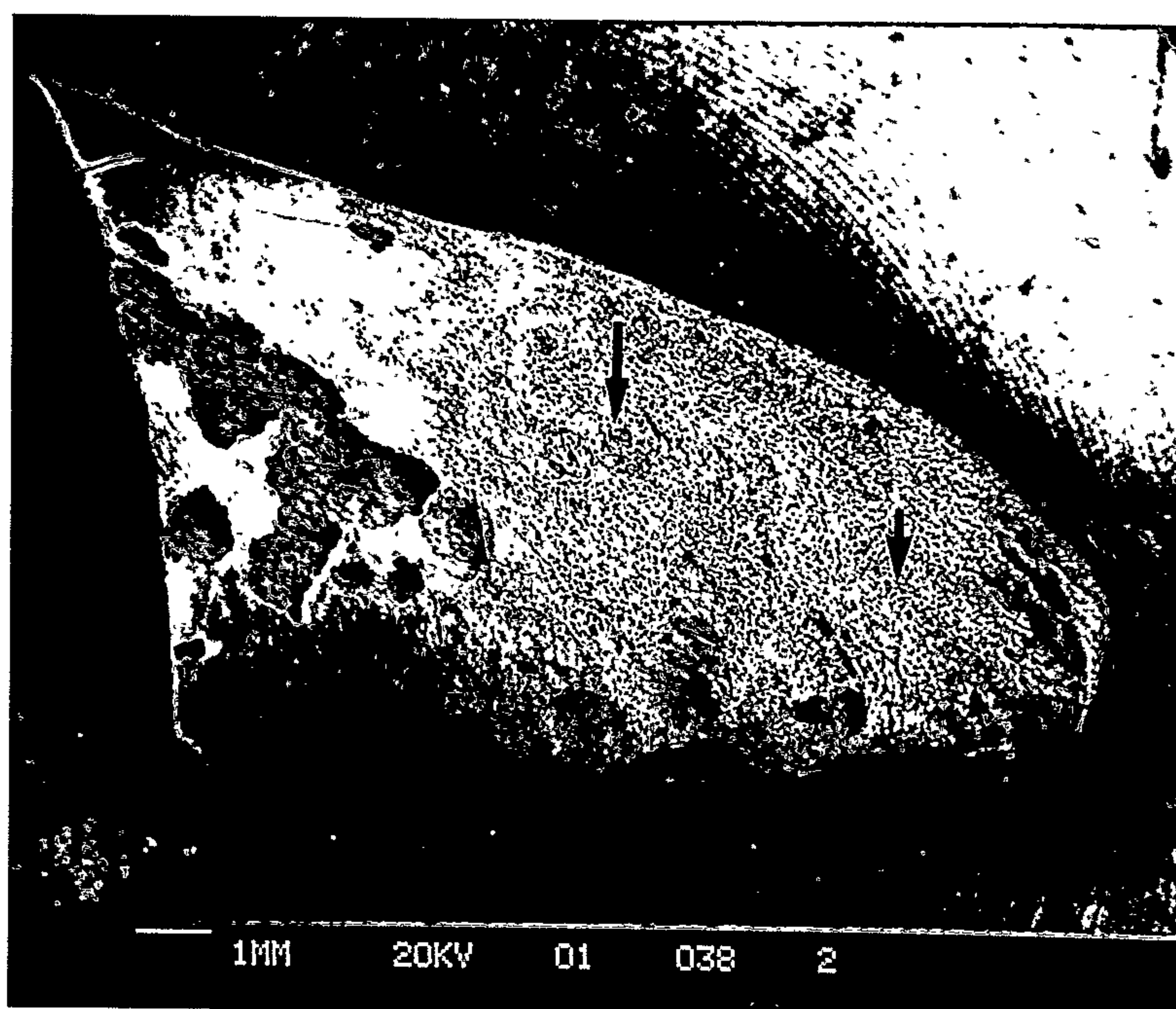


Fig. 21 Patient M.B. Detached palatal root. Here are seen very deep resorption bays at the trifurcation (sectioned end) and the root apex - both involved dentine. The "pinhole" areas are preparation artefacts (arrowed) showing many cementocyte lacunae in cellular cementum.

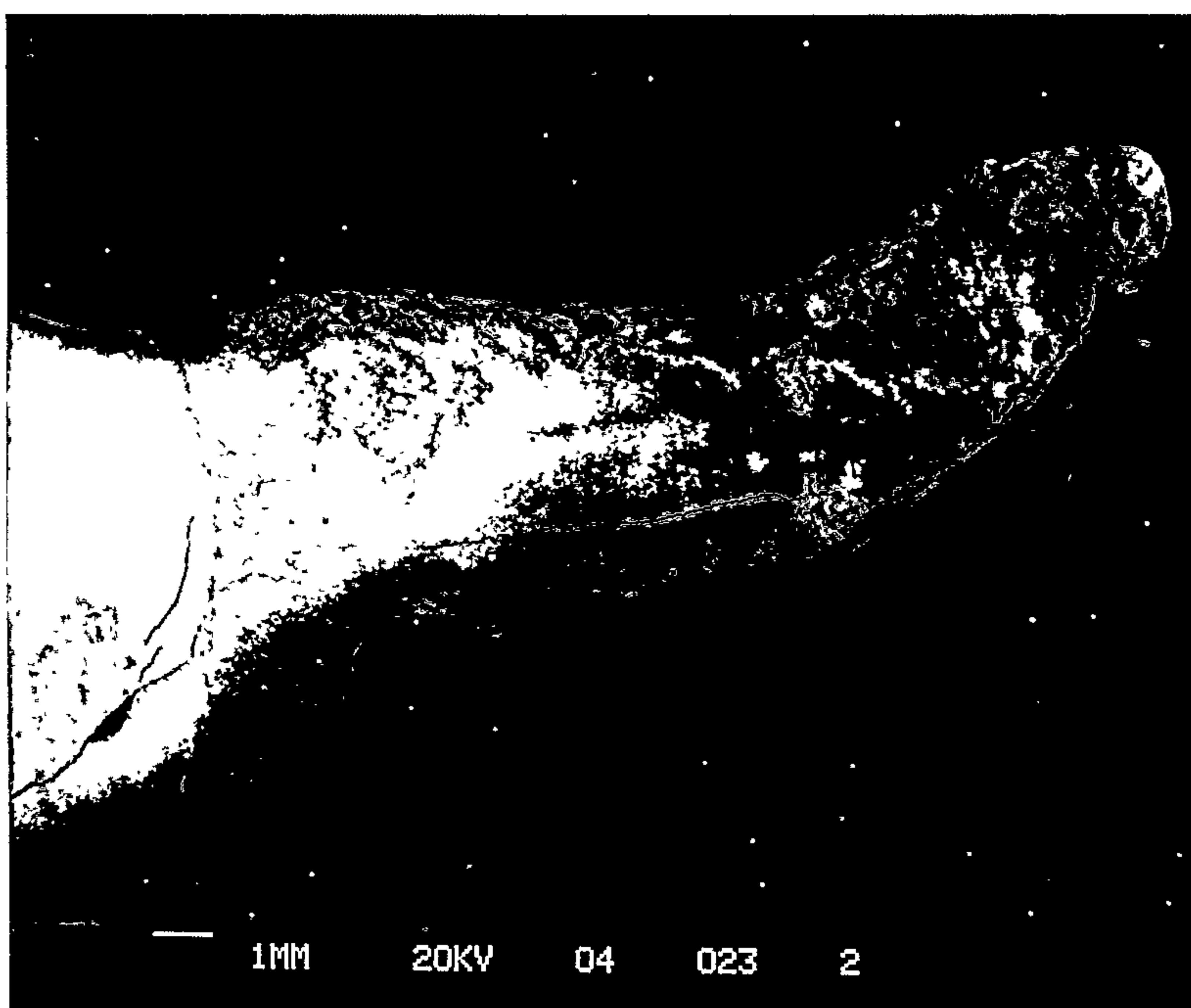


Fig.22 Patient M.S. Many resorptive bays appear along the buccal surface of this root. Once again they are congregated mostly at the coronal third and apical area of the root.

