Analysis of elemental composition using Proton Induced X-ray and Gamma ray Emissions in,

Part 1: Orthodontically induced root resorption craters of rat molar cementum following exposure to systemic fluoride.

Part 2: Human cementum (a) following heavy and light orthodontic forces (b) orthodontically induced root resorption craters.

ELAINE LIM BDS (Univ. Medal)

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Faculty of Dentistry
University of Sydney
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Dedication

It was during a difficult time in my life I managed to find strength with the support of my family and close friends. Their kindness and beautiful hearts enabled me to learn to look forward to the future and to smile again. I am extremely grateful to these special and precious people. Thank-you for helping me heal.

The completion of this Thesis and Degree marks this new chapter in my life. I have been blessed with a second chance – I have learnt what it truly means to *live*.

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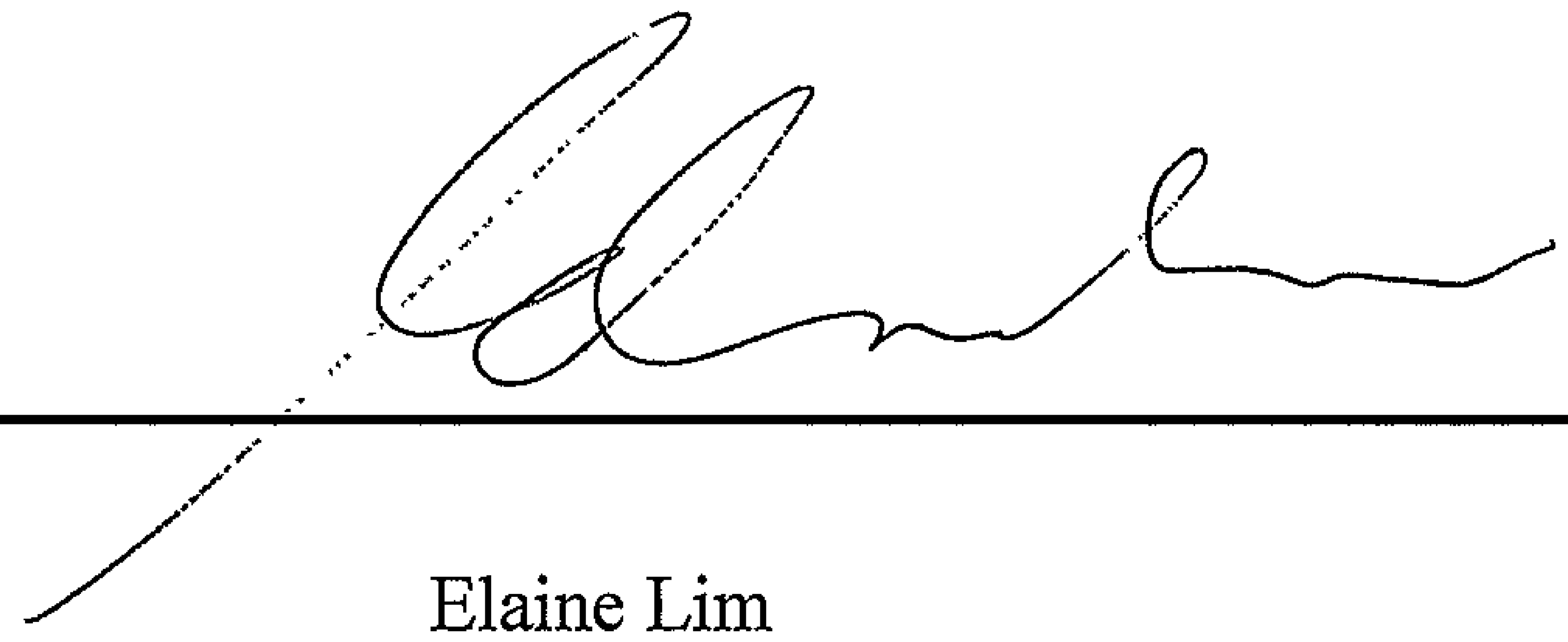
My post-graduate colleagues for all the laughter – we made the journey.

Declaration

CANDIDATE CERTIFICATE

This is to certify that the candidate carried out the work in this thesis in the Orthodontic Department, University of Sydney and has not been submitted to any other University or Institution for a higher degree.



Elaine Lim

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ABBREVIATIONS

CEJ	Cementoenamel Junction
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GEMOC	Geochemical Evolution and Metallogeny of Continents
MDL	Method (mean) detection limit
NiTi	Nickel Titanium
nm	Nanometer
NMP	Nuclear Microprobe
OIIRR	Orthodontically Induced Inflammatory Root Resorption
PDL	Periodontal ligament
PIGE	Proton Induced Gamma Emissions
PIXE	Proton Induced X-Ray Emissions
S1	Subject 1
S2	Subject 2
TMA	Beta-titanium-molybdenum alloy

1. INTRODUCTION

Root resorption refers to loss of tooth structure, which may be physiological (exfoliation of primary teeth) or pathologic (replacement (ankylosis), inflammatory or idiopathic).[1,2] If the cementum is mechanically damaged, multi-nucleated cells will arrive near the surface and resorption will occur.[3] Presence of such cells characterises inflammatory resorption, which may be transient (stimuli present for short duration with minimal damage) or progressive (longer duration).[4]

Root resorption resulting from orthodontic treatment is an unpredictable adverse effect involving transient inflammatory surface resorption. This process has been termed Orthodontically Induced Inflammatory Root Resorption (OIIRR).[1] There are three classifications for the severity of OIIRR: Cemental or Surface Remodelling, Dentinal Resorption With Repair or Deep Resorption and Circumferential Apical Root Resorption.

The mechanism of OIIRR has not been fully elucidated. Following orthodontic force application, tooth movement is associated with a local compression of the periodontal ligament and the development of sterile necrosis.[5] This morphometric phase is followed by biochemical changes. The sequence of events involves fibre coalescence, hyalinisation, degradation of connective tissue matrices (extracellular and intracellular

pathways)[6] followed by demineralisation of Sharpey's fibres[7] and finally odontoclastic activity. The resorptive process initially occurs at the circumference of the necrotic hyalinized area. This is followed by resorption of the root surface in the central part of the necrotic zone.[8] The later stages also demonstrate areas of peripheral repair.[9,10]

The prevalence of root resorption in untreated persons ranges from no resorption to 90%.[11,12] In a ten-year evaluation of the quality of orthodontic treatment, involving 3,300 patients, root resorption between 1-3 mm occurred in all fixed appliances cases.[13]

Associated risk factors for increased incidence of root resorption have been suggested to include: individual susceptibility, genetics, hormonal imbalance, medical history, nutritional balance, age, dental history, tooth type, duration of treatment, amount of tooth movement, appliance type, type of tooth movement and magnitude of orthodontic force.[14]

There is currently no consensus on how, or indeed whether, root resorption can be prevented. However, several strategies have been suggested on ways to possibly minimise root resorption. These include: limiting treatment duration,[15,16] using light intermittent forces,[17] assessment of medical history and familial tendency,[18,19] control of habits[20] and, if required, cessation of treatment.[21,22]

Unlike bone, cementum has a greater capacity to resist resorption. However, this feature is not yet fully understood. Explanations include: presence of cellular barriers, precementum and the mineral content of cementum.

Cementum is the tooth's dynamic interface to the periodontal environment. Similar to other hard tissues, hydroxyapatite in cementum is not pure, and contains elements from its microenvironment.[23] The minerals in the circulating fluid can react with cementum. In particular, the fluoride ion reacts aggressively with hydroxyapatite.[23] When the root surface is breached, repair matrices become attached to the resorbed surface.[24] Following the detachment of odontoclasts the cementogenic cells re-populate. This is followed by electron-dense globular accumulations indicating re-mineralisation.

The opposing hard tissues of cementum and bone have differences chemically, physically and physiologically. Such differences may explain why cementum does not participate in general body metabolism and as a result remains unaffected by many pathologies which affect bone.[23]

A study in the veterinary literature appears to be unique in its evaluation of elemental composition of teeth with odontoclastic resorption lesions.[25] This study found teeth affected by this pathology had greater concentrations of sodium overall and less iron, whilst in cementum there was a significant

reduction in magnesium and fluorine. No conclusions were made regarding clinical relevance. Although this study provides useful information, it is notable that there was no consideration of elements within the lesions themselves. Furthermore, orthodontic literature has not focused on the effects of altered elements in relation to root resorption.

Literature has been sparse examining the direct relationship of fluoride's potential protective influence and the effect mineral content of cementum may have against orthodontic associated root resorption. Foo et al[26] used rats to induce orthodontic root resorption, and exposed part of the sample to systemic fluoride, with an estimated intake of 1 mg per day. It was demonstrated that the average crater volumes of teeth exposed to fluoride were about half the size. However, due to a large variation in results these differences were not significant ($p>0.05$).

Although, fluoride does not increase the physical hardness of cementum *per se*,[27] there are a number of possible mechanisms whereby fluoride may impart a protective effect against orthodontically induced root resorption (as opposed to its well described effects on bone resorption). These include: direct effect on osteoclasts, alteration of shapes of resorption pits and the mineralisation of cementum.[28] Thus fluoride may be potentially linked to the prevention of OIIRR.

There are various methods to study elemental composition of teeth. Available techniques include microprobe analysis. The nuclear microprobe employs proton induced X-ray emission (PIXE) and proton induced Gamma ray emission (PIGE), which allows mapping of multiple trace elements at micron resolutions. Compared to other available techniques, the Commonwealth Scientific and Industrial Research Organisation-Geochemical Evolution and Metallogeny of Continents Nuclear Microprobe (CSIRO-GEMOC NMP) provides the best trace element spatial and quantitative analysis. However, this technology does not lend itself well to bulk sample analysis. Rather, the data gathered is respected for its high quality.

The aim of this thesis was to develop a methodology using the CSIRO-GEMOC nuclear microprobe machine in order to analyse the elemental composition in tooth root cementum & root resorption craters, and whether they undergo alterations following orthodontic force.

In order to achieve these aims three separate studies were developed which constitute this Thesis:

Part 1: Root resorption craters of rat molar cementum following exposure to systemic fluoride. This study examined the impact fluoride had on the

elemental content of cementum and within orthodontically induced root resorption craters.

Part 2a: Human cementum following heavy and light orthodontic forces. This study explored the effect orthodontic force had on cementum elemental concentration and distribution.

Part 2b: Human root resorption craters. This study aimed to quantitatively and spatially characterise the elemental content of a "typical" OIIRR crater.

It is hoped that this Thesis will contribute to our knowledge of orthodontic root resorption and may form a basis from which further research can be conducted in order to help understand and potentially prevent or minimise this treatment side-effect.

2. REVIEW OF THE LITERATURE

2.1 Root resorption

2.1.1 History

Root resorption in secondary teeth was initially described in 1856 by Bates.[29] This was later demonstrated radiographically.[30]

2.1.2 Definition

Root resorption refers to loss of tooth structure, which may be physiological (exfoliation of primary teeth) or pathologic (replacement (ankylosis), inflammatory or idiopathic).[1,2] Mineralized tissues of the permanent dentition are not normally resorbed.[4] They are protected in the root canal by dentine and odontoblasts, and on the root surface by cementum and cementoblasts.[31,32] If the cementum is mechanically damaged, multi-nucleated cells will arrive near the surface and resorption will occur.[3] Presence of such cells characterises inflammatory resorption, which may be transient (stimuli present for short duration with minimal damage) or progressive (longer duration).[4]

2.1.3 Classification of root resorption

Three types of external root resorption have been defined: surface resorption (self-limiting process followed by spontaneous repair), inflammatory resorption (root resorption which has reached infected necrotic pulp or infected leukocyte zone) and replacement resorption (replacement by bone leading to ankylosis).[33]

An alternative classification of external root resorption has been proposed by Ghafari:[34] Inflammatory Resorption (which results from inflammation to a specific stimulus, phagocytic cells and inflammatory mediators eventually affecting dentinal tubules or pulpal tissues), Surface Resorption (transient inflammation confined within the root's more superficial layers, which is usually followed by repair) and Progressive Resorption (with or without bone substitution).

Root resorption associated with orthodontic treatment involves transient inflammatory surface resorption. This process has been termed, Orthodontically Induced Inflammatory Root Resorption (OIIRR).[1]

Brezniak and Wasserstein[35] describe three classifications for the severity of OIIRR:

1. *Cemental or Surface Remodelling* – superficial resorption followed by repair

2. *Dentinal Resorption With Repair or Deep Resorption* – Cementum and outer dentine are resorbed. Repair with cementum and final root form may differ from the original.

3. *Circumferential Apical Root Resorption* – resorption of root apex resulting in a shortened root.

External surface repair occurs in the cementum only. Therefore, once tooth material is lost beyond the cementum, complete regeneration of the original root morphology is impossible.

2.1.4 Mechanism of root resorption

The mechanism of OIIRR has not been fully elucidated, however, fundamentally it has been described in terms of a local inflammatory reaction.[36]

Mineralised tooth root surface undergoes resorption when odontoclasts gain access via a breach in the formative cell layer,[4] when precementum is damaged[4] or when mineral and matrix coincide.[7]

Following orthodontic force application, tooth movement is associated with a local compression of the periodontal ligament and the development of sterile necrosis.[5] This morphometric phase is followed by biochemical changes. The sequence of events involves fibre coalescence, hyalinisation, degradation of connective tissue matrices (extracellular and intracellular pathways)[6] followed by demineralisation of Sharpey's fibres[7] and finally odontoclastic activity.

The resorptive process initially occurs at the circumference of the necrotic hyalinized area. This is followed by resorption of the root surface in the central part of the necrotic zone.[8] The later stages also demonstrate areas of peripheral repair.[9,10]

Brudvik and Rygh used rats and mice to demonstrate the cells involved in root resorption.[8,37] Mono-nucleated, TRAP (tartrate resistant acid phosphatase) negative (non-clast) cells were located at the periphery of the necrotic zone. These resembled macrophages and/or fibroblasts. In the later stages of the resorptive process, multinucleated TRAP-positive giant cells without a ruffled border and mono-nucleated TRAP-positive macrophage-

like cells remove necrotic tissue and surface cementum.[9] These cells are presumably derived from the mono-nucleated phagocytic system.

2.1.5 Incidence

2.1.5.1 Incidence Untreated Population

Root resorption occurs in untreated as well as orthodontically treated populations. The prevalence of root resorption in untreated persons ranges from no resorption to 90%.[11,12] Henry and Weinmann[12] found the histological evidence of root resorption craters on 261 permanent human teeth was distributed across the root, with 76.8% of the resorption areas in the apical third, 19.2% in the mid-root region and 4% in the gingival third. There were more resorption craters on the mesial and buccal root surfaces compared with the distal and lingual surfaces. On average the root resorption craters were 0.73 mm in length and 0.10 mm in depth, with the number of craters increasing with age. However, 85% of the resorption areas showed evidence of repair. It was concluded that it is normal for teeth to undergo a certain degree of physiologic resorption, although the morphology of such craters is small, shallow and usually undergo repair.

2.1.5.2 Incidence Treated Population

Root resorption resulting from orthodontic treatment is prevalent and is an unpredictable adverse effect. This creates a potential for damage to teeth and a compromised orthodontic result. In a ten-year evaluation of the quality of orthodontic treatment involving 3,300 patients, root resorption between 1-3 mm occurred in all fixed appliances cases.[13] After treatment, 41% of adult patients had increased root resorption of over 2.5 mm in one or more teeth,[38] whilst an incidence of 93% of treated adolescents has been recorded.[39] Other studies, more recently, have demonstrated less root resorption associated with orthodontic treatment. Cental incisors suffered an average of 0.77 ± 0.42 mm during treatment and after six month follow-up post-treatment, this had increased to 1.67 ± 0.64 mm.[40]

2.1.6 Risk factors and Aetiology

2.1.6.1 Biologically Related Factors

2.1.6.1.2 Individual susceptibility

Root resorption varies between and within individuals and changes occur over time.[21] This maybe the result of individual susceptibility due to endogenous factors.[41] An increase in the ligand receptor activator of

NFkappaB (RANKL) and a decrease in osteoprotegrin production is evident in those who suffer from severe root resorption.[42] It is believed that the compression of periodontal ligament (PDL) cells associated with teeth suffering from severe root resorption produce large amounts of RANKL and result in an up-regulation of osteoclastogenesis.

2.1.6.1.3 Genetics

Root resorption may be due to genetic influence as demonstrated in the experience of related individuals.[43] One-hundred and three siblings, who had undergone orthodontic treatment, were examined for crown-root lengths on orthopanoramic radiographs and lateral cephalograms. Hereditability estimates were high, with the exception of the mandibular incisors. Root resorption may possibly have an autosomal dominant, autosomal recessive or polygenic mode of inheritance.[18] Al-Qawasmi established a link between interleukin genes and external apical root resorption.[44,45] Samples homozygous for the IL-1B allele 1 had over five times the risk of greater than 2 mm of root resorption, compared to the non-homozygous group. The report describes a genetic marker for this cytokine, which may identify those at risk prior to commencement of orthodontics. Another gene, which may have an effect is TNFRSF11A, which encodes for Tumour Necrosis Factor receptor. This mediates the signalling to osteoclastogenesis.[46] Thus the genetic contribution has important implications in the pathogenesis and

may explain the variations seen in individuals who experience external root resorption.

Ethnicity may also play a role. In a sample of 868 patients it was found that Caucasian and Hispanic patients experienced less root resorption than those of an Asian background.[14] However, this may need reassessment, as there was a discrepancy in the sizes of the samples used.[47]

2.1.6.1.4 Hormonal imbalance

Hormonal imbalances affect bone metabolism. These have also been linked to root resorption. Three hormones primarily control the metabolism of mineralised tissues – Vitamin D (1,25-Dihydroxycholecalciferol), calcitonin and parathyroid hormone.[48]

Vitamin D undergoes a pathway of hydroxylation to form the steroid hormone 1,25-Dihydroxycholecalciferol, resulting in increased calcium absorption in the kidney. The thyroid gland secretes calcitonin, which is an inhibitor of bone resorption. The parathyroid glands secrete parathyroid hormones, resulting in the mobilisation of calcium in bone and increased phosphate excretion. These hormones act in unison to maintain calcium homeostasis.

Root resorption has been related to systemic disorders, including hyperparathyroidism,[49] hypothyroidism,[50] hypo- and hyperpituitarism,[51,52] hypophosphatemia[53] and Paget disease.[54] In contrast, Linge and Linge suggest hormonal imbalances are not an aetiological factor *per se*, but rather, may serve to influence the resorptive process.[55] Similarly, Goldie and King did not support secondary hyperparathyroidism, created in response to parathyroid hormone (PTH) secretion in hypocalcaemic and lactating rats, as being primarily responsible for an increase in root resorption.[56] In fact, it has been demonstrated that increased bone resorption was associated with decreased root resorption. However, Engström observed an increase in amount of root resorption in hypocalcaemic rats both histologically and biochemically.[57]

In contrast, hormones may also suppress root resorption. Sterol-treated rats demonstrated a reduction in orthodontic related root resorption compared with controls, thus suggesting steroid treatment reduces the activity of clastic cells.[58]

2.1.6.1.5 Medical History

Asthmatics and allergy sufferers may be more susceptible to root resorption during orthodontic treatment.[59,60] McNab et al[59] found an increased incidence of root blunting in asthmatics compared to a control group, using

orthopanoramic radiographs. The upper first molar teeth were found to be the most susceptible and it was suggested that inflammatory mediators produced in asthma might increase root resorption. Davidovitch et al[61] correlated an increased risk of root resorption with asthma and allergies. Acute use of corticosteroid drugs in the treatment of such conditions has also been related to an increase in root resorption.[62]

Medications such as bisphosphonates (inhibitors of bone resorption used in the treatment of osteoporosis) and calcitonin may also have a role in altered susceptibility to OIIRR.[46] Other medical issues such as alcoholism may also influence root resorption. Chronic alcoholics are possibly at an increased risk of developing the most severe grade of root resorption during orthodontics.[63] This is because ethanol inhibits the hydroxylation of vitamin D3, therefore preventing calcium homeostasis. This causes a rise in parathyroid hormone, which causes an increase in mineralised tissue resorption.

2.1.6.1.6 Nutritional Balance

A deprivation of dietary calcium and vitamin D in rats has been related to root resorption.[57] Engstrom et al[57] compared two groups of male Sprague Dawley rats – one fed a low calcium and deficient vitamin D diet and the other served as a control. Both groups were then treated with an expander

between their maxillary incisors after three weeks on their respective diets. Over a period of 14 and 21 days the rats were sacrificed. It was demonstrated that the group exposed to the diet deficient in calcium and vitamin D had hypocalcaemia, an increased alkaline phosphatase activity and higher systemic circulating parathyroid hormone, which is associated with an increased number of osteoclasts in the periodontal ligament.[64] Tooth movement was greater in this group, with rapid and more extensive bone resorption in the bony compression zone. It was concluded that the severity of root resorption increased after orthodontic treatment and related this to greater alveolar bone resorption.

However, other studies have suggested that nutrition plays only a minor role in orthodontic root resorption. Goldie and King found fewer root resorption craters in their study group of rats which were calcium deficient.[56]

2.1.6.1.7 Age

Chronological aging has been associated with changes in dental hard and soft tissues. Changes such as a reduction in bone remodeling response, altered vascularity and increased cementum width may relate to an increase in root resorption observed in adults.[14,65,66] However, other studies do not support this assertion.[67,68]

Dental age may also influence a tooth's susceptibility to root resorption, in that open apices may better resist apical resorption.[55,69] However, Hendrix et al found teeth with incompletely formed roots did not achieve what was considered a normal root length post-treatment.[70] Although this may be attributed to non-control of radiographic projection between pre- and post-treatment radiographs and such differences may be due to differences in study design.[71]

2.1.6.2 Tooth Related Factors

2.1.6.2.1 Dental History

The presence of root resorption prior to orthodontic treatment is highly correlated with the degree and quantity of root resorption during and after treatment.[68,72]

Certain abnormal root forms have been related to an increase in orthodontic root resorption. This includes morphologically abnormal roots such as dilacerations, fine, and pipette-shaped roots[16,18,73] and blunted or shortened roots,[18,74] but excludes invaginations.[75] In contrast, other studies have demonstrated blunt root form is less susceptible to resorption.[14,76,77] In a comparison between pointed, pipette, blunted, normal, dilacerated and incomplete root post-orthodontic treatment, it was shown that susceptibility

to resorption was most for dilacerated roots, followed by pipette and pointed roots.[14]

Traumatised teeth have been shown to have a greater loss of root length after orthodontic treatment.[55] However, traumatised teeth without a history of associated root resorption are not resorbed more than non-traumatised controls.[33,78]

Root-canal treated teeth have been subject to conflicting observations. Wickwire et al showed an increased incidence of root resorption of endodontically treated teeth during orthodontic treatment.[79] Whereas, Mirabella and Artun[80] and Thilander et al[81] oppose this view, and found less resorption. Remington et al., concludes that an increase in dentine density resists resorption.[82] More recently, a review of 2,500 cases showed that there was no statistical difference in apical root resorption in endodontically treated teeth compared to vital teeth.[83] Therefore, teeth free of pulpal pathology and successfully treated non-vital teeth are at no greater risk of root resorption compared with vital teeth.

In addition to the tooth itself, the surrounding alveolar bone may also play a role in susceptibility to root resorption. Tooth movement through denser bone may increase root resorption.[65,84] This may be attributed to fewer marrow spaces in dense alveolar bone, which means fewer resorptive cells

for bone remodelling.[65] Goldson and Henrikson found a two-fold increase in frequency and an eight-fold severity of resorption during Begg treatment due to the proximity of roots to compact cortical bone during Stage II treatment.[85] Conversely, Wainwright reported bone density has no relationship to the extent of resorption.[86] Vardimon et al[87] found that teeth located in dense buccal cortical plate in a subject group of monkeys demonstrated no more resorption than roots in less dense bone, thus concluding density was not a primary predisposing factor.

Malocclusion may be a risk factor predisposing root resorption. Increased overjet,[88] openbite[72] and Class III malocclusions[89] have been associated with an increased risk. However, VonderAhe was unable to find a correlation between root resorption and different classifications of malocclusion.[90] Overbite has also been found to be unrelated.[14]

Non-physiological forces from habits such as finger-sucking,[88] nail-biting,[20] and tongue/lip dysfunction,[18] may increase the risk of external apical root resorption.

2.1.6.2.2 Tooth type

Individual teeth have varied susceptibility to root resorption. Maxillary incisor teeth are most vulnerable to root resorption, but this may be due in

part to the distance they may need to be moved to establish a normalised position.[11,66,90-92] The maxillary incisors are the most frequently affected teeth, laterals more than centrals, followed by the mandibular incisors, distal root of mandibular first molars and second premolars.[93] Other studies have also found the anterior segment more vulnerable compared to the posterior teeth, incisors experiencing more resorption than canines, and maxillary teeth being more affected than mandibular teeth.[14]

2.1.6.3 Mechanical and treatment Factors

2.1.6.3.1 Duration

Duration of treatment has been associated with increased risk and severity of apical root resorption.[71] This has been demonstrated in human studies. Stenvik and Mjör, compared 35 experimental and control human premolar teeth from 10 to 13 year olds.[15] The experimental teeth had forces of 35-250 g applied over 4 to 35 days. An increase in treatment time was associated with increased root resorption. Furthermore, it was concluded that duration of force application was more critical than force magnitude. Harry and Sims also examined human premolar teeth and determined root resorption by scanning electron microscopy, following the application of 50 g, 100 g and 200 g intrusive forces over 14, 35 and 70 days.[17] They also found a

relationship between an increase in resorption and treatment time. Increased treatment time has also been shown to result in a greater width and depth of root resorption craters.[94]

On the contrary, other investigations have not supported a correlation between increased root resorption and treatment time.[90,95] Dermaut and DeMunck[11] intruded maxillary incisors with a modified Burstone Arch (0.018" Australian Wire) engaged in Begg brackets in a group of 20 patients whose ages ranged from 11 to 37 years. The intrusive force was in place for an average of 29 weeks. The extent of root resorption was determined using periapical radiographs and no correlation was found between extent of root resorption and duration of treatment.

2.1.6.3.2 Amount of tooth movement

The increase in incidence of root resorption of anterior maxillary teeth may be related to the distance these teeth are moved orthodontically.[96]

2.1.6.3.3 Appliance Type

Removable appliances cause less root resorption compared with fixed appliances,[55] with Standard Edgewise being more detrimental than straight-wire techniques.[97] No differences have been demonstrated between sectional

and continuous mechanics[98] nor between Speed and Edgewise techniques.[99] There may be a difference between Begg and Edgewise, with Begg having less[100] or more[85] resorption, however Malmgren et al[78] found no difference. The amount of resorption is also similar for 0.018" and 0.022" slot brackets and steel compared to titanium archwires.[14]

The use of elastics may also have an effect on resorption. Intermaxillary elastics were shown to increase the amount of root resorption,[55] although Sameshima and Sinclair[66] found no difference. Class III elastics used for anchorage purposes have been demonstrated to cause resorption to the distal root of the mandibular first molar.[69]

Rapid expansion has been related to root resorption. The use of rapid maxillary expansion appliances causes resorption of the anchor teeth.[81,101] Conversely, Sameshima and Sinclair suggest there is no difference with expansion.[14]

2.1.6.3.4 Type of tooth movement

Intrusive movements appear to result in the most root resorption.[102] Other tooth movements such as torque, tipping, maxillary expansion and translation can also cause root resorption,[22,55,90,94] although there may be less root resorption with translation compared with movements involving tipping due to stress concentration.[81]

Force constancy is also another issue. There is no agreement as to whether continuous or discontinuous forces result in less root resorption. Intermittent force has been suggested to produce less resorption, with the cessation of force allowing time for recovery of the cementum.[103]

Acar et al[103] used contralateral human premolar teeth with 100 g of continuous tipping force on one side and discontinuous force on the other over 9 weeks. It was concluded that discontinuous forces resulted in less root resorption. However, this study utilised force application via elastics, which therefore relied on patient compliance. In contrast, Owman-Moll et al[104] found no difference in the amount or severity of resorption. This study applied a buccally directed continuous and interrupted force of adolescent patients over a four and seven week period.

More recent volumetric studies of resorption areas have lent support to the relationship of increased resorption with an increase in buccal and intrusive force.[105,106] Since OIIRR is part of the hyalinisation elimination process for a force directed, for example, in the buccal direction, it would be expected that the greatest changes in root mineral content would be at the cervical third of the buccal and apical third of the lingual surfaces.[5] However, more recently it has been shown that significant tissue changes occur at both tension and compression areas.[107]

2.1.6.3.5 Magnitude of orthodontic force

Optimal force has been defined as 26 g/cm^2, beyond which ischemia of the periodontal ligament vasculature may trigger processes which inadvertently result in root resorption.[108] However, there is some disagreement regarding the relationship between the level of force and its effect on root resorption.

Owman-Moll and co-workers argue that there is large inter-individual variation.[109,110] They found no differences in frequency or severity of resorption using 50 g compared to 100 g and 200 g of buccal force in adolescent human premolars. The experimental intervals were one month and seven weeks. Similarly, Reitan[111] found only a weak correlation between the extent of resorption and force using 25 g and 240 g of intrusion applied to human premolars. This experiment was also conducted in adolescents and was over a period of 10 to 47 days. However, these studies were conducted over a relatively short period.

In contrast to these histological and radiographic studies, which fail to support a relationship between force and root resorption, a number of animal studies have demonstrated an increase in root resorption with increased orthodontic force magnitude. King and Fischlschweiger[112] applied 50 g and 200 g of force in rats. Lighter forces were associated with less resorption. Primates have also been used in root resorption studies.

Dellinger[113] used *Macaca Speciosa* monkeys and applied intrusive force to the upper first premolar teeth. The higher force groups of 100 g and 300 g showed much greater root resorption compared to the 10 g and 50 g groups. However, due to morphological and functional difference between animals and the human dentoalveolar structures, animal studies may not be directly applicable to humans. Importantly, animals have denser alveolar bone with reduced marrow spaces, and this may influence the resorptive process. Furthermore, rats demonstrate a consistent presence of root resorption even without exposure to orthodontic force.[114]

In support, experiments on human teeth have also shown a positive relationship between increased force and resorption. Electron Microscope technology has been used to demonstrate that higher force is associated with a greater volume of resorption craters. Harry and Sims[17] used 50 g, 100 g and 200 g intrusive force and, following extraction and analysis with a scanning electron microscope, they concluded an increased rate of lacunae development. Casa[94] used 300 cN and 600 cN torquing force to maxillary first premolars, over a period of a month. High pressure zones are more susceptible to resorption.[115] Areas undergoing high force (225 g) compression had significantly more resorption than areas under tension and other regions of the tooth root.[116]

2.1.7 Prevention, Management and Clinical implications of root resorption

There is currently no consensus on how or indeed whether, it is possible to prevent root resorption. Strategies have been suggested on how to possibly minimise root resorption. These include:

1. *Limit the treatment duration*[15,16]
2. *Light and intermittent forces*[17]
3. *Assessment of medical history and familial tendency*[18,19]
4. *Control habits*[20]
5. *Halt treatment*[21,22]

Where apical resorption is noted during treatment, cessation of force for two to three months reduced resorption compared to those who continued treatment.[117] In general it has traditionally been recommended that radiographs be taken six months after treatment begins.[118] For patients with blunt and pipette-shaped apices, a three month regimen of radiographic review is suggested.[73] More recent findings suggest a future for biological markers rather than radiographs to evaluate root resorption. Testing of gingival crevicular fluid for Dentine Sialoprotein and Dentine Phosphoryn

could be used as biological markers for monitoring root resorption during treatment.[119]

Where severe resorption has occurred treatment compromises will need to be accepted.[120] In extreme cases endodontic treatment may be required.[121] Although a majority of patients experience some degree of root resorption, the risk of tooth loss is not increased.[122] The equivalent loss of periodontal support at the crestal alveolar bone level compared to the root apex is disproportionate, with apical loss much less detrimental.[123] A tooth with 5 mm of apical root loss has 25% loss of periodontal attachment.[124]

In the long-term, no loss of tooth has been reported.[90] The most extreme consequence of root resorption was increased mobility.[82] It has been concluded that root resorption as a result of orthodontic treatment does not pose long-term harm to the patient's dental health.[71] However, over a period of 5 to 15 years, where the remaining tooth structure is less than 9 mm, long-term mobility may continue.[118]

2.1.8 Cementum and resistance to root resorption

Cementum is similar to bone,[125] but behaves differently in response to orthodontic force application. Unlike bone, cementum is not fully resorbed. The exact mechanism of how it is able to resist resorption has not yet been elucidated. Explanations include:

1. *Cellular barriers*

Cells that form a covering over dental tissue may provide a barrier against odontoclasts. This has been demonstrated by the use of a replanted tooth as a root resorption model in monkeys.[33] The inner cellular layer of the periodontal ligament consists of cementoblasts, fibroblasts, osteoblasts, endothelial and perivascular cells. This is thought to provide a protective and repair mechanism.[33]

2. *Precementum*

The precementum layer is an unmineralised matrix and has been thought to have a resistance to resorption.[126] Osteoid[127] and predentin[15] are also uncalcified mineralised tissues and also demonstrate a reduced susceptibility to resorption.

3. Mineral content

The susceptibility of root resorption has been related to the degree of cementum mineralisation.[12] Henry and Weinmann found that cervically positioned acellular cementum is more mineralised and was more resistant compared to less mineralised cementum. Reitan and Rygh[65] reported cementum density may confer greater resistance to resorption. However, Jones and Boyde[128] do not believe mineral content of dental tissue influences susceptibility to root resorption.

2.1.9 Mineral content of teeth and its relationship to OIIRR

Literature directly examining the mineral composition of OIIRR craters in humans remains elusive. Element changes in cementum following orthodontic force have been studied,[107] but no direct examination of mineral composition of the resorptive lesions has been made. A study in the veterinary literature appears to be unique in its evaluation of the elemental composition of teeth with odontoclastic resorption lesions.[25] This study focused on cats. These lesions were described as idiopathic surface defects established by odontoclasts unrelated to caries. Since literature is sparse in this area of interest, from the description of this study, its findings may be

assumed to be somewhat equivalent to external inflammatory root resorption seen by the dental profession in human patients. Furthermore, the elemental composition of cat teeth is similar to humans.[25] This study used nuclear microprobe analysis and compared overall dental tissue of those suffering from resorptive lesions and normal cat teeth. They found teeth affected by this pathology had greater concentrations of sodium overall and less iron, whilst in cementum there was a significant reduction in magnesium and fluorine. No conclusions were made regarding clinical relevance. However, future studies focusing on diet, elemental composition of teeth and the development of such lesions to demonstrate a direct relationship was recommended. Although this study provides useful information, it is notable that there was no focus on minerals within the lesions themselves, and as per the usual limitations of standard microprobe machines, only provided "spot-scanning".[129]

Root resorption remains an important consideration in orthodontics, as it is a common occurrence. Its aetiology, biological mechanisms, prevention and management are not yet fully elucidated. However, the accumulation of histologic, chemical and biological based research is contributing greatly to our understanding of this issue.

2.2 Cementum

2.2.1 Tooth root cementum

Teeth are supported within the jaw by four tissue layers – gingivae, periodontal ligament and alveolar bone and cementum.[130] Cementum is a mineralised layer overlying tooth dentine, covering the entire root surface.[130-132]

Cementum is adhered to dentine on its inner surface, whilst on the outer side it is continuous with the periodontal ligament. This serves its main function of providing attachment to the collagenous periodontal ligament fibres. Cementum is a dynamic tissue and its cells are responsive and adaptive.[133]

Although cementum is similar to bone, chemically and physically, there are marked differences. Cementum does not have innervation and is avascular. It is also less readily resorbed compared with bone. This feature has been attributed to its unique physical and biological properties, pre-cementum, density of Sharpey's Fibres and location of epithelial cell rests.[131] However, the composition of dental cementum has not been studied to the extent of other mineralised tissues.[23]

2.2.2 Classification of cementum

Cementum has three classifications – (1) Time formation (Primary or Secondary), (2) Presence of cells (Cellular or Acellular) and (3) Cementoblastic or fibroblastic origin of collagenous fibres (Extrinsic, Mixed or Intrinsic Fibre Cementum).[130,133]

Acellular cementum has no cells. It covers the cervical third of the root and its border with dentine is not clearly demarcated. Its rate of development is relatively slow and does not increase substantially with age. There is a virtual absence of pre-cementum. In contrast, cellular cementum has lacunae and canaliculi containing cementocytes along with their processes. It covers the apical two-thirds of the root and is clearly demarcated from dentine. Its rate of development is relatively fast and its incremental lines are further apart. Cellular cementum continues to form throughout life and is characterised by the presence of pre-cementum.

Extrinsic fibres are related to the periodontal ligament from where their cells are derived. Sharpey's Fibres continue into the cementum in the same direction as the principal fibres of the periodontal ligament, that is, perpendicular or oblique to the root surface. Intrinsic fibres are derived from cementoblasts. These run parallel to the root surface and approximately

perpendicular to the extrinsic fibres. Mixed fibres refers to when both intrinsic and extrinsic fibres are present.[134]

The varieties of cementum have been categorised as follows:[135,136]

1. *Primary Acellular Intrinsic Fibre Cementum*

This type of cementum assists in tooth attachment. Prior to periodontal ligament (PDL) formation, cementoblasts form a collagenous matrix. Following the formation of the first 15-20 μm, its fibres connect to the PDL.

2. *Primary Acellular Extrinsic Fibre Cementum*

This layer is the main source of attachment. All collagen is derived as Sharpey's Fibres from the periodontal ligament. These fibres are well mineralised at the point of insertion. Therefore, this layer exhibits a greater degree of mineralisation.[23] It covers two thirds or more of the tooth root.

3. *Secondary Cellular Intrinsic Fibre Cementum*

Absence of Sharpey's fibres means it has no role in tooth attachment. It may be found in patches in the apical region. This structure may be a temporary phase, with extrinsic fibres subsequently gaining reattachment, or it may represent a permanent region without attaching fibres. It generally corresponds to secondary cellular cementum and is found in the apical third of the root and in the interradicular areas. It is absent from anterior teeth. Although this type of cementum is generally cellular due to the rapid speed of formation, development is occasionally slower which results in cells not being incorporated. A cementoid layer is present. Both Acellular Extrinsic and Cellular Intrinsic Fibre Cementum may be present in alternating layers known as Cellular Mixed Stratified Cementum.

4. *Secondary Cellular Mixed Fibre Cementum*

Its function is adaptive and makes up the majority of secondary cementum present on a tooth. Where the formation rate is slow, cellular mixed-fibre cementum – which is generally less well mineralised – results. It is characterised by a laminated structure, cementocytes (located in lacunae with processes in canaliculi) and by the presence of a cementoid layer.

5. Acellular Afibrillar Cementum

This form of cementum may be regarded as a developmental anomaly and has no supportive or structural role. This is the only type of cementum which does not contain any collagen fibres. It is sparsely distributed, thin, acellular and consists of well-mineralised ground substance that may be of epithelial origin. It covers cervical enamel or intervenes between fibrillar cementum and dentine, which is thought to develop at this site following the loss of reduced enamel epithelium.

6. Intermediate Cementum

Located only at the apex. It features cellular debris and has no functional role.

7. Mixed Stratified Cementum

This type has a layered pattern of Acellular Extrinsic and Cellular Intrinsic cementum reflecting its role in the adaptive process. Cellular Intrinsic Fibre, Cellular Mixed Fibre and Cellular Mixed Stratified Cementum are located more apically and confirm microradiographic[137] and electron microprobe studies[138] which found that apically located cementum is less mineralised. This has been explained by the presence of non-mineralised structures, such as cementocyte lacunae, in the 'cellular' types of cementum.[23]

2.2.3 Development

Cementum formation begins when root dentine formation commences, under the influence of Hertwig's Root Sheath. Cells from the dental follicle differentiate to become cementoblasts. These commence the synthesis of collagen and ground substance that form cementum. They also facilitate mineralisation similarly to dentine, and consequently hydroxyapatite crystals are deposited on the organic matrix. Cementum is formed slowly prior to eruption and is laid down in layers. This layering is seen as 'reversal lines' in adult teeth. Once the tooth erupts, cementum begins to form more rapidly, causing the entrapment of cementoblasts in the forming mineralised tissue. This in turn, results in the formation of cellular and acellular cementum. Cellular cementum is associated with a reduced fluoride content, as its rapid formation does not allow the time for its accumulation compared to that of acellular cementum.[139]

2.2.4 Chemical properties

Cementum contains 22% water, 45% inorganic material and 33% organic material by volume. On a wet-weight basis it contains 12% water, 65% inorganic and 23% organic material.[140] However, cementum is not uniform.[141] Different cementum types have varied degrees of

mineralisation.[135] The principal inorganic component is hydroxyapatite. The concentration of trace elements tends to be greater superficially. This includes the level of fluoride. Fluoride is in higher concentration in acellular compared with cellular cementum. The non-collagenous material is likened to that found in bone. The organic component is mainly collagen, most of which is Type 1. It has been noted that the percentage of dental root tissues' chemical components vary between samples, although the relative constituents are consistent within species.[23]

2.2.5 Physical properties

Cementum thickness is greatest at the root apex, approximating 50-200 μm, and at the cervical region thins to 10-15 μm.[131] The elasticity, density and hardness of cementum may impart important characteristics in its response to mechanical and biological stimuli.[142] Microhardness has been tested using indentation and resin embedding techniques. Using the Micro Ultra-Indentation System (UMIS-2000; Campbell, Australia) Poolthong et al[143] determined that cementum had reduced hardness (0.8-0.9 GPa) and elasticity (11.5-12.1 GPa) apically. Cervically, the values of hardness (1.4-1.6 GPa) and elasticity (11.5-12.1 GPa) were higher. However, such requirements for tooth sample preparation may distort the accuracy of quantitative analysis. Malek et al[141] overcame such limitations by using the UMIS-2000 programmed at 5 mN of contact force with a 20 μm diamond

indenter. The part of the tooth not embedded was oriented with a jig to allow identification in three planes of space. They found the cervical third was less hard than previously reported, 0.59 ± 0.05 GPa, and it had elasticity of 9.9 ± 1.5 GPa. The apical third had a value of 0.29 ± 0.12 GPa and elasticity of 3.99 ± 1.3 GPa.