x 5

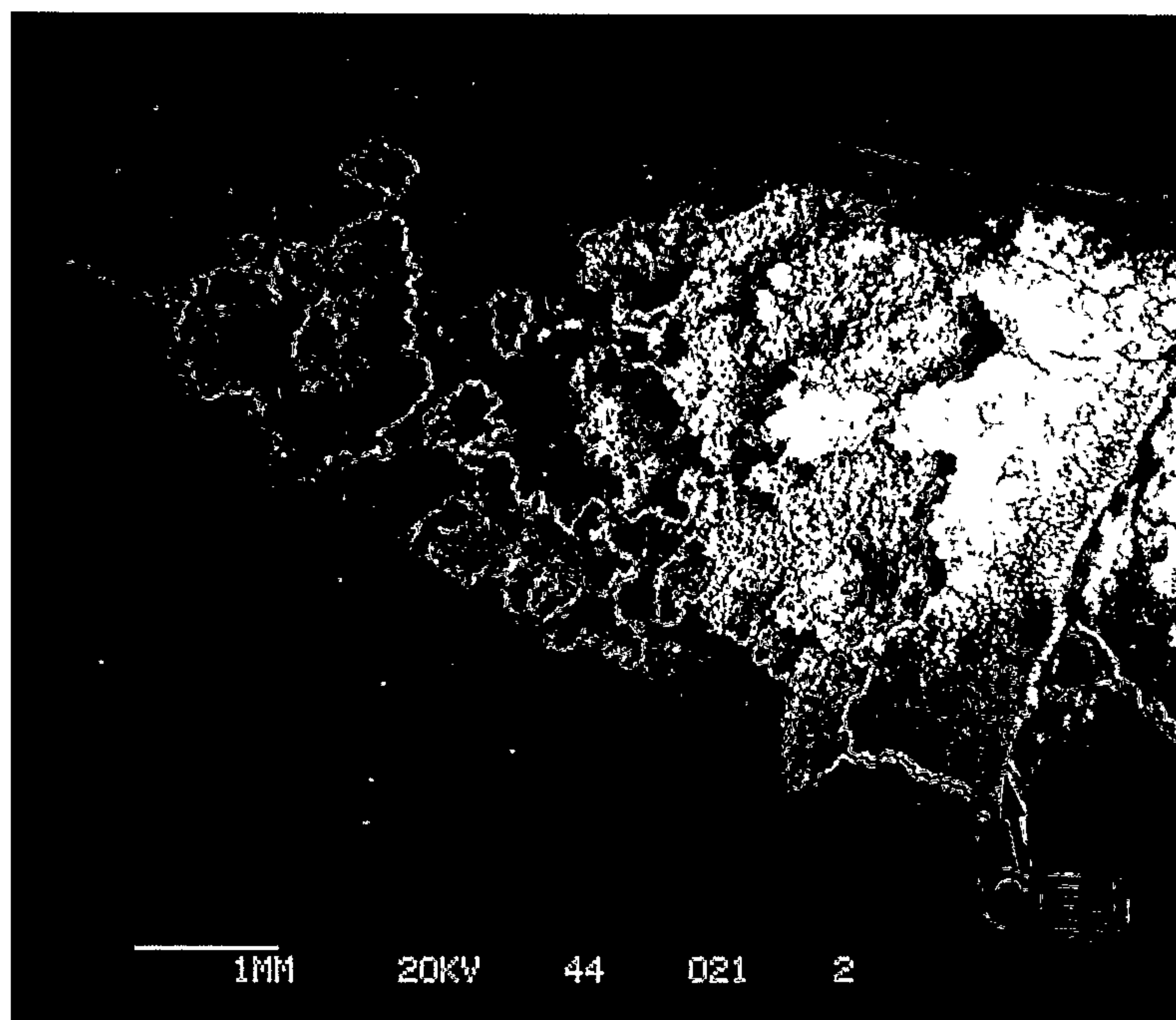


Fig. 23 Patient M.S. Resorption bays typical of Group II. Here are seen cliff like sides to the bays. The "islands" of acellular cementum are left when Howships lacunae join together.

C.E.J. Cemento-enamel junction.

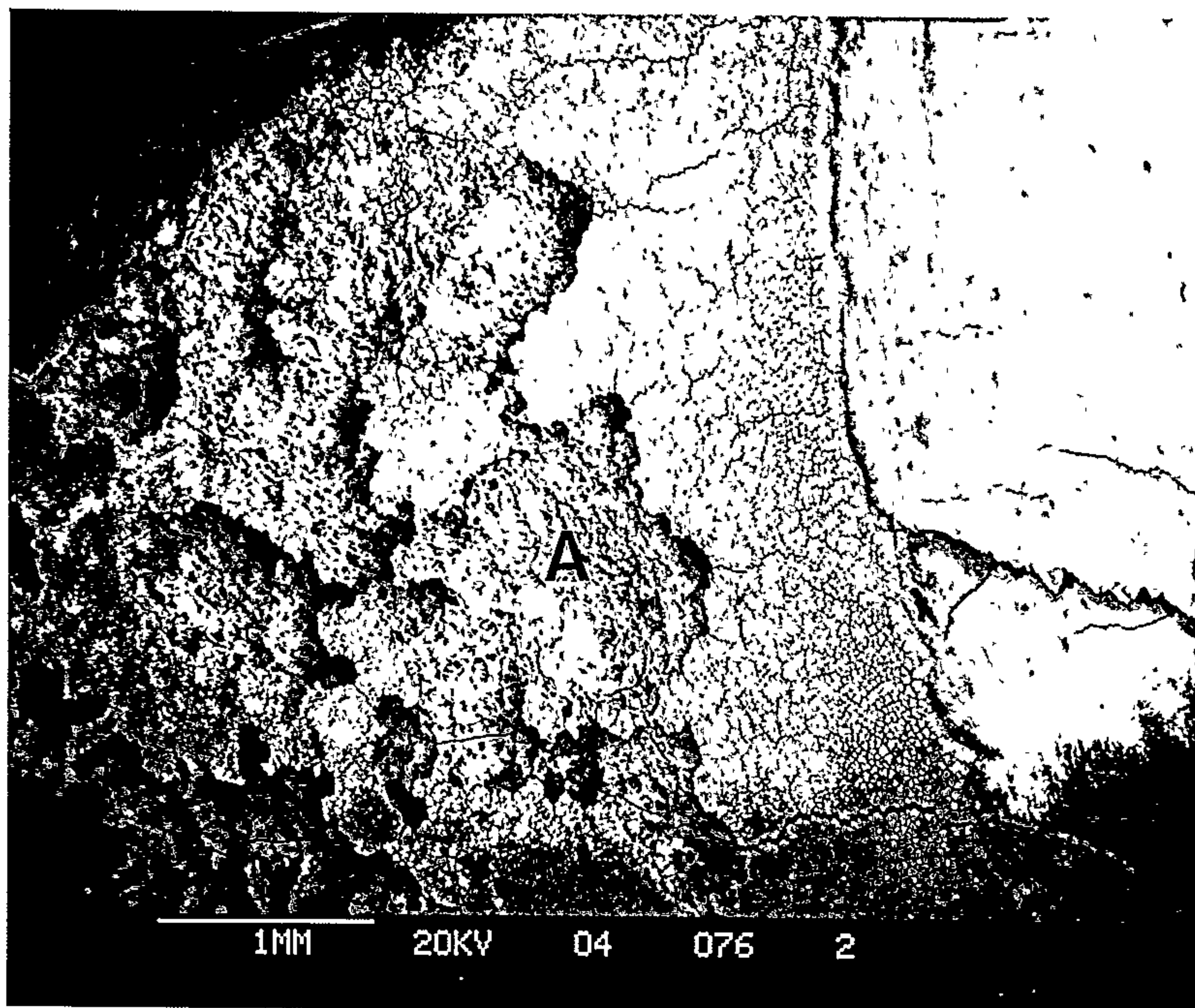


Fig. 24 Patient M.S. Higher magnification shows greater destruction and undermining of the root surface.