The physical properties of cementum are dynamic in response to applied orthodontic forces, but reflect gradients seen in normal mineral composition. The trend of reduced hardness and elastic modulus from cervical to the apical end of the tooth is maintained after exposure to application of 25 g and 250 g buccally directed orthodontic force.[144] These observations are in agreement with the histological and physical properties of cellular and acellular cementum type distribution.

However, testing of hardness is only an indication of degree of mineralisation and does not provide information on individual percentages of elements.[145] Tooth mineral composition can be assessed using microprobes. Rex and co-workers used an electron microprobe technique to study the effect of force on tooth minerals.[107] When a tooth is exposed to light force (25 g) there is no apparent alteration in tooth mineral composition. However, a decreased mineral content of cementum has been demonstrated following increased orthodontic force.[107] Heavier forces (225 g) resulted in marked changes in mineral content. There was an increase in

calcium and phosphate in areas of compression, and a reduction in calcium in areas of tension. In contrast fluoride was inversely related to calcium and phosphate changes. With regards to fluoride, however, overall there was no significant difference between light, heavy or control teeth.

Various explanations may support the trend of altered of mineral content with orthodontic force:

1. *pH changes in microenvironment*. The inflammatory process involved in tooth movement results in the local drop in pH level, which could lead to dissolution of mineral content of the tooth root surface.[146,147]

2. *Cell mediated response*. Lowering the pH of tissues results in increased activity of osteoclasts whilst inhibiting osteoblasts.[36] This mechanism may have a similar effect on odontoclasts and odontoblasts.[107]

3. *Homeostasis*. Osteoblasts activate calcium channels, which lead to an increase in intracellular calcium, resulting in hypocalcaemia. Physiologic processes then act to restore balance.[148] In support, hypocalcaemic states in rats have been associated with an increased

severity of root resorption.[57] In contrast, Goldie and King[56] did not demonstrate the same findings.

Physical properties are a by-product of the mineral content. Quantitative assessment of calcium, phosphorus and fluoride concentrations demonstrate a reduction of mineral concentration towards the apex.[149] There is no difference between buccal and lingual surfaces, except for increased fluoride bucco-cervically. There is a significant difference between the upper half of the root compared to the apical part. Thus the mid-third of the root is assumed to reflect an average distribution of mineral content of the tooth root. However, the distribution of minerals within mature root tissue shows a great variability.[23]

2.2.5.1 Presence of Calcium and Phosphate

Few studies have quantitatively detailed the distribution of minerals and elements of tooth roots and the majority have focused on crowns of teeth (Table 2.1). Calcium and phosphate have been shown to be distributed with no significant difference along the root surface.[150-152] However, there may be an increase of calcium and phosphate at the cervical cementum with age.[150] An explanation suggested was that this might be due to environmental exposure via the oral cavity. From the superficial layer of cementum towards the pulp, there may be an increasing concentration of

these minerals.[153] However, other studies have shown little difference.[154,155] Rex and co-workers, using an electron microprobe, demonstrated calcium and phosphate concentrations were the same buccally and lingually.[107] Whilst the concentration cervical to apical decreased, the converse was found for the outer to inner surface, which demonstrated an increasing gradient from the cervical to middle third. There was no difference at the apical third.

Percentage weight of calcium has been reported to range from 24.0% to 29.24% dry weight as a mean total.[150,151,156] Percentage ash ranges from 35.6% to 42.4%.[152] The mean percentage weight concentration has been shown to vary between root and region of root surface – buccal-cervical 30.05%, buccal-middle 28.63%, buccal-apical 27.16%, lingual-cervical 29.69%, lingual-middle 28.90% and lingual apical 26.96%.[138] Phosphate also varies in distribution through the tooth structure – buccal-cervical 13.70%, buccal-middle 13.16%, buccal-apical 12.35%, lingual-cervical 13.72%, lingual-middle 13.27% and lingual apical 12.28%.[138]

Another study, which used electron microprobe analysis, reported very different results.[157] A calcium/phosphate ratio of 1.8-2.2% was recorded at the cemento-enamel junction, 1.65% at the coronal third, 1.3% at the furcation and 1.65-1.3% apically. Study design issues may limit the value of these figures. In particular, impacted third molars were used. The

preparation of these teeth involved root scaling to remove the periodontal ligament, which may have damaged the cementum. Furthermore these samples were not sectioned. Failure to provide a flat surface from which to project x-ray beams can result in significant background scatter[158] and thus may influence the results.

2.2.5.2 Presence of Fluoride

Fluoride has a varied distribution through and across the tooth surface. It also depends on age and environmental fluoride exposure. In general, there is an increase with age and ingestion of fluoridated water.[152,159] The fluoride concentration was on average 45-65% ash weight.

Fluoride ion electrode has been used to study the concentration of fluoride in cementum. Nakagaki et al[160] examined the enamel and cementum in 20 premolars. The subjects were from areas with a community water supply which was fluoridated at 0.1 ppm or less. The superficial cementum contained a higher concentration of fluoride. There was an increase in cementum concentration of fluoride with age, which varied from 200-3000 ppm. Sugihara et al[161] used the same methodology as Nakagaki et al[160] on 10 adult lower incisors. At the cervical region a fluoride concentration of 1509 ppm was recorded, and at the apex there was 1372 ppm. The fluoride concentrations increased with age. Also using the same methodology as the

previous two studies, Kato et al[162] examined children between six to nine years old, who lived in an area with water fluoridation of less than 0.1 ppm. The average fluoride concentration ranged between 150-450 ppm.

The distribution of fluoride varies across teeth. Buccal-cervically it is present at 1.13%, buccal-mesially 0.91% and buccal-apically 0.62% wt, whilst on the lingual surface fluoride is distributed cervically at 0.96%, mesially 0.91% and apically 0.57% wt.[138]

2.2.6 Dynamic Properties

Cementum is the tooth's dynamic interface to the periodontal environment. Mineralisation during development occurs on average at a rate of 3 μm per year, but depends on the cementum and tooth type being formed.[163] The mineral content post-development does not seem to change significantly with age.[23] This is not so for root dentine, whose tubules become obliterated with maturity.[131]

Similar to other hard tissues, hydroxyapatite in cementum is not pure and contains elements from its microenvironment.[23] Even though cementum is sometimes referred to as "bone-like" there are marked differences. Bone tissue actively participates in the physiological exchange of elements. In

contrast, cementum is mostly excluded from such metabolic processes.[23] This may be attributable to the specific non-collagenous proteins unique to cementum. In particular, the protein which mediates the attachment of connective tissue cells differs from bone sialoprotein and osteoprotegrin.[164] In addition is the cementum-derived growth factor.[165] Following root resorption, these proteins may be exposed and could possibly influence the initiation of the repair process.[23]

The minerals in the circulating fluid can react with cementum. In particular, the fluoride ion reacts aggressively with hydroxyapatite.[23] In contrast, the opposing alveolar bone is constantly remodelled and thus does not accumulate such minerals to the same extent as cementum.

When the root surface is breached, repair matrices become attached to the resorbed surface.[24] Following the detachment of odontoclasts the cementogenic cells re-populate. Within their lacunae they initiate the attachment of the repair matrix to the thin decalcified layer of remaining collagen fibrils. The new matrix and original collagen fibrils then integrate. These repair cells and tissue matrices are homologous to the original root structure. This is followed by electron-dense globular accumulations indicating re-mineralisation. These events reflect those which occur during tooth root development.[23]

Damage and subsequent repair to the mineral structure, in the form of dissolution of crystallite, also occurs. However, this process is usually countered by remineralisation. A dynamic exchange of minerals occurs superficially and this limits the extent of more minor resorptive defects. Subjacent unaffected tissue provides a reservoir for diffuse transition of elements.[23] A relative time-frame for re-mineralisation can be extrapolated from that measured for fluorine, which is incorporated into enamel within one hour from the microcirculation.[166]

Therefore, the opposing hard tissues of cementum and bone are different chemically, physically and physiologically. Such differences may explain why cementum does not participate in general body metabolism and as a result remains unaffected by many pathologies which affect bone.[23] Cementum is dynamic and this is highlighted by its reparative properties.

Study	Tooth type	Number of teeth analysed	Calcium (% wt)	Phosphate (% wt)	Fluoride	
					F in H_20	% wt
Neiders[151]	Premolars	5	Cervical: 25.62, Midroot: 26.04	Cervical: 12.92, Midroot: 13.48	Not specified	Not determined
Hals and Selvig[154]	Variable	Not specified	Not specified	Not specified	Low-F area	Outer surface: 0.5-0.6, CDJ: 0.15. Overall 1.3-1.9
Tödal and Hals[153]	2 Maxillary incisors, 1 premolar	3	24.0	11.6	Not specified	0.37 (0.16-0.7)
Hennequin and Douillard[156]	Mandibular third molars	25	Midroot: 29.24 ± 0.57	Midroot: 13.49 ± 0.31	Not specified	Not determined
Crawford, Sampson, de Bruin[167]	Permanent Molars	6	Not determined	Not determined	Community water source for last 5 years, South Australia	0.9-2.4

Table 2.1: Summary of microprobe studies on human cementum and findings of Calcium, Phosphate, Fluorine concentrations expressed in percentage dry weight (% wt). Table continued overleaf.

Chaudhri[168]	Type not specified	15	Not determined	13.0%	Community water source, South Australia	Not determined
Rex et al[107]	Premolars	36	Heavy force (HF): overall 27.69, cervical 28.87, middle 28.35, apical 26.95. Light force (LF): overall 28.91, cervical 30.75, middle 30.32, apical 28.59.	HF: overall 12.96. LF: overall 13.31.	Community water source since birth, NSW, Australia	HF: 0.859. LF: 0.830.

Table 2.1 continued: Summary of microprobe studies on human cementum and findings of Calcium, Phosphate, Fluorine concentrations expressed in percentage dry weight (% wt).

2.2.5.3 Trace elements

Trace elements are present in cementum. However, it has been reported that their distribution and significance has not been studied in detail.[23] Manganese is present in 0.5-0.9% wt.[151,152,154] However, higher values of 1.3-1.4% have been reported.[157] This ion is present in the hydroxyapatite crystal lattice. It has been suggested that magnesium could be important in contributing to cementum mineralisation and may play a role in controlling the growth of hydroxyapatite crystals.[157] Manganese increases from superficial cementum towards the cementodentinal junction.[154] Overall it is found at higher concentrations in the deeper root surface layers.[23] The concentration of manganese increases from the cervical region to apex and also increases with age.[152] In contrast, an abrasive micro-sampling technique has demonstrated that the overall concentration remained unchanged over time.[169] The cementum fluoride concentration was found to be inversely proportional to magnesium,[169] whereas manganese is found in similar concentrations to calcium.[23]

Citrate is also present in cementum and has been shown to be present at 0.86 ± 0.06% wt.[159] Carbonate is present in a concentration of 2.79% wt and for both these elements there is no inverse relationship with fluoride, unlike that observed in enamel.[159]

The presence of zinc has been noted in cementum.[170,171] Modulation of osteoclastic resorption of bone and dental tissue in the presence of zinc has been examined.[171] It has been established that the lacunae developed on tooth cementum, in the presence of extracellular zinc, were fewer in number and had smaller surface areas.

Like zinc, strontium is another element which has been related to reducing bone resorption.[172] The dental profession has used strontium in its desensitisation products, in order to occlude dentine tubules.[173] In addition, strontium found in water is incorporated into dental tissue.[174] There is conflicting evidence of the effect strontium has on cementum solubility. An increased presence of strontium has been shown to increase cementum and enamel solubility.[175,176] However, it has also been shown to decrease solubility when administered in the presence of fluoride.[177] Furthermore, the effect of strontium in combination with fluoride appears to be therapeutically additive, whereby an increasing mineralisation and density of dentine effectively reduced tooth sensitivity.[175]

Other elements have been found in cementum using an electron microprobe analysis. Sulfur is present in range from 0.1-0.3%, sodium is present at 0.3%.[154] Copper has also been found in cementum.[170]

2.3 Fluoride

2.3.1 General

Fluorine is an element, of which fluoride is its ionic form. Fluorine has an atomic weight of 19 and is the most electronegative element on the periodic table. It is widely found in the environment, both in organic and inorganic compounds.

Fluoride is found in teeth and has played an important role in the dental profession since being highlighted by Browne in 1892 in relation to the development of quality enamel. In the 1930s, fluoride was introduced as a preventive regimen against caries. It was later that McKay made a correlation between higher levels of fluoride in community water supplies as an aetiologic factor for "mottling", or fluorosis.[178] In 1936 Dean established that levels below one-part per million would not cause fluorosis.[179] It is now wide-spread that industrialised countries fluoridate their water supplies to bring naturally deficient areas in line with the accepted 0.7-0.12 ppm range. The three major benefits for dental health commonly promoted are:

1. *Reduction in solubility of enamel by conversion of hydroxyapatite to fluorapatite*. The chemical formula being $Ca_{10}(PO_4)_6(OH)_2 + 2F^- \rightarrow Ca_{10}(PO_4)_6F_2 + 2OH^-$ in the presence of low concentrations of fluoride. Higher concentrations of fluoride results in some of these ions being adsorbed onto the crystal surfaces but the rest combine with calcium ions from the lattice to form calcium fluoride, which liberate phosphate ions: $Ca_{10}(PO_4)_6(OH)_2 + 2OF^- \rightarrow 10CaF_2 + 6PO_4 + 2OH^-$.

2. *Direct inhibitory effect on oral micro-organisms*. This is achieved by interfering with their glycolytic pathway, reducing their acid output and carbohydrate metabolism, which results in a reduction of polysaccharides (i.e. plaque).

3. *Promotion of remineralization*. This occurs post-eruption to enamel.[180]

Fluoride received through the water supply or diet is 93% absorbed. With most being excreted by the kidneys, the remainder is deposited into the mineralised tissues of the body – bones and teeth. Fluoride has a high affinity for calcium phosphate and therefore accumulates readily in the body. When fluorine binds, the apatite crystals of mineralised tissue increases, and thus results in increased resistance to solubility. In

mineralised tissues fluoride is not static, and is exchanged by diffusion into the surrounding tissue fluid, saliva or plaque.

Fluoride absorption in the body is via oral and gastrointestinal absorption and plasma fluoride. In plasma there are two forms – ionic and non-ionic forms. The ionic form is higher where there is increased fluoride intake. Plasma fluoride in rats is lower than humans. A fluoride water concentration of 100 ppm in rats is equivalent to 20 ppm in humans.[181]

Arguments against community fluoridation point out that with an excess of fluoride, side effects may occur which throw into question the safety of the product. Medical problems which may occur include skeletal fluorosis, which reduces joint mobility and causes discomfort in movement.[182] It has also been linked to neurological changes and Alzheimer's Disease.[183] Safety concerns are related to the chemical structure of apatite which is $Ca_5(PO_4)_3R$, where the R-group can be fluoride, chloride or hydroxyl ion. Apatite is the main source of fluorides used in water fluoridation. To make the final product safe, silicon is added. Apatite is the raw material for the manufacture of phosphate fertilisers and is an aluminium by-product. However, safety policies in its manufacture are implemented and the sensible use of fluoride is supported world-wide by governing dental associations.[178]

2.3.2 Fluoride and dentistry

Fluoride is an agent used by the dental profession primarily to prevent caries. Its effects are mostly utilised topically, rather than systemically.[184] However, even systemic sources, such as water fluoridation, are useful as a preeruptive source of fluoride as well as providing additional topical effects after eruption. All sources of fluoride that an individual is exposed to contributes to the "reservoir" of fluoride from which teeth can benefit.

In Australia there is naturally occurring fluoride in the water source ranging from 0.1-0.4 ppm, and in the large urban populous areas has been increased to meet 1.0 ppm. The New South Wales Sydney Water Department Annual Report 2006 specifies that 95% of samples taken over a year should have 0.9 to 1.5 mg/L of fluoride in the community water system of this State. Concerns regarding dental fluorosis have focused on the additive effects of fluoride gained through substances other than the community water supply. Dental fluorosis is a "qualitative defect in enamel", which is the result of increased ameloblasts during enamel formation.[184] Clinically this is seen as white flecks in its mildest form, to severe mottling and porosity of the defective outer tooth surface. On an extreme level, fluoride can also be toxic. A dose of 2 mg daily, during the time of tooth formation, will produce fluorosis, and 5 mg/kg is a probable toxic dose (Commonwealth Department of Health, Australia 1985). Thus, if fluoride supplements were to be

recommended for therapeutic purposes, all sources of fluoride that the individual may be exposed to need consideration. In an orthodontic demographic (adolescents and adults) exposure is likely to be in the form of toothpastes (1 mg F/g paste), mouth rinses (approximately 0.05% NaF), food (0.81-1.46 mg) and beverages (including water, 1.10-1.89 mg). On average it is estimated an adult will consume 2.13-3.95 mg of fluoride in a day (Commonwealth Department of Health, Australia 1985).

Systemic fluorides are available in drops and tablets. This regimen is usually limited to those of high caries risk. Tablet forms are recommended to be chewed, rather than swallowed, to maximise topical effects. However, there is an interest in systemic fluorides for use other than for caries, such as its potential role in prevention of endodontic related and orthodontic root resorption.[26]

2.3.3 Fluoride and its relationship to cementum

Fluoride concentration in teeth is higher than in bone, and is highest in the cementum.[152] Fluoride distribution varies across the surface and depth of teeth.[139]

Fluoride gradient in rats has been demonstrated. Kato et al[185] used experimental groups given 25, 50 and 100 ppm fluoridated water over 10 weeks. This was compared to a control group that was given distilled water. Fluoride was found to be highest pulpally and reduced to the cemontoenamel junction. At this point it then increases to the root surface. The fluoride concentration increases with increased concentration of systemic fluoride.[186] Other rat studies have shown similar results. Ito et al[187] looked at the effect of the cessation of fluoride intake and found that there was a reduction in concentration in the superficial surfaces.

Fluoride distribution in rat teeth has been shown to be similar to human teeth. In human teeth there is a increasing gradient from inner to the outer surface of tooth roots.[149] Mineral composition on the buccal root surface demonstrated a fluoride distribution, which was greater cervically, and had a reduced concentration towards the apex. Otherwise, there is no difference in gradient of calcium, phosphate or fluoride concentrations between or across tooth surfaces.[149] That is, from outer to inner surface of the tooth and from cervical to apical thirds of the tooth there is decreasing concentrations of these elements. Furthermore, such distribution remains consistent, even when the tooth has been exposed to forces up to 225 g.[107] A suggested reason as to why studies have demonstrated an increased concentration of fluoride cervically is due to greater exposure via topical distribution through tooth exposure in the oral cavity.[152]

2.3.4 Use of fluoride to protect teeth against root resorption

Studies examining the role of fluoride and its influence on root resorption have been in the area of endodontics and dental trauma. Research has mainly focused on the protocol following tooth avulsion. It may be beneficial to treat teeth with fluoride to minimise future potential resorption, as investigated by Coccia.[188] This study used 129 teeth, which had been avulsed in children. These teeth had closed apices and were reimplanted more than 12 hours after the incident. Two groups were studied, those teeth stored in saline were compared to those treated with 2% neutral sodium fluoride. Endodontic treatment was provided. It was found the teeth treated with fluoride were less susceptible to root resorption, but this was a function of extraoral storage time. These results have been supported by other studies on human teeth.[189]

Animal studies have shown similar results. In monkeys, storage of avulsed teeth in 1M of sodium fluoride for 18 to 54 hours was effective in reducing root resorption.[190] In rats, Bjorvatn and Massler[191] found that even a 2% sodium fluoride or 1% stannous fluoride solution of 5 minutes was effective in reducing resorption after three years. However, Barbakow et al[192] cautioned against immersion in 2% acidulated sodium fluoride for 30 minutes, as after three weeks resorption was seen similar to the control

group and after the fourth week ankylosis occurred. The concentration of fluoride may also have a negative effect, with a 10% stannous fluoride solution found to inhibit normal healing processes.[193]

The effect of fluoride on mechanical injury to the periodontium has been investigated.[194] Injury to rat tooth roots was achieved using a needle to puncture the cementum at the level of the gingival margin every three hours, for three times, over one day. The group receiving systemic sodium fluoride (25 mg/kg) via a gastric tube showed a reduced extent of trauma and root resorption. A conclusion was made that fluoride suppressed the root resorption induced by the injuries to the periodontal tissues.

Literature has been sparse examining the direct relationship of fluoride's potential protective influence and the effect mineral content of cementum may have against orthodontic associated root resorption. Foo et al[26] used rats to induce orthodontic root resorption and exposed part of the sample to systemic fluoride, with an estimated intake of 1 mg per day. It was demonstrated that the average crater volumes of teeth exposed to fluoride were about half the size. This was also evident in the group exposed to no orthodontic force but were given fluoridated drinking water. However, due to a large variation in results these differences were not significant at a level of $p>0.05$ (Figure 2.3). This study was limited as it only examined pooled volumetric data for craters on each tooth. Further examination, with respect

to both individual craters, and discriminating between length and depth parameters may yield more information.

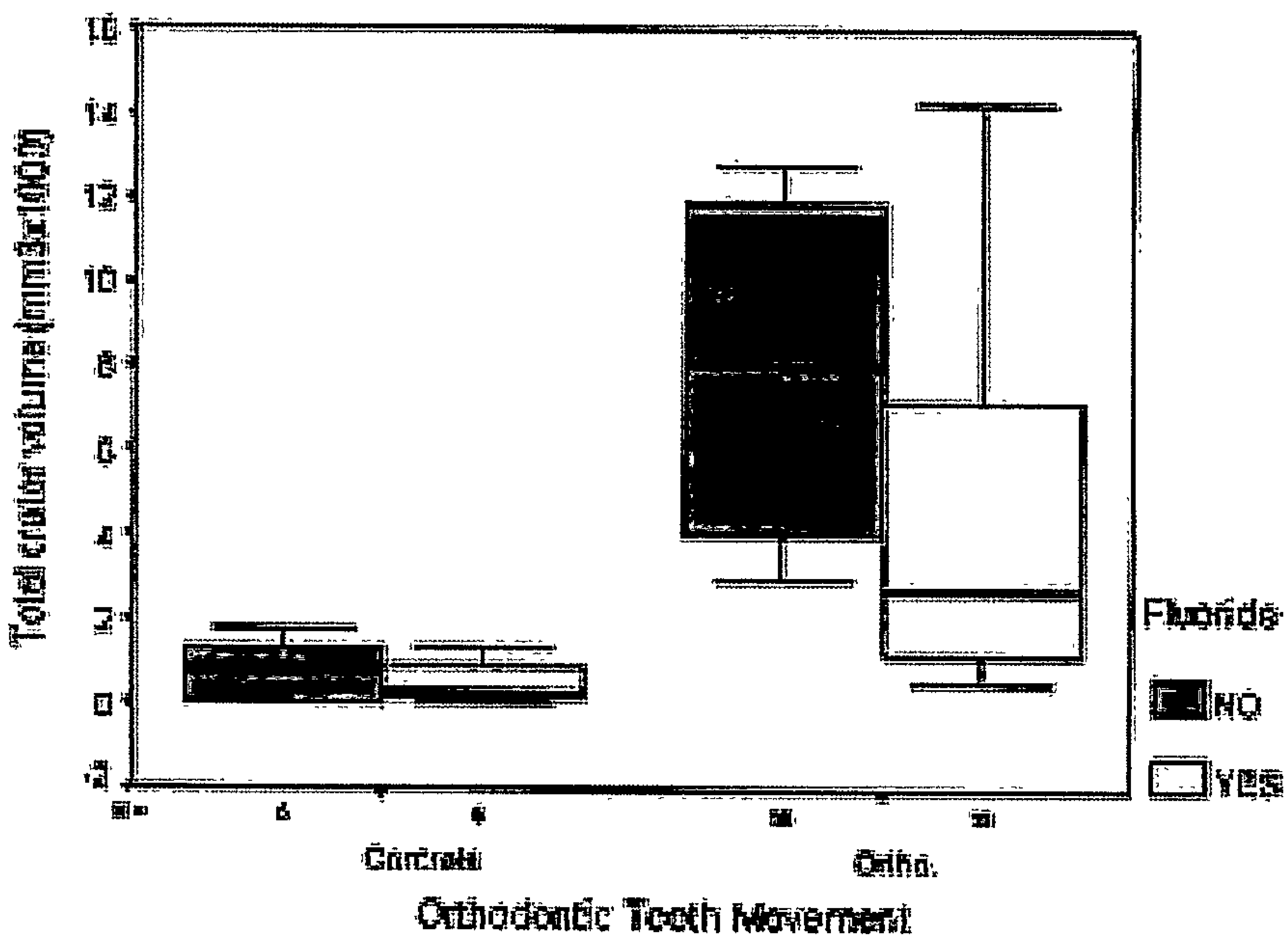

Figure 2.1: Box plot graph of resorption craters (volume) in experimental groups. *(Source: Foo et al., 2007, with permission)*

2.3.5 Mechanism of fluoride and its relationship to OIIRR

Although, fluoride does not increase the physical hardness of cementum *per se,*[27] there are a number of possible mechanisms that fluoride may impart a protective effect against orthodontically induced root resorption (as opposed to its well described effects on bone resorption):

1. *Direct effect on osteoclasts:*
   a. Osteoclastic activity has been shown, in culture, to alter in the presence of fluoride[195]
   b. Osteoclastic secretory function is suppressed[196]
   c. Furthermore, this affects the release of calcium and magnesium, thus the subsequent pattern of osteoclast adherence and motility is altered.[195] Fluoride has been observed to inhibit the activity of adjacent resorbing cells.[197]
   d. Fluoride may also promote osteoblastic activity[198]

2. *Alteration of shapes of resorption pits:*
   a. Resorption pits made by osteoclasts are shallower but wider.[195]

3. Mineralisation of cementum:

a. Fluoride is taken up by the root surface of teeth[198]

b. Cementum incorporates fluoride into its mineral lattice converting hydroxyapatite to fluorapatite[131]

c. The increased crystallite size is more resistant to dissolution.[199,200]

Fluoride's effect on osteoclasts depends on the dosage level. Sodium fluoride at 0.5-1.0 mM on a local level reduces the number of resorption lacunae made by individual osteoclasts and reduces the resorbed area. This is achieved from an intake of approximately 1 mg NaF/kg body weight per day in rabbits.[201] The inhibition of osteoclastic movement and a reduction in depth of resorption pits resulted from 15 mg/l NaF in rats.[195] A similar effect was achieved using 15 mg/kg for 21 days in another study.[202] A single high dose of fluoride was found to decrease osteoclast density and reduce the number of active osteoclasts whilst increasing inactive ones not attached to the bone surface.[203]

An understanding of the chemical and biological structure of cementum is vital, as it is the interface at which OIIRR occurs. The elemental composition of cementum may play a role in the extent and severity of the resulting lesion. An understanding of the effect root resorption has on minerals may also lead to potential preventive measures being elucidated.

2.4 Methodological considerations

2.4.1 Methods used in Orthodontically Induced Inflammatory Root Resorption studies

Animals have been used in the investigation of root resorption. Differences in the animal model pertinent to root resorption is that alveolar bone is denser and root resorption is prevalent in teeth which have not had force applied.[204]

Ideally, samples from human teeth would better represent a clinical situation. However, due to ethical considerations and suitability of patients for such trials there is limited access to such teeth. Furthermore, human fluoride consumption cannot be strictly controlled as fluoride is an abundant element in the environment.[205]

2.4.2 Sample Preparation and storage

Minimal preparation in studies which analyse tooth mineralisation is recommended, especially for cementum, which is a complex heterogenous connective tissue.[206] Testing the physical properties of teeth and limitations

of machines employed mean that specimens often require embedding in resin. This procedure itself may alter the physical properties of cementum by dehydration from the exothermic setting reaction and inflow of resin into the specimen.[207] Certain inexplicable findings in electron microprobe analysis of mineral content of cementum have been attributed to specimen preparation.[107] Consequently, studies have attempted to use techniques which minimally prepare tooth specimens.[208]

Methods which bypass the embedding process, yet allow sections of calcified tissues to be obtained are more ideal for studies examining mineral distribution and content. Freezing samples prior to sectioning is a method that has been previously used. It was shown that calcified tissues were satisfactorily preserved, whilst allowing for thin sections of sample to be taken.[209]

Another consideration, in addition to preparation of sample teeth, is how the samples are stored. Various storage media have been used for teeth. Purified and filtered water has been found to be appropriate for enamel and dentine. In this media it was found to cause the least changes to surface chemistry and optical properties, compared to distilled water plus thymol, phosphate-buffered saline with thymol, 70% ethanol, and 10% buffered formalin.[210] With regards to minimal mineral effects to cementum Milli-Q® (deionised water, Millipore, Bedford, Mass, pH = 7.2) is an appropriate media for

cleaning and storage up to nine months.[208] The reason why different storage media have varied effects upon surface hardness and mineralisation is that for hydroxyapatite, adsorption, diffusion and dissolution are determined by the surface charge and electrochemical nature of the ionic solid. The charge develops as a consequence of reactions when the tooth is suspended in aqueous solution, which in turn depends on the pH of the media. Milli-Q® and alcohol are close to physiologic pH, whereas other media such as Miltons® solution has a pH of 9.5. Absence of storage media, leading to desiccation, can alter the physical properties of dentine. However, such changes are reversible upon rehydration.[211]

2.4.3 Microprobe

The advantage of using a microprobe is that is possible to relate the distribution of elements to the physical structure of the tissue specimen.[153] Previous studies in the dental field have employed this mechanism to study elements in tooth roots, and it is suited to quantify the mineral content of teeth.[212] However, the electron microprobe machines used in the past were limited. The machine and computer programme to be used in this present study is unique in its ability and accuracy for detecting trace elements.[213] Such results, from the nuclear microprobe (NMP) developed at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Australian Research Council's National Key Centre for

Geochemical Evolution and Metallogeny of Continents (GEMOC), to examine root resorption craters have not been previously presented, as verified by the machine's operators.

2.4.3.1 General introduction to nuclear microprobes

In the late 1970s, Harwell was frustrated by low current density attainable by unfocused MeV ion beams used for analysis of small regions. Such analysis required extremely long measurement periods. Harwell went on to develop a method to focus high-energy ion beams with quadrupole lenses. This then provided a useful large beam current density from which analytical methods could be produced. By mid-1990s 40 different types of nuclear microprobes were available worldwide.

The nuclear microprobe has developed as a result of techniques commonly used in material sciences and geology. These techniques employed proton induced X-ray emission (PIXE) and proton induced γ-ray emission (PIGE) which are surface analytical techniques for mapping multiple trace elements at micron resolutions.

2.4.3.2. Principles and Components of a NMP

A nuclear microprobe analysis requires the generation of high-energy proton beams in a tandem accelerator. This is used to systematically scan the surface of the sample. When the protons collide with surface sample atoms the result is a number of reactive products. These products are characteristic x-rays, secondary electrons, gamma rays and transmitted and backscattered protons.[132]

During analysis the core electrons are ejected from a sample atom, causing destabilisation. In order to restore the stability of this atom, an outer shell electron drops into to the lower shell to occupy the vacancy. In doing so, there is a release of x-rays, which are characteristic for each element present in the sample. The x-ray wavelength is an identifier of the elements present in the sample, whilst their intensity describes the concentration.[214]

Each nuclear microprobe worldwide has different components and configurations, thus this discussion is now limited to the machine used in the present study, namely the NMP developed at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Australian Research Council's National Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC) (Figure 2.1).

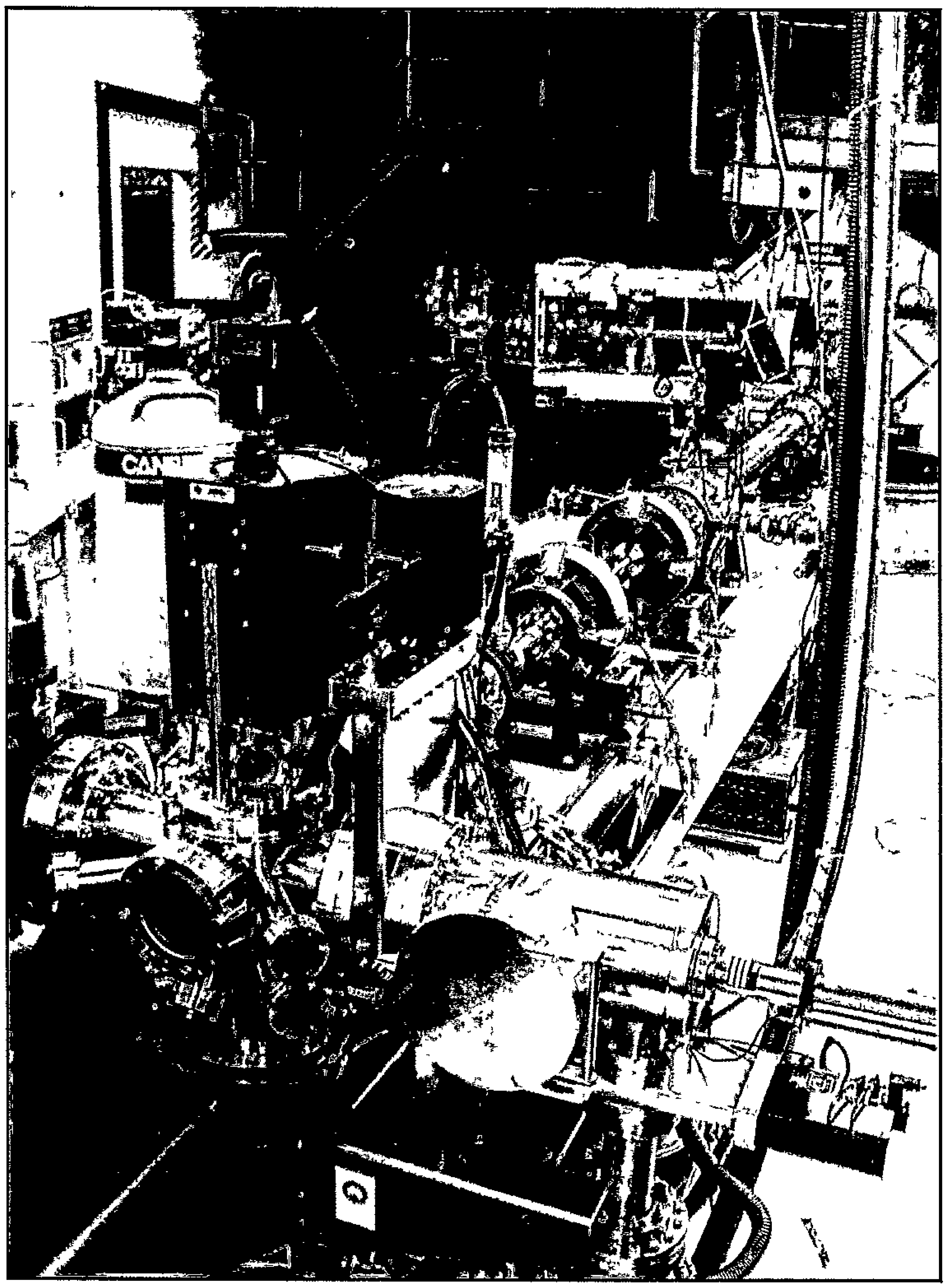

Figure 2.2: CSIRO-GEMOC NMP (NMP) Machine Commonwealth Scientific and Industrial Research Organisation (CSIRO), Melbourne, Australia.

This instrument delivers a proton beam via a 3 MeV tandem accelerator. Which is collimated by divergence and object slits. Object slits are formed by 5 mm tungsten rods, which are configured in a "v-shape". The slit can vary from 0-1200 μm. The object slits are located 2.6 meters from the divergence slits. The divergent slits are made of 1 mm thick tantalum plates which are motorized to allow linear movement. The degree of aberration in the focused beam-spot at a specific beam current can be adjusted, by using the slit gaps and altering the distance between the object and divergence slits.[129]

The lens system is used to focus the protons into micron dimensions ready for scanning across the sample. The CSIRO-GEMOC NMP uses a unique quintuplet magnetic quadrupole lens system. This offers the advantage of achieving high demagnification with a short overall system length of 4.7 meters.[129] It is desirable to focus the MeV ions into 1 μm diameter probe, or smaller. This is difficult to achieve. A single magnetic quadrupole lens acts on the beam by contracting it, then expanding it. As it travels through the system, however, it accumulates aberrations. It is most desirable to have a lens with the largest demagnification with a short image distance.[158] The machine to be used in this study is able to achieve this.[129]

The resultant x-rays from the scanning of the sample are detected by a germanium solid-state detector (Ultra LE Ge, Canberra, USA). This is

located 16 mm from the target. It has a 100 mm^2 aluminium filter that is 10 μm thick with a 32 μm beryllium window. A second x-ray detector identifies the major elements. Each individual emission co-ordinates are marked in two dimensions, enabling elemental distribution images to be recovered.

The magnitude of the background radiation produced determines the detection limits of the NMP. In particular, this technique generates Bremsstrahlung or braking radiation through target nuclei scattering. However, this magnitude is lower compared to background radiation produced by electrons. Therefore, the NMP has a much better detection limit than an electron probe.[158] Method Detection Limits (MDL) are calculated using Poisson statistics with the equation: $MDL = 3.26 \sqrt{2B}$, where B is the background.[213]

2.4.3.3 Advantages and Limitations of NMP Analysis

Compared to other available techniques, the CSIRO-GEMOC NMP provides superior trace element spatial (resolution of 1-2 μm) and quantitative analysis. The NMP has low detection limits for the elements found in teeth and is better than other non-destructive techniques, which include the electron probe and energy dispersive X-ray analysis. Traditional

electron probe techniques only provide point-analyses. Furthermore, the NMP being used analyses a number of elements at any one time. The result is therefore quantitative multi-element data. However, the most valuable aspect of using this machine is by far the minute detail which is generated. The machine takes up to 12 hours to scan the surface of a single sample, depending on the detail required. Therefore, this technology does not lend itself well to bulk sample analysis. Rather, the data gathered is respected for its high quality.

The NMP is a non-destructive analysis with regards to both the beam itself and the method by which samples need to be prepared. The beam has very little energy over the first 30 μm. The sample requires minimal preparation compared to other techniques.[206]

The limitations of the NMP arise primarily from the extremely high expense to run samples through the machine and its limited accessibility. In addition, a high level of operator expertise is required to operate a NMP. The only machine available which is more sensitive to elements than the NMP is laser ablation (LA-ICP-MS).[215] However, laser ablation destroys samples and only provides the results of total concentration. It also cannot be used for isotopic analysis. This is a major limitation for elements in human teeth found to be below 1 ppm (such as lead). Furthermore, interferences from neighbouring elements may contaminate the signal of the element of

interest. Another current disadvantage is the inability for this machine to detect phosphorus with accuracy. The system is not calibrated for this element, but this issue is in the process of being addressed for the near future. Electron microprobe machines are more valuable in establishing concentrations for this particular element.

Currently, there is no available technique that can scan and detect elements on a non-flat surface. Three-dimensional elemental technology would be ideal, as all root resorption craters on a tooth could be assessed with minimal interference by tooth preparation. The NMP is no exception to this limitation. This means that teeth must be sectioned and polished to a flattened surface, allowing reflection of gamma and x-rays. Thus realistically only one crater per tooth can be scanned. Furthermore, analysing a non-uniform structure means that as the sample thins down (for example at a tooth's apex) the proton beam, which penetrates 60 μm into the sample, may reach the opposing surface. In teeth, this means that the results could be skewed towards higher values where dentine readings may include minerals present in underlying cementum.

It is essential that research analysing mineral content of biological structures employ techniques that allow the samples to remain chemically and physically unaltered. The CSIRO-GEMOC NMP is able to analyse calcified samples and meet such specifications better than other current techniques.

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4. Manuscript One

Part 1: Analysis of elemental composition using Proton Induced X-ray and Gamma Ray Emissions in orthodontically induced root resorption craters of rat molar cementum following exposure to systemic fluoride.