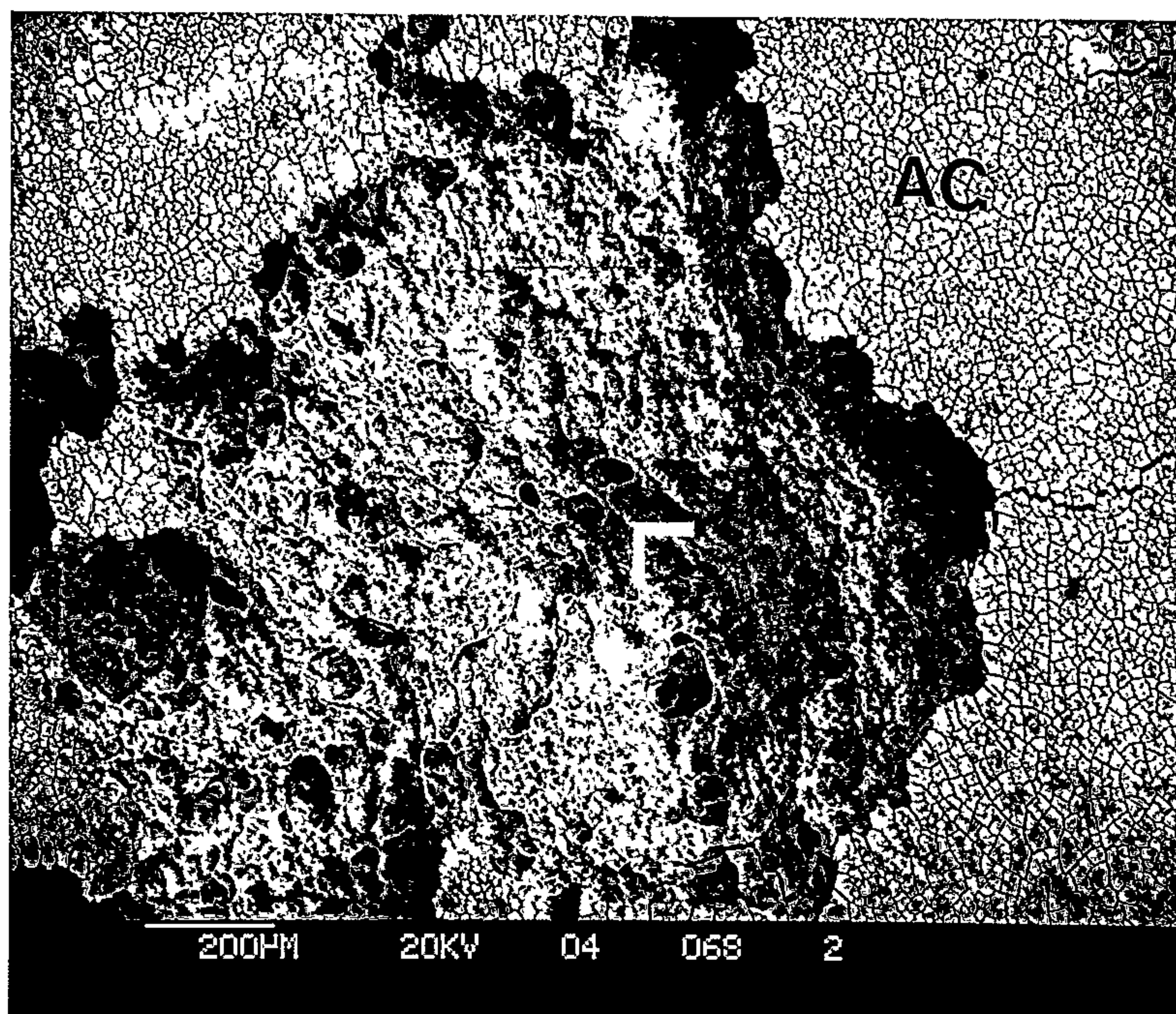


Fig. 25 Patient M.S. Higher magnification of bay at A Fig.24. Note the many tightly arranged Howship's lacunae.

A.C. Acellular cementum

x 60

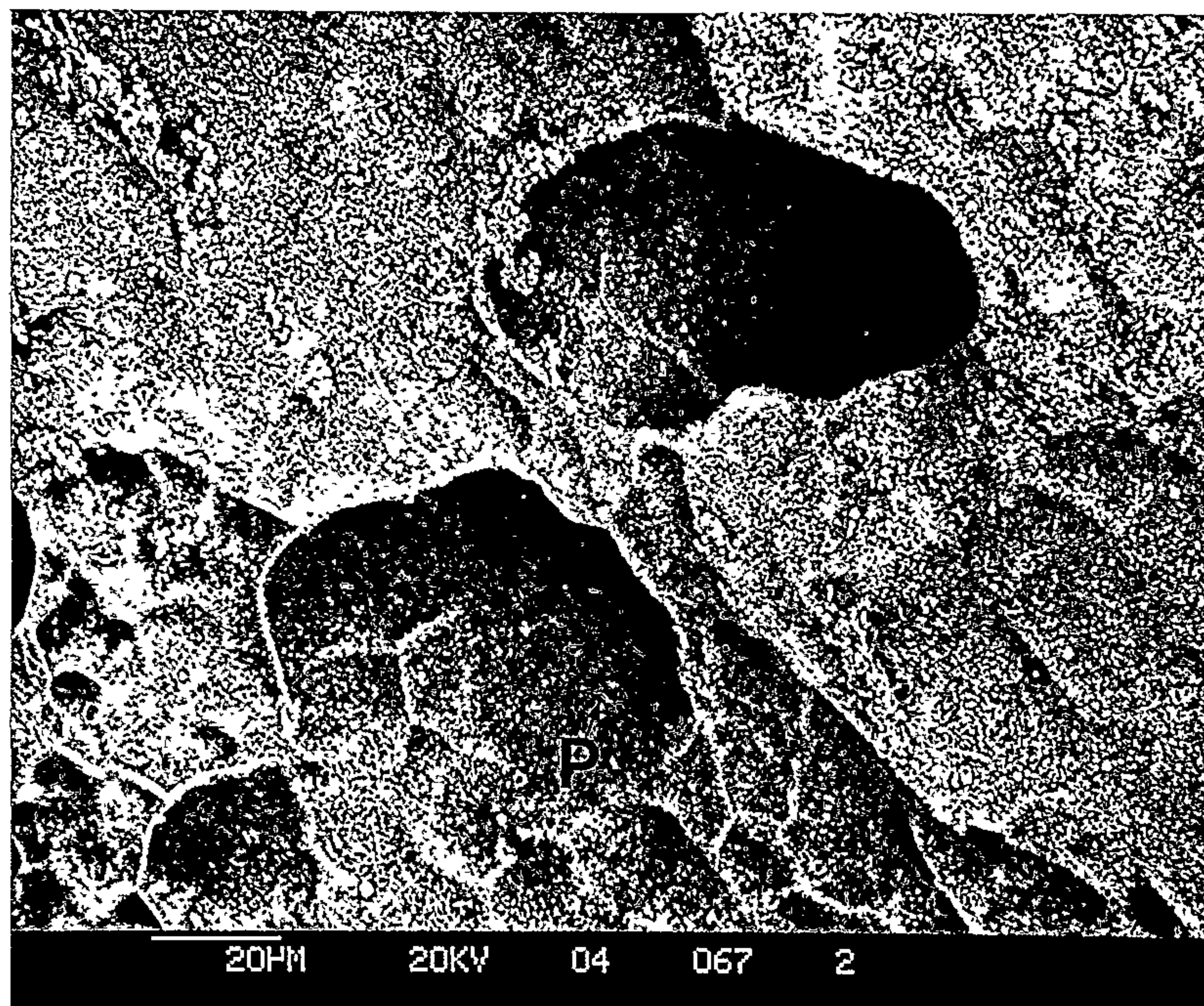


Fig. 26 Patient M.S. Area as arrowed in Fig.25 shows , where a number of Howship's lacunae have joined to form a deep concavity. Note the exposure of dentine as evidenced by presence of dentinal tubules. A typical dentinal tubule complete with peritubular dentine is at P.

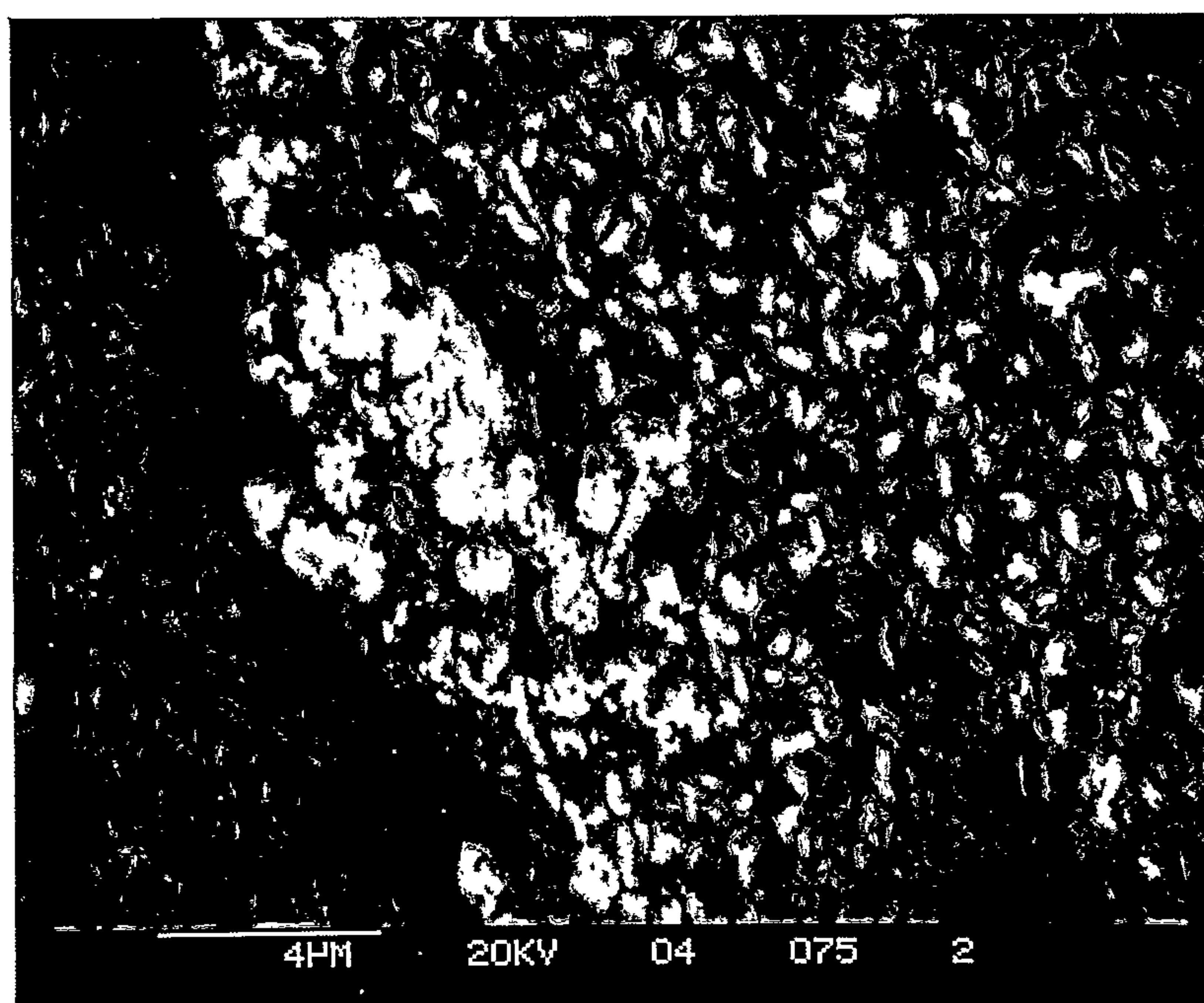


Fig. 27 Patient M.S. Mineralised collagen front of dentine at floor of Howship's lacunae from Fig. 26.

x 5000



Fig. 28 Patient S.T. Gross resorptions bays on buccal surface. Once again steep-sided bays and islands of acellular cementum.
Note the presence of resorption bays on the distal surface of the root. (D).