This manuscript is to be submitted to the American Journal of Orthodontics and Dentofacial Orthopedics.

For the purpose of this thesis this manuscript is extended and will be shortened for publication.

Elaine Lim, BDS (Uni. Medal)

Postgraduate Student, Discipline of Orthodontics,

Faculty of Dentistry,

University of Sydney.

Dr D Belton, PhD

Manager, Nuclear Microprobe Applications Exploration and Mining,

CSIRO, MARC, School of Physics,

University of Melbourne.

Dr P Petocz, PhD

Associate Professor, Department of Statistics,

Macquarie University.

Dr M Arora, BDS, MPH, PhD

Senior Lecturer, Population Oral Health Unit,

Faculty of Dentistry,

University of Sydney.

Associate Professor G Shen, BDS, MDS, PhD

Associate Professor, Discipline of Orthodontics,

Faculty of Dentistry,

University of Sydney.

Professor M Ali Darendeliler, BDS, PhD, Dip Ortho, Cert. Orth, Priv. Doc
Professor and Chair,
Discipline of Orthodontics,
Faculty of Dentistry,
University of Sydney.

Address for correspondence:
M. Ali Darendeliler
The University of Sydney
Discipline of Orthodontics
Faculty of Dentistry
Level 2, 2 Chalmers Street
Surry Hills NSW 2010 Australia
Phone: +61 2 93518314
Fax: +61 2 93518336
Email: adarende@mail.usyd.edu.au

4.1 Abstract

Introduction: Root resorption resulting from orthodontic treatment is an unpredictable adverse effect. There is currently no consensus on how to minimise or prevent the development of this problem. Literature examining the potential protective influence of tooth cementum minerals against orthodontically induced inflammatory root resorption (OIIRR) has been sparse. Fluorine may be extrapolated as an important element, and could have a role in minimising the extent and severity of resorptive lesions. The present study appears unique in its aim of examining the elemental content of tooth cementum within OIIRR lesions and the effect of systemic fluoride.

Method: Two groups of seven week old Winstar rats were divided and exposed to systemic fluoride (100 ppm) or non-fluoridated drinking water (n = 20). The experimental period lasted two weeks. Orthodontic tooth movement was implemented by a Nickel Titanitum closing coil with a force of 100 g. The molar teeth were then dissected and prepared for cross sectioning through the largest mesial mid-root crater. The samples were then mounted and scanned using the Commonwealth Scientific and Industrial Research Organisation and the Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents Nuclear Microprobe (CSIRO-GEMOC NMP) and deconstructed using its associated software. An analysis of variance was

used for statistical comparison of elements and to determine the effect of fluoride, and unaffected tooth structure compared to root resorption craters. A student t-test was used to compare root crater lengths and depths of the Fluoride versus No-Fluoride groups.

In order to examine elemental content of teeth minimal sample preparation and a non-destructive analysis technique is ideal. The NMP used satisfied these criteria and provided spatial (resolution of 1-2 μm) and quantitative elemental measurements.

Results: Root resorption lesions of the group exposed to fluoride were significantly reduced in length and depth ($p<0.01$). The mineral content of root resorption craters of the Fluoride group had higher concentrations of fluorine and zinc ($p<0.01$). There was less calcium in craters of the No-fluoride compared with the Fluoride group ($p<0.05$).

Conclusion: Cementum quality (influenced by systemic fluoride exposure) may impact the extent of orthodontically induced resorptive defects.

4.2 Introduction

Root resorption resulting from orthodontic treatment is an unpredictable adverse effect involving transient inflammatory surface resorption. This process has been termed Orthodontically Induced Inflammatory Root Resorption (OIIRR).[1] The mechanism of OIIRR has not been fully elucidated. Following orthodontic force application, tooth movement is associated with a local compression of the periodontal ligament and the development of sterile necrosis.[2] This morphometric phase is followed by biochemical changes. The sequence of events involves fibre coalescence, hyalinisation, degradation of connective tissue matrices (extracellular and intracellular pathways)[3] followed by dissolution of Sharpey's fibres[4] and finally odontoclastic activity. The resorptive process initially occurs at the circumference of the necrotic hyalinized area. This is followed by resorption of the root surface in the central part of the necrotic zone.[5] The later stages also demonstrate areas of peripheral repair.[6,7]

Associated risk factors for increased incidence of root resorption have been suggested to include: individual susceptibility, genetics, hormonal imbalance, medical history, nutritional balance, age, dental history, tooth type, duration of

treatment, amount of tooth movement, appliance type, type of tooth movement and magnitude of orthodontic force.[8]

There is currently no consensus on how to, or indeed whether it is possible to, prevent root resorption. However, strategies have been suggested on ways to possibly minimise root resorption. These include: limiting treatment duration,[9,10] using light intermittent forces,[11] assessment of medical history & familial tendency,[12,13] control of habits[14] and, if required, cessation of treatment.[15,16]

Literature has been sparse examining the direct relationship of fluoride's potential protective influence and the effect mineral content of cementum may have against orthodontic associated root resorption. Foo et al[17] used rats to induce orthodontic root resorption, and exposed part of the sample to systemic fluoride, with an estimated intake of 1 mg per day. It was demonstrated that the average crater volumes of teeth exposed to fluoride were about half the size. However, due to a large variation in results these differences were not significant at a level of $p<0.05$.

The present study appears to be unique in examining the elemental content of OIIRR craters. Such information may increase our understanding of this process and the possible protective effects that elements, such as fluorine, may impart to cementum.

Although fluoride does not increase the physical hardness of cementum *per se*,[18] there are a number of possible mechanisms whereby fluoride may impart a protective effect against orthodontically induced root resorption (as opposed to its well described effects on bone resorption). These include: direct effect on osteoclasts, alteration of shapes of resorption pits and the mineralisation of cementum.[19] Thus fluoride may be extrapolated as a potential preventive agent against the severity of OIIRR.

There are various methods to study elemental composition of teeth. The nuclear microprobe employs proton induced X-ray emission (PIXE) and proton induced γ-ray emission (PIGE), which allows mapping of multiple trace elements at micron resolutions. Compared to other available techniques, the Commonwealth Scientific and Industrial Research Organisation and the

Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents Nuclear Microprobe (CSIRO-GEMOC NMP) provides superior spatial resolution (1-2 μm) and quantitative data on elemental concentrations. As yet this machine has not been used in the study of cementum root resorption lesions.

The aim of this thesis was to develop a methodology to use the CSIRO-GEMOC NMP in order to analyse the elemental composition of root resorption craters following the intake of systemic fluoride. Furthermore, potential preventive mechanisms and/or risk factors for orthodontic root resorption were examined in relation to the findings.

4.3 Materials and Methods

4.3.1 Sample

This study used twenty seven-week old female Wistar rats (Westmead Hospital Animal Ethics Committee, Project: 134.12-03). The rats were allowed one week to acclimatise to their new laboratory environment. They were then randomly divided into two groups of 10 animals. Group One had orthodontic tooth movement and received deionised water, which was not fluoridated. Group Two had orthodontic tooth movement and received fluoridated deionised water (100 ppm). Sodium fluoride was dissolved into Milli-Q® (deionised water, Millipore, Bedford, MA, USA) to meet this concentration level. Water was given *ad libitum*. Every two to three days, the water was monitored and replenished as necessary.[17]

4.3.2 Laboratory Procedure

4.3.2.1 Orthodontic tooth movement

Orthodontic tooth movement was implemented by use of a Nickel Titanium (NiTi) 100 g closing coils (NiTi 10-000-06, GAC International Inc, USA). The

NiTi coil was ligated to the rat's left first mandibular molar by means of a silk suture. The coil was activated via ligation to the mandibular incisors with steel ligatures (Figure 1).[17] Attachment of the nickel titanium coils was performed under anaesthetic. The rats were administered a gaseous anaesthetic agent (Halothane), followed by the anaesthetic agents Xylazine (10 mg/kg) and Ketamine (90 mg/kg).

The experimental period lasted two weeks. After which the rats were sacrificed, using carbon dioxide. Their mandibles were dissected and sectioned mesial and distal to the left first mandibular molar. The samples were stored in Milli-Q®. This has been shown to have an insignificant effect on leaching of trace elements from cementum samples.[20,21]

4.3.3 Sample Preparation

4.3.3.1 Dissection and preparation of rat first molar teeth

The teeth were progressively dissected, with the aim of minimising fracture of the fine rat molar roots and avoiding contact below the cementoenamel junction, from the segment of mandible. This was achieved by severing any

remaining marginal gingivae, and then removing approximately one-third of the alveolar bone surrounding the tooth followed by luxation using a blunt-ended periosteal elevator. The dissection was carried out under a light-microscope (WILD M3B®, Heerbrugg Switzerland). Following dissection the teeth were cleaned with sterile gauze soaked in Milli-Q® and gross periodontal ligament fibres manually removed with tweezers.[22] The teeth were then stored in Milli-Q® at ambient room temperature (23° ± 1°).[20]

4.3.3.2 Locating root resorption craters

All root resorption craters were located on each tooth using an Olympus SZCTV microscope® (Tokyo, Japan). The largest mid-root crater on the mesial root of each tooth was identified. Reference points and co-ordinates were established and measurements (of the length and midpoint for each crater) were made using the AnalySIS® software program and a micrometer (μm) ruler. Measurements were made to the nearest 1 μm. Using an Olympus ColorView 2® camera, a true image of this crater was recorded.

4.3.3.3 Specimen sectioning

A "Wax Marker System" was developed by the author to indicate the point at which the tooth required sectioning. This achieved the goals of marking a microscopic point, which could be seen macroscopically for hand sectioning and allowing minimal interference with tooth minerals. The initial microscope photographs allowed re-location of the midpoint of the root resorption crater of interest (Figure 2).

This technique involved softening the centre point of approximately 1 x 1 cm^2 sheet of wax (Moyco Union Broach™ Dental wax) with hot water delivered via a pipette. Under microscopic view the wax was pushed over the tooth root to the point of sectioning (Figure 3).

The tooth was then floated in Milli-Q® crown-down in ice-cube trays (Figure 4). These were then frozen for 24 hours. The wax was removed, leaving the exposed root portion to be cut and the exact point/region of interest embedded in the Milli-Q® ice-block. Specimens were then sectioned transversely (Figure 5), in layers from the apex, through to the identified mid-point of the root resorption crater. This was achieved using Fine and Superfine Sof-Lex Discs™ (3M) under Milli-Q® irrigation, to a surface polish of <0.2 μm.

4.3.3.4 Root resorption crater dimensions

Using the Olympus SZCTV microscope®, AnalySIS® software program and a µm-ruler, measurements were taken to determine the depth of the sectioned craters to complement the measurements of maximum length taken previously. A line was constructed from the two points marking the outer edge of the root resorption crater. Lines were then drawn perpendicular to the constructed line to establish the deepest point of the crater.

4.3.3.5 Specimen preparation for NMP

The specimens were then mounted on glass slides with a double-sided carbon adhesive tape. The slide and specimens were carbon coated (evaporated) in a vacuum at 10^{-4} Torr with an approximately 20 nm layer. The glass slide was then encased in a metal stub designed specifically for the NMP (Figure 6).

4.3.4 Sample Analysis

4.3.4.1 NMP

The spatial distribution of multiple elements based on x-ray and gamma ray emissions was measured in the resorption craters and surrounding non-resorbed cementum of the sample tooth-roots. This study used the NMP developed by the Commonwealth Scientific and Industrial Research Organisation and the Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents (Melbourne, Victoria, Australia).

The analysis was performed with 3.0 MeV protons and the beam focused at 1 x 1.8 μm^2. Scanning was electrostatically driven in the Y-axis between 800-1500 μm with the stage stepped in the x-axis (step-size of 2.5 μm) to generate a rectangular image. The beam current was maintained at 4 nA. The total accumulated charge for average size area was approximately 20-25 μC. An aluminium absorber of 100 μm was used between the target and Germanium (Ge) detector (Canberra Ultra-Ge Detector©). Software to evaluate spectra was Geo-PIXE II™ Version 3.8. The elements detectable under gamma rays were Sodium (Na), Fluorine (F), Manganese (Mn), Aluminium (Al) and Silicon (Si). Whilst under x-rays Calcium (Ca), Iron (Fe), Nickel (Ni), Copper (Cu), Zinc

(Zn), Bromine (Br), Rubidium (Rb), Strontium (Sr), Tin (Sn), Barium (Ba) and Lead (Pb) were measurable.

4.3.4.2 Analysis of data using Geo-PIXE II™

Geo-PIXE II™ Version 3.8 Computer Program was used to extract the raw data generated by the scanning process (Figure 7).[23] A manual analysis of regions, to provide quantitative data, was conducted by a function that allowed shapes to be drawn over the downloaded image. The regions analysed were a "traverse" through the middle of the deepest point of the root resorption crater and adjacent cementum. Readings from dentine below the crater, at the crater marginal cementum, as well as corresponding areas of distant physically unaffected root structure, of the same tooth surface, were recorded (Figure 8). This was repeated for each slice generated from both the x-ray and gamma ray scans. In addition to the quantitative data, the information was also used to process Spectral (elemental) Graphs and Picture Plots. Spectral graphs are traverse concentration profiles of each element, showing the pattern of distribution through the tooth structure. Picture Plots are qualitative representations (maps) of relative concentrations, distributed across the scanned region, for each element.

4.3.5 Statistical Analysis

Statistical analysis using independent student t-tests was conducted to compare the crater lengths and depths of Fluoride vs No-Fluoride groups. There was an appropriate assumption of normality. A p-value of less than 0.01 was taken to indicate statistical significance.

In addition to the aforementioned statistics used to indicate significance for the crater length and depth measurements, elemental concentrations were also statistically analysed. SPSS Version 14 (Statistical package for social sciences, SPSS Inc., Chicago, Ill, USA.) software program was used. An analysis of variance (ANOVA) was conducted to examine the concentrations of elements (F, Mg, Na, Zn and Ca) and the factors included were Fluoride versus No-fluoride, Root Resorption Crater versus Normal Tooth Structure and Cementum versus Dentine. Significant interactions between factors were also included in these models. A multivariate ANOVA was used to examine the effects of these factors on the complete collection of elements as a whole.

The error of the measurement was calculated for F, Mg, Na, Ca and Zn and was based on triple measurements performed on Fluoride and No-fluoride randomly selected samples. An ANOVA was performed, using each group of repeated

measurements as a unit. The root mean square error was used to give the standard error of measurement. The coefficient of variation (CV) was also calculated from the standard error (SE) measure as a percentage of the mean.

Given the large number of dependent tests conducted, a p-value of less than 0.01 was taken to indicate statistical significance, while p-values between 0.01 and 0.05 were assigned "marginal" status.

4.4 Results

4.4.1 Crater Measurements

Depth and length measurements were taken of the root resorption craters, which were later subjected to NMP scanning. This crater represented the largest crater on the mesial surface (direction of the orthodontic force) of the mid-root region. When maximum depth and length measurements of Fluoride and No-fluoride groups were considered separately, the results demonstrated a highly significant difference (p=0.001) (Figures 9 and 10). The values for the root resorption craters in the No-Fluoride group had a mean length of 467.01 μm (± 192.94) and depth of 46.73 μm (± 5.96). The Fluoride group had significantly smaller craters in length and depth. Their mean length was 225.14 μm (± 51.13) and depth was 20.76 μm (± 2.78). The range of depth and length measurements was less in the fluoridated group. When the lengths and depths were considered together there was a marginally significant difference between the two groups (p=0.055). This may be due to the sample size and/or individual crater morphology. Therefore, the Fluoride group had significantly reduced lesion depth and length compared to the non-fluoridated group, but only when these measurements were considered separately.

4.4.2 Elemental Concentrations

The Fluoride and No-Fluoride groups were analysed for their elemental content. The error of the measurement was found to be minor (Table 1). The results for each tooth sample were divided for the purposes of evaluation into: root resorption crater cementum (representing the margin of the lesion), root resorption crater dentine (representing the surface of the crater floor and its immediate sub-surface layer), and the cementum & dentine of the adjacent tooth physically unaffected by resorption. Multivariate ANOVA analysis, taking the group of minerals as a whole, demonstrated significant differences between Fluoride/No-Fluoride ($p<0.01$), Dentine/Cementum ($p<0.01$), with a marginally significant interaction ($p=0.01$). However, there were no significant differences between overall elemental concentrations in Root Resorption and Normal Tooth Structure ($p=0.27$), although there was a marginal interaction between Fluoride/No-Fluoride and Root Resorption/Normal Tooth ($p=0.027$). Essentially, the largest differences were between Fluoride/No-fluoride, followed by Dentine/Cementum.

When individual elements were assessed the Fluoride group had significantly more fluorine concentration in their cementum, compared to the No-fluoride group ($p<0.01$) (Figure 11). Overall the Fluoride group had a greater concentration of fluorine (mean concentration 18661.04 ppm) compared with the No-Fuoride group (mean concentration 9791.25 ppm) (Table 2). However, both Fluoride and No-fluoride groups had a similar distribution pattern of fluorine through the teeth (Figure 12 and 13).

There was no significant difference between magnesium in any of the analysed groups (Figure 14). Whereas, sodium demonstrated significantly higher concentrations in the Fluoride group (mean concentration 1409.54 ppm, standard error 440.96) compared to the No-fluoride group (mean concentration 8232.04 ppm, standard error 440.96) ($p<0.01$). There was significantly more sodium in dentine (mean concentration 12639.79 ppm) versus cementum (mean concentration 9633.79 ppm) ($p<0.01$) (Figure 15). There were no other significant differences.

Aluminium had marginally significant increases in cementum (mean concentration 307.125 ppm, standard error 55.33) compared to dentine (mean

concentration 125.21 ppm) ($p<0.05$). However, there were no other differences noted (Figure 16).

Zinc had marginally significantly greater concentration in the Fluoride group (mean concentration 270.29 ppm, standard error 16.06) compared to the No-fluoride group (mean concentration 174.04 ppm) ($p<0.05$). The root resorption craters had more zinc in their dentine (mean concentration 207.92 ppm, standard error 22.72) compared to the non-root crater tooth structure (mean concentration 188.75 ppm) ($p<0.01$) (see Figure 17).

Strontium had significantly higher concentrations in the dentine (mean concentration 244.58 ppm, standard error 7.93) of all the examined groups compared to cementum (mean concentration 194.79 ppm) ($p<0.01$). There were no other significant differences for this element (Figure 18).

Calcium was found to be significantly higher in the dentine (mean concentration 37.97%, standard error 1.42) compared to cementum (mean concentration 23.71%) ($p<0.01$). There was also a marginally significant difference between the No-fluoride (mean concentration 26.10%, standard error

1.42) and Fluoride groups (mean concentration 35.58%) ($p<0.05$) (Figure 19). The overall pattern of distribution of calcium in the Fluoride group was low superficially, which quickly peaked in the dentine. Whilst in the No-fluoride group there was a more gradual increase in cementum distribution (Figure 20 and 21).

An analysis of the total elemental concentrations demonstrated a significant difference between Fluoride & No-fluoride groups (Table 3) and dentine & cementum comparisons ($p<0.01$). However, the difference between root resorption crater tooth structure and normal tooth, also between the dentine and cementum of the Fluoride and No-Fluoride groups was marginally significant ($p<0.05$).

In summary, the Fluoride group overall had significantly altered cementum elemental content. These teeth had higher F, Zn and Na ($p<0.01$). Also, the root resorption craters of this group had significantly increased concentrations of F and Zn ($p<0.01$) and marginally significant increased Ca concentrations ($p<0.05$).

4.5 Discussion

4.5.1 Crater Size

A previous publication by Foo et al[17] which examined volumetric size of OIIRR craters of rats exposed to fluoridated water was only able to establish a non-significant trend towards smaller craters. The present study used a different approach to measure the dimensions of selected craters. There was a significant difference demonstrated when length and depth of the root resorption craters were considered separately. However, similar to the aforementioned study, when considered together, only a marginal significance was demonstrated. This finding may be in part due to the limited sample sizes in both these studies.

Alternatively, a possible explanation for the significant difference in length and depth of craters may be the effect fluoride has on osteoclast attachment and resorption patterns. Taylor et al[24] examined the effects of fluoride on osteoclasts and found that resultant lacunae were longer, but shallower. This pattern of resorption may be implicated to support the notion that the OIIRR craters on cementum in samples of the fluoride group were of an altered morphology, in addition to having altered size. Therefore, this may be a reason why the values were significant when considered separately, but not as mean

volumes. Thus, fluoride may affect the shape, extent and severity of root resorption craters.

The present finding also has implications for research studying root resorption craters, as length and depth may need to be considered separately. Using mean volumes may mask the true extent of resorption.

4.5.2 Element Distributions

Overall there was only a marginally significant difference between the Fluoride/No-Fluoride groups and the elemental concentration of root resorption craters and normal tooth structure. This may be due to the ability for cementum to resist root resorption to a limited degree.[25]

Resorption is usually followed by remineralization. A dynamic exchange of minerals occurs superficially and this limits the extent of more minor resorptive defects. Subjacent unaffected tissue provides a reservoir for diffuse transition of elements.[26] The minerals in the circulating fluid can also react with cementum. A relative time-frame for re-mineralisation can be extrapolated from that measured for fluorine, which is incorporated into enamel, occurs within one hour from the microcirculation.[27] When the root surface is breached, repair

matrices become attached to the resorbed surface.[28] Following the detachment of odontoclasts the cementogenic cells re-populate. This is followed by electron-dense globular accumulations indicating re-mineralisation. This biomineralisation process together with a new paradigm has been more recently established suggesting fluoride is an active participant in the precipitation process and nature of biogenic apatites.[29] The role of fluoride was suggested as being vital in calcium phosphate formation for teeth *in vivo*, effecting both the process and characteristic of the final products. Fluoride was seen to accelerate the hydrolysis of acidic precursors and increase apatite growth rates via precipitation.[29] The present study supports the proposal that cementum has inherent abilities to resist resorption. Furthermore, this may mean that pre-treatment cementum quality impacts on the ability for tooth roots to resist damage, as the outcome of root resorption reflects the original mineral concentration. Secondly, that the presence of fluorine may increase "repair" (or limit destruction) by being an active participant in accelerating calcium phosphate precipitation. Therefore, fluoride may be extrapolated as a potential preventive agent in limiting the extent of orthodontically induced root resorption craters.

Fluorine concentration in teeth has been previously shown to reflect environmental exposure to this mineral.[30] There was a significantly increased fluorine concentration in the cementum of rats that were experimentally

exposed to fluorine (Figure 22 and 23). This may also demonstrate that short-term exposure, during the experimental period of two-weeks, to fluoridated drinking water was already reflected within the tooth root structure. This is in agreement with the concept that minerals in the circulating fluid can react with cementum. In particular the fluoride ion reacts aggressively with hydroxyapatite.[31] Therefore, it is expected that fluorine reaches tooth roots in patients who are exposed to systemic fluoride. This may have clinical implications since it would not only be the history of fluoride intake, but also exposure during orthodontic treatment, which may influence the dynamic exchange of elements at the cementum interface, and subsequently root resorption.

When comparing the root resorption crater dentine, both Fluoride and No-Fluoride groups had less fluorine concentration compared to 'normal' dentine. A similar pattern was found in the cementum. This means that root resorption craters have reduced fluorine concentrations. However, in the Fluoride group the concentrations of fluorine remained significantly higher than the group not exposed to fluoridated water. Mineral dissolution is said to occur as a result of the OIIRR process and may have caused this general reduction in fluorine concentration at the periphery and in the depths of the lesions.[31]

In contrast to this loss of fluorine associated with root resorption craters, magnesium maintained its concentration between and within the groups. This is in disagreement with a previous study looking at overall mineral concentrations of cat teeth exposed to resorptive pathology.[32] However, the present study's finding that magnesium is maintained within the local region may relate to the cementum's role as a dynamic interface. Magnesium is present in the hydroxyapatite lattice and has been suggested to be important in contributing to cementum mineralisation and plays a role in controlling hydroxyapatite crystal growth.[33] The finding that magnesium is similar in both the root resorption craters and normal tooth structure may mean that this element is able to resist the process of dissolution better than the elements that fall in concentration.

Unlike the elements that were maintained or reduced in concentration in root craters, zinc actually increased. Zinc was present in higher concentrations in the deeper parts of the craters and in the group exposed to fluoridated water (Figure 24 and 25). Like magnesium, the presence of zinc may be an important contributor to the ability for teeth to resist OIIRR.

Zinc may play a vital role in the dynamic processes affecting cementum. Modulation of osteoclastic resorption of bone and dental tissue in the presence of zinc has been examined.[34] It was established that the lacunae developed on

tooth cementum, in the presence of extracellular zinc, were fewer in number and had smaller surface areas.

Sodium was higher in dentine and in the fluoridated group. An increase in sodium for the Fluoride group could be attributed to the sodium fluoride in their drinking water. In contrast the root resorption craters did not have a significantly greater concentration of sodium. This is in disagreement with a study which looked at overall mineral concentrations in root resorption lesions in cats, and found that the teeth with resorption craters had higher concentrations of sodium.[32] However, the significance of sodium concentration has not previously been examined in relation to root resorption.

In contrast to sodium, calcium was in lower concentration within the root resorption craters, but followed the same pattern of distribution – having higher concentration in dentine compared to the cementum.[35] Of note is the maintenance of higher concentrations of calcium in all parts of the teeth in the rat sample exposed to systemic fluorine. This may relate to the finding that teeth exposed to fluoride have smaller OIIRR craters and are thus inferred to be more resistant to root resorption.[17]

Aluminium and strontium were present in higher concentrations in cementum. Unlike previous studies that suggest a relationship in the uptake of strontium, zinc and fluorine,[36] the present study did not demonstrate such trends.

There is conflicting evidence of the effect strontium has on cementum solubility. An increased presence of strontium has been shown to increase cementum and enamel solubility.[37,38] However, it has also been shown to decrease solubility when administered in the presence of fluoride.[36] Hydroxyapatite can reduce in solubility by up to 50%.[38] Like zinc, strontium is another element which has been related to reducing bone resorption.[39] However, implications of this for root resorption are unknown.

Ideally, the morphology and mineral content of OIIRR craters should be studied in three-dimensions without the need to prepare the samples. The use of NMP machines must meet the condition for a flat polished surface for reliable data to be generated. Thus, only one crater per tooth could be examined. The choice of using the largest mid-root crater on the surface exposed to the direction of the force (mesial root surface) was intended to maximise the representation and ensure greater consistency of the samples. Mid-root minerals have been suggested to reflect on average the entire tooth root,[40] whilst the location of craters at sites of compression have been shown to be associated with root resorption lesions.[41] Such issues may be addressed with the development of

future technologies. Nevertheless, with current limitations this study was able to demonstrate the elemental distribution and concentrations in OIIRR craters.

4.6 Conclusions

1. Elemental distribution across root resorption craters was demonstrated successfully with the developed methodology.
2. Overall tooth root structure seemed to resistant major alterations to its pattern of elemental distribution as a result of the OIIRR process.
3. OIIRR craters of the group exposed to systemic fluoride had reduced lengths and depths, possibly due to altered shape and size.
4. Systemic fluoride intake was associated with increased concentrations of fluorine and zinc, which may have contributed to a trend towards maintenance of higher calcium concentrations within these root resorption lesions.
5. Pre-treatment cementum quality and systemic fluoride during orthodontic force application may influence the extent and severity of root resorption defects.

4.7 References

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4.8 Figures

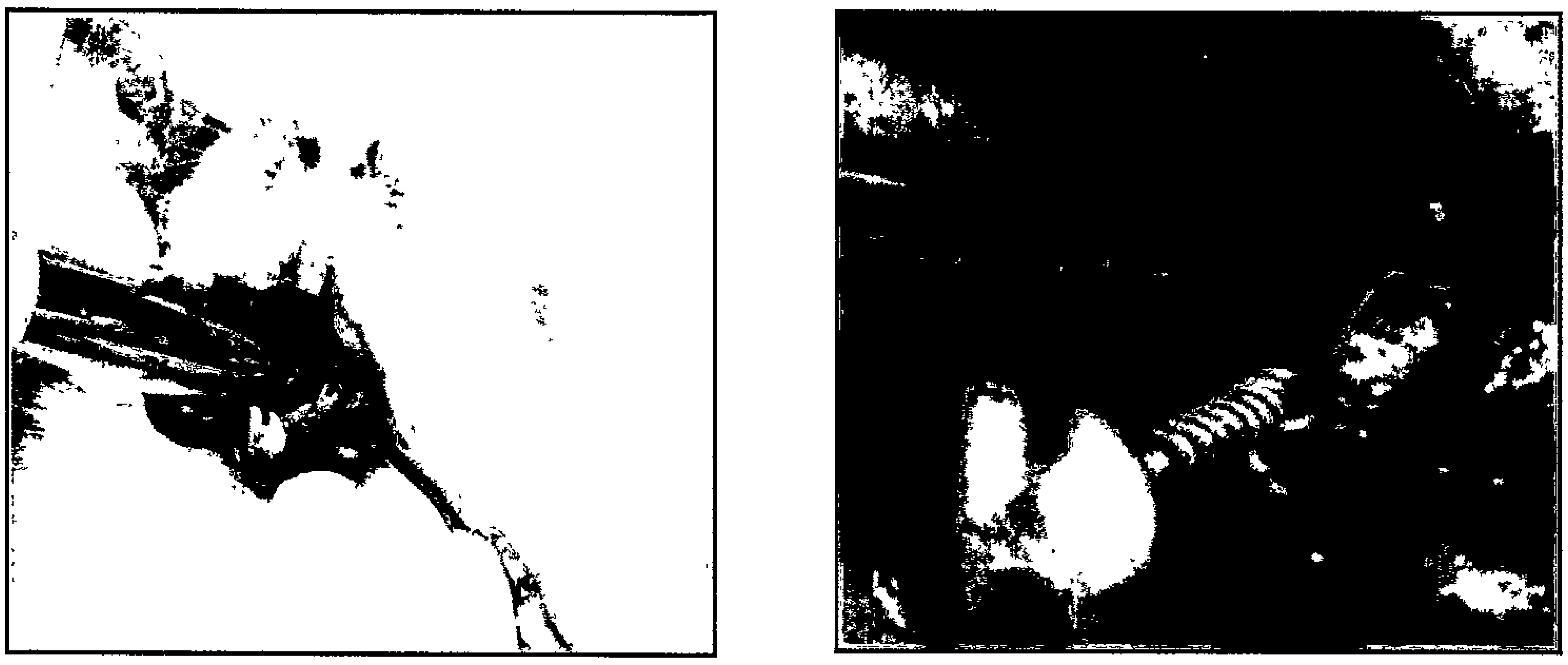

Figure 1: Preparation of force mechanism to induce root resorption using NiTi coil spring attachment between rat molar and incisor *(Courtesy of E Low)*.

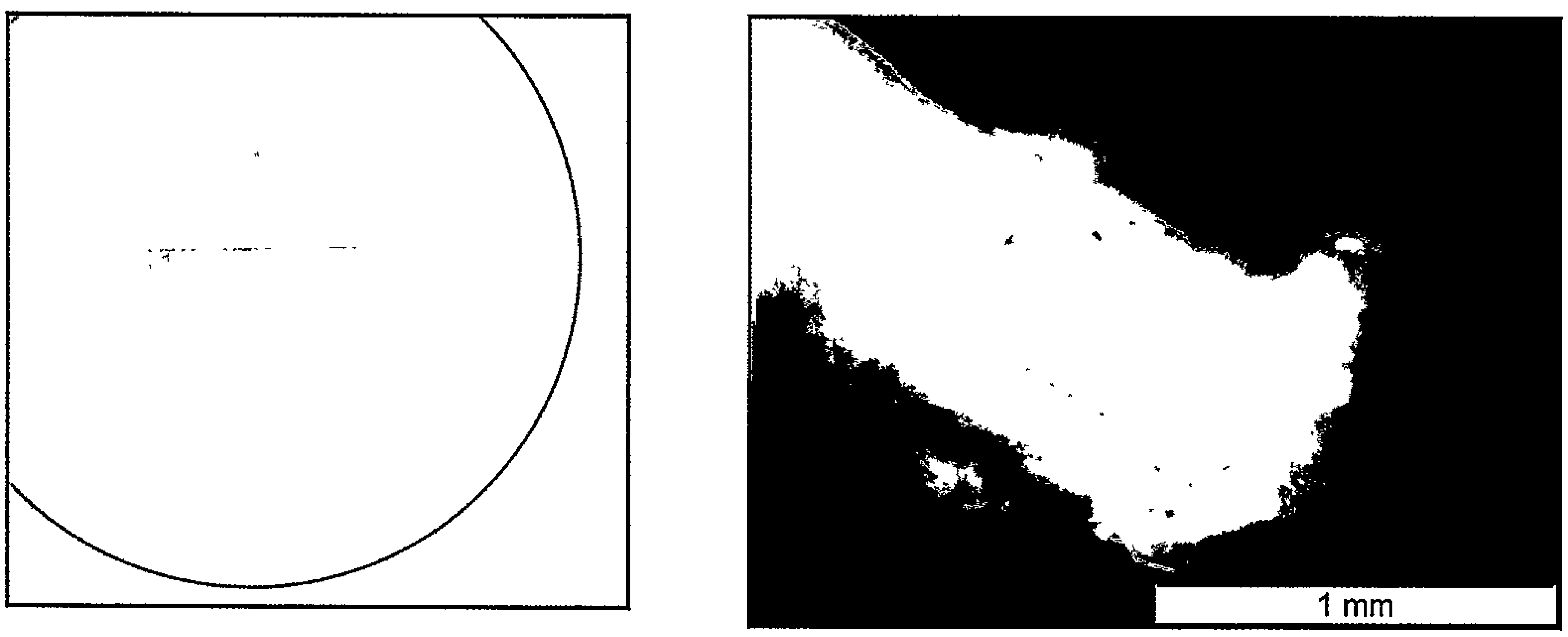

Figure 2: Micron Ruler used in conjunction with the Olympus SZCTV microscope® to measure root resorption crater. Photograph of rat molar taken with Olympus ColorView 2® camera.

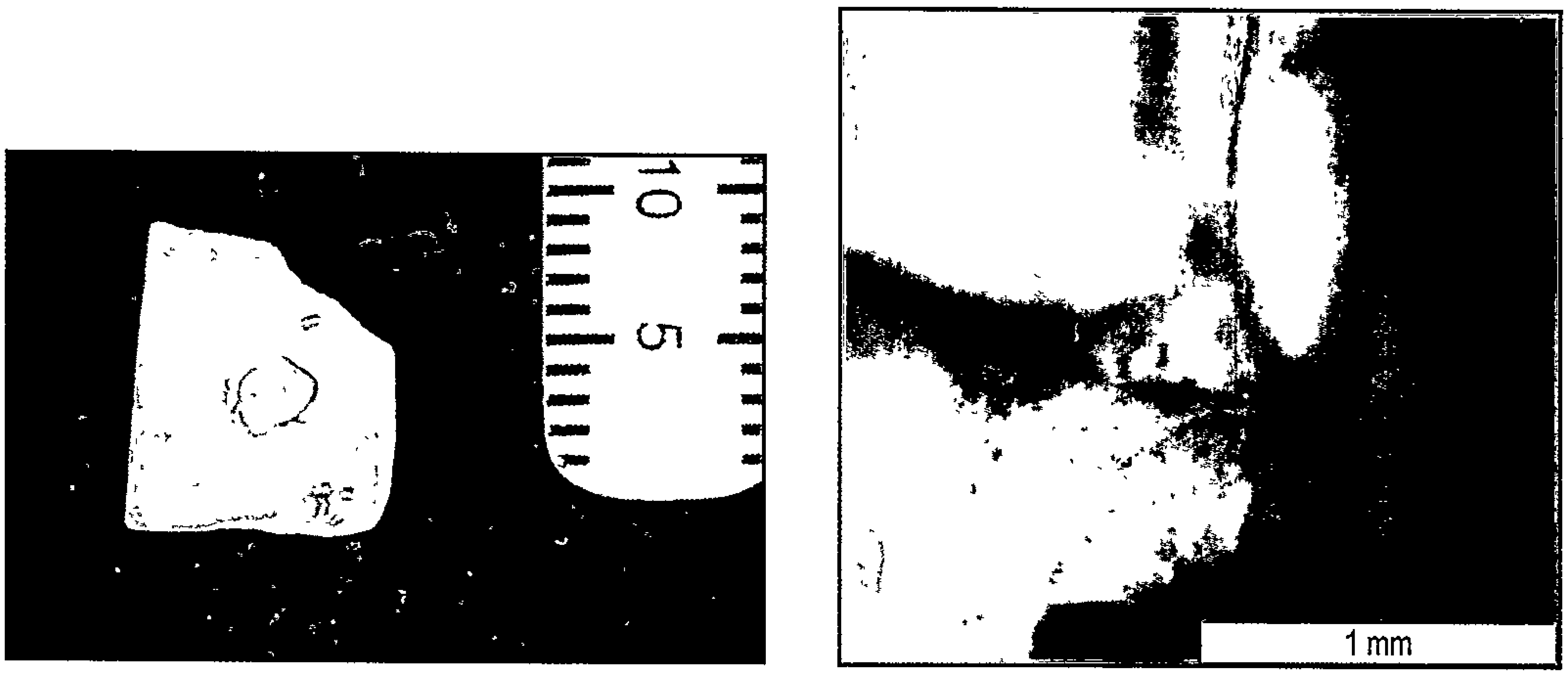

Figure 3: Microscopic view of the Moyco Union Broach™ Dental wax pushed over the tooth root to the point to be sectioned.

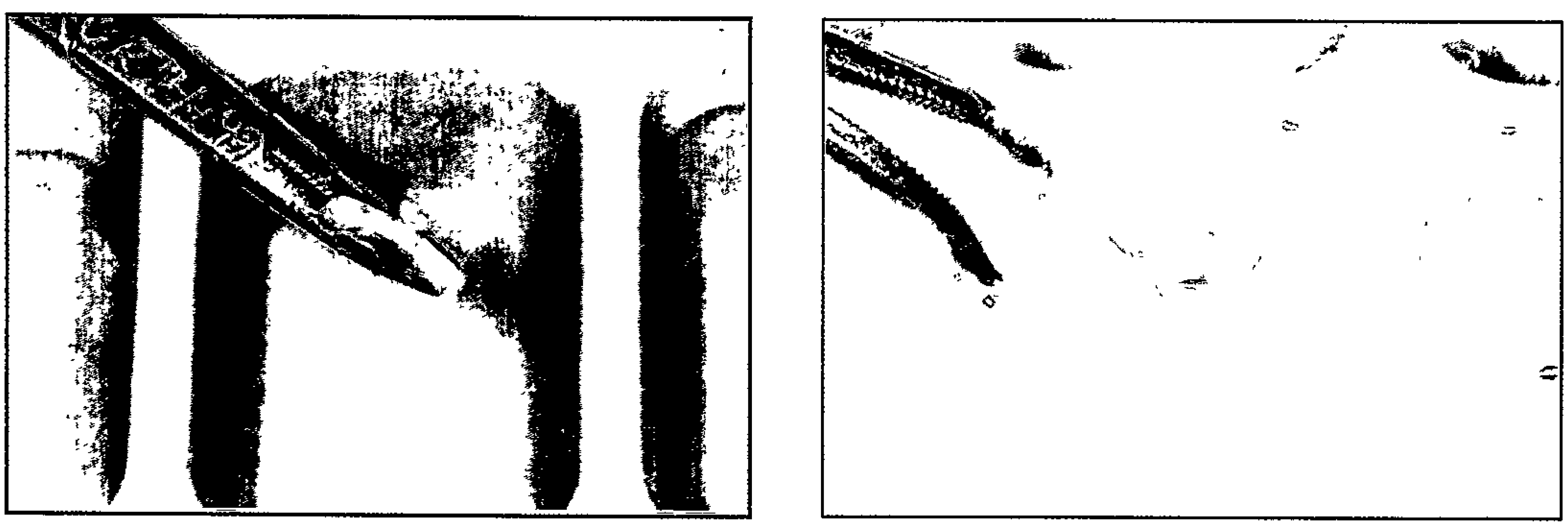

Figure 4: Sample tooth being floated in Milli-Q® crown-down in ice-cube trays.