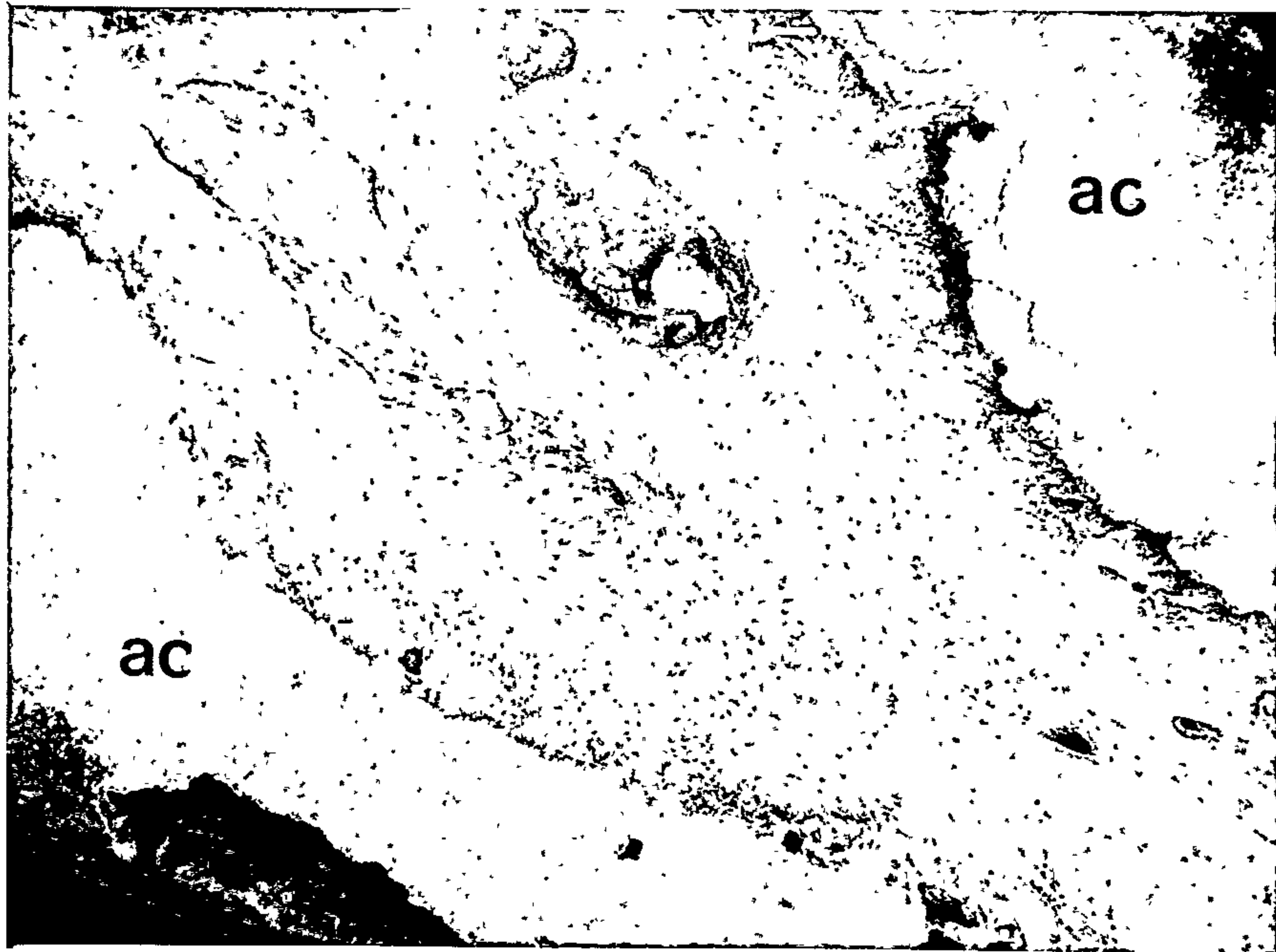


Fig.29 Patient S.T. Higher magnification of large bay in Fig.28 Note the depth of the bay in lower left hand corner (D) in Fig. 28.

ac acellular cementum

x 25



Fig. 30 Patient S.T. Higher magnification of smaller bay (S) in Fig. 28 showing the classical features of Group II lesions, i.e. ragged cliff sides and undermining.
ac acellular cementum.



Fig. 31 Patient S.T. Floor of large bay depicts an active resorption front with typical arrangement and distribution of Howship's lacunae. ac acellular cementum.

x 500

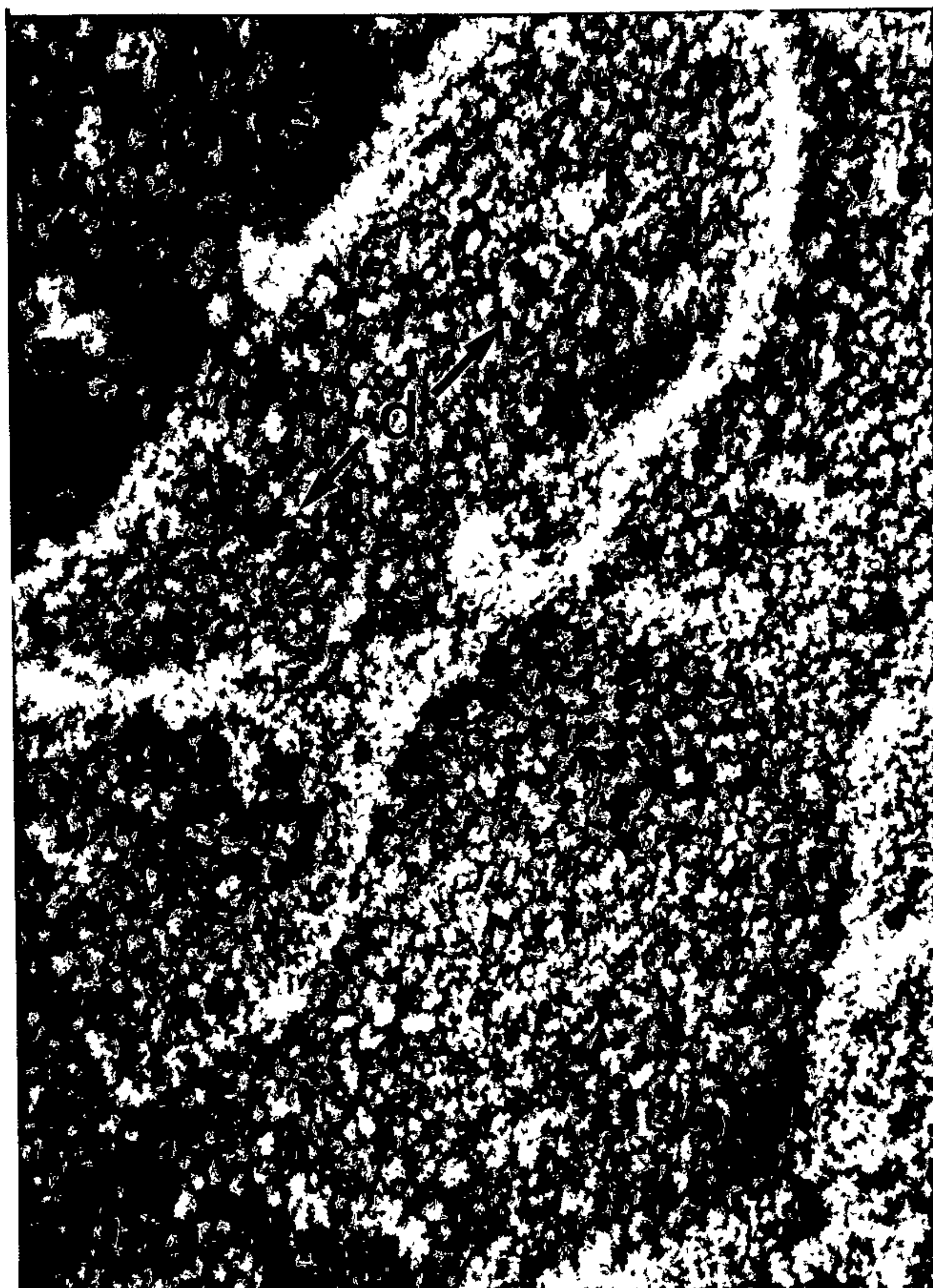


Fig. 32 Patient S.T. Higher magnification of floor of Howship's lacunae from Fig.31 shows dentinal involvement as evidenced by the presence of dentinal tubules at d.