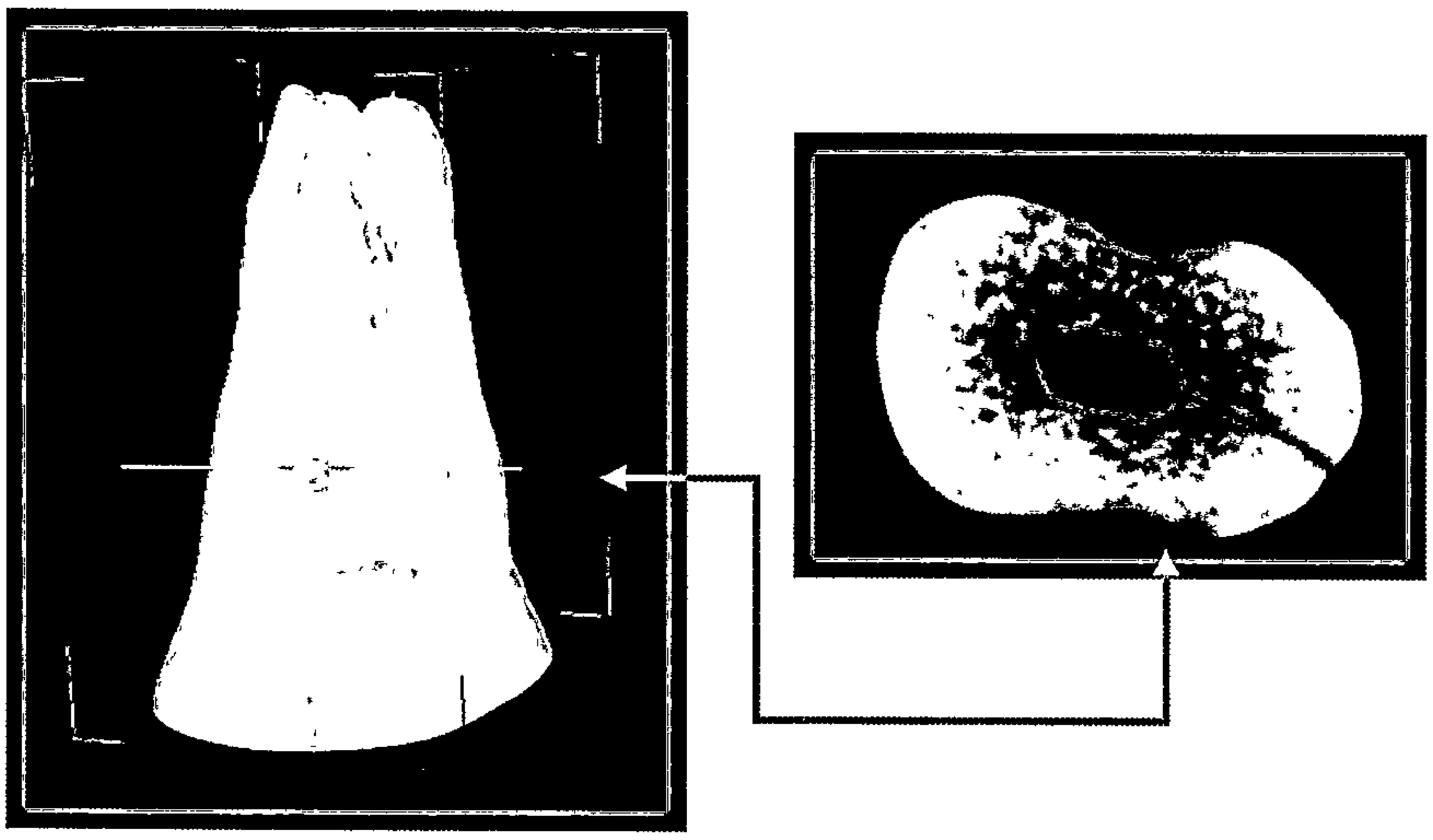

Figure 5: Illustration from Scanning Electron Microscope (*modified from image courtesy of LJ Barbagallo*) to demonstrate the transverse section taken through the root resorption crater of interest.

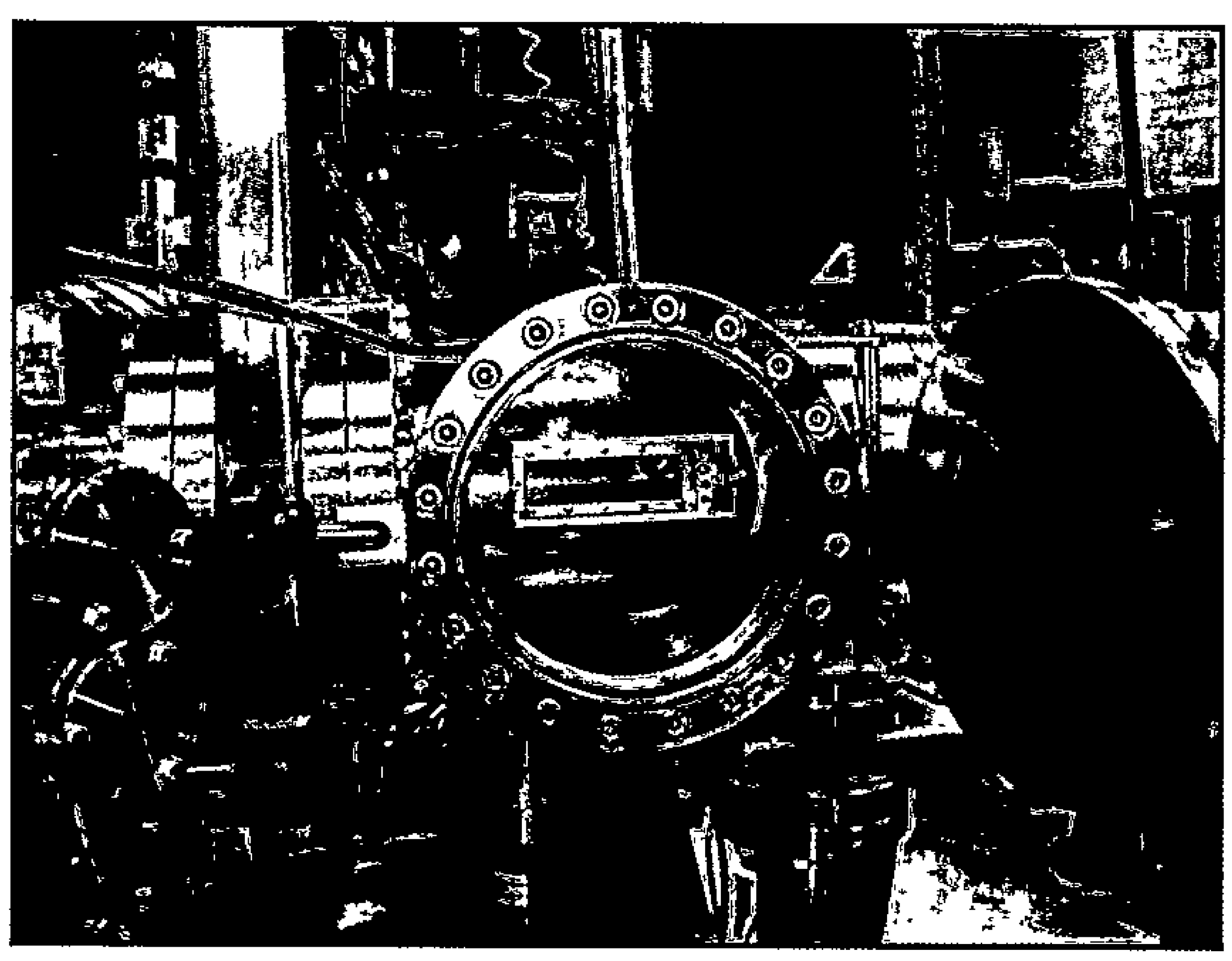

Figure 6: Metal Stub holding glass slide with sample teeth placed in the NMP machine (Commonwealth Scientific and Industrial Research Organisation and the Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents, Melbourne, Australia).

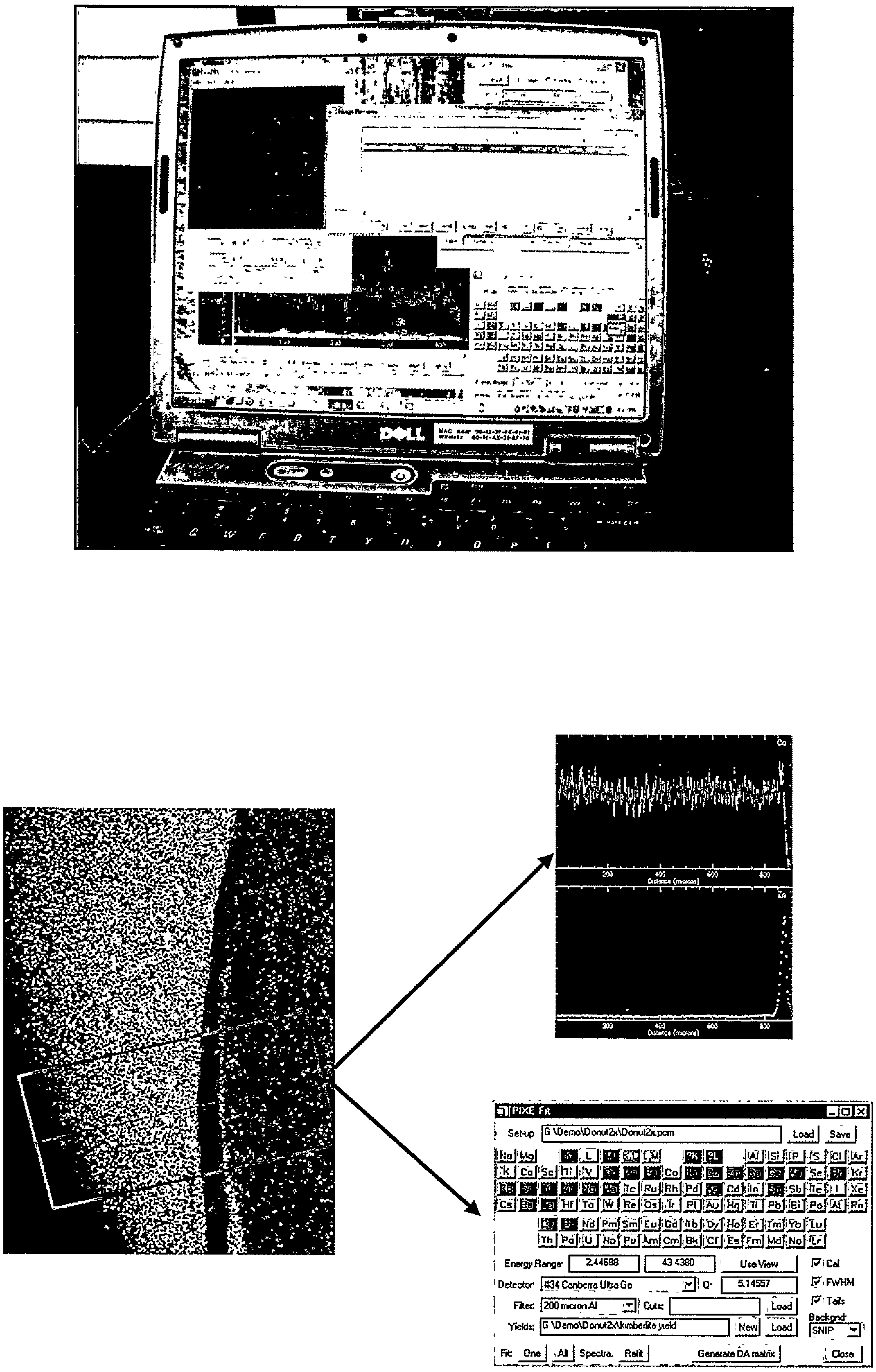

Figure 7: Geo-PIXE II™ Version 3.8 Computer Program used to deconstruct the raw data.

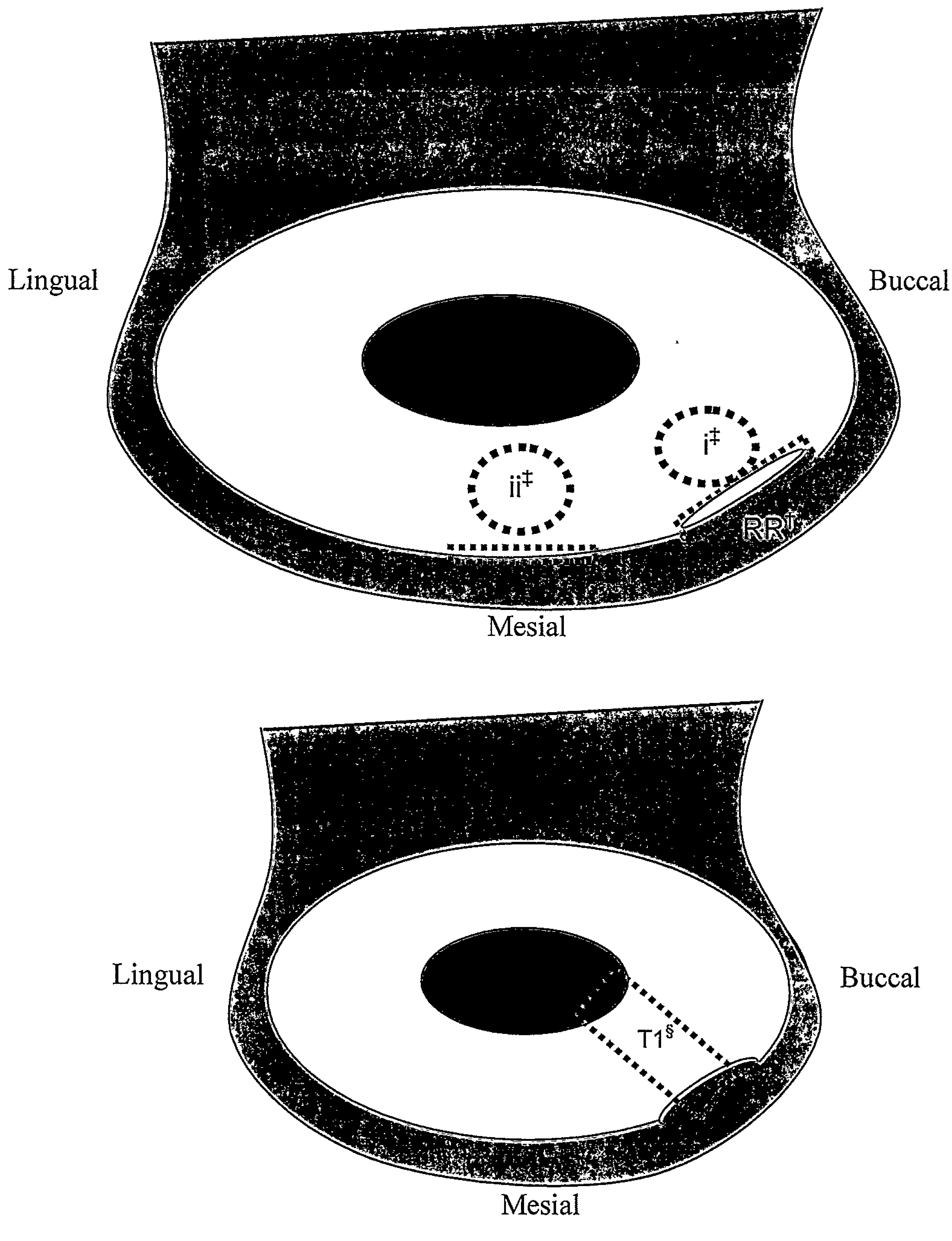

Figure 8: Diagrammatic representation of regions deconstructed and analysed to give mean concentrations, detection limits and errors from scanned samples (red outline).

RR† Root resorption crater, representation of marginal cementum

i‡ Root resorption crater, representation of dentine floor of lesion and sub-surface

ii‡ Normal (physically unaffected) tooth structure, representation of dentine and cementum

T1§ Traverse section through root resorption crater

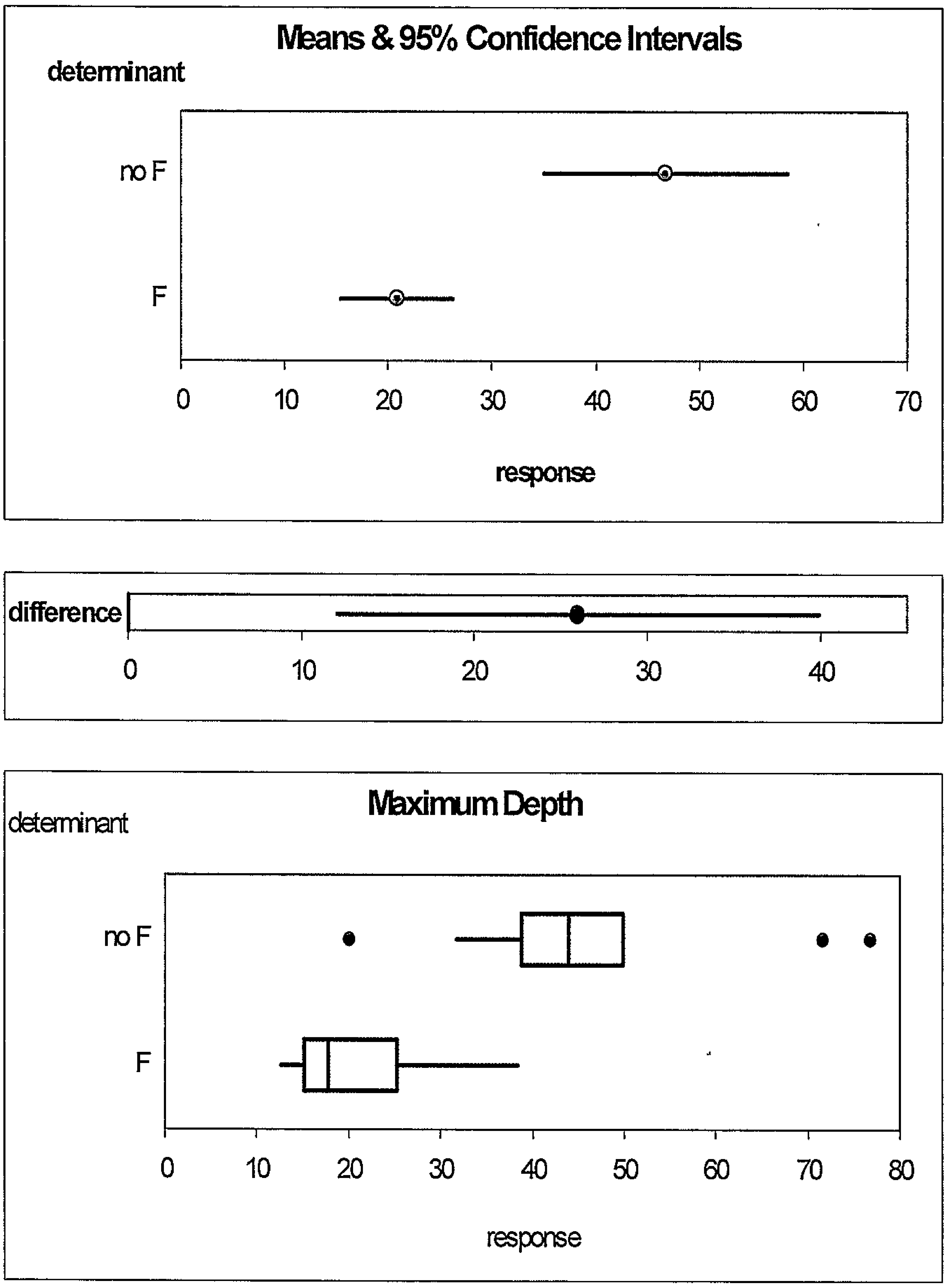

Figure 9: Maximum depth of root resorption craters Fluoride vs No-Fluoride.

*P = 0.002

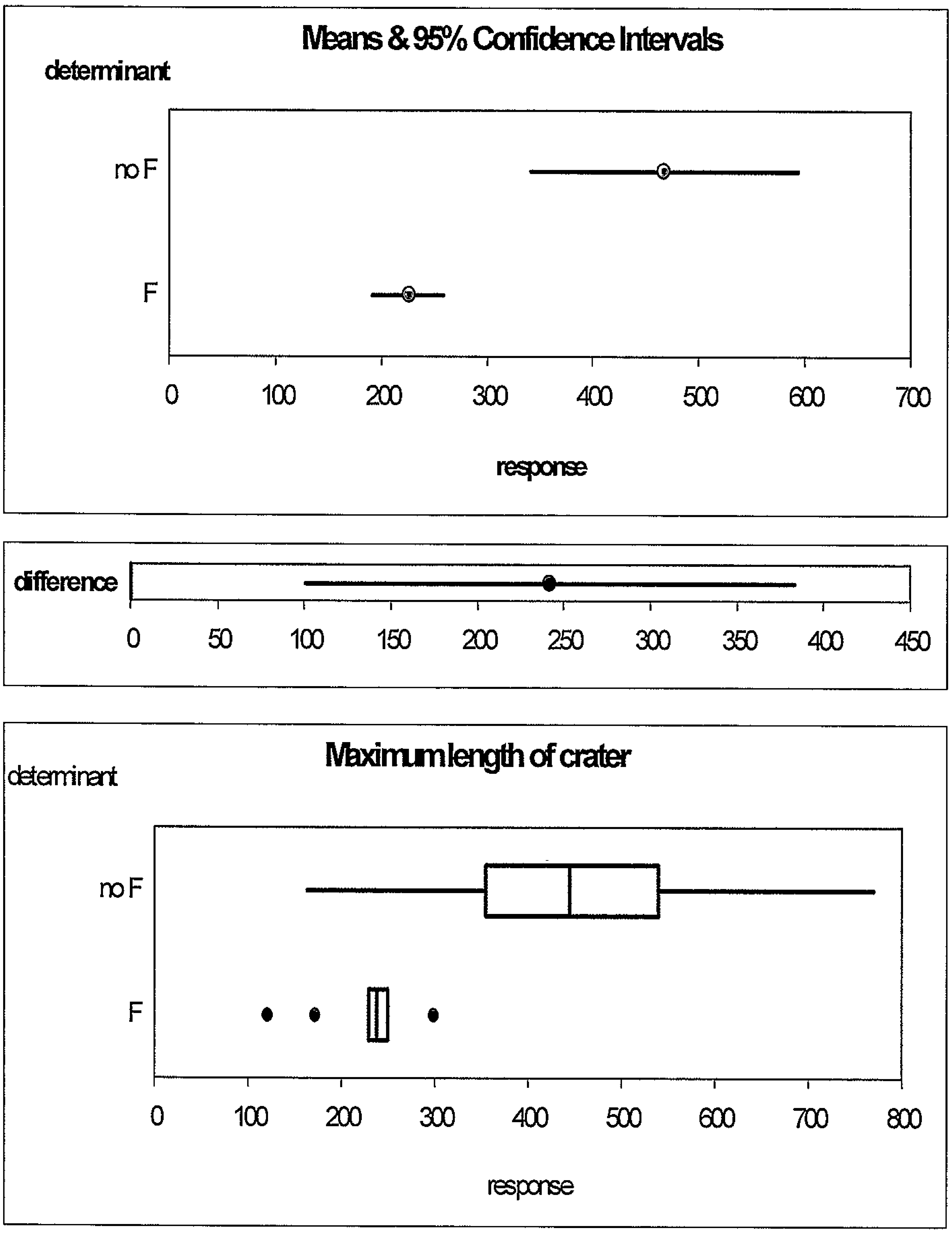

Figure 10: Maximum length of root resorption craters Fluoride vs No-Fluoride.

*P = 0.001

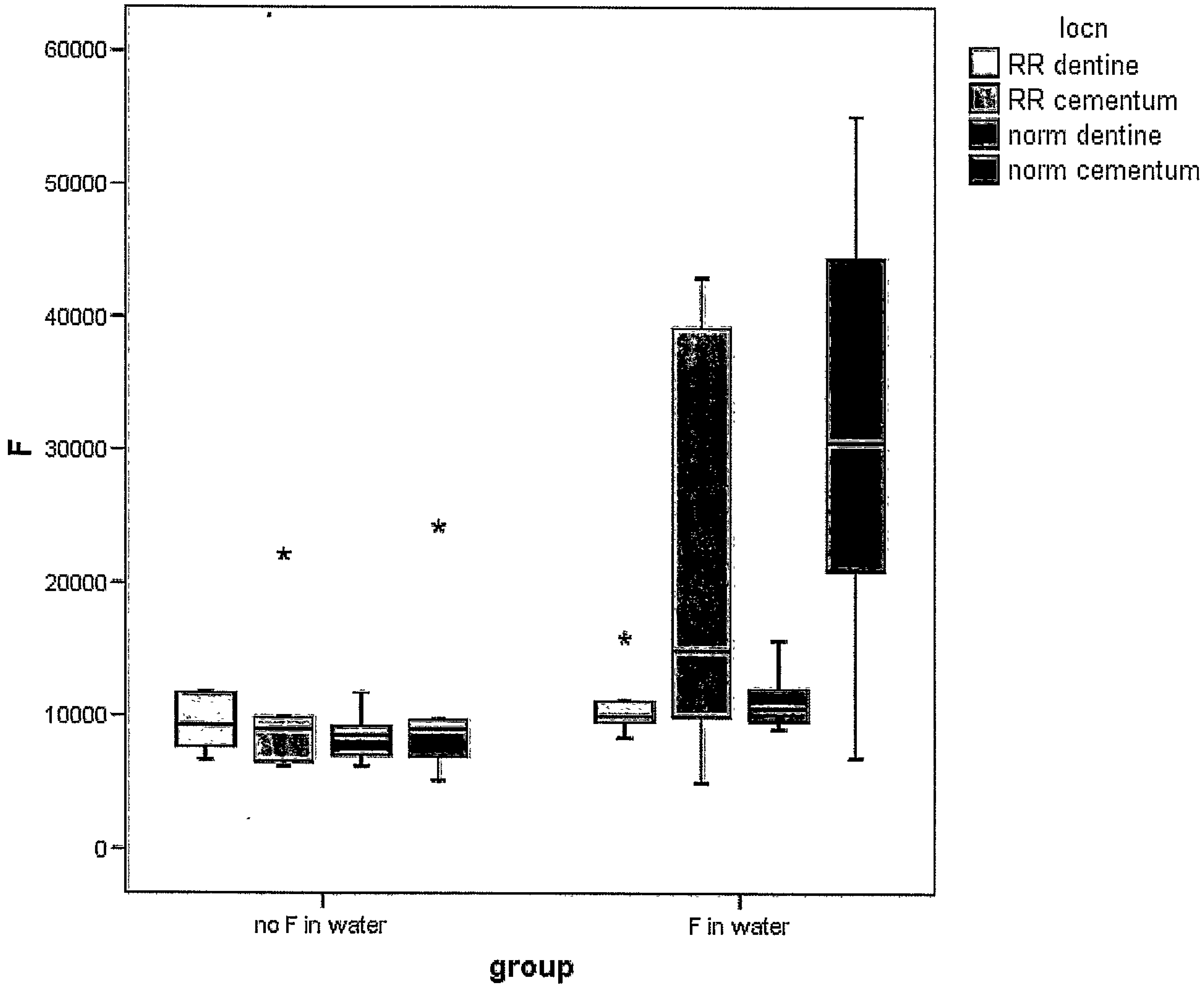

Figure 11: Mean fluorine (F) concentrations (ppm) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

* Possible outlier

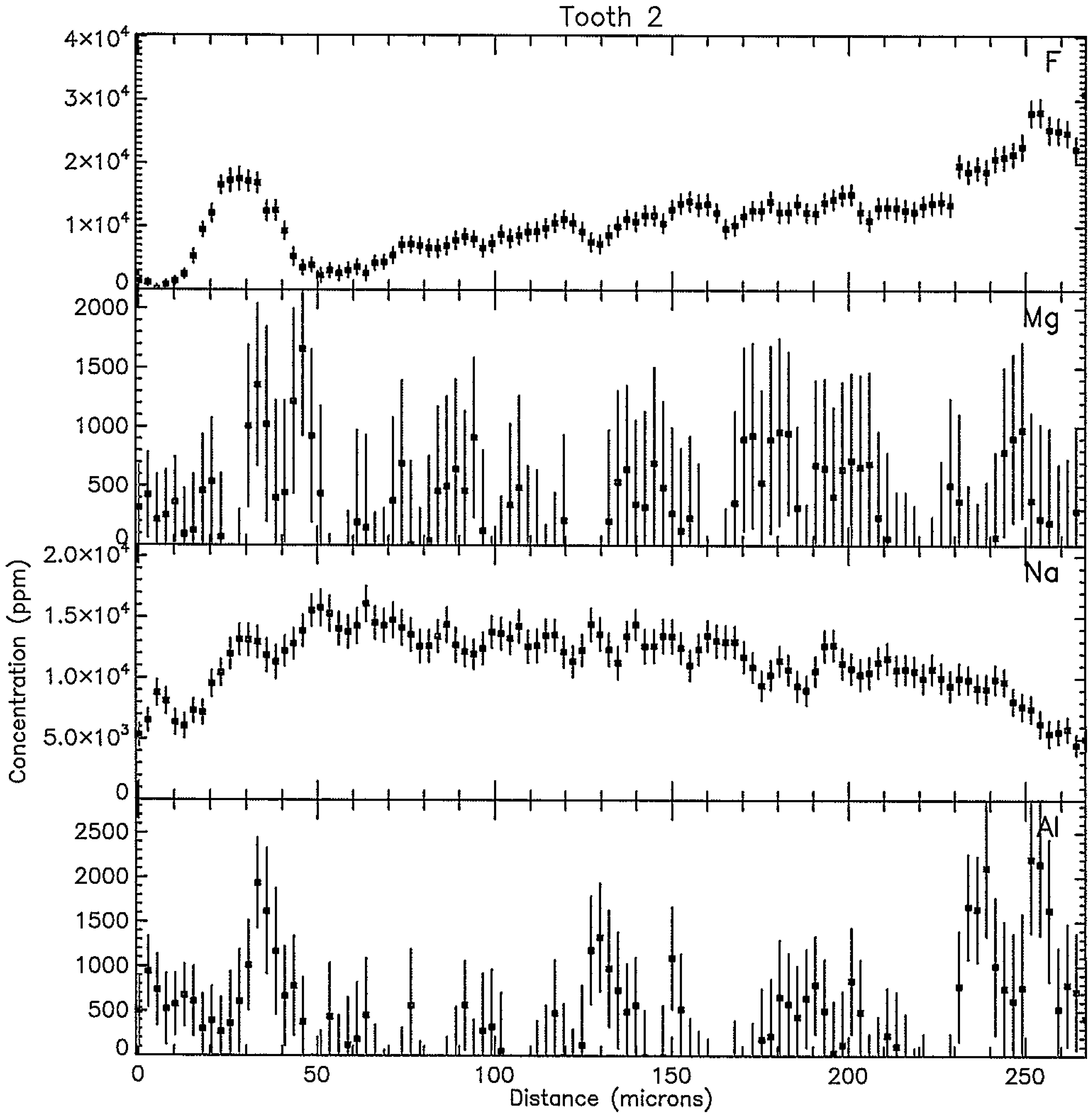

Figure 12: PIGE Spectral Plot (traverse concentration profile) demonstrating mineral concentrations through a root resorption crater of Sample 2 (No-fluoride Group). Left of page to right corresponds to cementum through to pulp. Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

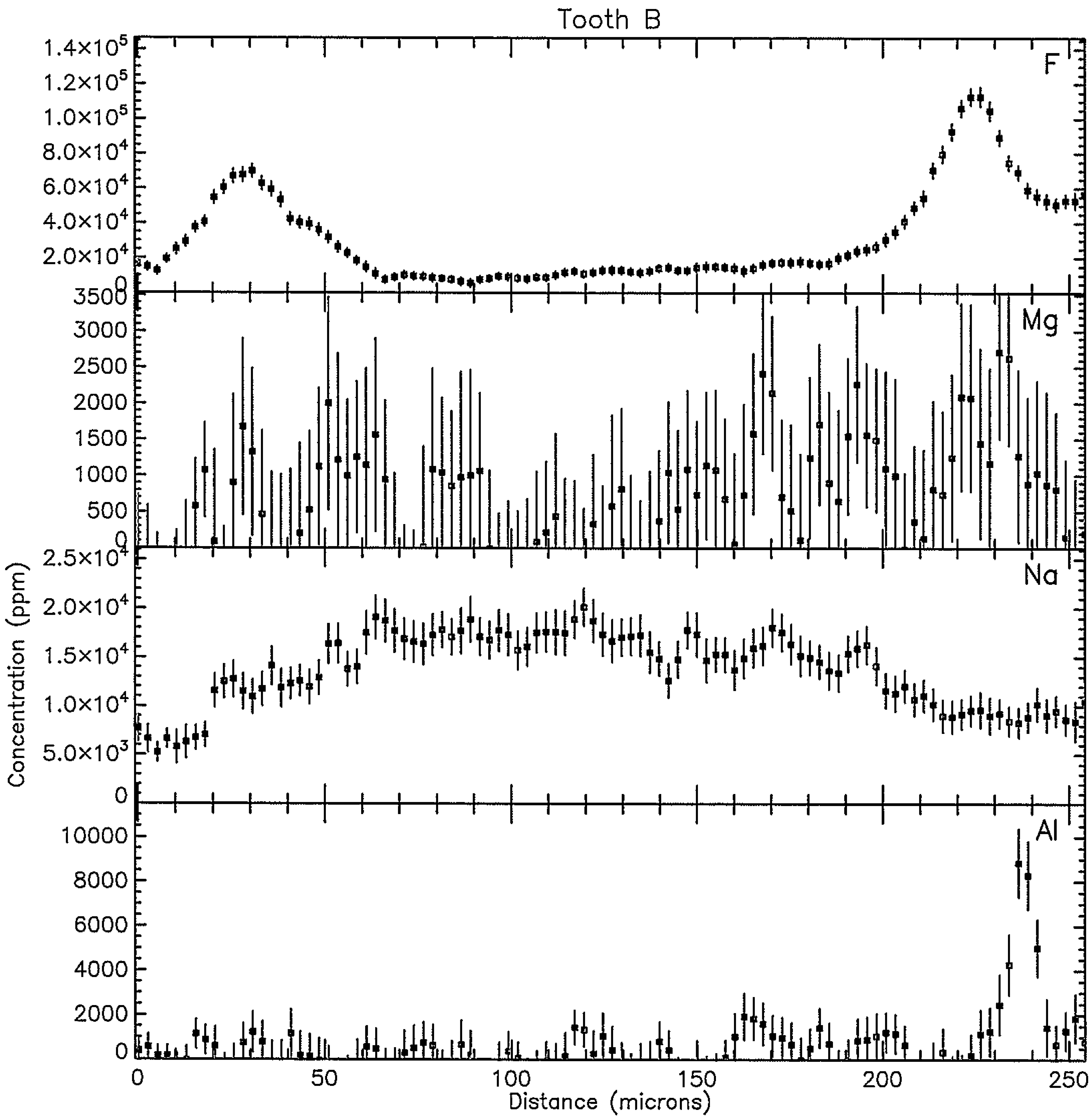

Figure 13: PIGE Spectral Plot (traverse concentration profile) demonstrating mineral concentrations through a root resorption crater of Sample B (Fluoride Group). Left of page to right corresponds to pulp through to cementum. Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

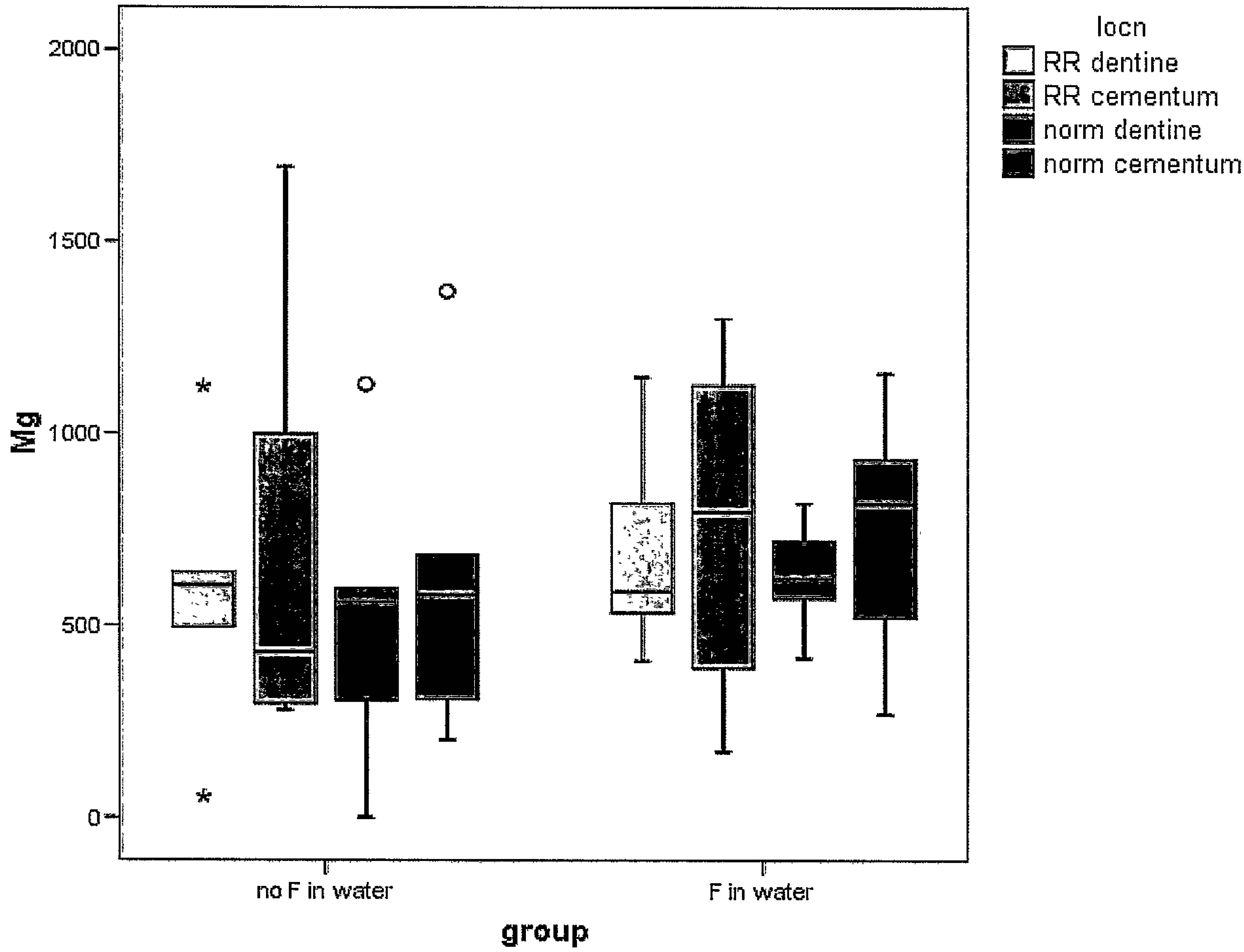

Figure 14: Mean magnesium (Mg) concentrations (ppm) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

* Possible outlier

° Probable outlier

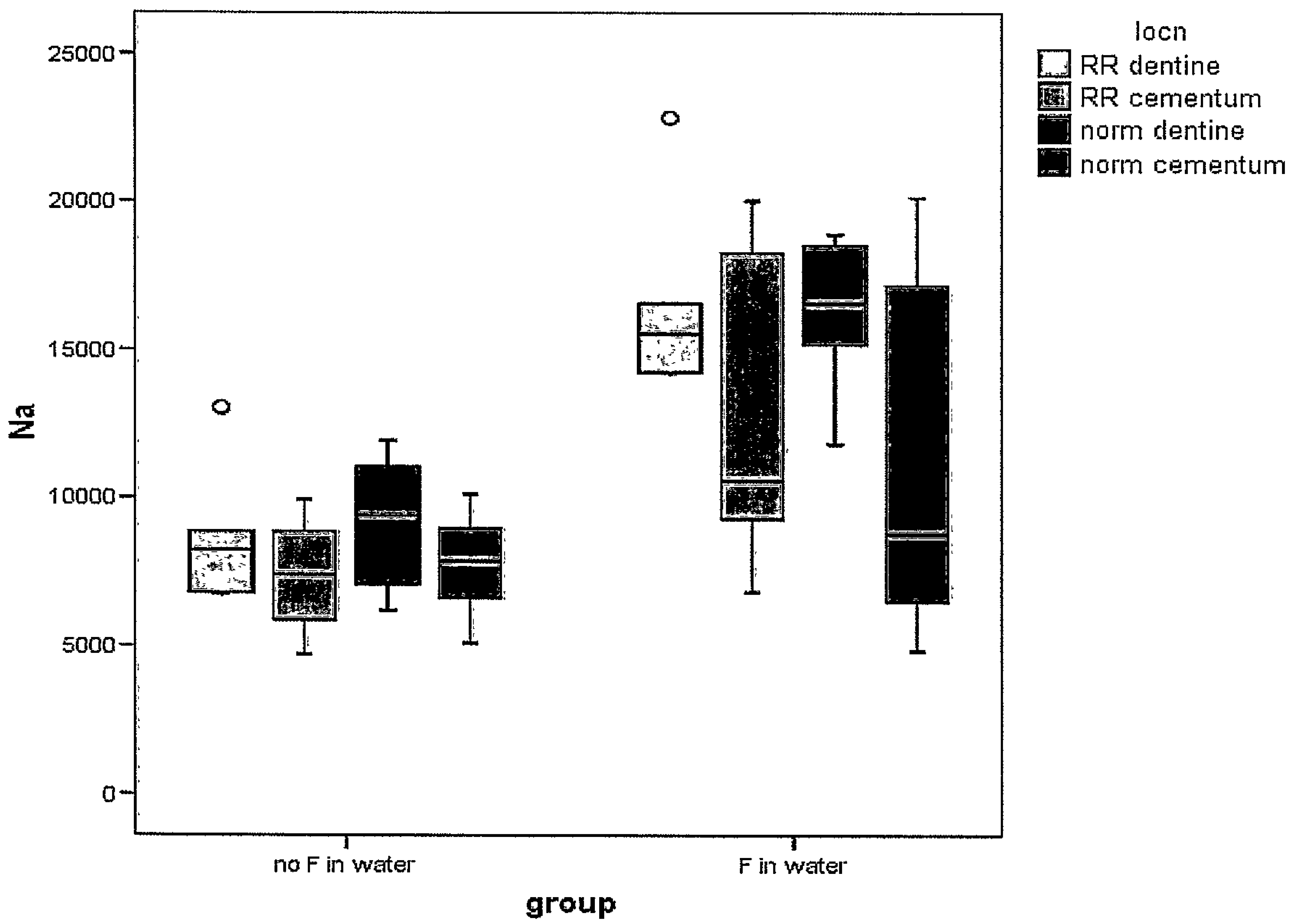

Figure 15: Mean sodium (Na) concentrations (ppm) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

° Probable outlier

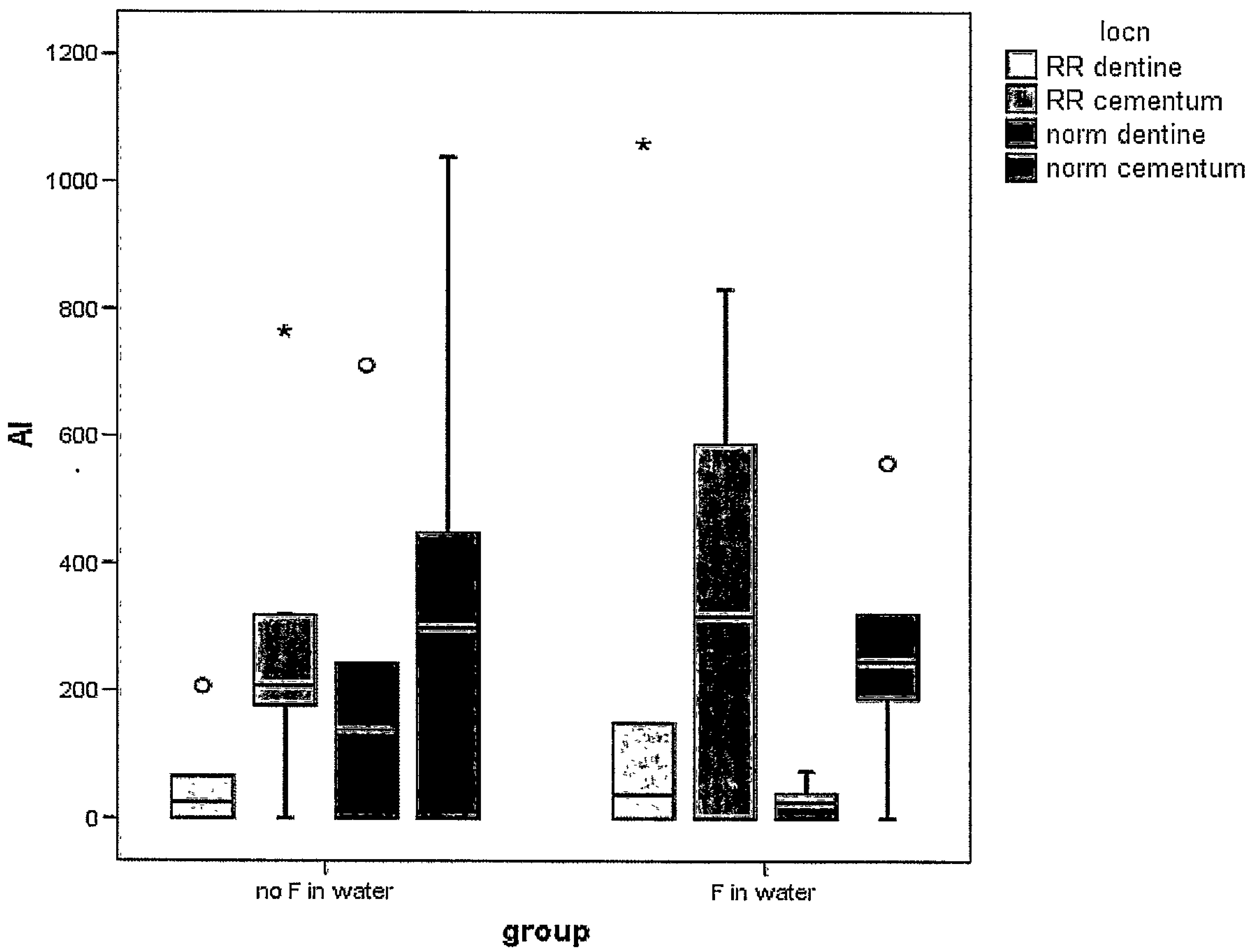

Figure 16: Mean aluminium (Al) concentrations (ppm) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

* Possible outlier

° Probable outlier

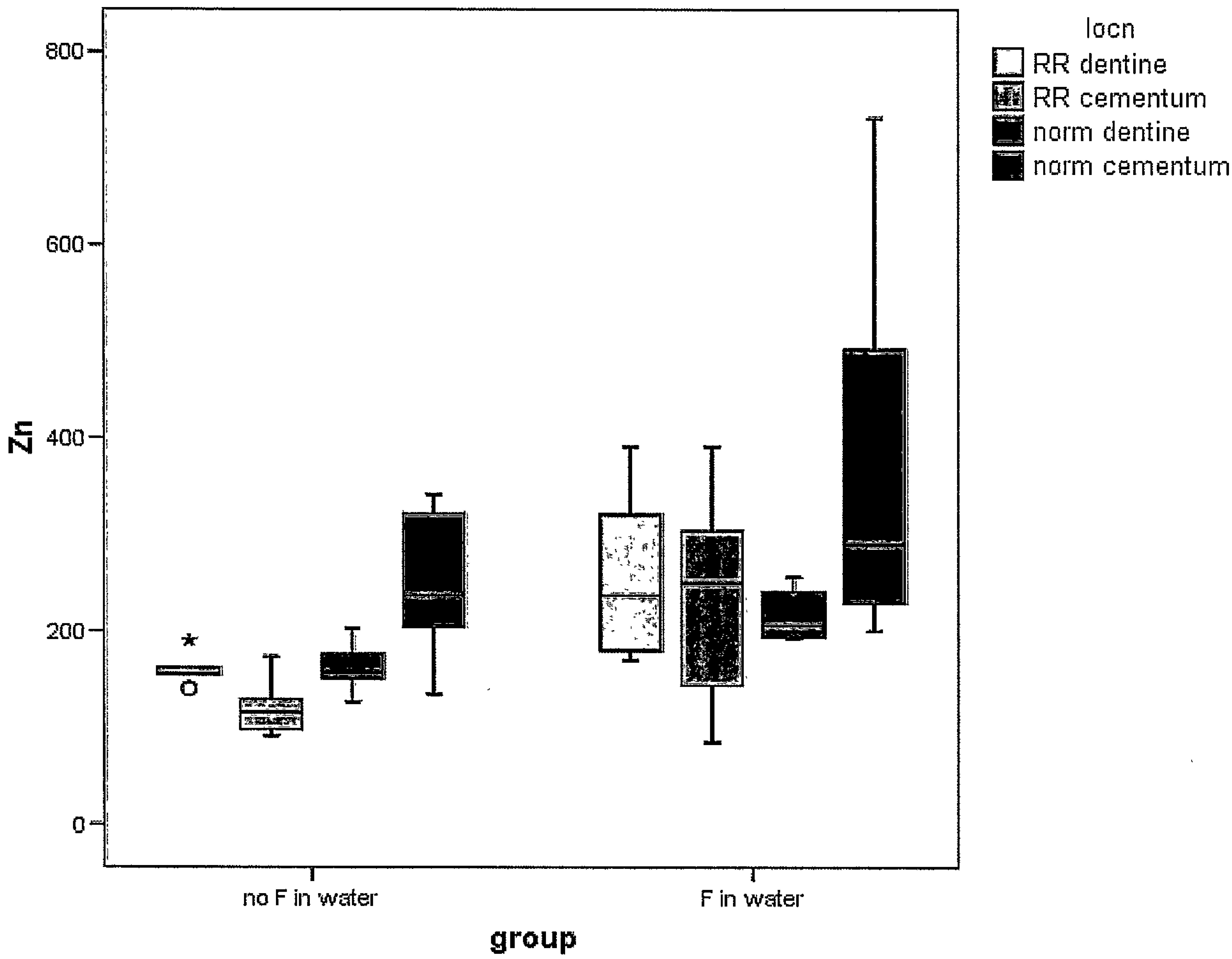

Figure 17: Mean zinc (Zn) concentrations (ppm) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

* Possible outlier

° Probable outlier

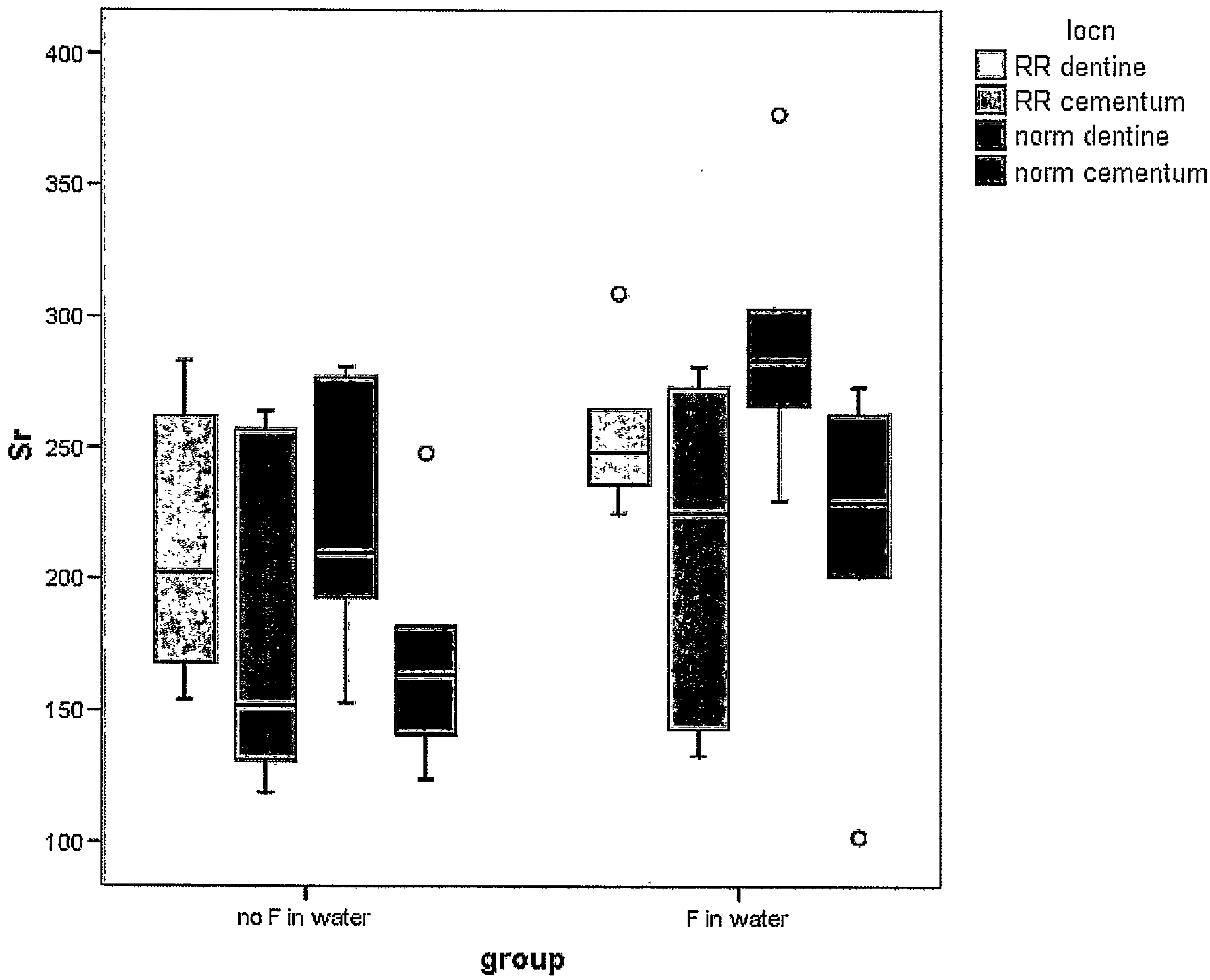

Figure 18: Mean strontium (Sr) concentrations (ppm) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

° Probable outlier

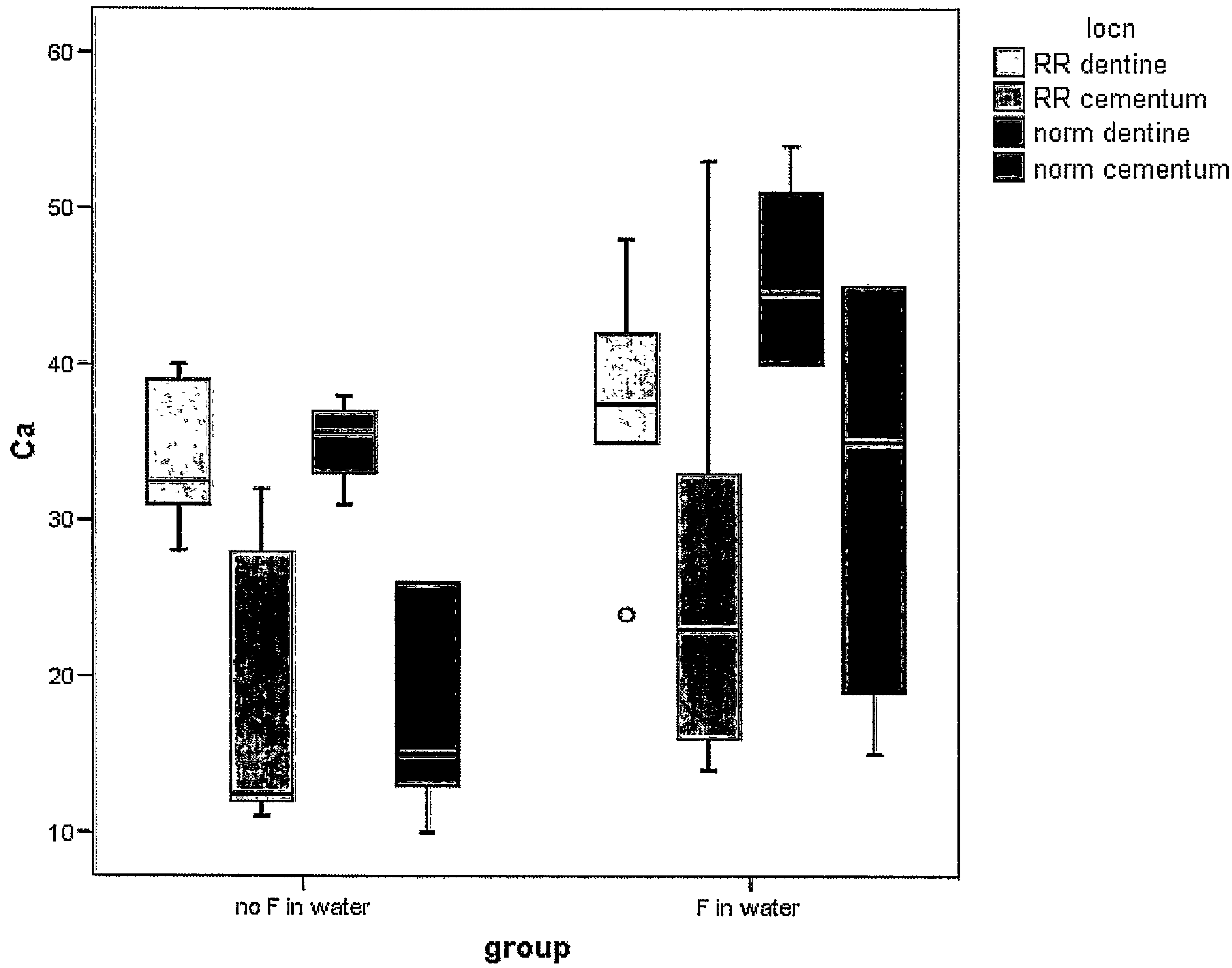

Figure 19: Mean Calcium concentrations (%) for No-fluoride vs Fluoride Groups divided according to location within the tooth.

° Probable outlier

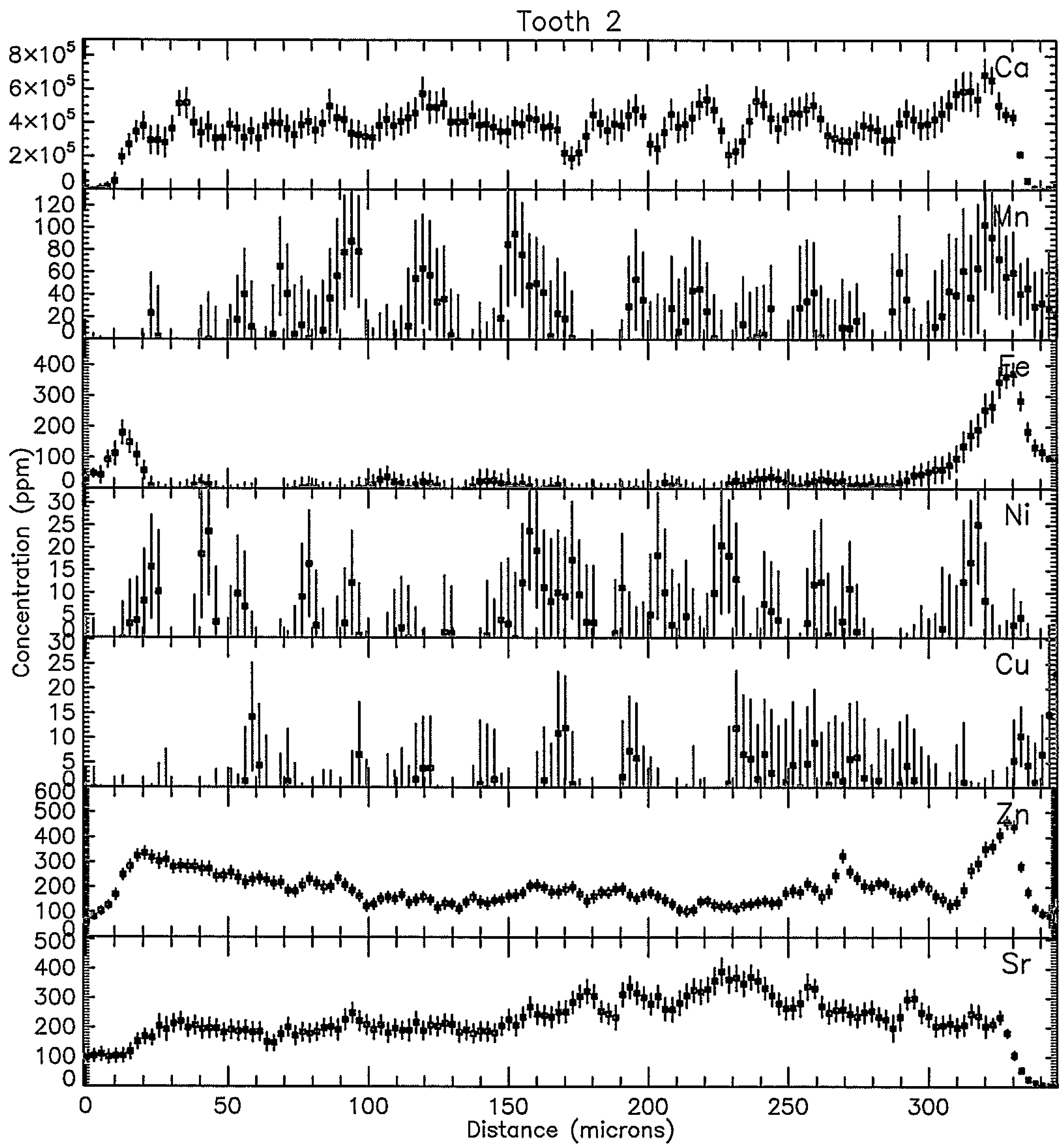

Figure 20: PIXE Spectral Plot (traverse concentration profile) demonstrating mineral concentrations through a root resorption crater of Sample 2. Left of page to right corresponds to cementum through to pulp. Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

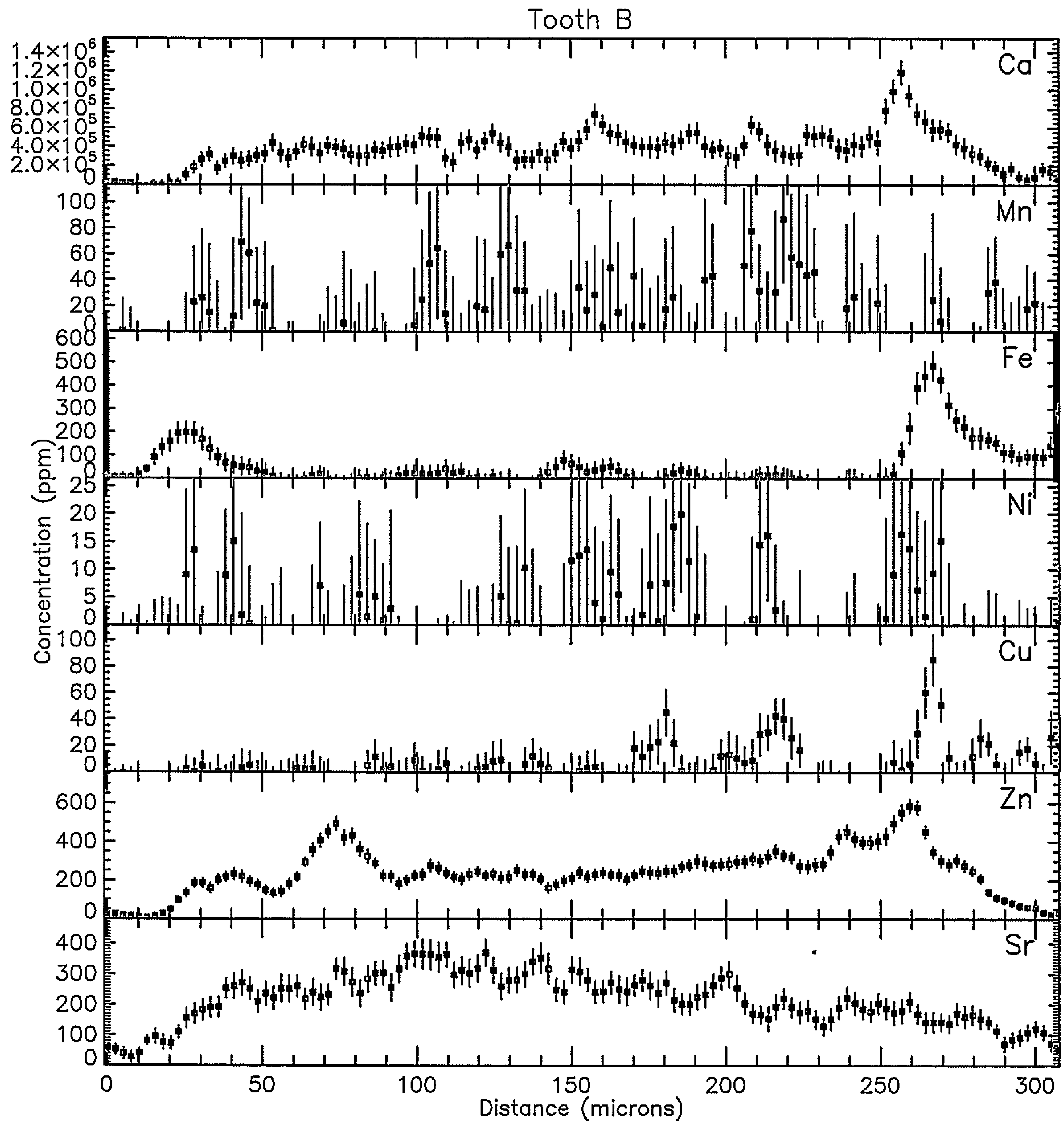

Figure 21: PIXE Spectral Plot (traverse concentration profile) demonstrating mineral concentrations through a root resorption crater of Sample B. Left of page to right corresponds to pulp through to cementum. Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

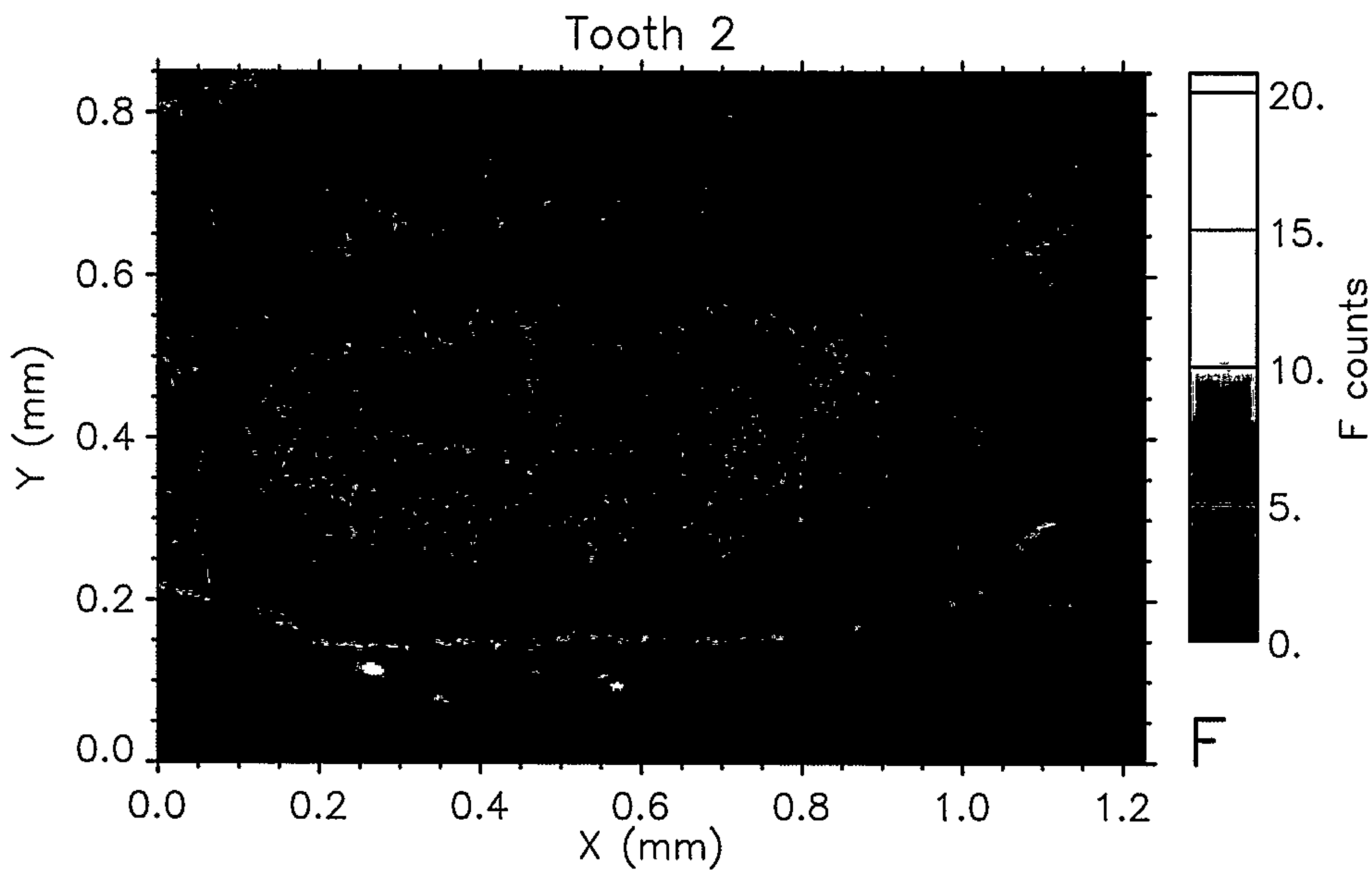

Figure 22: PIGE Picture Plot demonstrating distribution of mineral concentration of fluorine in Sample 2 (No-fluoride).

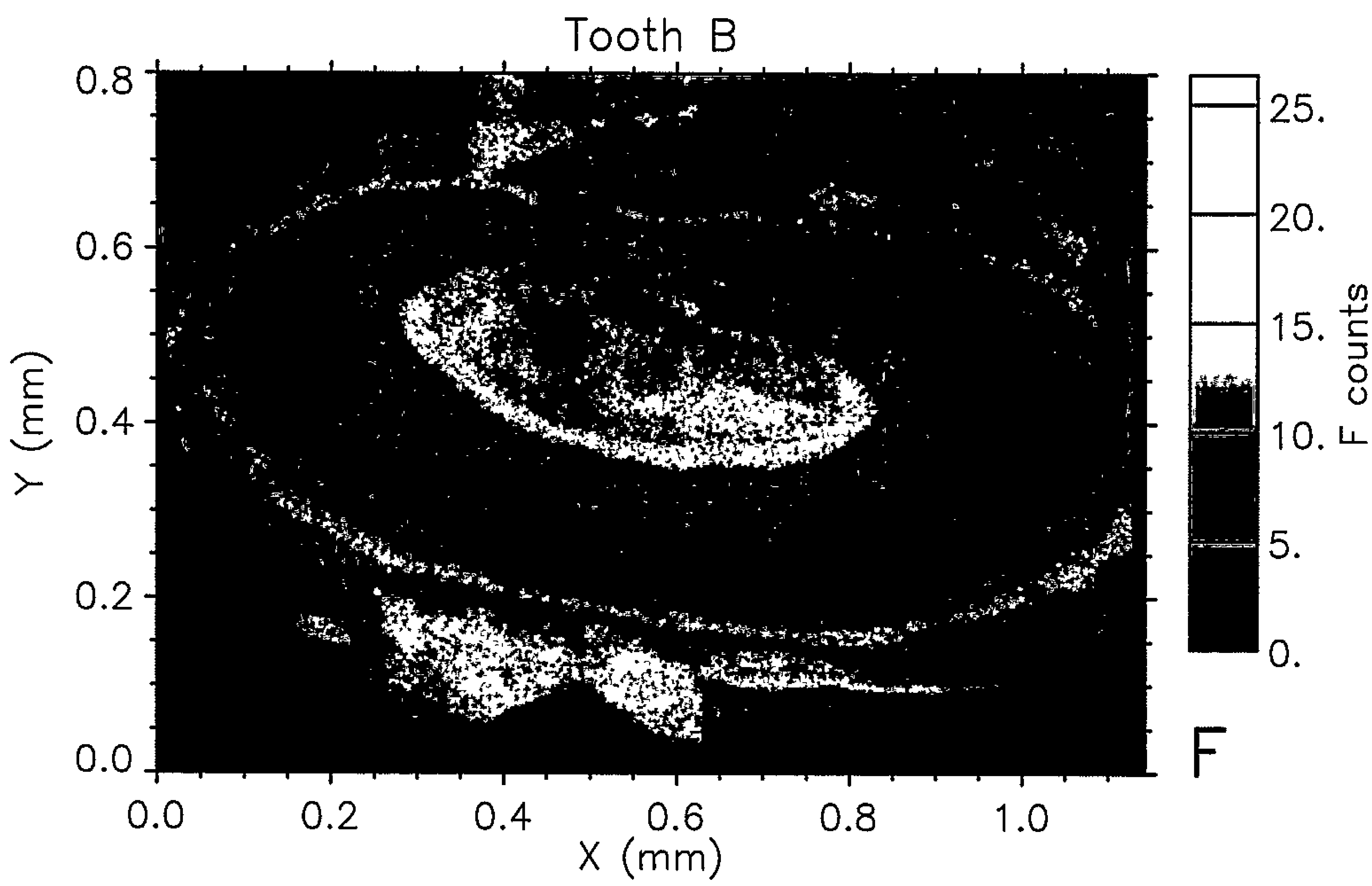

Figure 23: PIGE Picture Plot demonstrating distribution of mineral concentration of fluorine in Sample B (Fluoride Group).

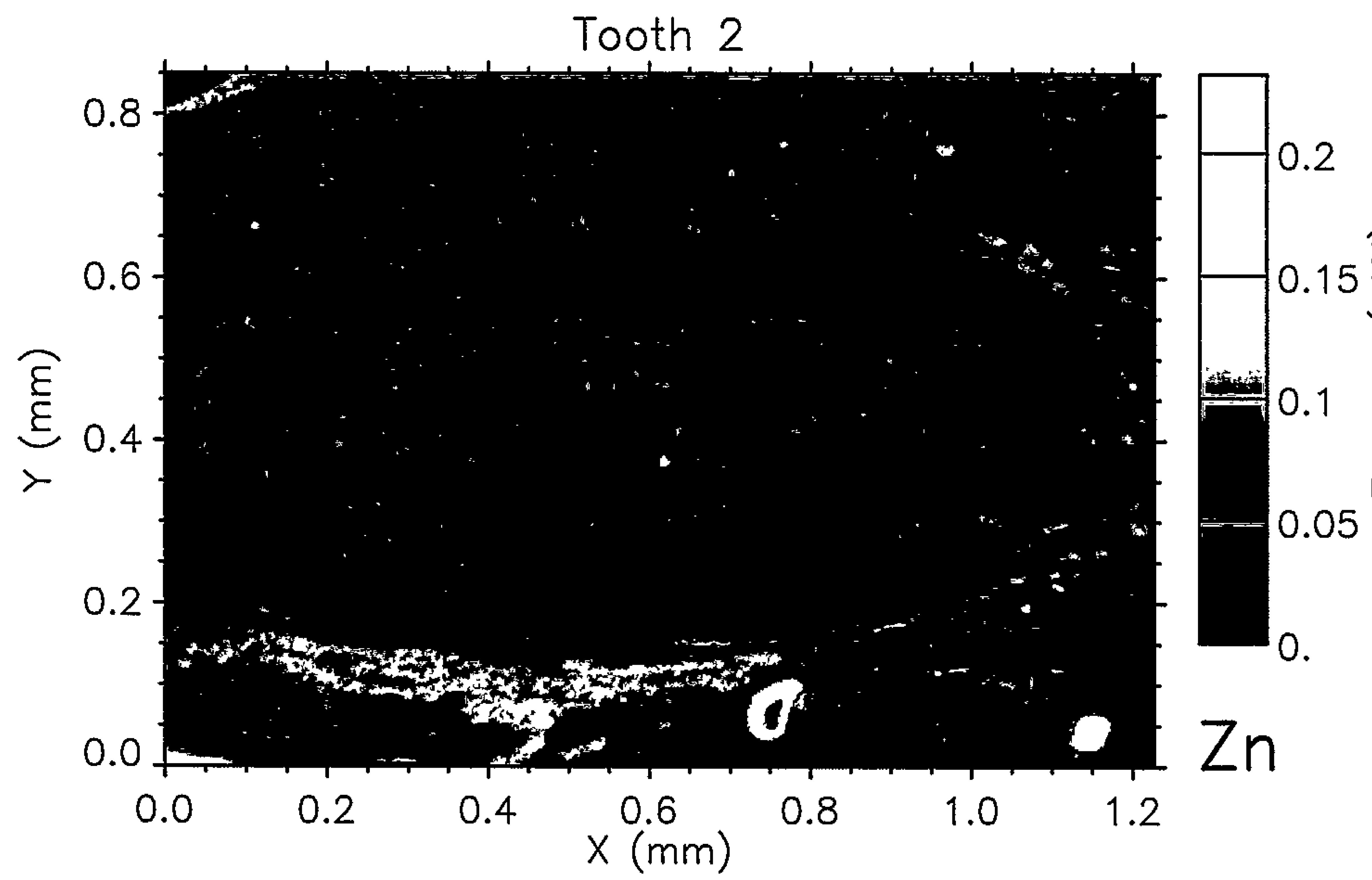

Figure 24: PIXE Picture Plot demonstrating distribution of mineral concentration of zinc in Sample 2 (No-Fluoride Group).

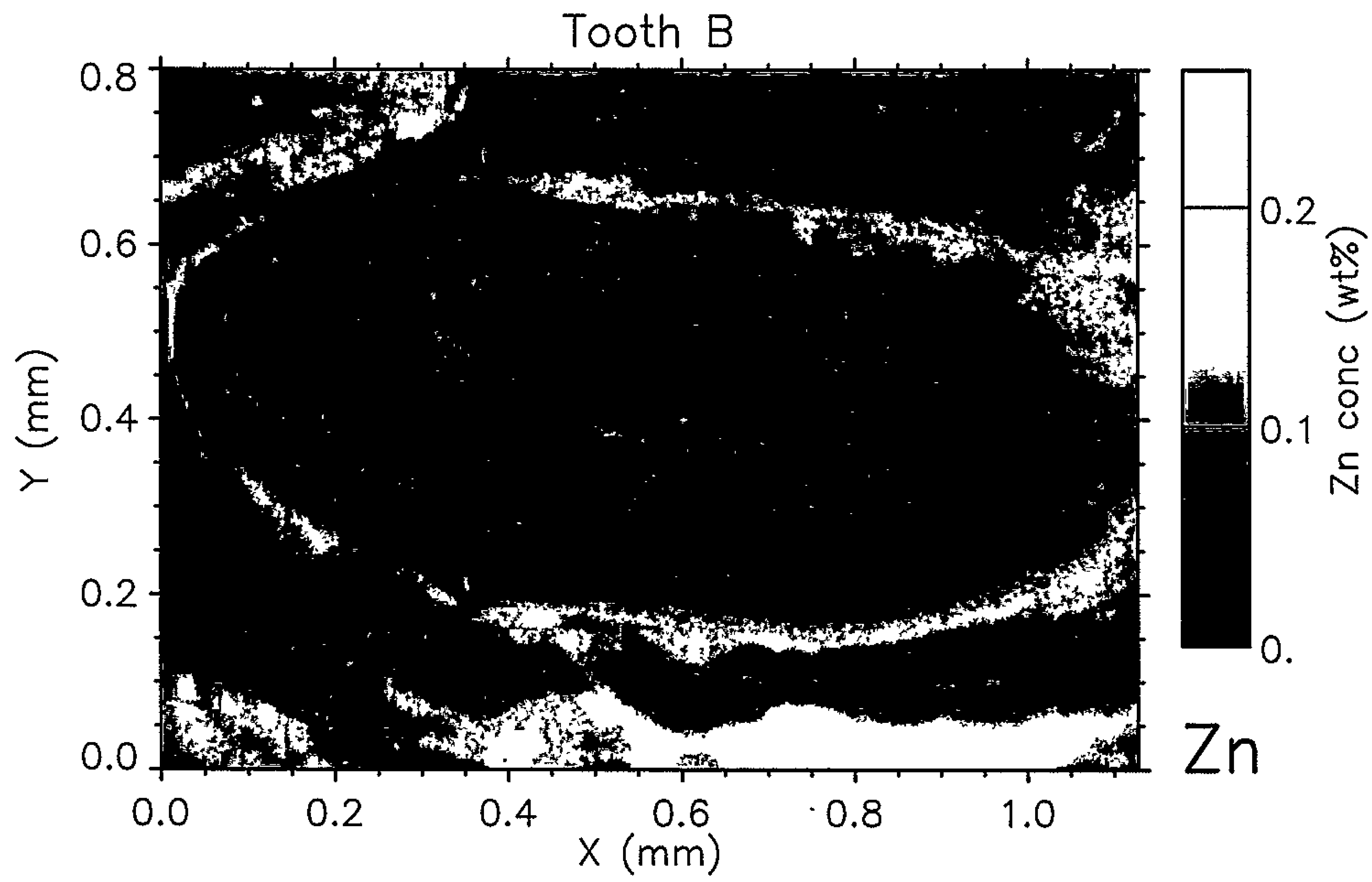

Figure 25: PIXE Picture Plot demonstrating distribution of mineral concentration of zinc in Sample B.

4.9 Tables

Mineral	Standard Error	Coefficient of Variation
F	249	2.0%
Mg	50	9.4%
Na	339	3.8%
Ca	1.4	3.9%
Zn	28	7.6%

Table 1: Error of the Measurement

Group	Analysis Region	Mean Concentration*†
No-Fluoride in drinking water	Root resorption crater dentine	8553.83
	Root resorption crater cementum	10474.83
	Normal dentine	9430.83
	Normal cementum	10705.5
Fluoride in drinking water	Root resorption crater dentine	10822.67
	Root resorption crater cementum	21166.33
	Normal dentine	11267.17
	Normal cementum	31388.0

Table 2: Mean fluorine concentrations for dentine and cementum in No-fluoride vs Fluoride groups.

* ppm

† standard error 3151.51

Mineral	Fluoride Group‡	No-fluoride Group‡	Standard Error
F*	18661.04	9791.25	16.06
Zn*	270.29	174.04	1575.75
Na*	14091.54	8232.04	440.96
Ca†	35.58%	26.10%	1.42

Table 3: Mean mineral concentrations for Root Resorption Craters of No-fluoride vs Fluoride groups.

* $p<0.01$

† $p<0.05$

‡ ppm unless stated otherwise

5. Manuscript Two

Part 2a: Analysis of elemental composition using Proton Induced X-ray and Gamma ray Emissions in human cementum following heavy and light orthodontic forces.