x 800

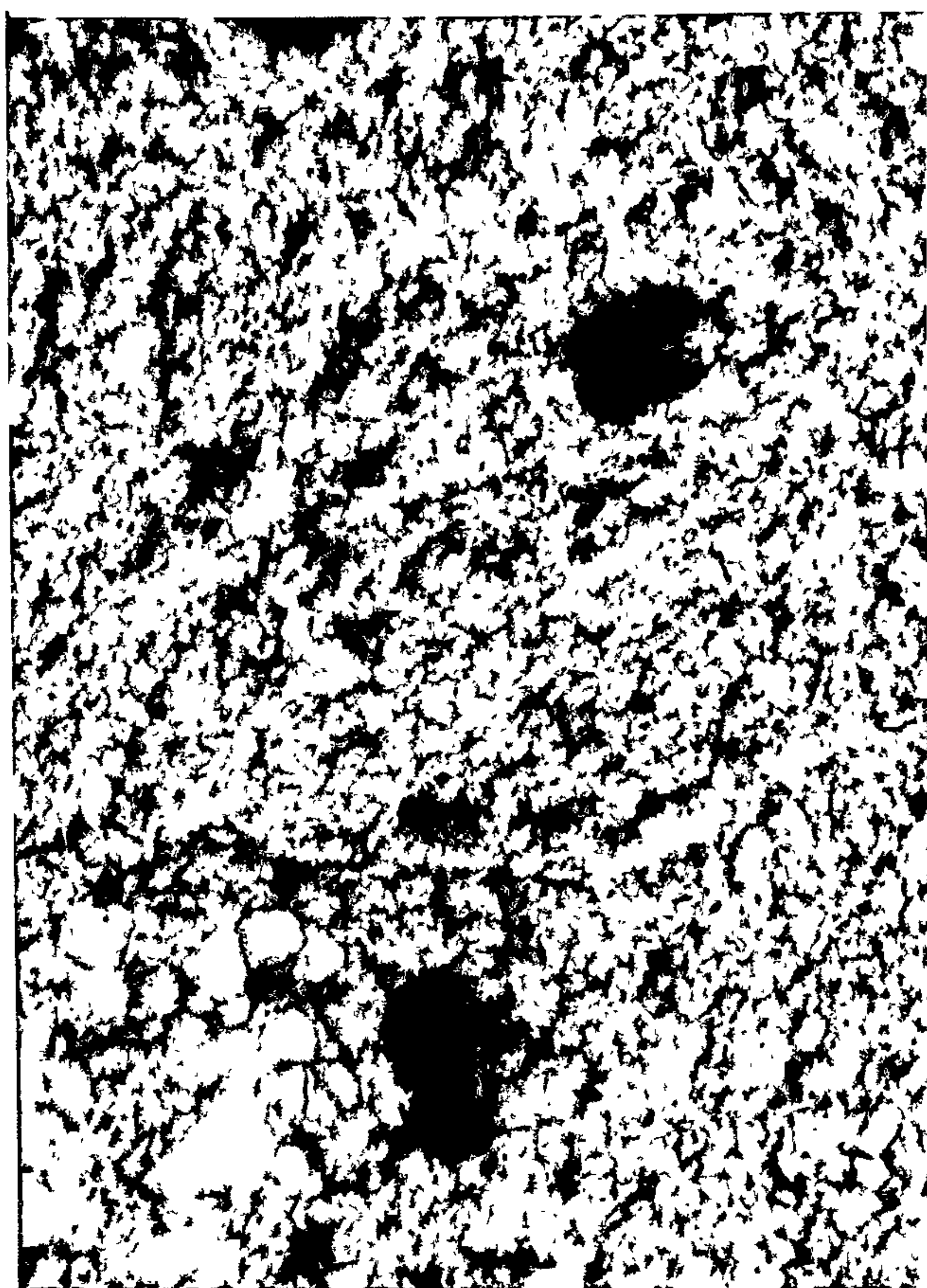


Fig. 33. Patient S.T. At another part of this large bay are to be seen repair fronts with the ever present mineralised collagen bundles and cementocyte lacunae. See r in Fig. 31.

x 1000



Fig. 34 Lower premolar from patient C.A. (control teeth),
i.e. not subject to orthodontic force. There
is no sign of resorptive destruction on this tooth.

x 5

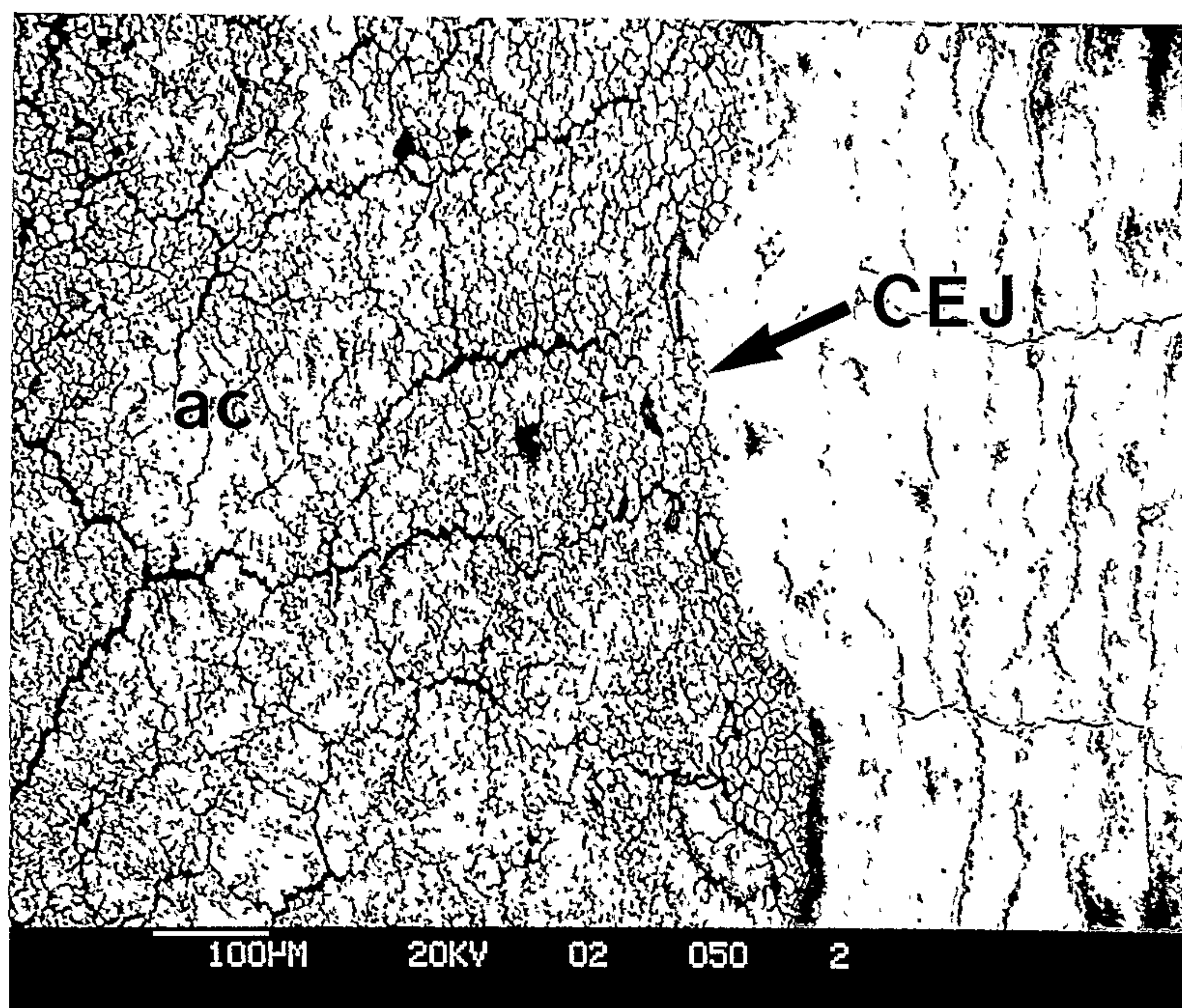


Fig. 35 Patient C.A. Cervical area of Fig. 34. Note the typical appearance of acellular cementum (ac) and the scalloped effect of the cemento-enamel junction. C.E.J. The cracks are artefacts.