This manuscript is to be submitted to the American Journal of Orthodontics and Dentofacial Orthopedics.

For the purpose of this thesis this manuscript is extended and will be shortened for publication.

Elaine Lim, BDS (Uni. Medal)

Postgraduate Student, Discipline of Orthodontics,

Faculty of Dentistry,

University of Sydney.

Dr D Belton, PhD

Manager, Nuclear Microprobe Applications Exploration and Mining,

CSIRO, MARC, School of Physics,

University of Melbourne.

Dr P Petocz, PhD

Associate Professor, Department of Statistics,

Macquarie University.

Professor M Ali Darendeliler, BDS, PhD, Dip Ortho, Cert. Orth, Priv. Doc

Professor and Chair,

Discipline of Orthodontics,

Faculty of Dentistry,

University of Sydney.

Address for correspondence:

M. Ali Darendeliler

The University of Sydney

Discipline of Orthodontics

Faculty of Dentistry

Level 2, 2 Chalmers Street

Surry Hills NSW 2010 Australia

Phone: +61 2 93518314

Fax: +61 2 93518336

Email: adarende@mail.usyd.edu.au

5.1 Abstract

Introduction: Cementum is the interface of the tooth's response to orthodontic induced inflammatory root resorption. Study of cementum structure following orthodontic force may help to increase our understanding of the resorptive process and the potential role elements may have in its prevention.

The aim of this study was to conduct an analysis of the elemental composition of human root cementum, following heavy and light orthodontic force using the Commonwealth Scientific and Industrial Research Organisation and Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents Nuclear Microprobe (CSIRO-GEMOC NMP). Furthermore, a methodology was established for this machine, enabling more accurate readings of cementum than previously published from tooth root samples that could remain relatively unaltered for the scanning process.

Method: Four teeth, which met inclusion criteria, were analysed. Buccal directed force of 25 g (light) and 225 g (heavy) were imparted by 0.016" and 0.017 x 0.025" beta-titanium-molybdenum alloy springs, respectively. The left teeth were designated experimental teeth and their contralateral teeth served as controls. Following the experimental period of 4.1 weeks,

the teeth were extracted. Samples were sectioned longitudinally, embedded in epoxy resin, polished and prepared for analysis by the CSIRO-GEMOC NMP. Six pre-determined dentine-cementum points per tooth (800 x 800 μm) were analysed and deconstructed using the Geo-PIXE II™ Version 3.8 Program.

Results: The CSIRO-GEMOC NMP was able to detect fluorine, magnesium, sodium, calcium, iron, zinc and strontium. General trends for these elements support those of previous studies. However, there was marked inter-individual variation for absolute concentrations. Orthodontic force below 250 g did not appear to consistently alter the pattern of cementum elemental distribution. However, there was a significant reduction of overall zinc & fluorine, and a marginally significant reduction in strontium, concentrations comparing heavy and light force with controls ($p<0.01$).

Conclusion: Findings indicate that cementum may have the capacity to resist significant element alterations. However, the reduction in Zn and F following exposure to orthodontic force may have implications for subsequent root resorption.

5.2 Introduction

Orthodontically Induced Inflammatory Root Resorption (OIIRR)[1] refers to root resorption resulting from orthodontic treatment. OIIRR is an unpredictable adverse effect involving transient inflammatory surface resorption. The exact mechanism of OIIRR is unknown. The severity of the outcome of this process may be related to the orthodontic force level imparted on the tooth.[2] Cementum is an integral part of this process. Understanding its structure may help to elucidate more information regarding its role in protecting teeth and its ability to normally resist resorption.

Cementum is an important dynamic interface between the tooth and the periodontal environment. Similar to other hard tissues, hydroxyapatite in cementum is not pure, and contains elements from its microenvironment.[3]

Trace elements are present in cementum. Manganese has been reported to be present at 0.5-1.4% wt.[4-7] The cementum fluoride concentration was shown to be inversely proportional to magnesium.[8]

Previous studies have detected citrate in cementum at a concentration of 0.86 ± 0.06% wt.[9] Carbonate was also present at 2.79% wt and for both these elements there was no inverse relationship with fluoride, unlike that

observed in enamel.[9] Concentration of sodium has been estimated at 0.3%.[5] Zinc and strontium have also been noted in tooth roots.[10,11] Strontium, like fluorine, is an agent used by the dental profession in topical applications on tooth surfaces.[11]

Fluoride has a varied distribution through and across the tooth. Its concentration depends on age and environmental fluoride exposure. In general, there is an increase with age and ingestion of fluoridated water.[4,9] The fluoride concentration has been estimated to average 45-65% ash weight. In human teeth an increasing gradient from inner to the outer surface of tooth roots has been demonstrated.[12]

Quantitative assessment of calcium, phosphorus and fluoride concentrations have indicated a reduction of mineral concentration towards the apex.[12] There was no difference between buccal and lingual surfaces, except for increased fluoride bucco-cervically. There were significant differences between the upper half of the root compared to the apical part. However, the distribution of minerals within mature root tissue shows a great variability.[3]

Orthodontic force and its relationship to cementum minerals has previously been examined. Rex and co-workers[13] used an electron microprobe technique to study the effects of light (25 g) and heavy (225 g) force. Following light force, there was no apparent alteration in tooth mineral

composition. However, a reduction in elemental concentration was demonstrated following increased orthodontic force. Heavier forces resulted in more marked changes. There was an increase in calcium and phosphate in areas of compression, and a reduction in calcium in areas of tension. In contrast fluoride was inversely related to calcium and phosphate changes. With regards to fluoride, however, overall there was no significant difference between light, heavy or control teeth.

Various explanations have been used to support the trend of altered mineral content with orthodontic force, including:

1. pH changes in microenvironment:[14,15] the inflammatory process involved in tooth movement results in the local drop in pH level, which could lead to dissolution of mineral content of the tooth root surface.
2. Cell mediated response:[13] lowering the pH of tissues results in increased activity of osteoclasts whilst inhibiting osteoblasts.[16] This mechanism may have a similar effect on odontoclasts and odontoblasts
3. Homeostasis:[17] osteoblasts activate calcium channels, which lead to an increase in intracellular calcium, resulting in hypocalcemia. Physiologic processes then act to restore balance. In support, hypocalcaemic states in rats have been associated with an increased

severity of root resorption.[18] In contrast, Goldie and King[19] did not demonstrate the same findings.

Thus the mineral content presented by a tooth could reflect the dissolution of crystallites due to the resorptive process. However, it could also represent subsequent repair mechanisms. This is because the resorptive process could be countered by remineralization. A dynamic exchange of elements may occur superficially limiting the extent of more minor resorptive defects. Subjacent unaffected tissue could also provide a reservoir for diffuse transition of elements.[3]

There are various methods to study elemental composition of teeth. The nuclear microprobe employs Proton Induced X-ray Emissions (PIXE) and Proton Induced γ-ray Emissions (PIGE), which allows mapping of multiple trace elements at micron (μm) resolutions. Compared to other available techniques, the Commonwealth Scientific and Industrial Research Organisation and Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents Nuclear Microprobe (CSIRO-GEMOC NMP) provides a powerful combination of element spatial (resolution of 1-2 μm) and quantitative analysis. This technology has not previously been employed to study tooth root elements in the context proposed.

The NMP is a non-destructive analysis with regards to both the beam itself and the method by which samples need to be prepared. The beam deposits little energy over the first 30 μm of sample penetration. Furthermore, the sample requires minimal preparation compared to other techniques.[20,21] This means fewer potential disturbances to the elemental content of the sample. However, a condition for NMPs is a flat surface for scanning to maximise reliability of x-ray and gamma ray detection.[22] Therefore, samples lacking smooth surfaces require sectioning. This technology is not suitable for bulk sample analysis, but the data gathered is respected for its high quality.

The aim of this study was to analyse the elemental composition of superficial human tooth root structure following heavy and light orthodontic force using the CSIRO-GEMOC NMP. Furthermore, a methodology was established for this machine, enabling detailed quantitative and qualitative readings.

5.3 Materials and Methods

5.3.1 Sample

Subject one (S1) was a 13.5 year old female. The second subject (S2) was a 15.1 year old male. Maxillary first premolar teeth from these individuals were used, thus a total of four teeth were analysed for this section (Ethics Committee of the Central Sydney Area Health Service and CSAHS Human Ethics Review Committee, United Dental Hospital, Sydney, Australia, Project: 5/98). The samples met the following inclusion criteria:[23]

1. Bilateral maxillary first premolar teeth to be extracted for orthodontic purposes
2. Complete apexification
3. No history of trauma, dental restorations, pathology or developmental abnormalities
4. No history of bruxism
5. No medical history that may affect dental development
6. Knowledge of birth place and residence to present
7. Knowledge of fluoride consumption history

The subjects were born and resided in Sydney, Australia where the water supply is fluoridated to 1.0 ppm. They were both exposed to topical fluoride

in the form of dentifrice and occasional professional application. Water consumed was through mains tap water.

The health of these teeth was determined clinically and radiographically with a long-cone paralleling technique.

5.3.2 Clinical Procedure

The maxillary left first premolar tooth of S1, received the light force. A 25 g buccally directed force was applied to the tooth using a 0.016" beta-titanium-molybdenum alloy (TMA®) (Ormco, CA) spring (tooth designated L7). The heavy force applied to the maxillary left first premolar tooth of S2, had 225 g buccally directed force applied by a 0.017" x 0.025" TMA® (Ormco, CA) spring (tooth designated H17). These springs consisted of an activated segment of archwire, engaged in 0.022" SPEED brackets (Strite Industries, Canada) bonded to the first permanent molar and the experimental tooth (Figure 1). The right contralateral teeth served as a control and had SPEED brackets bonded to them (S1 control designated L8 and S2 control designated H18). The force magnitude was measured to the nearest gram using a strain gauge (Dentarum, Germany). Glass ionomer cement (Transbond, 3M Unitek™) was bonded on the occlusal surfaces of the lower first molar teeth to minimise occlusal trauma to the maxillary first premolars during the experimental period.[24] After 4.1 weeks the upper first

premolar teeth of the subjects were extracted. Instructions were given to the oral surgeons to avoid forceps contact on and apical to the cervical cementum. The teeth were stored in 5 ml of Milli-Q® and then underwent ultrasonic cleaning for 10 minutes to remove remaining periodontal ligament and biological debris.[25] The teeth were then disinfected in 70% alcohol for 30 minutes and stored in Milli-Q® at ambient room temperature (23° ± 1°).[21]

5.3.3 Sample preparation

Part of the crown of the sample teeth was removed using a high-speed diamond bur and Milli-Q® irrigation. Following seven days of air-drying, the teeth were embedded in epoxy resin [Procure 812 (ProSci Tech, Qld, Australia), Nadic Methyl Anhydride (NMA) (ProSci Tech, Qld, Australia) and Benzyldimethylamine (BDMA) (Probing and Structure, Qld, Australia) in ratio of 2.7:2.3:1, respectively]. These were then oven cured for 24 hours at 60°. The teeth were then sectioned longitudinally from a buccal-lingual direction, using a diamond blade (Leco, MI, USA) mounted on an Accutom (Struers, Denmark).

Polishing was then performed manually on a DP-U2 polishing machine (Struers, Denmark). The sandpaper grit used was P400 followed by P1200 (Leco, MI, USA). A final polish was achieved on an 8" diameter, 203 mm

PAN W PSA polishing disc (Leco, MI, USA) with 6 μm water based polycrystalline diamond suspension (Allied High Tech Products Inc., CA, USA). Following satisfactory polishing, as assessed under light microscope, a second section was made 0.5 cm from the first cut to achieve flat parallel surfaces. These were then mounted on metal stubs using carbon sticky paper. Carbon dag was then added and the sample carbon coated.[12] The Nuclear Microprobe machine developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents (GEMOC) (Melbourne, Victoria, Australia) was then used for analysis.

5.3.4 Sample Analysis

5.3.4.1 NMP

The spatial distribution of multiple elements was measured at six pre-determined dentine-cementum points per tooth (Figure 2). Spot scanning of 800 μm x 800 μm areas was conducted, on the buccal and lingual, at designated cervical (cementoenamel junction), middle (mid-point taken as half-way between the apical and cervical areas scanned) and apical (area taken coronal from a perpendicular at the level of the tooth apex either side

of the apical foramen) regions (Figure 2). The analysis was performed with 3.0 MeV protons and the beam focused at 1 x 1.8 μm^2. The beam current was maintained at 4 nA. An aluminium absorber of 100 μm used between target and Germanium (Ge) detector (Canberra Ultra-Ge Detector©). The elements detectable under gamma rays were sodium (Na), fluorine (F), magnesium (Mg), boron (B), aluminium (Al) and silicon (Si). Whilst under x-rays calcium (Ca), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), bromine (Br), rubidium (Rb), strontium (Sr), tin (Sn), barium (Ba) and lead (Pb) were measurable.

5.3.4.2 Spectral Deconvolution of Element Spectral Distribution Maps

Geo-PIXE II™ Version 3.8 Computer Program was used to extract and translate the data.[26] This program provided the tools for manual analysis of regions by a program function that allowed "shapes" to be drawn over the downloaded scanned image. These shapes calculated multiple scanned points producing average readings of the concentration of each element. Overall element distribution was determined by taking a "traverse outline" perpendicular to the edge of the image, marking the outer surface of the cementum and drawn for maximum coverage of the scan. Element concentration in dentine was assessed using the "circle" function to cover

the region, whilst for cementum the "box" function was used to overlie as much of this structure as possible, thereby improving the counting statistics. Information generated from this Program's functions included average concentrations of 500 plus readings per extracted region drawn and minimum detection limits (MDL) for the presence of elements. This was repeated for each slice generated from both the x-ray (PIXE) and gamma ray (PIGE) scans. In addition to the quantitative data, the information was also used to process Spectral (elemental) Graphs and Picture Plots. Spectral graphs are traverse concentration profiles of each element, showing the pattern of distribution through the tooth structure. Picture Plots are qualitative representations (maps) of relative concentrations, distributed across the scanned region, for each element.

5.3.5 Statistical Analysis

In addition to the analysis generated by the Geo-PIXE II™ 3.8 Computer Program,[22] differences between the overall dentine and cementum of heavy, light and control groups were further tested statistically.

An analysis of variance (ANOVA) was conducted for each element of interest (F, Mg, Na, Ca, Fe, Zn and Sr) using the following factors: force (control, heavy, light), surface (buccal, lingual), height (apical, middle, cementoenamel junction (CEJ)) and type (cementum, dentine). In each case

the accuracy of each of the multiple readings, done by the Geo-PIXE II™ software, of which the averages contribute toward a single value at a particular point that the machine measures, is assumed for statistical purposes. MINITAB® Version 14 statistical program was used. Bonferroni adjustments were conducted where appropriate. A p-value of less than 0.01 was taken to indicate statistical significance. P-values of less than 0.05 were considered marginally significant.

In addition, z-scores were calculated using the mean overall concentrations and their standard deviations for the purposes of making comparisons between heavy/light, heavy/heavy-control and light/light-control. This was done using the Excel (Microsoft® Office 2000) software program. The concentrations were considered equivalent to population-values, as there were over 500 measurements at each point. A p-value of less than 0.01 was taken to indicate statistical significance.

5.4 Results

1. Fluorine

Overall fluorine concentration ranged from 10149 ppm to 97184 ppm in the cementum. In the dentine the levels ranged from 2165 ppm to 19063 ppm. Fluorine followed the same trend in all teeth sampled its greatest concentration at the superficial cementum surface, then dropping sharply to lower levels in the dentine, towards the pulp (Spectral Graphs in Figures 3 to 9). Overall, fluorine was found to be significantly higher in the cementum compared to dentine ($p<0.01$) (Figure 10).

There was only a marginally significant difference overall between buccal/lingual surfaces ($p<0.05$). However, the samples did demonstrate individual differences. The heavy force group on the buccal had the highest cementum fluorine concentration at the apex and least at the CEJ – 94331 ppm to 67107 ppm (Table 1). The dentine on this side also demonstrated a decreasing trend, with the apex having the highest (4529 ppm) and the CEJ having the lowest (2604 ppm) concentrations (Table 2). In contrast, the lingual surface had a peak concentration in its middle third for both the cementum and dentine (78227 ppm and 2416 ppm, respectively).

In the cementum of the light force sample there was a low fluorine concentration lingually at the CEJ (43353 ppm) and a high value apically (55104 ppm), following the trend of the heavy force sample (Table 3). However, in contrast the buccal apical cementum had a lower concentration (7730 ppm) compared to the CEJ (52182 ppm). This was not seen in the dentine which followed the trend of the heavy force sample, generally having an increasing concentration from coronal to apical (Table 4).

The control teeth had marked individual variation, most strikingly in the apical dentine. There was a higher concentration in the light force control (lingual 19063 ppm and buccal 17243 ppm) and much less in the heavy force control (lingual 2982 ppm and buccal 3402 ppm) (Table 2 and 4). The heavy sample control had higher apical fluorine compared to the CEJ, but peaked in the middle cementum on the lingual side (93632 ppm). This was not reflected in the underlying dentine, which had its lowest lingual dentine concentration in the middle third (2873 ppm). A low concentration in the middle cementum was also present on the buccal side (2493 ppm).

The light force control also demonstrated the same trend as all the other samples of having higher apical and coronal values for both cementum and dentine. Once again, the middle third revealed concentrations,

which were in contradistinction to the establishing trends. The middle cementum on the buccal side had a concentration of 82290 ppm, following the reducing gradient from apical to CEJ regions (apical 93135 and CEJ 80675 ppm). Dentine on both surfaces also followed the high to low, apical-coronal, trend.

Comparison of teeth exposed to the orthodontic force compared to the controls revealed significant differences. Overall fluorine concentration was greatest for the control groups (42300 ppm), followed by heavy (38400 ppm) and the light force (2600 ppm) samples ($p<0.01$).

When the heavy force sample was compared to its contralateral tooth control the greatest differential was found in the buccal mid-third cementum (z-difference –39.25, $p=0.00$). Other noticeable differences included a reduced mineral concentration in the heavy force group at the buccal cervical cementum and the lingual apical cementum when compared to the control ($p=0.00$). Similar to the comparison between light and heavy forces, the heavy compared to its control demonstrated least difference in the lingual CEJ dentine (z-difference 0.89, $p=0.19$) and the lingual mid-third dentine (z-difference 1.85, $p=0.03$).

The light force sample contrasted its contralateral tooth control and the largest difference (z-score –80.37) was in the lingual middle-third

cementum ($p = 0.00$). The least difference was at the lingual mid-third dentine (z-difference 1.85, $p=0.03$). This was also seen when comparing the heavy group and its control.

Therefore, in general the fluorine distribution peaked in the cementum and declined sharply to a low consistent level through the dentine. There were high fluorine readings apically and at the CEJ. Mixed readings were measured for the middle areas.

There was a significant difference in fluorine concentration for light, heavy and control groups. Both heavy and light forces having reduced fluorine. Light force having the lowest concentration compared with the controls.

2. Magnesium

Overall the magnesium concentration in cementum ranged from 1795 ppm to 180 ppm (Table 1 and 3). For dentine its highest value was 2486 ppm and lowest was 521 ppm (Table 2 and 4). Spectral distributions showed a general trend of gradual increase in magnesium concentration from the outer surface, increasing toward the pulp. It is also notable that a marked rise occurred at the cemento-dentinal junction. This then marked a point where the concentration began to fluctuate markedly (Figures 3 to 9).

Magnesium demonstrated marginally significant differences between the apical, middle and cervical regions of the teeth (p=0.04) (Figure 11). However, in general the majority of areas on the teeth exposed to force showed insignificant differences with their contralateral controls. The heavy sample showed similarity with its control at the lingual cervical and middle, dentine and cementum regions ($p>0.05$). Both the heavy and the light group and their respective controls did not have significant difference at the buccal cervical cementum.

Therefore, the majority of comparisons demonstrated insignificant or only marginal significance between the groups.

3. Sodium

Sodium in cementum ranged from a low of 4613 ppm to 16889 ppm. In the dentine a concentration of 8271 ppm to 20636 ppm was noted (Tables 1 to 4). The spectral graphs showed that low concentrations were found in the cementum. This was followed by a gradual increase, then a plateau in the dentine, which was maintained. Higher concentrations were noted away from the superficial surfaces, in dentine. Compared to the other trace elements, sodium demonstrated more consistent trends (Figures 3 to 9).

Going from apical to coronal, the majority of surfaces examined had a sodium concentration that peaked in the middle-third of the tooth. This low-high-low trend from apical-middle-CEJ, respectively, occurred in all but the cementum in the lingual of the light and heavy force controls, and in the dentine of the heavy force control.

Comparison between the groups demonstrated significant differences in sodium concentration of the cementum (8400 ppm) and dentine (13500 ppm) ($p<0.001$) (Figure 12). Furthermore, the mid-third of the teeth had higher concentrations compared to the apex and cervical regions ($p<0.001$). There was a marginally significant difference between control/heavy/light force groups ($p=0.04$).

4. Calcium

Generally calcium concentration rose in the cementum and steadied, often with a slight drop at the dentine-cementum junction heading toward the pulp. However, in the apical spectral plots it is evident that the increase in concentration of cementum is more gradual (Figure 13). The concentration range of cementum calcium was 12.4% to 41.4%. For dentine the range was 26.2% to 45.1% (Tables 1 to 4).

Overall calcium was significantly higher in the dentine (34.0%) compared with the cementum (21.5%) ($p<0.001$). There was a

marginally significant difference between the apical/middle/cervical regions (p=0.011) (Figure 14). There were no significant differences found between controls/heavy/light forces.

Higher values were noted in the CEJ regions compared to the apex, although the majority of differences were minor. Most surfaces showed a peak concentration at the CEJ and a gradual reduction to the middle then apical thirds. The exceptions were the lingual of the heavy control and the lingual cementum of the light force and light control groups, which had a reduced concentration in the middle-thirds. In direct contrast, the lingual cementum of the heavy force, the buccal surface of the light force and the dentine of the light force control on both surfaces had slightly higher concentrations of calcium in their middle thirds (Tables 1 to 4).

When comparing the samples to each other most of the differences were insignificant. Therefore, calcium was relatively similar for all parts of the tooth and between samples, except for increased variability towards the apex.

5. Iron

Iron was not present in the cementum above the detection limit in some cases (Tables 1 to 4). There was marked individual variability in the

presence of iron. Although cementum demonstrated significantly higher concentrations compared with dentine ($p<0.001$) (Figure 15).

6. Zinc

Zinc followed a similar trend in all samples. That is, there was a peak in the cementum followed by fall in the dentine. The only exception was the more gradual decline towards the pulp in the apical regions. Comparison of cementum and dentine demonstrated a significant difference ($p<0.001$). The range of zinc varied in the cementum from 515 ppm to 1157 ppm, in the dentine the range was 49 ppm to 860 ppm (Table 1 to 4).

A high concentration at the apex compared to the CEJ was the most common trend found in all samples. This was significantly different when comparing middle and cervical regions ($p<0.01$) (Figure 16). The opposite (low concentration at the apex) was only seen in the buccal control light force cementum (Table 3).

Therefore, a generalised trend was observed for a high to low gradient for zinc concentration superficially to deeper surfaces and apically towards the crown of the tooth.

When comparing force and controls a significant difference was noted ($p=0.002$) with light and heavy forces having reduced concentrations. Zinc concentrations were lower in the light force group compared to heavy force group.

7. Strontium

Strontium followed a distribution across the cementum and through the dentine similar to that of zinc – peak concentration in cementum followed by a decline to a low level in the dentine (Spectral Plots Figure 13).

The concentration of strontium comparing buccal and lingual surfaces showed a tendency for the buccal surface to have a lower concentration. There was a general trend of higher strontium in cementum compared to dentine, but this was not significant.

Overall, there was a marginally significant difference between control/heavy/light force groups ($p=0.02$) (Figure 17). The force groups having reduced concentrations of strontium compared to the controls. With consideration to apical and coronal concentrations, the heavy and light force cementum groups were in contradistinction. Light force had low lingual apical concentrations whilst the buccal contralateral surface had a higher concentration compared to the cervical regions. This was

opposite for heavy force. However, the dentine of these groups was in agreement – reduced buccal apical concentrations (Table 1 and 4). Also in agreement were the high apical concentrations between cementum of the heavy and light control groups.

8. Comparison of elements

All the samples had individual variations in concentrations of all elements. The overall mineral distributions were similar for zinc and strontium. This is seen in the spectral graphs, where the pattern of a rise in cementum followed by a fall to low levels towards the pulp, are almost identical (see spectral plots in Figure 13). In contrast, sodium had higher concentrations in the deeper layers. Magnesium also had high concentrations away from the superficial surface – the concentration was maximal at the cementodentinal junction. Fluorine had its highest concentrations on the outer cementum (Figures 3 to 9).

In summary, there was an overall significant reduction of fluorine and zinc, with a marginally significant reduction of strontium, when comparing force groups with controls ($p<0.01$). However, there were no consistent site-specific areas of reduced concentrations.

5.5 Discussion

1. Fluorine

Previous studies have generally reported fluorine levels ranging from 0.15-0.9% wt.[4,9] These studies used ash weight which would actually correspond to even lower values when converted to dry weight.[27] Nevertheless higher values have been reported with fluorine levels reaching 90000 ppm in the cementum.[27] In the present study, fluorine ranged from 10149 ppm to 97184 ppm in the cementum. Factors that may have contributed to the higher fluorine levels observed include increased sensitivity of the detection method and the regions analysed.

With typical proton energies of 3 MeV, the NMP is particularly sensitive to lighter elements such as fluorine which have pronounced gamma ray yields at these energies.[22] Thus it may be reasonable to expect higher levels would be recorded compared to previous studies, especially studies that used techniques requiring bulk dissolution and destruction of samples.[28]

Another factor contributing to the higher levels is that only a superficial area of 800 x 800 μm was analysed. It has been consistently reported that fluorine is present in higher concentrations towards the outer cementum.[12]

Recording of occasional high values towards the apex, not only in the cementum but also in the dentine, may be due to microprobe machine limitations. Analysing a non-uniform structure means that as the sample thins down, for example at a tooth's apex, the proton beam – which penetrates 60 μm into the sample – may reach the opposing surface (Figure 18). In teeth this means that the results could be skewed towards higher values where dentine readings may include minerals present in underlying cementum. However, in general the results reflect previous studies[12,13] which indicate a trend towards greater fluorine on the buccal cervical parts of the root surface.

In terms of elemental content alteration as a result of teeth being exposed to orthodontic forces, there was a tendency for reduced fluorine concentration when comparing heavy force and its control, in areas of compression – buccal-cervical and apical-lingual areas. This was anticipated by a previous study but not demonstrated.[13] However, no definitive picture emerged in the present study. Even though a significant difference was found between the groups overall (controls having the highest fluorine concentrations), which may reflect a demineralisation process, when specific regions of the teeth were examined no consistent trends emerged. This is supported by Rex et al[13] where no significant difference in fluorine concentration was found when comparing heavy and light force groups to their controls. This

finding was rationalised by the belief that fluorine does not play an important role in the phenomenon of tooth movement and that there are large inter-individual variations in fluorine content.

An alternate explanation for this lack of a distinct mineral pattern is that fluorine remineralises rapidly. Enamel remineralization occurs within one hour from the microcirculation,[29] this may be extrapolated to cementum. Furthermore, fluorine can also re-incorporate into tooth structure without leaving the microenvironment of the remodeling unit.[30]

2. Magnesium

Overall trends supported previously published work suggesting the concentration of magnesium is lower at the surface compared to deeper layers.[5,27] Values reported ranged from 5000 ppm to 9000 ppm,[27] to higher values of 13000 ppm to 14000 ppm in an electron microprobe analysis.[7] The present study found concentrations in dentine of 521 ppm to 2486 ppm, whilst in the cementum values were lower and ranged from 180 ppm to 1795 ppm.

Peak concentrations of magnesium increased from the CEJ to the middle-third, however more often there was a decline at the apex. However, overall these trends were marginally significant. Previous studies demonstrate a concentration gradient which increases from the

cervical region to apex.[4] An explanation is that this may be due to the NMP gamma-ray penetration – at the apical end of the tooth the beam would possibly include a greater amount of cementum, beyond the dentine. It could be anticipated that if it were possible to limit the NMP beam depth to record dentine only, the concentration of magnesium at the apex would have been consistently higher.

Magnesium is present in the hydroxyapatite crystal lattice. It has been suggested that this element could be important in contributing to cementum mineralisation and may play a role in controlling the growth of hydroxyapatite crystals.[7] Like previous work magnesium was found to be present in similar concentrations to calcium.[3] In contrast, to reports that fluoride concentration is inversely proportional to magnesium[8] no such clear relationship was seen in this study.

In terms of the effect of force, when both the light and heavy force groups were compared to their controls, the main differences noted were in the lingual apical regions. Arguments have been put forward in support of anticipated alteration in mineral content with orthodontic force. These include changes in the microenvironment which result from the cell mediated response to force. The inflammatory process involved in tooth movement results in the local drop in pH level, which could lead to dissolution of mineral content of the tooth root surface.[14,15] The

cell mediated response results in increased activity of osteoclasts whilst inhibiting osteoblasts.[16] This mechanism may have a similar effect on odontoclasts and odontoblasts.[13] However, it should be noted that the differences in magnesium seen in the present study, between the groups exposed to force and the controls, were relatively small. Furthermore, when the groups were analysed there was no significant difference in magnesium concentration between force levels and controls.

3. Sodium

Sodium has been reported to be present at 0.3%.[5] Electron microprobe analysis has reported higher sodium at concentrations of 0.8%.[7] This is comparable to the present findings.

This study showed there were significantly higher sodium concentrations in the middle-third of the teeth and in the cementum. The finding that both sodium and fluorine are present in high concentrations in the cementum could have implications for root resorption. Sodium fluoride (0. 5 to 1.0 mM) has been shown to reduce resorption lacunae and resorption areas of osteoclasts.[30]

4. Calcium

The concentration of calcium demonstrated can be related to previous studies. Calcium has been reported to range from 24.0% to 29.24% dry weight as a mean total.[6,31,32] Percentage ash ranges from 35.6% to 42.4%.[4] The mean percentage weight concentration has been shown to vary between root and region of root surface – buccal-cervical 30.05%, buccal-middle 28.63%, buccal-apical 27.16%, lingual-cervical 29.69%, lingual-middle 28.90% and lingual apical 26.96%.[23]

However, another study, which used electron microprobe analysis, reported very different results.[7] A calcium/phosphate ratio of 1.8-2.2% was recorded at the cemento-enamel junction, 1.65% at the coronal third, 1.3% at the furcation and 1.65-1.3% apically. Study design issues may limit the value of these figures. In particular, impacted third molars were used. The preparation of these teeth involved root scaling to remove the periodontal ligament, which may have damaged the cementum. Furthermore these samples were not sectioned. Failure to provide a flat surface from which to project x-ray beams can result in significant background scatter[33] and thus would influence the results.

This present study demonstrated that calcium was relatively similar for all parts of the tooth and between samples. There was, however, a trend towards a decreasing concentration towards the apex, which was

marginally significant. These findings are in agreement with Rex and co-workers, who demonstrated calcium and phosphate concentrations were the same buccally and lingually.[13] Whilst the concentration cervical to apical decreased, the converse was found for the outer to inner surface, which demonstrated an increasing gradient from the cervical to middle third. An explanation given for a higher concentration at the cervical cementum was that this might be due to environmental exposure via the oral cavity.[34] This is supported by findings which suggest there is an increase of calcium and phosphate at the cervical cementum with age.[31] Therefore this study and the present study do not fully support previous reports, using various analytical techniques, where calcium has been shown to be distributed with no significant difference along the root surface.[4,6,31]

Even though differences were noted between experimental groups exposed to force compared to their controls, many of the differences were insignificant ($p>0.05$). A previous study suggests a relationship between force and reduced calcium concentration.[13] Such assumptions are based on the premise that orthodontic treatment induces a state of hypocalcaemia.[13] Furthermore, that cementum participates in calcium and phosphate homeostasis, which leads to the expectation of a reduction in calcium and phosphate with increased orthodontic force as it is supposedly mobilized from cementum.

However, the inability to produce unequivocal evidence to support these assumptions can be rationalised because even though cementum is sometimes referred to as "bone-like" there are marked differences. Bone tissue actively participates in the physiological exchange of elements. In contrast, cementum is mostly excluded from such metabolic processes.[3] Therefore, lack of notable mineral change is a finding, which can be supported with more evidence than the converse. This study has not demonstrated clear mineral changes with force, using a technique which records in high detail and is in agreement that cementum is actually a unique hard tissue of the body, which although is a participant in its local environment is overall somewhat resistant to relative alterations in its major elements.

5. Iron

Iron was present in small amounts, and in some areas below the detection limits. No consistent findings for this element were elucidated. Although overall more iron was found in cementum compared with dentine.

6. Zinc

The present study showed a peak zinc concentration in cementum followed by a drop in dentine. There was an increased concentration

towards the apex. This follows the observation during tooth development that most zinc is deposited prior to tooth eruption and is concentrated at the cementum surface and pulpal surface.[29] Zinc rapidly localises in newly deposited matrix in enamel.[35]

The presence of a higher concentration of zinc in cementum may be important in relation to the dynamic processes that affect the tooth root. Modulation of osteoclastic resorption of bone and dental tissue in the presence of zinc has been examined.[36] It was established that the lacunae developed on tooth cementum, in the presence of extracellular zinc, were fewer in number and had smaller surface areas. The teeth exposed to force had a significantly reduced concentration of zinc. A reduction in zinc may therefore imply an increased susceptibility to the resorptive process.

7. Strontium

Strontium, zinc and fluorine demonstrated similar trends. This supports the observation that these elements are adsorbed in a similar manner.[37] However, strontium was not significantly increased in cementum. Therapeutically, the dental profession has used their combined effects.[38] Strontium is used in desensitisation products, in order to occlude dentine tubules.[11] There is conflicting evidence of the effect strontium has on

cementum solubility. An increased presence of strontium has been shown to increase cementum and enamel solubility.[38,39] However, it has also been shown to decrease solubility when administered in the presence of fluoride.[37] Hydroxyapatite can reduce in solubility by up to 50%.[39]

Like zinc, strontium is another element which has been related to reducing bone resorption.[40] Strontium did demonstrate marginally significant differences between control and force groups. However, implications of this to root resorption have not been clearly demonstrated in relation to OIIRR.

8. Overall

The general patterns of elemental distribution observed in this study support the findings previous studies. Although, the elements studied demonstrated a larger range and in all cases reported higher concentrations than previous findings, most notably fluorine. There was consistency in terms of general trends, especially at deeper levels of the tooth. However, differences were noted and there was marked individual variation. This supports previous descriptions of cementum.[3] Where comparisons were drawn using absolute mean values between changes at different regions of the teeth exposed to orthodontic force and controls no clear picture emerged.

Even if tooth movement did alter the cementum mineral interface, it could be assumed that any loss of elements would see its re-incorporation rapidly from the microenvironment.[30] Thus the marked differences in concentration values may not so much reflect changes, due to altered environment, but could possibility be due to individual variations in cementum mineralisation. The only elements to show significant overall differences with force were fluorine and zinc, also strontium which demonstrated marginal significance. Both the light and heavy force groups having reduced concentrations compared to the controls. These elements have been associated with reducing the solubility of tooth structure and/or affecting the resorption as a result of osteoclastic activity.[36,40,41] This may imply that the presence of these surface elements may impart a protective mechanism to the tooth, and that their subsequent reduction in concentration with orthodontic force decreases this potential. Interestingly, the light force group had greater reduction in concentrations of fluorine and zinc compared to the heavy force group, but this is probably due to the heavy force teeth having a greater concentration of these elements to begin with (as seen with their contralateral control), rather than a reflection of a resorptive process.

Despite reduction in concentrations of some elements, overall trends remained the same as for teeth not exposed to orthodontic force.

Previously it had been concluded that there was a reduction in calcium following heavy force.[13] The present study could not demonstrate clear and unequivocal findings of cementum alterations with tooth movement in specific areas on the tooth's surface. If element concentration was to decline, it may be expected in areas of compression where most root resorption has been shown to occur.[42] In contrast, the previous study examining the relationship between force and mineral concentration, found a reduction at the tooth surfaces in areas of anticipated tension.[13] Neither could be supported with the results of the present study.

In contrast to bone, cementum is mostly excluded from physiologic metabolic processes.[3] This may be attributable to the specific non-collagenous proteins unique to cementum. In particular, the protein which mediates the attachment of connective tissue cells differs from bone sialoprotein and osteopontin.[43] In addition, is the presence of cementum-derived growth factor.[44] Following root resorption, these proteins may be exposed and could possibly influence the initiation of the repair process.[3] The minerals in the circulating tissue can react with cementum. Particularly fluoride ions which react aggressively with hydroxyapatite.[3] In contrast, the opposing alveolar bone is constantly remodelled and thus does not accumulate such minerals to the same extent as cementum.

When the root surface is breached, repair matrices become attached to the resorbed surface.[45] Following the detachment of odontoclasts the cementogenic cells re-populate. Within their lacunae they initiate the attachment of the repair matrix to the thin decalcified layer of remaining collagen fibrils. The new matrix and original collagen fibrils then integrate. These repair cells and tissue matrices are homologous to the original root structure. This is followed by electron-dense globular accumulations indicating re-mineralisation. These events reflect those which occur during tooth root development.[3]

Damage and subsequent repair to the mineral structure, in the form of dissolution of crystallite, also occurs. However, this process is usually countered by remineralisation. A dynamic exchange of minerals occurs superficially and this limits the extent of more minor resorptive defects. Subjacent unaffected tissue provides a reservoir for diffuse transition of elements.[3]

Even though an orthodontic force initiates bone remodeling[46] these processes do not seem to impact cementum in the same manner. Therefore, although cementum is dynamic it possesses unique features, which under certain circumstances may resist environmental stresses. This may explain the lack of definitive site-specific alterations of mineral distribution with orthodontic force seen in this study.

A limitation of this study is that spot analyses were recorded. This meant only selective regions of the tooth root were scanned. Also, there were few samples included in the study. This was due to time and funding constraints. However, the present study has developed a methodology, which may form the basis of future studies examining elements in cementum utilising the same technology.

5.6 Conclusions

1. NMP technique was able to study cementum and dentine of the tooth root. Elements detectable were F, Mg, Na, Ca, Fe, Zn, Sr.
2. The distribution trends for these elements support those of previous studies.
3. There was marked inter-individual variation for absolute mineral concentrations.
4. Heavy (250 g) and light (25 g) orthodontic force did not appear to alter the pattern of elemental distribution across the tooth root.
5. However, overall concentrations of fluorine and zinc were significantly reduced, which may have implications for the susceptibility of the teeth to OIIRR.

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5.8 Figures

Figure 1: Intraoral view of experimental side. Force application using SPEED brackets (Strite Industries, Canada) and orthodontic wire (*courtesy of MA Darendeliler*).

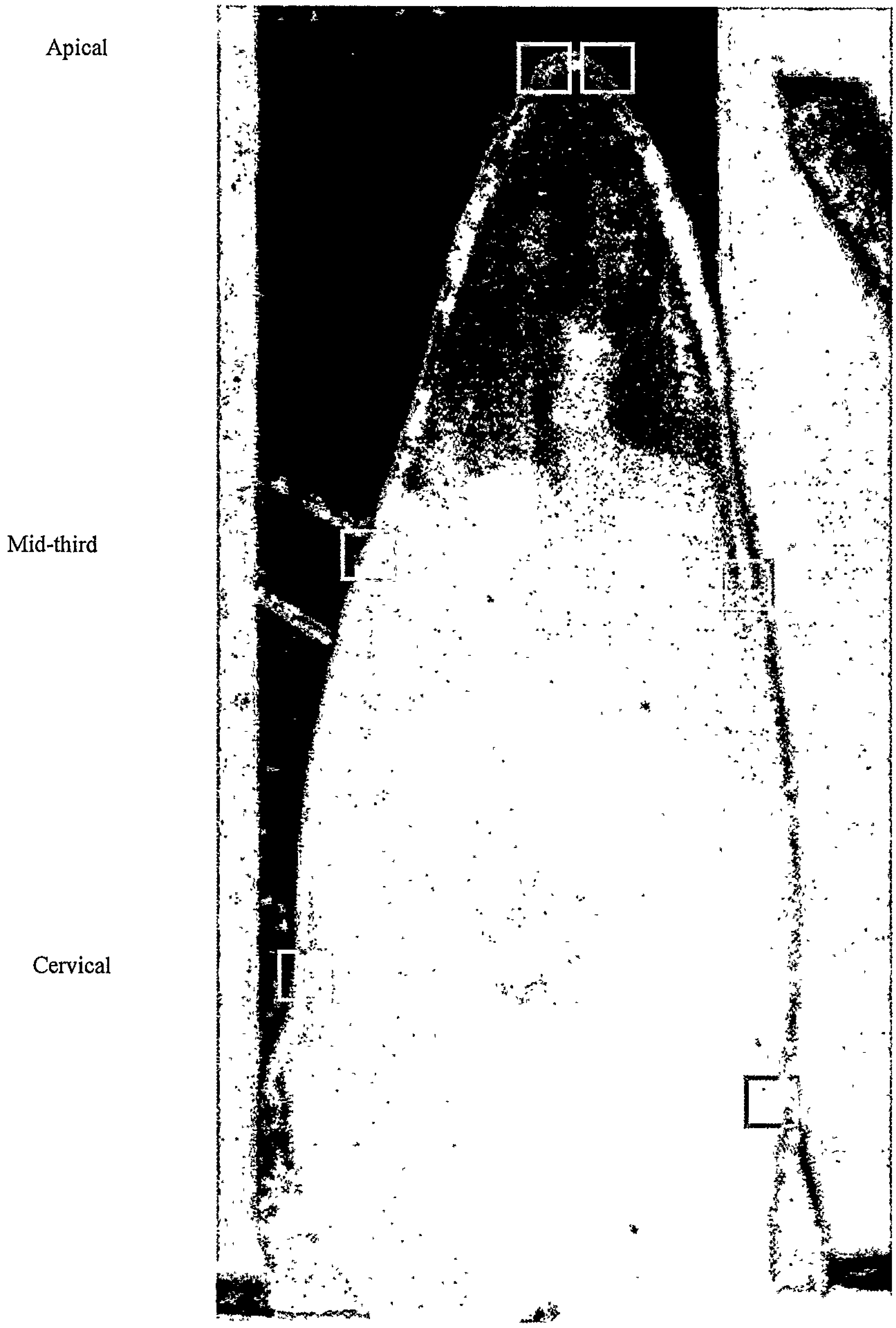

Figure 2: Longitudinal-section of human tooth sample, with illustrative representation of scanning areas.