x 100

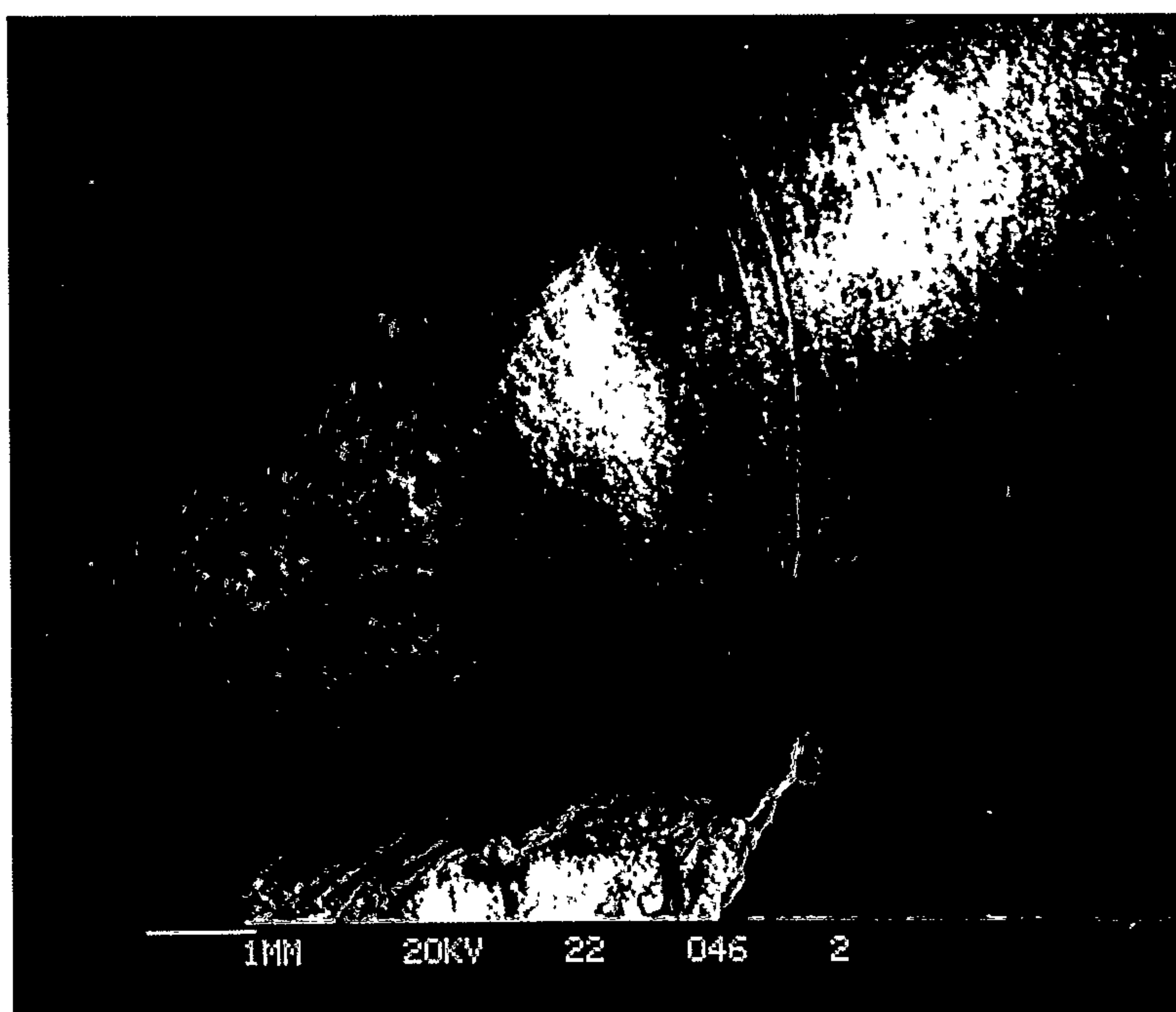


Fig. 36 Patient C.A. Undamaged root shows some early hypercementosis. Note the ability of the electron microscope to illuminate the incremental lines in cementum - the lines of Salter.

x 10.



Fig. 37. Patient S.T. Resorptive lesion and gathering of clastic cells.

x 25

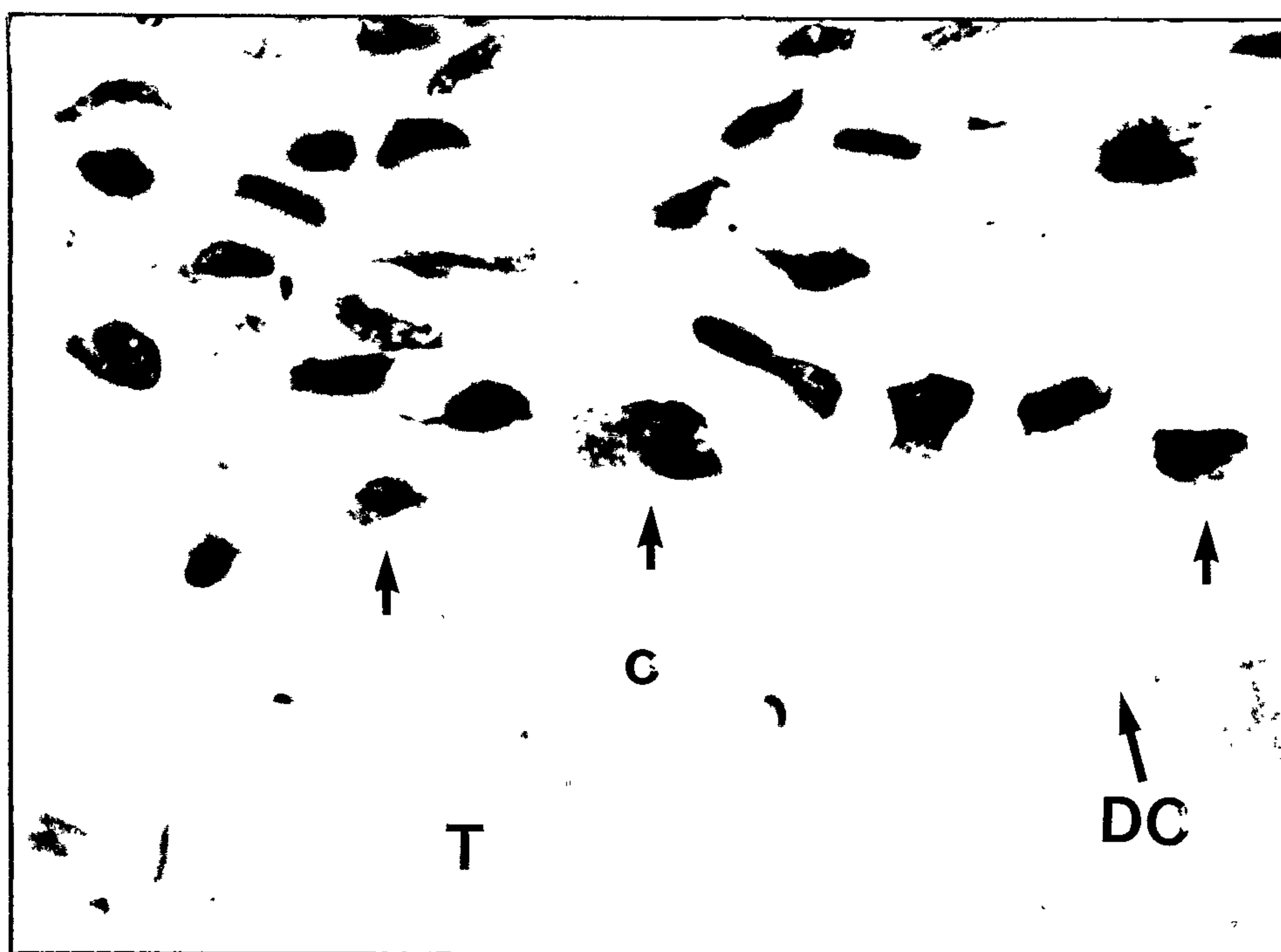


Fig. 38. Patient L.McL. Repair of resorption bay by new cementum. Three cementoblasts (arrowed) are in various stages of being "buried" into lacunae.

c - cementum (collagen)

T - Terminal branches of dentinal tubules.

DC - Dentino - cemental junction.

x 100

As the activation of all appliances in Group II ceased at 3 weeks, (the remainder of the treatment being spent in retention) it follows that a residual load was present which caused resorption to predominate over repair. Zimring and Isaacson (1965) tell us that the residual load in rapid maxillary expansion dissipates in 5-7 weeks. Then why was the tooth of patient S.T. still undergoing active resorption after 4 months retention? One can only postulate that relapse forces were present which kept pressure on the tooth - alveolar bone interface. The fact that active resorption was still present in patient S.T. is further borne out by the photographs of odontoclasts resorbing away cementum in Experiment 2.

Although areas of resorption in Group II were decidedly deeper than those in Group I, generally speaking lesions of both groups were comparatively shallow. Only the superficial layers of dentine were exposed as evidenced by the minute diameter of the peripheral dentinal tubules.

This discussion must bring forth the inevitable question - Is the life span of the tooth shortened due to use of expansive forces? From the present study there is nothing to indicate that Nature will not take care of the teeth by repairing the lesions. Whether the repair cementum has the desired clinical qualities of normal cementum is a matter for further study. Does the tooth reattach itself to the alveolar bone in resorptive areas or does the presence of repair cementum lessen the chances of

Sharpey's fibre growth? Clinical observations over the many years that these two methods of tooth movement have been used would indicate that the longevity of the tooth is the same as for the non-orthodontically treated tooth.

SUMMARY

The objectives of this present study were to show, if possible, by qualitative means that slow continuous expansion was less destructive to the root surface of a tooth than rapid intermittent expansion. The scheme was to follow the investigation at "a clinician's level" rather than get "bogged down" with extensive histological detail. It is believed by the author that this is the first time that these two means of maxillary arch expansion have been compared in this way.

The literature review was able to produce some important points which were verified in this study:

- (i) The greater the force used the more destruction one can expect to the root surface.
- (ii) The Quad-Helix appliance allowed repair to keep pace with resorption.
- (iii) Odontoclasts (or osteoclasts) are present in the resorption bays and take an active part in resorption.
- (iv) Both rapid and slow expansion have a particular role in orthodontic treatments.
- (v) The scanning electron microscope as a means of studying root resorption is an ideal instrument to use.

A total of forty teeth were examined. Of these, twenty were the lower teeth not subjected to orthodontic forces.

Fourteen of these "control" teeth showed evidence of root resorption. All of these teeth were examined under the light microscope. Only one tooth from this group was examined under the S.E.M. (see Fig. 34). In this case no sign of root resorption was present.