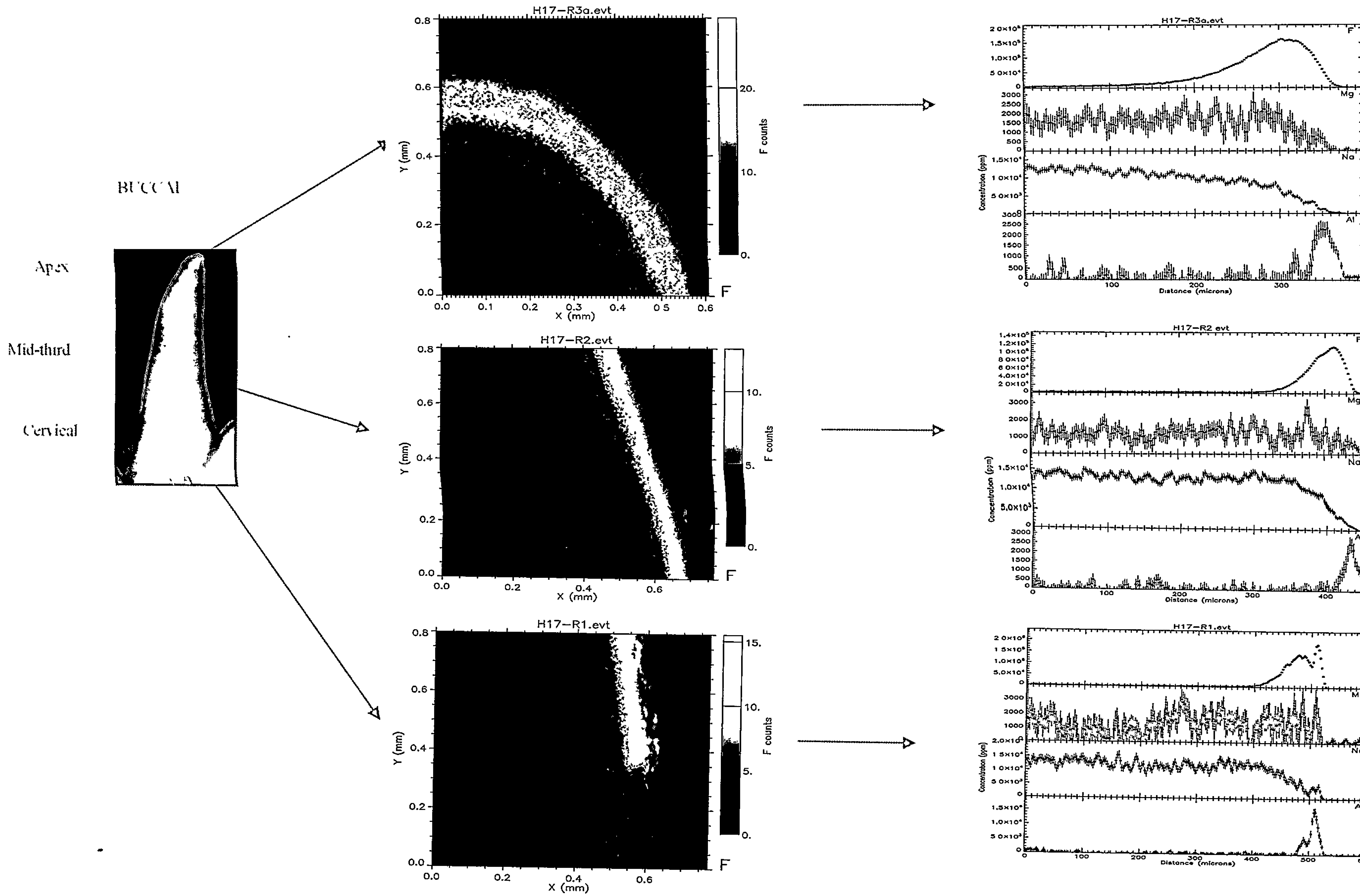

Figure 3: Heavy Force Sample (H17) buccal surface for fluorine (ppm). Picture Plots and Spectral Graphs (left to right equivalent to distance from pulp to cementum) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

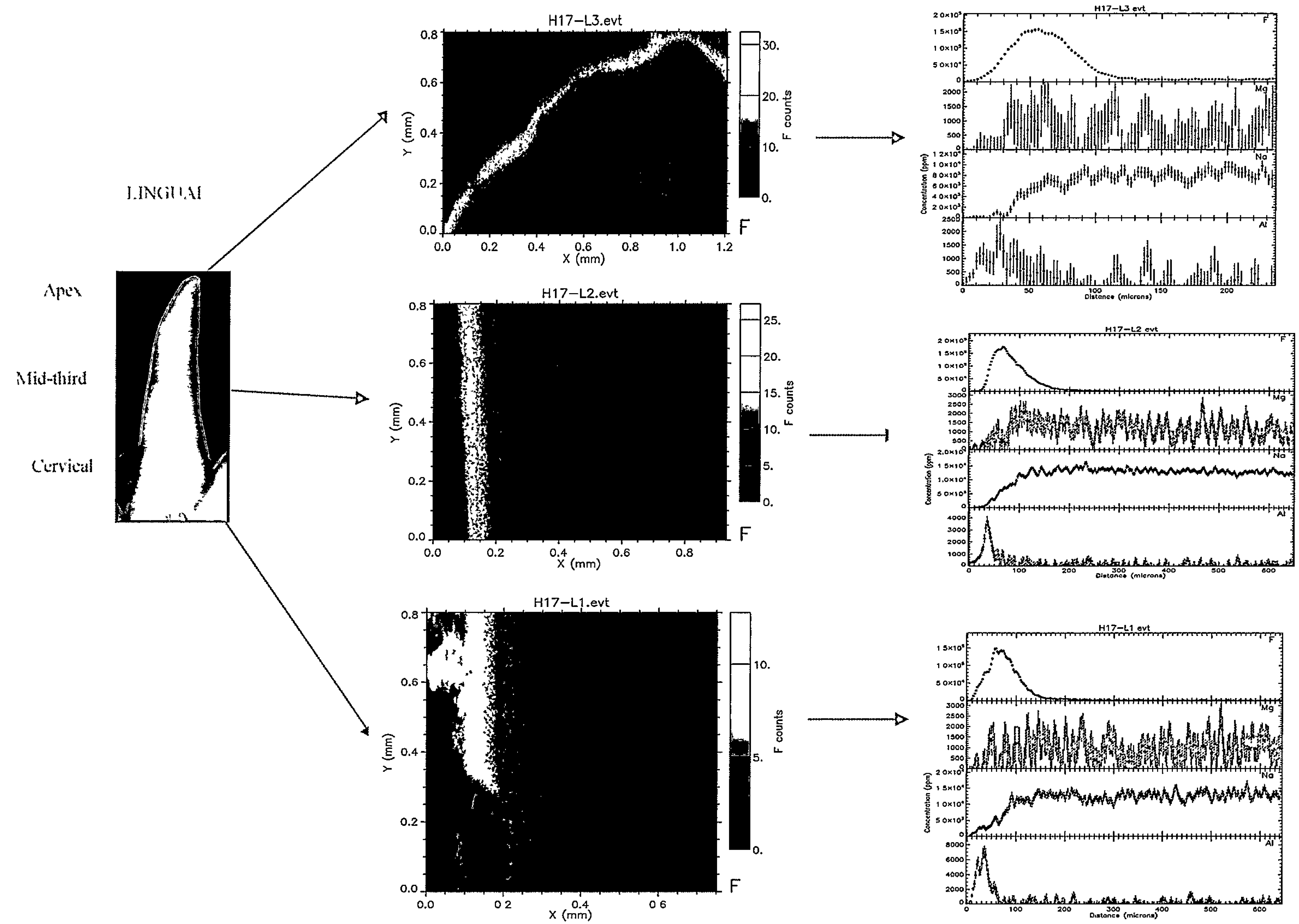

Figure 4: Heavy Force Sample (H17) lingual surface for fluorine (ppm). Picture Plots and Spectral Graphs (left to right equivalent to distance from cementum to pulp) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

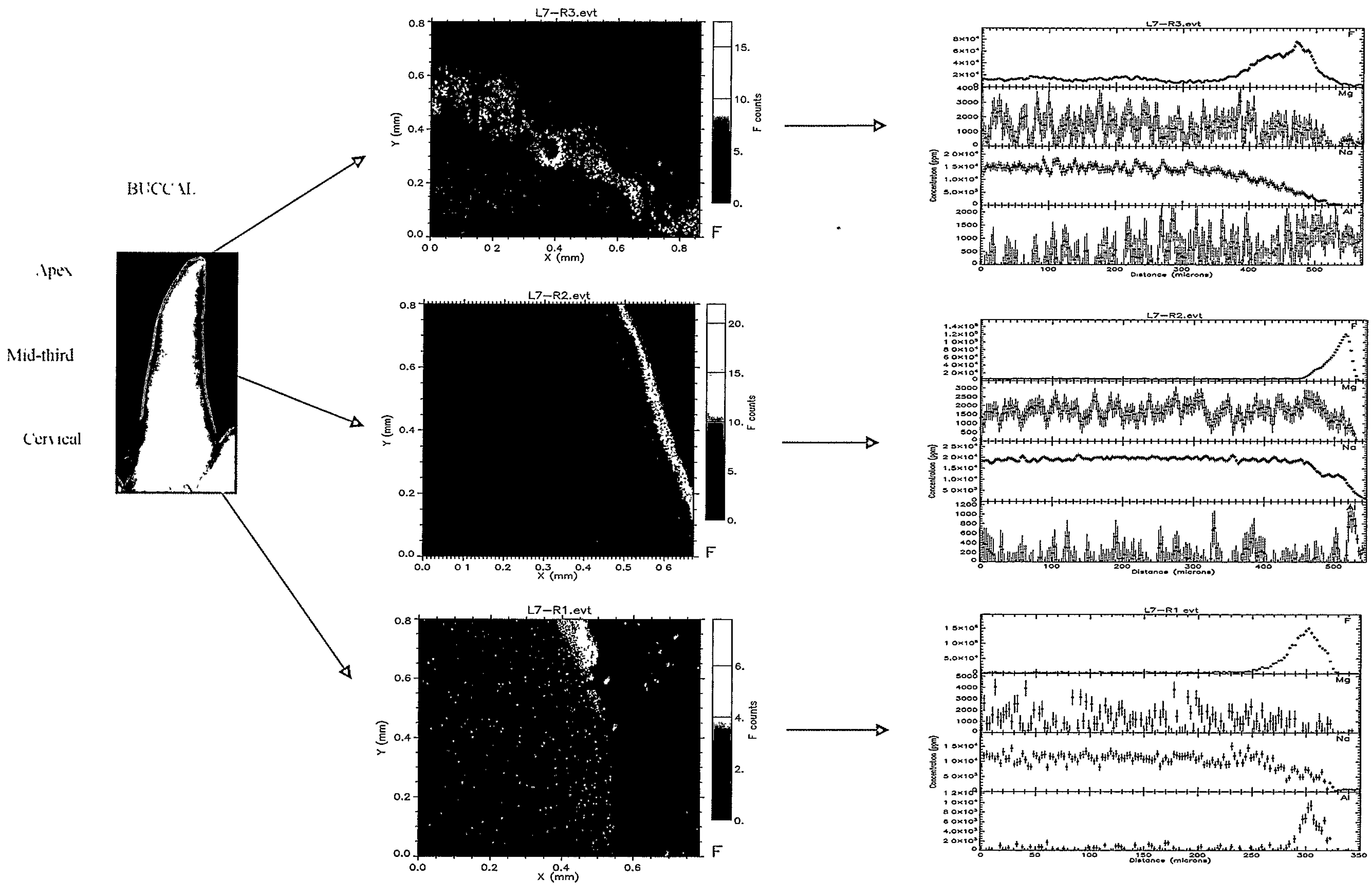

Figure 5: Light Force Sample (L7) buccal for fluorine. Picture Plots and Spectral Graphs (left to right equivalent to distance from pulp to cementum) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

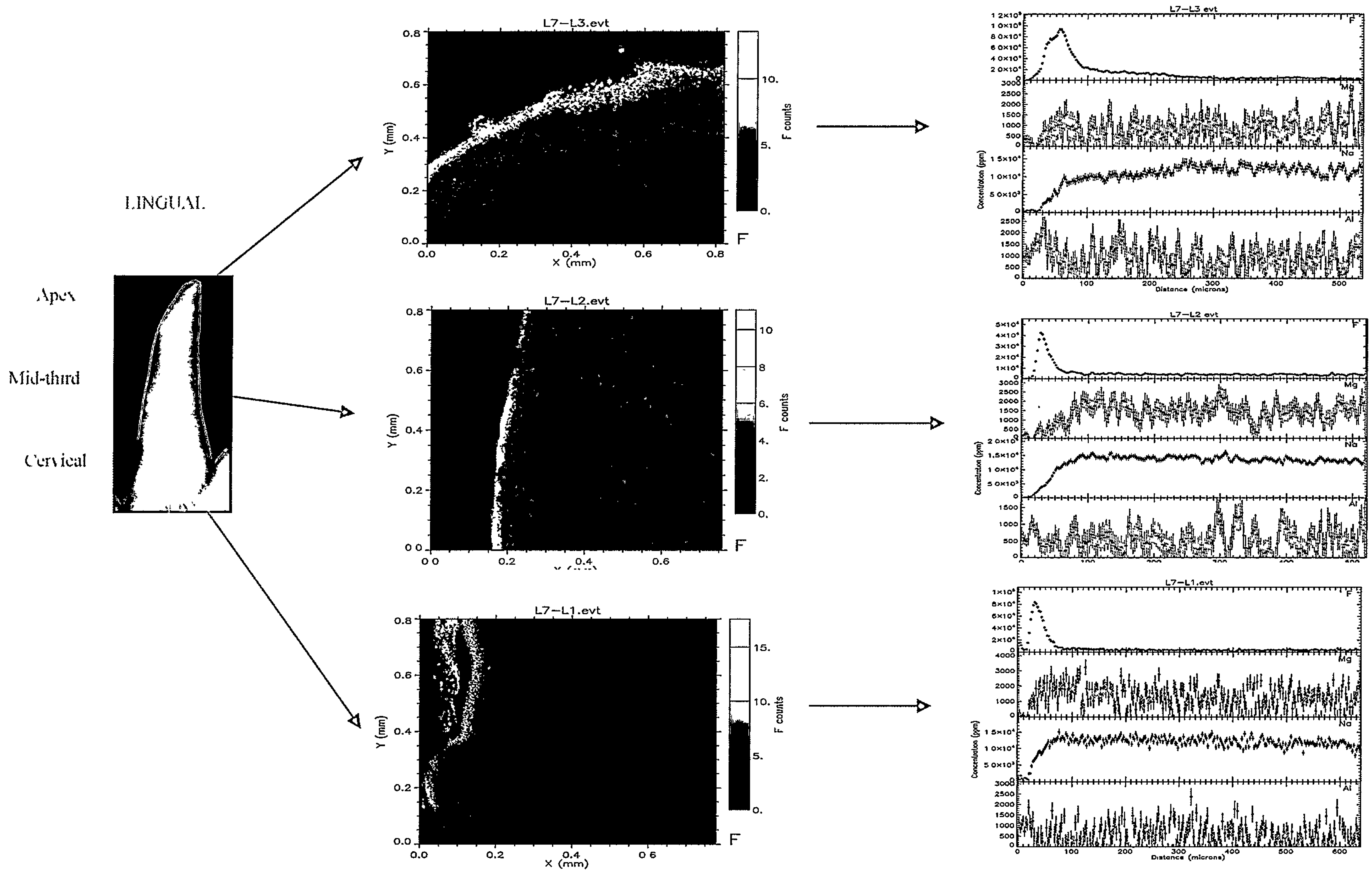

Figure 6: Light Force Sample (L7) lingual for fluorine. Picture Plots and Spectral Graphs (left to right equivalent to distance from cementum to pulp) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

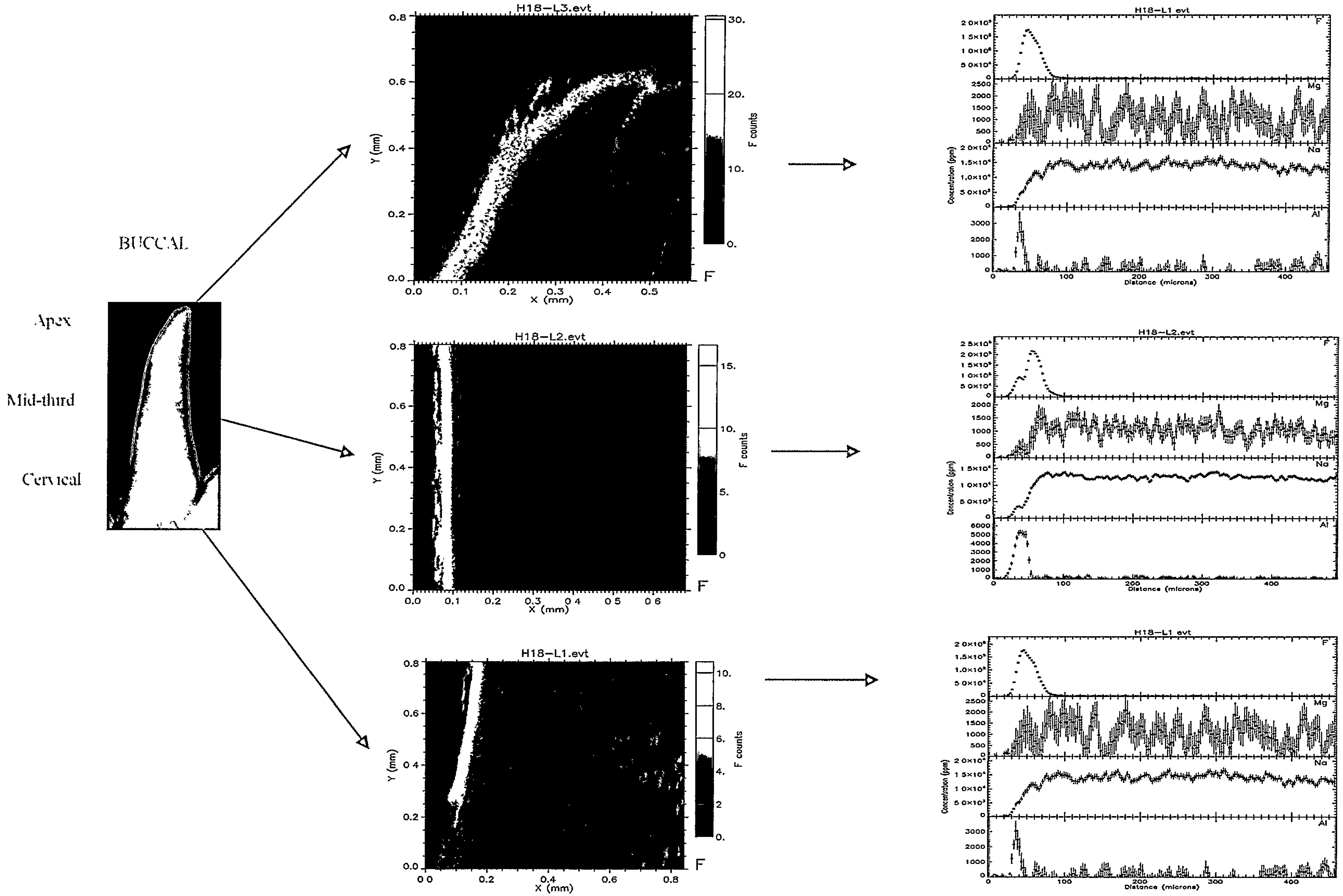

Figure 7: Control heavy force sample (H18) buccal for fluorine. Picture Plots and Spectral Graphs (left to right equivalent to distance from cementum to pulp) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

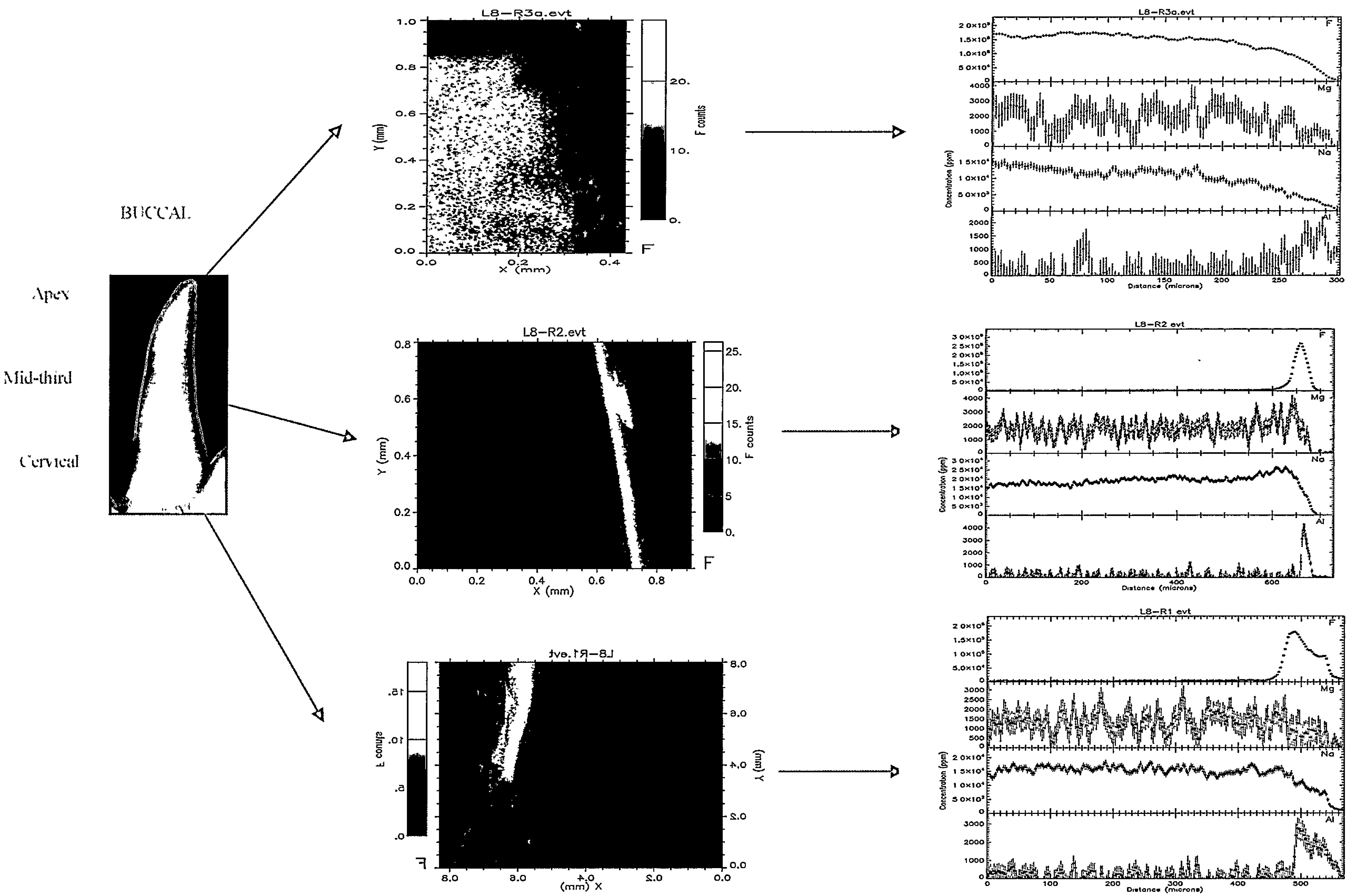

Figure 8: Control light force sample (L8) buccal for fluorine. Picture Plots and Spectral Graphs (left to right equivalent to distance from pulp to cementum) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

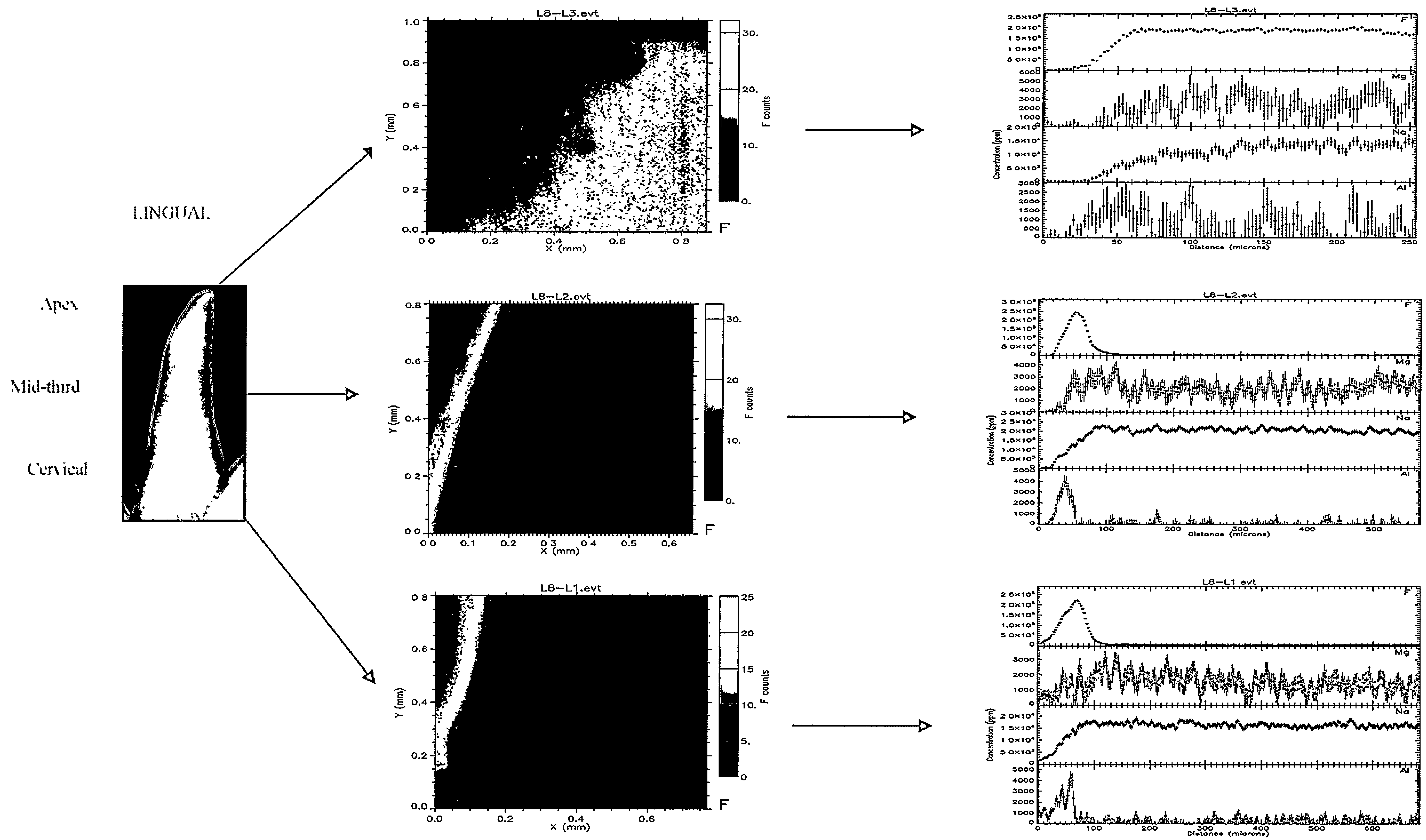

Figure 9: Control light force sample (L8) lingual for fluorine. Picture Plots and Spectral Graphs (left to right equivalent to distance from cementum to pulp) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

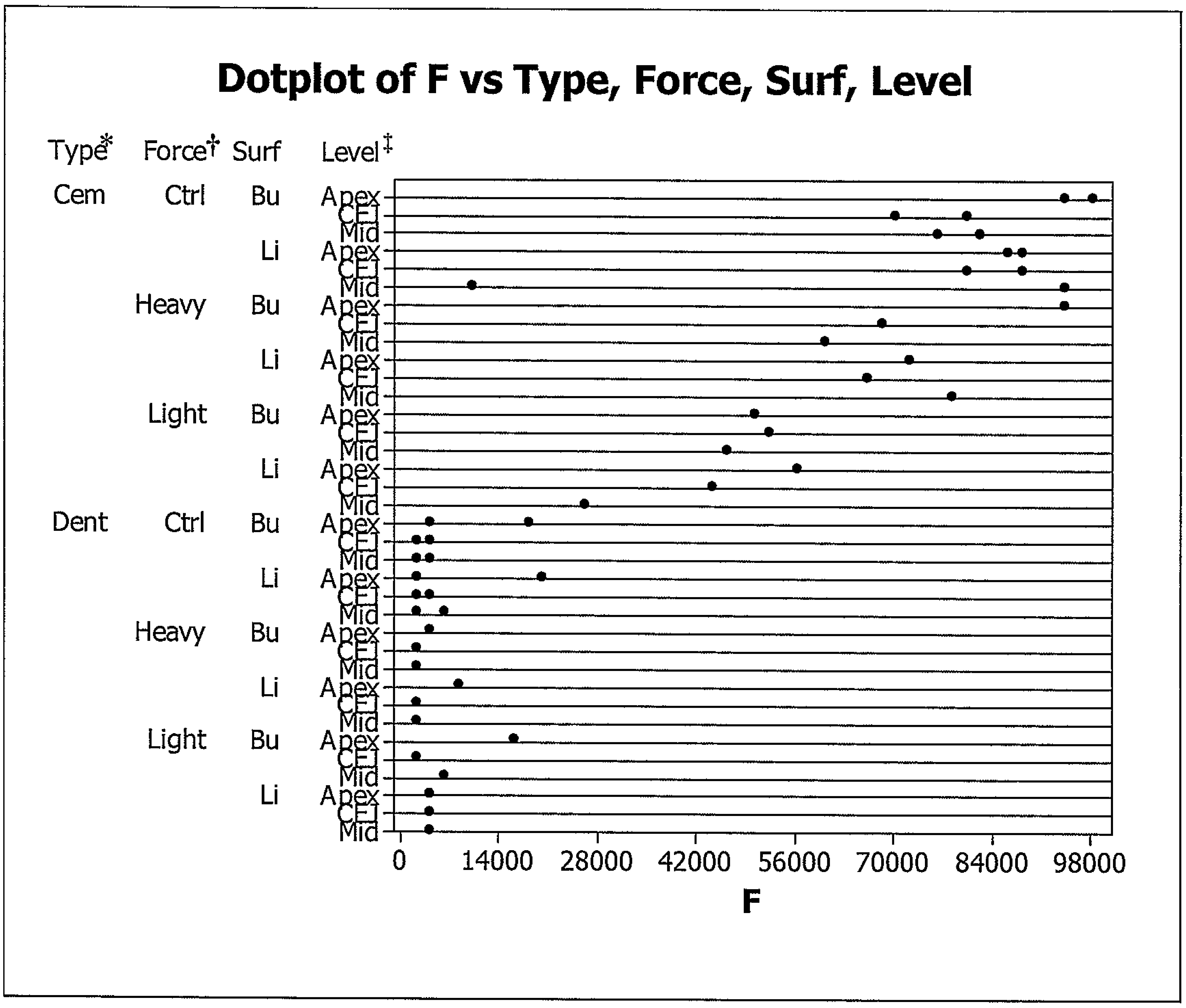

Figure 10: Fluorine concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).

* p<0.001. Cementum 6400 ppm. Dentine 3700 ppm.

† p=0.009. Control 42300 ppm. Heavy Force 38400 ppm. Light force 26000 ppm.

‡ p=0.04 marginal significance

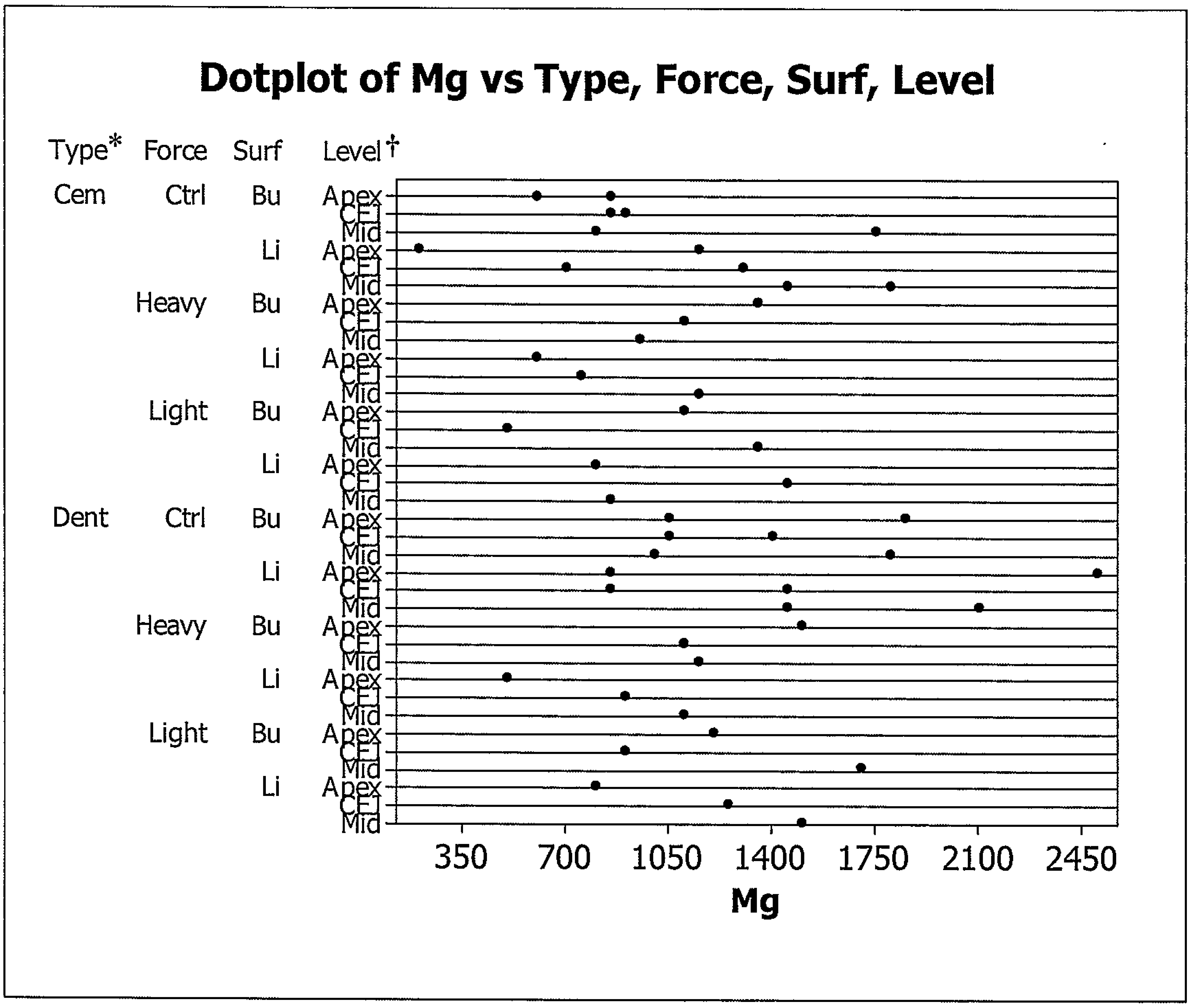

Figure 11: Magnesium concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).

* p=0.02 marginal significance

† p=0.04 marginal significance

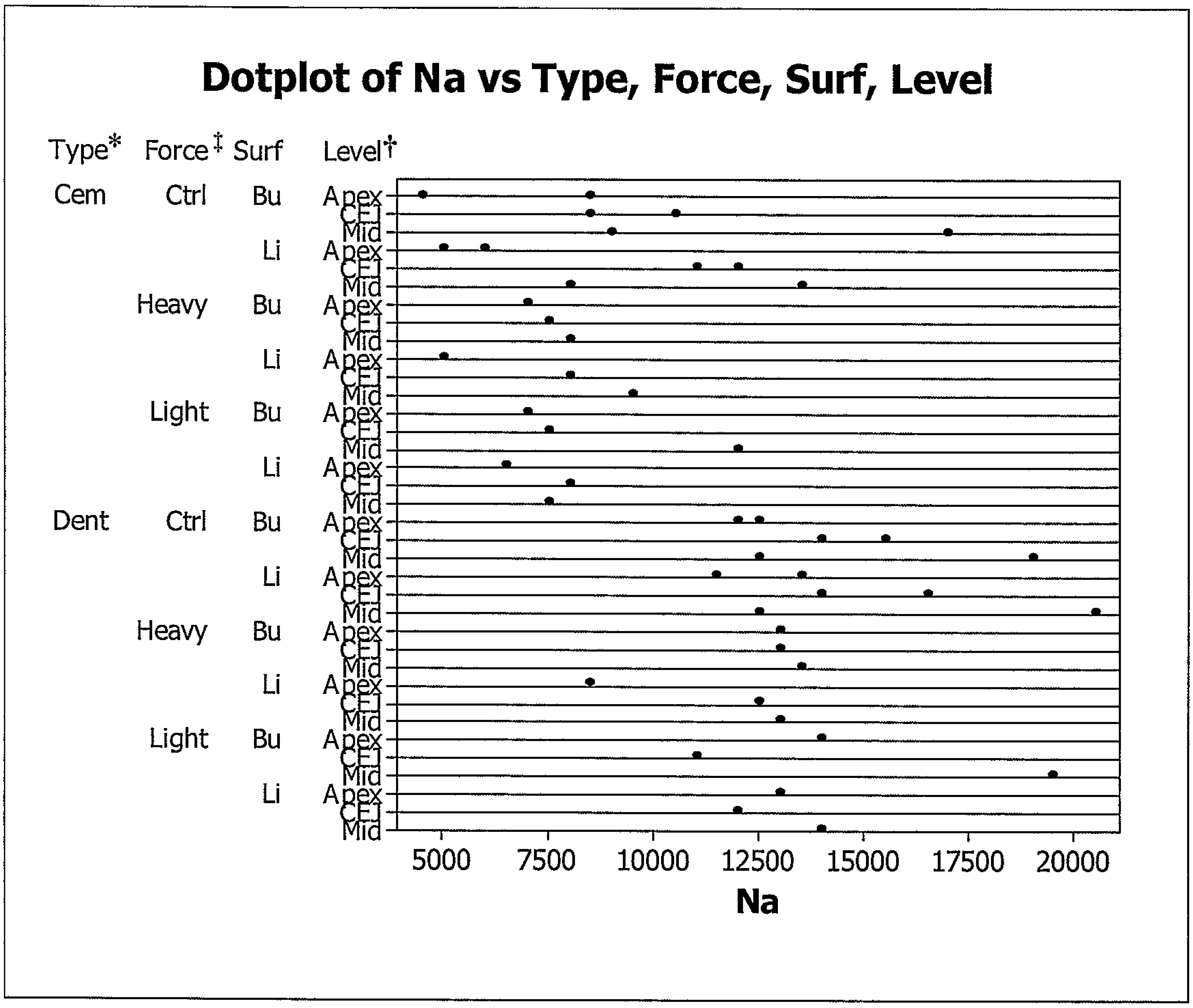

Figure 12: Sodium concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).

* $p<0.001$. Cementum 8400 ppm. Dentine 13500 ppm.

† $p<0.001$. Apex 9000 ppm. Middle 12800 ppm. Cervical 11100 ppm.