In studying the twenty "test" teeth, twelve were subjected to low continuous force using a Quad-Helix appliance (Group I) and eight were subjected to high intermittent forces using a Hyrax screw appliance (Group II). Photographs showing resorption on samples of these teeth were obtained. Features of resorption and repair, ascertained from these photographs, have been described in detail for both groups.

A sample tooth from each group was demineralised and after histological preparation, examined under the light microscope. Odontoclasts, resorption bays and repair fronts were able to be shown.

Generally, the greater the force used, the more destructive the resorptive lesion. However, there was an attempt by the body defence mechanism to repair all lesions.

Repair was more advanced in every instance in the Group I lesions.

The author is in agreement with Henry and Weinmann (1951) that it is common to find root resorption on teeth not

subjected to orthodontic force. Barber and Sims (1981) found no evidence of root resorption on a sample of non orthodontically treated teeth.

That the scanning electron microscope is able to show "deeply embayed" surfaces has been seen in the study and this reiterates the work of Boyde and Lester (1967)

The author agrees with Sognaaes (1963) and Tayer et al (1981) that a "proliferative response of cells" accompanies tooth movement and that this cell increase was aimed at production of resorption cells.

Boyde and Lester (1967) saw "resorption evidenced by the presence of Howships lacunae with clearly defined edges" when the dentinal layer had been reached. They also saw the presence of dentinal tubules with peritubular dentine standing above the surrounding intertubular dentine. The photomicrographs in this study agree with these findings of Boyde and Lester.

The present study also agrees with the work of Henry & Weinmann (1951), Isaacson, Wood and Ingram (1964), Storey (1973^A), Cotton (1978) and Hicks (1978) that if you used lighter forces, you could expect less damage to the tooth root surfaces.

Finally this study agrees with Barber and Sims (1981) - that of all the resorption bays studied "rarely was

resorption or repair encountered alone."

CONCLUSIONS

The following conclusions were derived from the present study.

1. Both rapid maxillary expansion and slow continuous expansion cause root resorption of teeth subjected to their forces. The resorptive defects are located mainly on the buccal surface.
2. Teeth subjected to slow expansion had shallower defects than those subjected to rapid expansion, even when total treatment time was comparable.
3. Repair occurred together with continuing resorption in both groups. However, in the slow expansion group there was more repair than resorption taking place.
4. Odontoclastic cells were present in resorptive areas of teeth from both groups.
5. 70% of control teeth i.e. (lower teeth not subjected to orthodontic force) showed slight evidence of root resorption.

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APPENDIXA BRIEF INTRODUCTION TO THE SCANNING ELECTRON MICROSCOPE

Bowen and Hall (1975) sum up the advantageous qualities of the scanning electron microscope.

"The scanning electron microscope (S.E.M.) is an instrument designed primarily for studying the surfaces of solids at high magnification. In this respect it may be compared with the optical microscope. The images are qualitatively similar but the S.E.M. possesses much greater resolution and depth of field. If this were all, then the S.E.M. would still be a most useful microscope and indeed a very large number of its applications utilise only these advantages. But there are additional benefits which arise from using electron beams rather than light beams in image formation, since the interaction of electrons with solids is more diverse than that of photons, and correct use of the S.E.M. can yield much more information - for example, on crystal orientation, chemical composition, magnetic structure or electric potential in the specimen..

In brief the scanning electron microscope is able to present a nearly three dimensional recreation of the object on a two dimension picture over a wide range of magnifications. Thus it is ideal to study the convex surface of a tooth. The depth of focus is improved 300 times and the resolution at least 10 times as compared with the light microscope.

HOW DOES IT OPERATE?

Images are formed in the S.E.M. by a quite different mechanism than that in an optical microscope. There is no objective lens used, but instead, images are built up point by point in a manner similar to a closed circuit television display.

Bowen and Hall (1975) explain "A fine, high energy beam of electrons is focussed to a point on the specimen. This causes the emission of electrons (with a wide spread of energies) from the point on the surface, and the emitted electrons are collected and amplified to give an electrical signal. If this signal is now used to modulate the intensity of a beam of electrons in a cathode ray tube (CRT) display, one point of the image is formed on the CRT. To build up the complete image, the electron beam in the microscope is scanned over an area on the specimen surface (the pattern of scan is called a raster) while the beam in the CRT display is scanned over a geometrically similar raster. The image on the CRT is thus a map of the intensities of the electron emission from the specimen surface."

For imaging the surface of a specimen in the S.E.M. we make use of the emission of secondary electrons and of back scattered electrons. For tooth imaging purposes the back scattered electrons provided a better signal source. Secondary electrons often indicate a high spot

on a tooth with a line of high optical intensity. This high lighting or "charging" effect was not present when the back scattered electron mode was used for tooth examination.

CONSTRUCTION OF THE S.E.M.

The essential features of the microscope are:-

1. An electron gun that produces a narrow beam of electrons accelerated thro' a potential difference of up to approx. 50kV.
2. Two or three lenses to focus the electron beam as finely as possible.
3. A system to deflect the beam over the raster on the specimen.
4. A specimen stage permitting movement, tilt and rotation of the specimen.
5. A method of collecting and amplifying the emitted electrons.
6. Cathode ray tubes to display the image.
7. Electronic circuits to supply and control the electron gun. accelerating voltage. Lens currents, 1 scan generator and signal amplification.

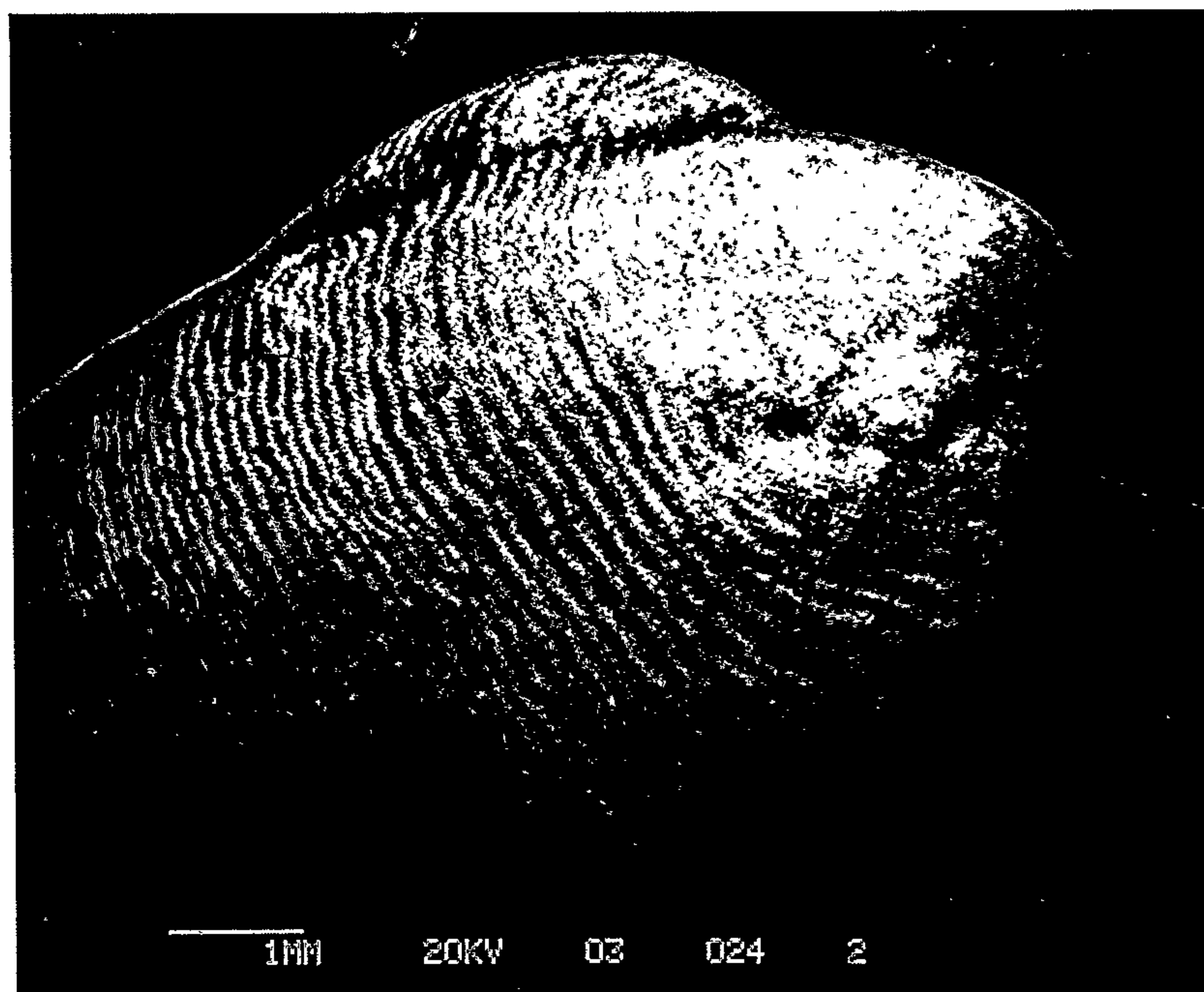


Fig. 39 Lower premolar crown from Patient C.A. This oblique angle photomicrograph shows the imaging qualities of backscattered electrons when used for dental studies. The Perikymata (or surface manifestations of the striae of Retzius) are shown to great advantage. x 12.

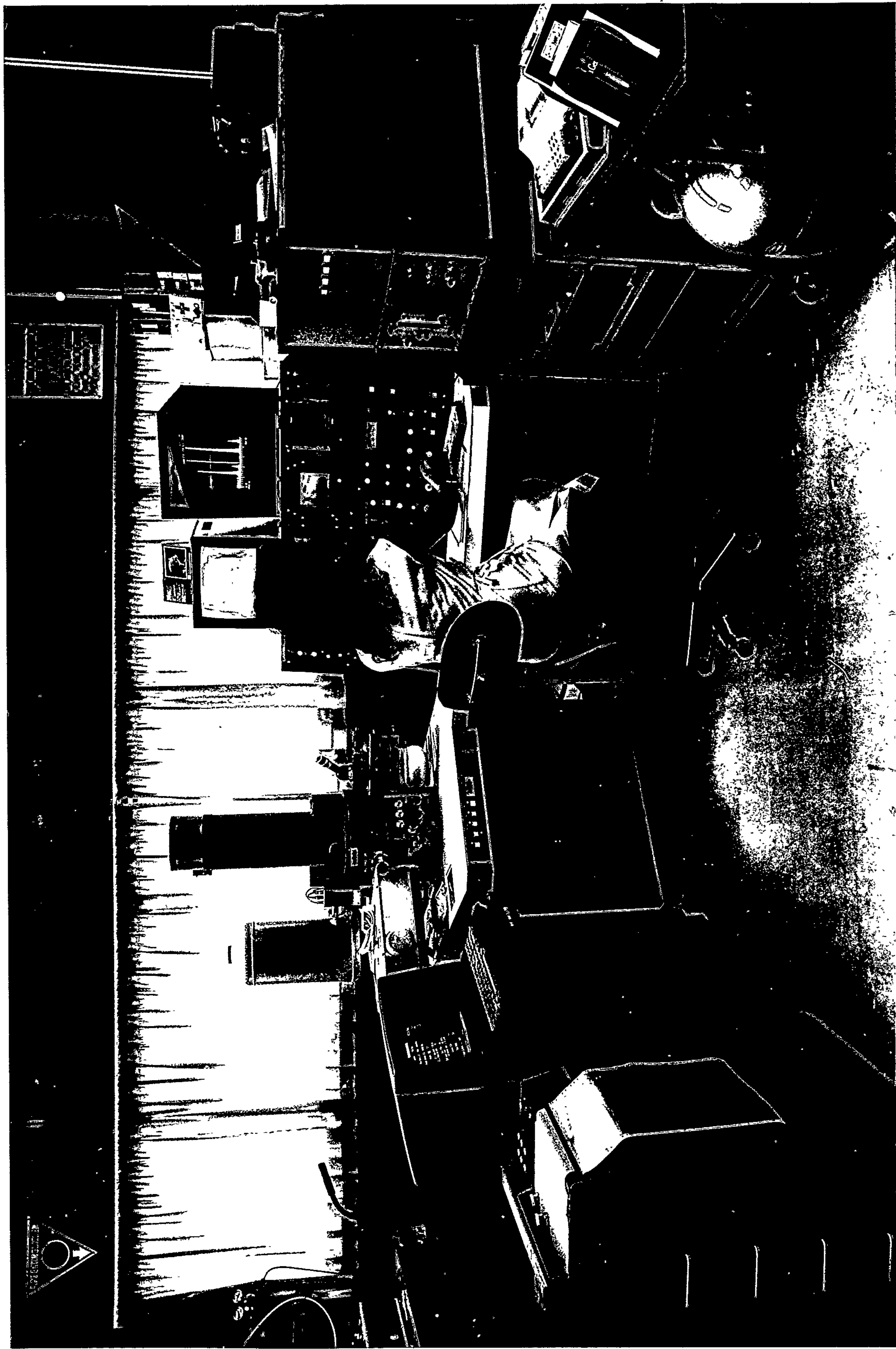


Fig. 40 The Cambridge Stereoscan 150 Mk.II scanning electron microscope as used by the author.

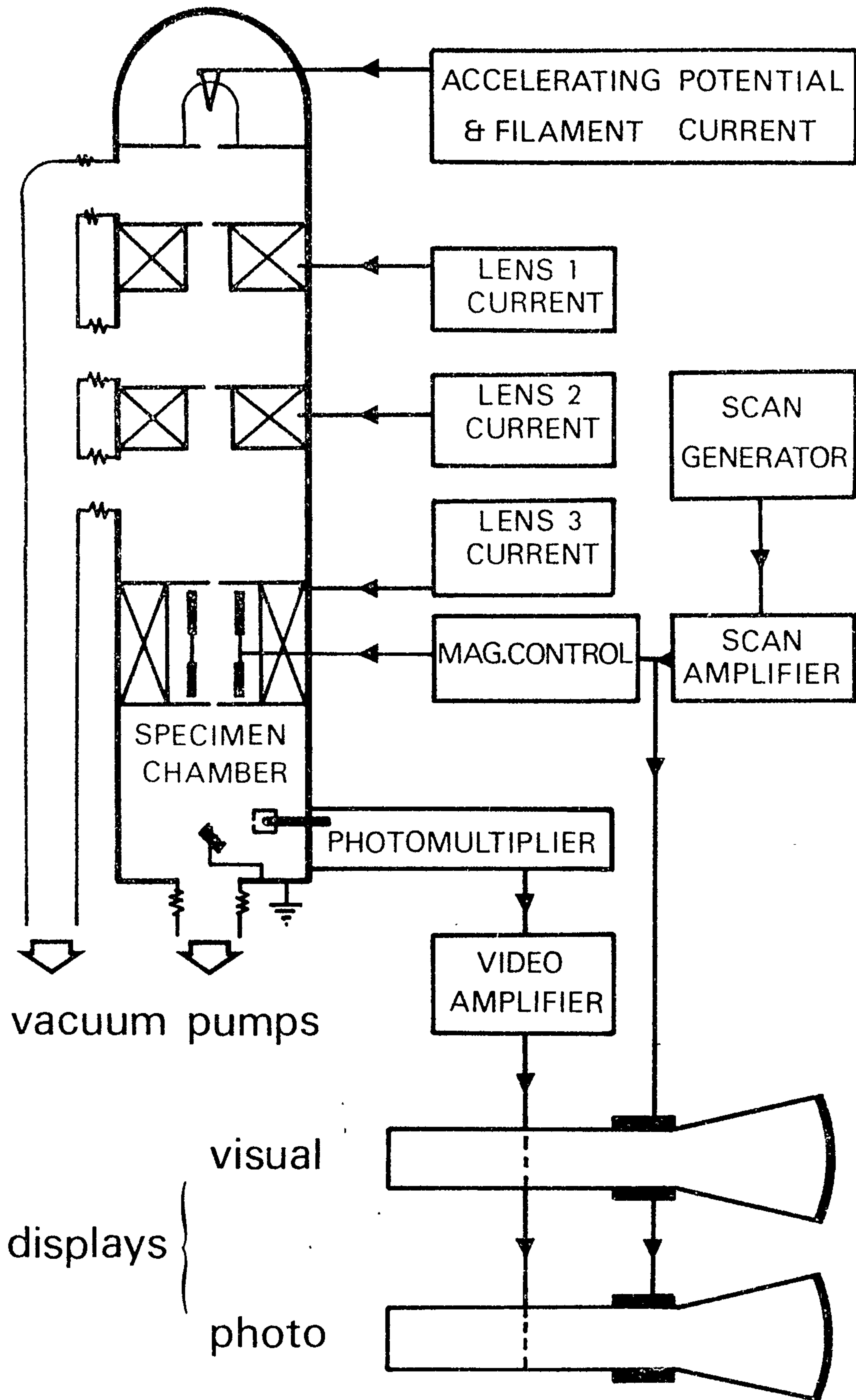


Fig. 41. Schematic diagram of the working of a scanning electron microscope.



Fig. 42 Tooth mounted on specimen stub before placing
in specimen chamber of scanning electron
microscope.

8. A high capacity system to maintain a pressure between 10^{-5} torr and permit rapid evacuation after changing the specimen.

SPECIMEN PREPARATION

Ohnsorge and Holm (1973) state that "Since the specimen itself and not a replica is being examined it must be able to withstand

- (a) electron bombardment
- (b) high vacuum

A difficult problem encountered with biological specimen, is the high water content. Teeth, because of the impervious nature of enamel and dentine, are particularly prone to retain their water content.

The specimen is fixed to the specimen stub with a conductive silver glue. It then is coated with an electron conductive coating usually carbon or gold or both. By using a sputter coater it is possible to get better adherence of the conductive coating because the metal atoms contain more energy on reaching the specimen.

Heavy metal coating gives a high emission rate of secondary electrons and good resolution. Also it is important for specimens such as teeth that increases in temperature be avoided. The metal coating thus helps to reduce electron

penetration and heat is conducted away more efficiently.

The tooth specimen is now able to be placed in the specimen chamber of the S.E.M. wherein it can be tilted and rotated. This ability enables the operator to gauge such phenomena as the depth of resorption bays with a certain degree of accuracy.

Thus for the present study the S.E.M. proved to be a most valuable asset.