‡ $p=0.04$ marginal significance

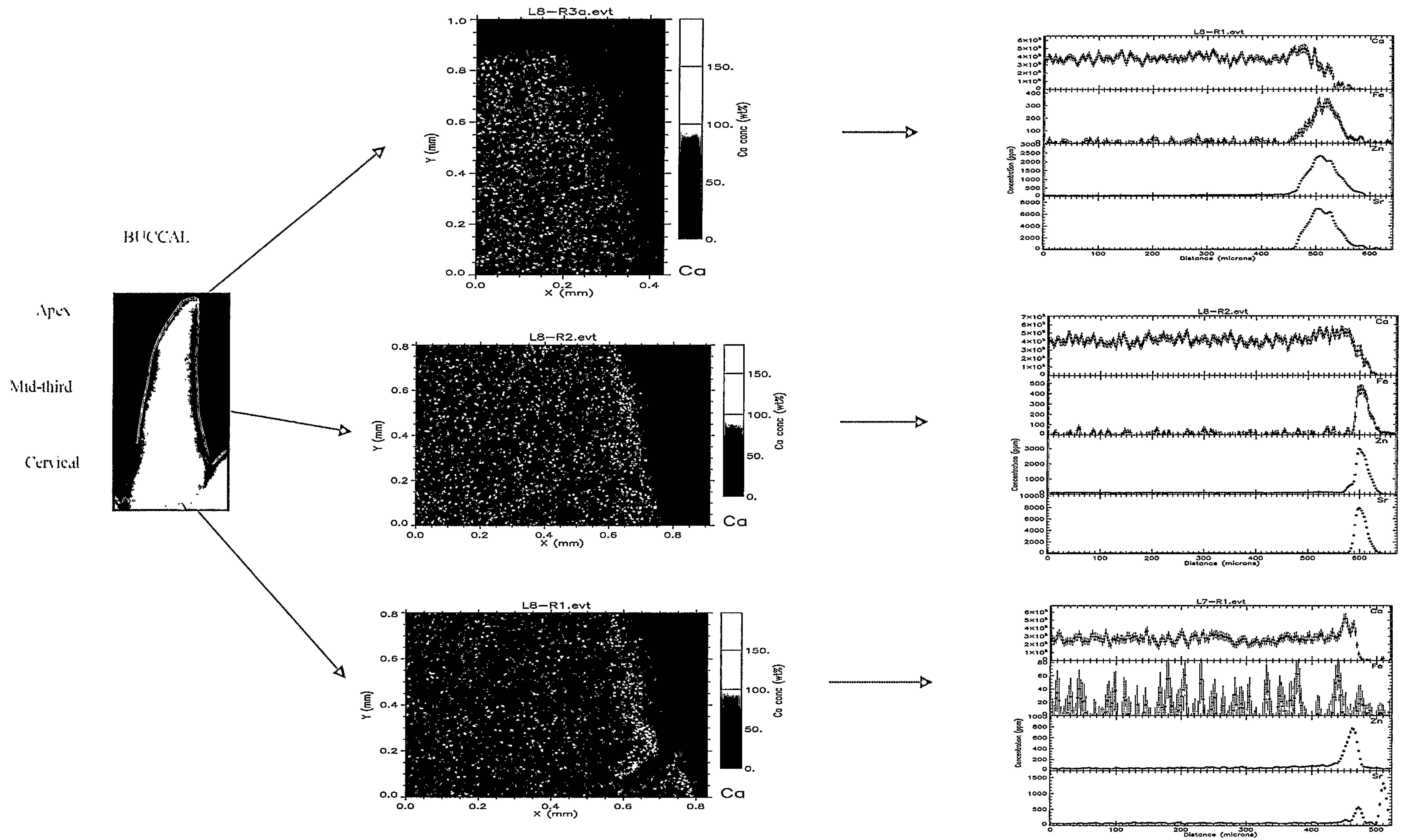

Figure 13: Control light force sample (L8) buccal for calcium. Picture Plots and Spectral Graphs(left to right equivalent to distance from pulp to cementum) generated using the Geo-PIXE II™ Version 3.8 Computer Program.

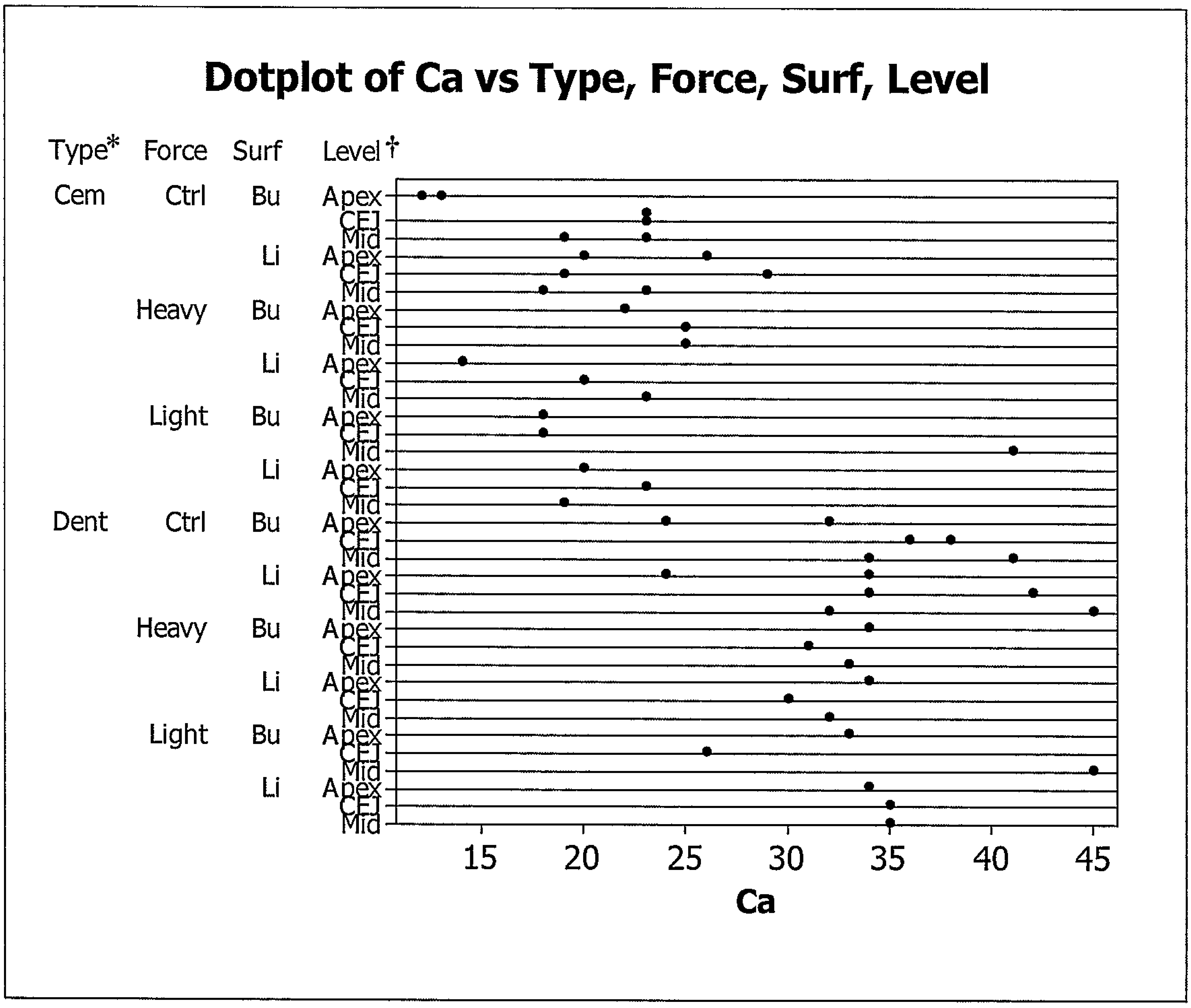

Figure 14: Calcium concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).

* $p<0.001$. Cementum 21.5%. Dentine 34.0%.

† $p<0.011$. Marginal significance

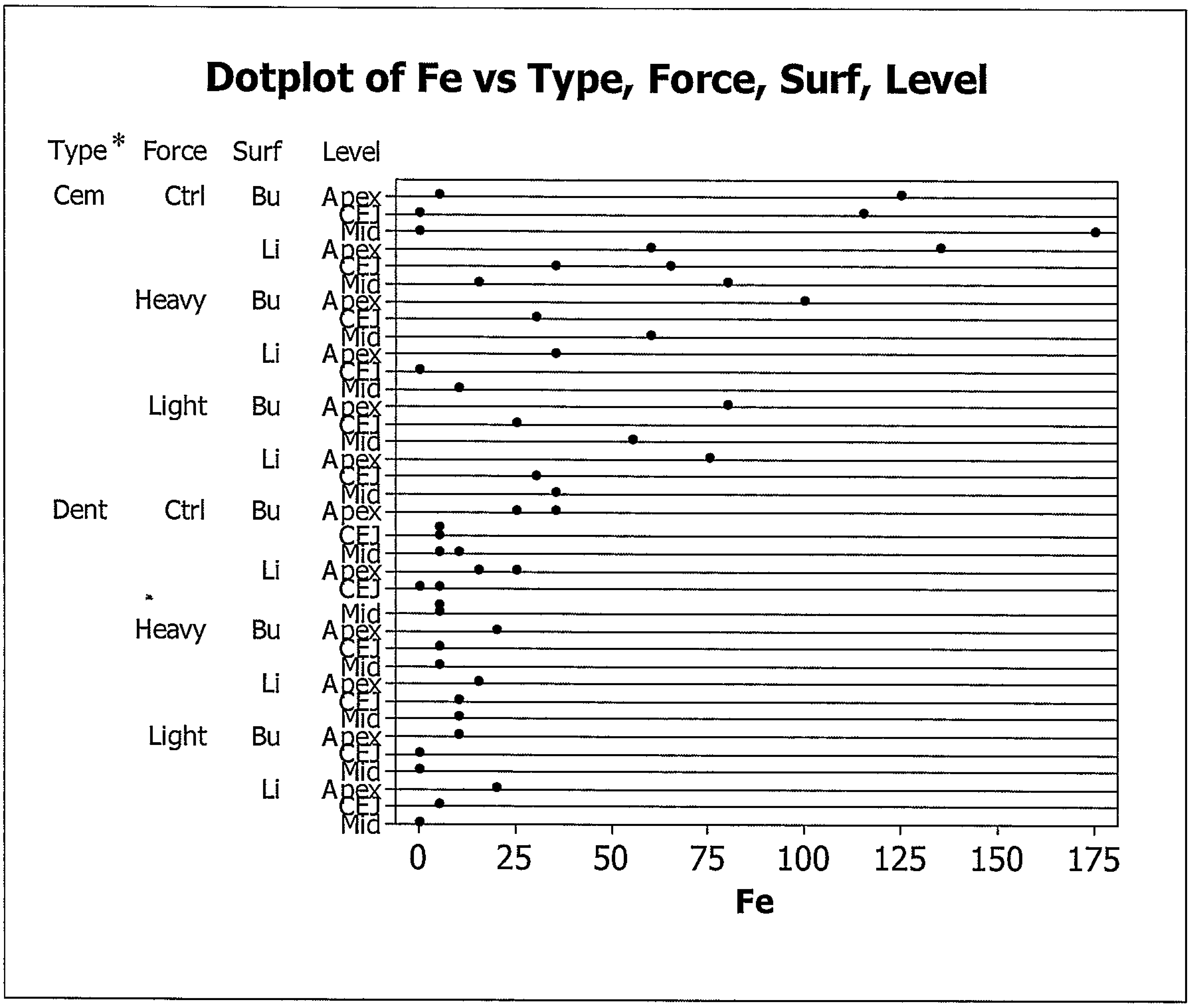

Figure 15: Iron concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).
* $p<0.001$. Cementum 54.1%. Dentine 7.9%.

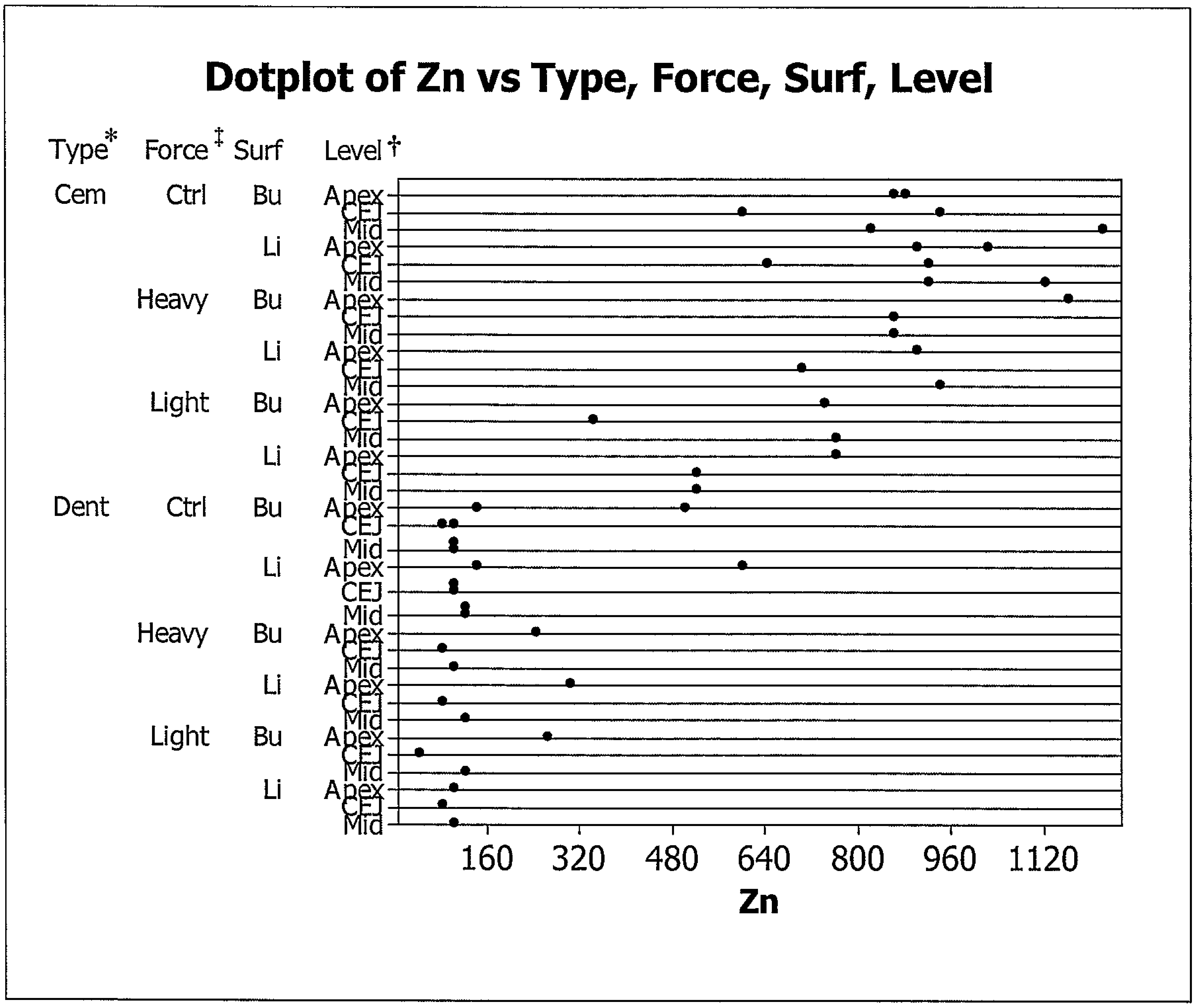

Figure 16: Zinc concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).

* $p<0.001$. Cementum 813 ppm. Dentine 142 ppm.

† $p<0.011$. Apex 578 ppm. Middle 485 ppm. Cervical 368 ppm.

‡ $p=0.002$. Control 543 ppm. Light 361 ppm. Heavy 527 ppm.

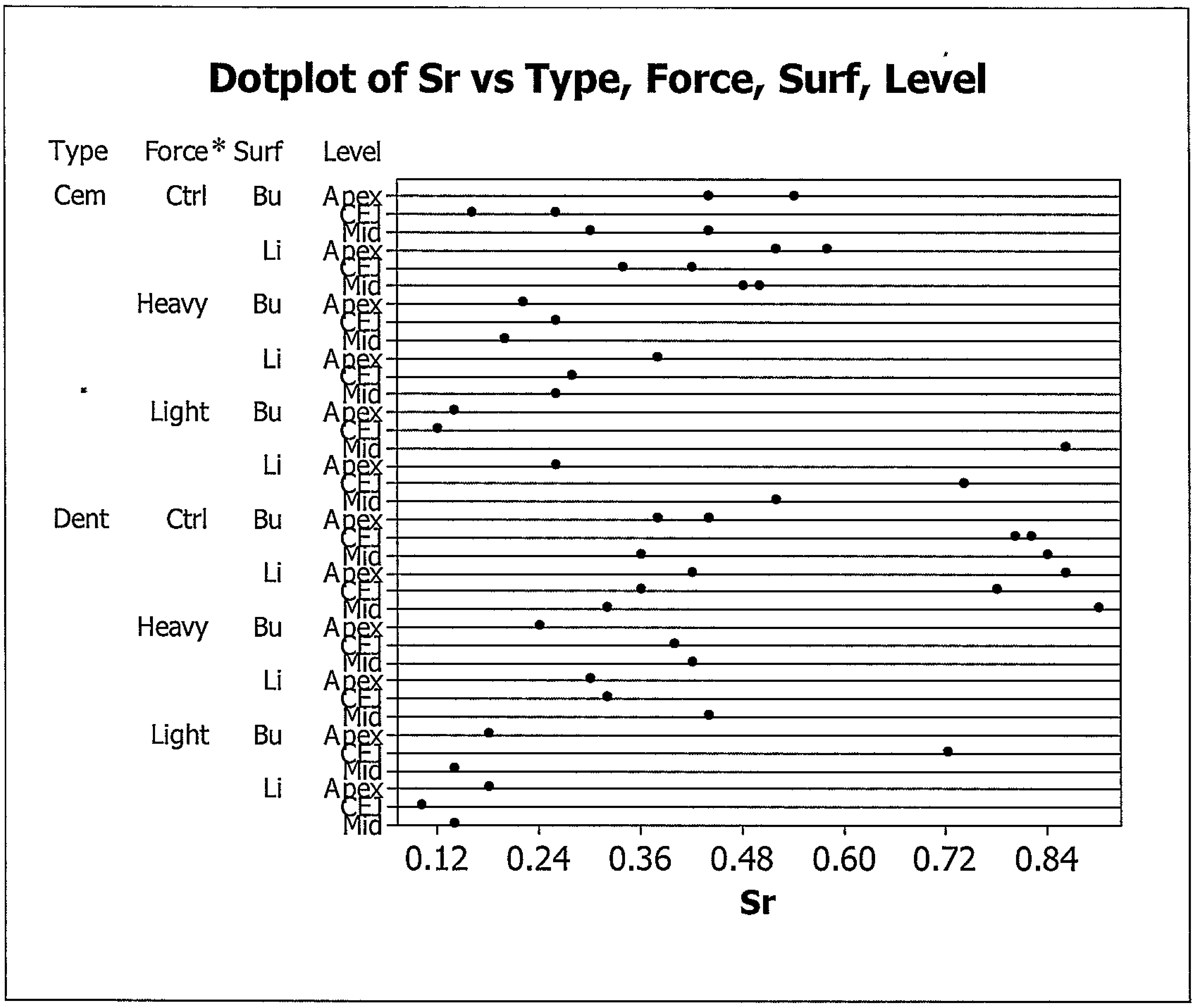

Figure 17: Strontium concentration (ppm) comparing Type (Cementum/Dentine), Force (Control/Heavy/Light), Surfaces (Buccal/Lingual), Level (Apex, Middle, Cervical).

* p=0.02. Marginal significance

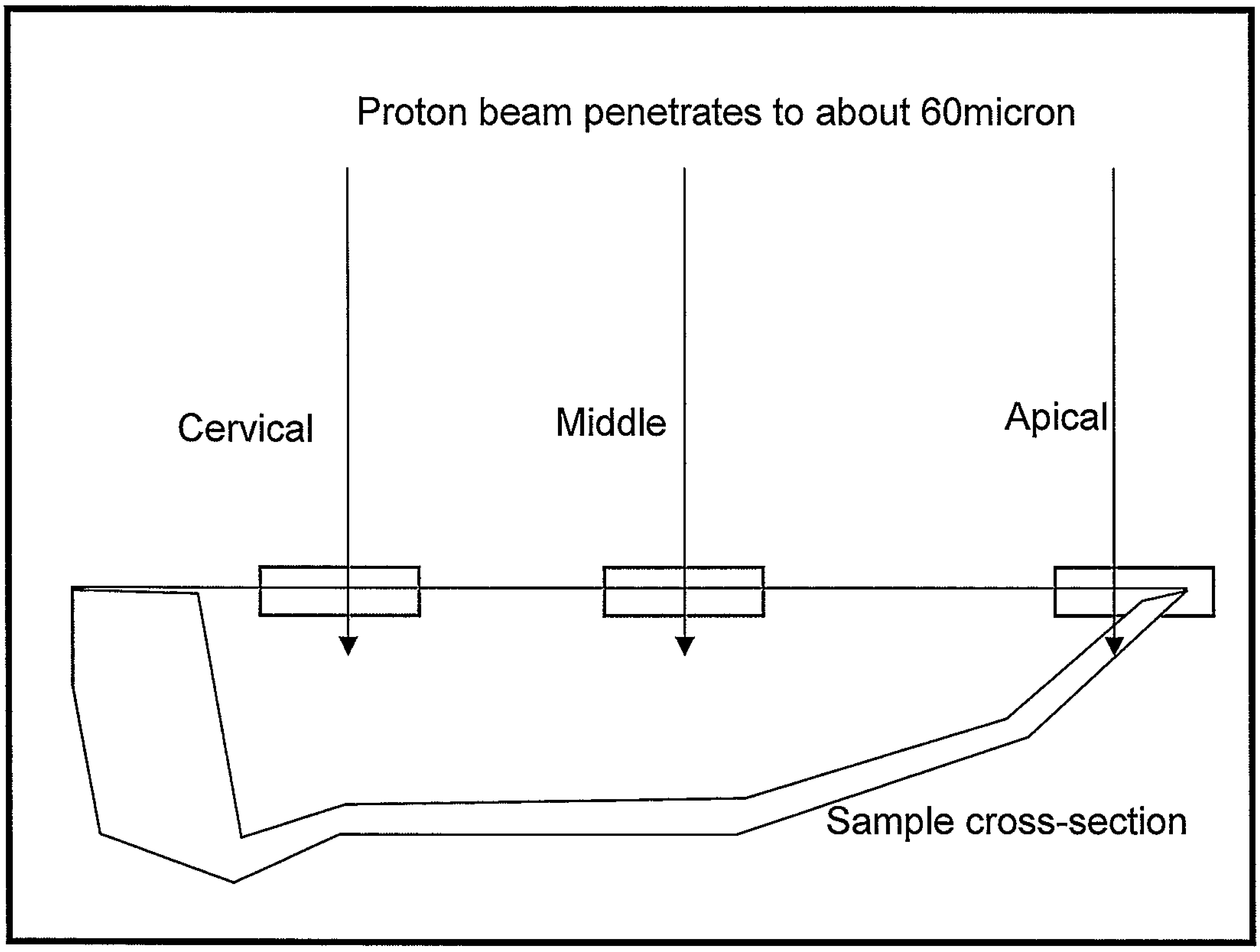

Figure 18: Diagram of sample in cross-section demonstrating CSIRO-GEMOC NMP beam penetration during scanning. Unexpected high recordings at the apex may be due to tooth morphology and machine limitations. As the tooth thins down toward the apex of the root, the proton beam penetrates through the dentine of the apical region and into the cementum below (as indicated by the arrows). Thus the gamma and x-rays are generated by both dentine and cementum. Subsequent recordings will reflect elemental concentrations of both these tooth structures.

5.9 Tables

Point of analysis	Element	Control (Heavy Force)		Heavy Force	
		Lingual	Buccal	Lingual	Buccal
Cervical	F	79090±366	69144±513	66986 ± 467	67107±300
	Mg	700±99	871±139	726±121	1079±82
	Na	11000±128	8679±178	8020±153	7480±99
	Ca %	29.3±0.9	22.8±0.7	20±0.9	25±1
	Fe	33±3	<MDL†	<MDL†	31±4
	Zn	910±4	593±3	692±4	863±5
	Sr %	0.344±10	0.1564±8	0.282±11	0.261±12
Middle	F	93632±325	76952±320	78227±220	60355±278
	Mg	1439±79	777±81	1166±59	967±76
	Na	7796±95	8874±104	9692±74	7769±96
	Ca %	23.4±0.9	18.5±0.8	22.7±0.6	24.7±7
	Fe	16±3	<MDL†	8±2	61±3
	Zn	1125±4%	816±3	930±3	868±3
	Sr %	0.473±13	0.431±11	0.2654±7	0.1961±7
Apical	F	86242±389	97184±395	72248±530	94331±354
	Mg	180±86	602±92	596±127	1374±87
	Na	6042±109	8514±119	5239±159	7204±101
	Ca %	25.8±0.8	12.4±0.9	14±1	22.1±0.8
	Fe	61±3	6±3	37±5	98±4
	Zn	907±3	860±4	903±7	1157±5%
	Sr %	0.526±12	0.53±14	0.377±20	0.227±10

Table 1: Human Cementum Heavy Force vs Control mean values

*All values in ppm unless otherwise indicated

† Below Method Detection Limit

Point of analysis	Element	Control (Heavy Force)		Heavy Force	
		Lingual	**Buccal**	**Lingual**	**Buccal**
Cervical	F	2922±51	2509±88	2165±61	2604±61
	Mg	856±36	1051±61	908±41	1120±43
	Na	13890±60	14070±103	12672±69	12940±71
	Ca %	33.9±0.3	36±0.3	29.5±0.4	30.5±0.3
	Fe	7.3±1	4±9	8±1	6.1±1
	Zn	102.8±0.7	95.6±0.6	79.5±0.7	78.5±0.7
	Sr %	0.365±0.7	0.821±0.8	0.321±0.8	0.391±0.8
Middle	F	2873±55	2493±61	2416±45	2658±65
	Mg	1464±38	1018±41	1078±30	1147±45
	Na	12680±62	12502±69	12935±50	13372±76
	Ca %	32.2±0.3	12.4±0.9	22.7±0.6	32.8±0.4
	Fe	5.7±0.9	6±3	7.7±0.8	5±1
	Zn	110.4±0.7	860±4	112.3±0.6	102.7±0.8
	Sr %	0.329±0.7	0.53±14	0.439±0.6	0.415±0.8
Apical	F	2982±102	3402±197	7045±220	4529±122
	Mg	861±69	1069±124	521±121	1497±80
	Na	11419±110	12411±215	8271±188	12822±128
	Ca %	33.6±0.6	32±1	33.8±0.7	33.7±0.5
	Fe	17±2	27±3	15±2	18±1
	Zn	143±1	133±2	309±2	233±1
	Sr %	0.86±2	0.44±3	0.307±3	0.24±1

Table 2: Human Dentine Heavy Force vs Control mean values

*All values in ppm unless otherwise indicated

Point of analysis	Element	Control (Light Force)		Light Force	
		Lingual	Buccal	Lingual	Buccal
Cervical	F	88948±379	80675±365	43353±464	52182±480
	Mg	1313±102	921±95	1426±154	504±135
	Na	11928±141	10528±131	8075±200	7730±184
	Ca %	19±1	23±0.6	22.9±0.9	18.3±0.7
	Fe	67±6	115±5	32±6	26±4
	Zn	646±4	949±3	515±4	341±3
	Sr %	0.415±14	0.2651±7	0.743±8	0.128±7
Middle	F	10149±385	82290±349	26708±252	46076±285
	Mg	1795±107	1770±104	848±84	1364±99
	Na	13735±143	16889±149	7449±127	12101±139
	Ca %	18±1	23±1	19±7	41.4±0.7
	Fe	82±8	174±8	34±5	57±4
	Zn	927±6	1218±5	520±3	753±3
	Sr %	0.501±19	0.291±12	0.521±5	0.854±5
Apical	F	87226±1180	93135±1220	55104±530	7730±399
	Mg	1163±268	858±274	817±144	1115±120
	Na	5148±297	4613±273	6653±186	7204±154
	Ca %	20±2	13±1	20±1	17.6±0.6
	Fe	136±6	126±6	74±8	78±4
	Zn	1012±7%	885±7	768±6	739±3
	Sr %	0.575±26	0.433±22	0.256±16	0.1448±7

Table 3: Human Cementum Light Force vs Control mean values

*All values in ppm unless otherwise indicated

Point of analysis	Element	Control (Light Force)		Light Force	
		Lingual	Buccal	Lingual	Buccal
Cervical	F	4173±61	3742±62	3676±61	2795±150
	Mg	1433±41	1399±42	1268±41	883±103
	Na	16468±68	15604±70	12249±65	10995±166
	Ca %	42.3±0.3	38.4±0.4	34.7±0.4	26.2±0.3
	Fe	1±2	3±3	3±2	2±2
	Zn	92.1±0.6	74.2±0.7	73.7±0.8	49±0.6
	Sr	0.772±0.8	0.791±1	0.101±2	0.717±0.9
Middle	F	5523±75	4648±63	4122±65	5688±71
	Mg	2086±51	1804±44	1493±43	1697±48
	Na	20636±85	18884±72	13934±70	19373±78
	Ca	44.9±0.4	41.2±3	35.3±4	45.1±0.3
	Fe	3±3	3±2	2±2	2±2
	Zn	115.3±0.8	107.3±0.7	99.5±0.8	113±0.7
	Sr	0.89±1	0.832±0.8	0.136±1	0.148±1
Apical	F	19063±573	17243±783	4320±102	16815±182
	Mg	2486±133	1852±174	815±63	1209±86
	Na	13510±155	11822±198	13044±109	14148±139
	Ca %	23.7±0.8	23.6±0.8	34.3±0.6	32.6±0.6
	Fe	25±2	34±2	22±4	11±3
	Zn	595±3	508±2	104±1	261±2
	Sr %	0.413±10	0.379±4	0.181±2	0.183±2

Table 4: Human Dentine Light Force vs Control mean values

*All values in ppm unless otherwise indicated

6. Manuscript Three

Part 2b: Analysis of elemental composition using Proton Induced X-ray and Gamma ray Emissions in human orthodontically induced root resorption craters.

This manuscript is to be submitted to the American Journal of Orthodontics and Dentofacial Orthopedics.

For the purpose of this thesis the manuscript is extended and will be shortened for publication.

Elaine Lim, BDS (Uni. Medal)

Postgraduate Student, Discipline of Orthodontics,

Faculty of Dentistry,

University of Sydney.

Dr D Belton, PhD
Manager, Nuclear Microprobe Applications Exploration and Mining,
CSIRO, MARC, School of Physics,
University of Melbourne.

Dr P Petocz, PhD
Associate Professor, Department of Statistics,
Macquarie University.

Dr T Turk, BDS, PhD
Associate Professor, Department of Orthodontics,
University of Ondokuz Mayis.

Professor M A Darendeliler, BDS, PhD, Dip Ortho, Cert. Orth, Priv. Doc
Professor and Chair,
Discipline of Orthodontics,

Faculty of Dentistry,

University of Sydney.

Address for correspondence:

M. Ali Darendeliler

The University of Sydney

Discipline of Orthodontics

Faculty of Dentistry

Level 2, 2 Chalmers Street

Surry Hills NSW 2010 Australia

Phone: +61 2 93518314

Fax: +61 2 93518336

Email: adarende@mail.usyd.edu.au

6.1 Abstract

Introduction: Cementum is at the interface of Orthodontically Induced Inflammatory Root Resorption (OIIRR) process and its structure may help to elucidate its role in protecting teeth. Zinc and fluorine have been found to be present in cementum. These elements have been noted to modulate osteoclast activity and contribute to the mineralisation of hard tissue. Thus, elemental composition of cementum may play a role in the extent and severity of the resulting lesion. It may also lead to potential preventive measures being elucidated.

The aim of this study was to develop a methodology using the CSIRO-GEMOC nuclear microprobe machine to analyse the element composition and distribution of a human tooth root and orthodontically induced root resorption crater.

Method: A human tooth was subjected to a buccal directed orthodontic force (225 g) using a 0.017 x 0.025" beta-titanium-molybdenum alloy sectional wire. The experimental period lasted 4.1 weeks. The tooth was extracted avoiding contact with the root surface. A representative OIIRR crater with well-defined and unambiguous lesion margins was identified. The sample was cross-sectioned through the crater and prepared for

scanning with the CSIRO-GEMOC Nuclear Microprobe Machine. Geo-PIXE II™ Version 3.8 Program was used for analysis.

Results: The root resorption crater and normal tooth structure followed the same pattern of mineral distribution. Overall there was a general reduction of elemental content. However, within the root resorption crater higher fluorine, iron and zinc concentrations were noted, compared to equivalent unaffected tooth structure.

Conclusion: The implications of increased fluorine and zinc concentration within the resorption lesion may be that these elements could serve to influence the extent of the resorptive lesion. They may impart a protective effect to the tooth root surface due to their inherent capabilities of limiting osteoclast activity and/or reflect the re-mineralisation process.

6.2 Introduction

Orthodontically Induced Inflammatory Root Resorption (OIIRR)[1] refers to root resorption resulting from orthodontic treatment. OIIRR is an unpredictable adverse effect involving transient inflammatory surface resorption. The exact mechanism of OIIRR is unknown. Cementum is at the interface of this process. Its structure may help to elucidate more information regarding its role in protecting teeth and its ability to normally resist resorption.

Cementum is an important dynamic interface between the tooth and the periodontal environment. Similar to other hard tissues, hydroxyapatite in cementum is not pure, and contains elements from its microenvironment.[2] The minerals in the circulating fluid can react with cementum. In particular the fluoride ion reacts aggressively with hydroxyapatite.[2] In contrast, the opposing alveolar bone is constantly remodelled and thus does not accumulate such minerals to the same extent as cementum.

When the root surface is breached, repair matrices become attached to the resorbed surface.[3] Following the detachment of odontoclasts the cementogenic cells re-populate. This is followed by electron-dense globular accumulations indicating re-mineralisation.

Cementum behaves differently to bone in response to orthodontic force application.[4] Unlike bone, cementum is not fully resorbed. The exact mechanism of how it is able to resist resorption has not yet been elucidated. Explanations include:

1. Cellular barriers

Cells that form a covering over dental tissue may provide a barrier against odontoclasts. This has been demonstrated by the use of a replanted tooth as a root resorption model in monkeys.[5] The inner cellular layer of the periodontal ligament consists of cementoblasts, fibroblasts, osteoblasts, endothelial and perivascular cells. This is thought to provide a protective and repair mechanism.[5]

2. Precementum

The precementum layer is an unmineralised matrix and has been thought to have a resistance to resorption.[6] Osteoid[7] and predentin[8] are also uncalcified mineralised tissues and also demonstrate a reduced susceptibility to resorption.

3. Mineral content

The susceptibility of root resorption has been related to the degree of cementum mineralisation.[9] Henry and Weinmann found that cervically positioned acellular cementum was more mineralised and had increased

resistance compared to less mineralised cementum.[9] Reitan and Rygh reported cementum density may confer greater resistance to resorption.[10] However, Jones and Boyde do not believe mineral content of dental tissue influences susceptibility to root resorption.[11]

A number of trace elements are present in cementum.[2] Manganese is present in the hydroxyapatite crystal lattice. It has been suggested that magnesium could be important in contributing to cementum mineralisation and may play a role in controlling the growth of hydroxyapatite crystals. Overall it is found at higher concentrations in the deeper root surface layers.[2] The cementum fluoride concentration was found to be inversely proportional to magnesium.[12] Whereas, manganese is found in similar concentrations to calcium.[2]

Zinc has also been noted in cementum.[13,14] Modulation of osteoclastic resorption of bone and dental tissue in the presence of zinc has been examined.[14] It has been established that the lacunae developed on tooth cementum, in the presence of extracellular zinc, were fewer in number and had smaller surface areas. Zinc has been found to be a potent and selective inhibitor of osteoclastic bone resorption.[15]

Like zinc, strontium is another element which has been related to reducing bone resorption.[16] The dental profession has used strontium in its

desensitisation products, in order to occlude dentine tubules.[17] In addition, strontium found in water is incorporated into dental tissue.[18] There is conflicting evidence of the effect strontium has on cementum solubility. The increased presence of strontium has been shown to increase cementum and enamel solubility.[19,20] However, it has also been demonstrated to decrease solubility when administered in conjunction with fluoride.[21] Furthermore, this combination appears to be therapeutically additive, whereby an increasing mineralisation and density of dentine effectively reduced tooth sensitivity.[19]

Quantitative assessment of calcium, phosphorus and fluoride concentrations revealed a reduction of mineral concentration towards the apex.[22] There was no difference between buccal and lingual surfaces, except for increased fluoride bucco-cervically. There were significant differences between the upper half of the root compared to the apical part. Thus the mid-third of the root is assumed to reflect an average distribution of mineral content of the tooth root. However, the distribution of minerals within mature root tissue shows a great variability.[2]

A study in the veterinary literature appears to be unique in its evaluation of elemental composition of teeth with odontoclastic resorption lesions.[23] This study found teeth affected by this pathology had greater concentrations of sodium overall and less iron, whilst in cementum there was a significant

reduction in magnesium and fluorine. No conclusions were made regarding clinical relevance. Although this study provides useful information, it is notable that there was no consideration of minerals within the lesions themselves. Furthermore, orthodontic literature has not focused on the effects of altered elements within root resorption craters.

Literature has been sparse examining the direct relationship of fluoride's potential protective influence and the effect mineral content of cementum may have against orthodontic associated root resorption. Foo et al[24] used rats to induce orthodontic root resorption, and exposed part of the sample to systemic fluoride, with an estimated intake of 1 mg per day. It was demonstrated that the average crater volumes of teeth exposed to fluoride were about half the size. This was also evident in the group exposed to no orthodontic force but were given fluoridated drinking water. However, due to a large variation in results these differences were not significant ($p>0.05$). This study was limited as it only examined pooled volumetric data for craters on each tooth. Further examination, with respect to both individual craters and discriminating between length and depth parameters, may yield more information.

Most studies examining the role of fluoride and its influence on root resorption have been in the area of endodontics and dental trauma. Research has mainly focused on the protocol following tooth avulsion. It may be

beneficial to treat teeth with fluoride to minimise future potential resorption, as investigated by Coccia.[25] This study used 129 teeth, which had been avulsed. Two groups were studied, those teeth stored in saline were compared to those treated with 2% neutral sodium fluoride. It was found that the teeth treated with fluoride were less susceptible to root resorption. This is supported by other studies on human teeth.[26]

The effect of fluoride on mechanical injury to the periodontium has been investigated.[27] Injury to rat tooth roots was achieved using a needle to puncture the cementum at the level of the gingival margin, every 3 hours for 3 times, over one day. The group receiving systemic sodium fluoride (25 mg/kg) via a gastric tube showed a reduced extent of trauma and root resorption. A conclusion was made that fluoride suppressed the root resorption induced by the injuries to the periodontal tissues.

Although fluoride does not increase the physical hardness of cementum *per se,*[28] there are a number of possible mechanisms through which fluoride may impart a protective effect against orthodontically induced root resorption (as opposed to its well described effects on bone resorption):

1. Direct effect on osteoclasts:
    a. Osteoclastic activity has been shown, in culture, to alter in the presence of fluoride.[29]

b. Osteoclastic secretory function is suppressed.[30]

c. Furthermore, this affects the release of calcium and magnesium, and thus the subsequent pattern of osteoclast adherence and motility is altered.[29] Fluoride has been observed to inhibit the activity of adjacent resorbing cells.[31]

d. Fluoride may also promote osteoblastic activity.[32]

2. Alteration of shapes of resorption pits:

   a. Resorption pits made by osteoclasts are shallower but wider.[29]

3. Mineralisation of cementum:

   a. Fluoride is taken up by the root surface of teeth.[33]

   b. Cementum incorporates fluoride into its mineral lattice converting hydroxyapatite to fluorapatite.[34]

   c. The increased crystallite size is more resistant to dissolution.[35,36]

Fluoride's effect on osteoclasts depends on the dosage level. Sodium fluoride at 0.5-1.0 mM on a local level reduces the number of resorption lacunae made by individual osteoclasts and reduces the resorbed area. This is achieved from an intake of approximately 1 mg NaF/kg body weight per day in rabbits.[37] The inhibition of osteoclastic movement and a reduction in

depth of resorption pits resulted from 15 mg/l NaF in rats.[38] A similar effect was achieved using 15 mg/kg for 21 days in another study.[39] A single high dose of fluoride was found to directly affect osteoclasts.[40] An understanding of the chemical and biological structure of cementum is vital, as it is the interface at which OIIRR occurs. The elemental composition of cementum may play a role in the extent and severity of the resulting lesion. It may also lead to potential preventive measures being elucidated.

There are various methods to study elemental composition of teeth. Available techniques include microprobe analysis. The nuclear microprobe employs Proton Induced X-ray Emissions (PIXE) and Proton Induced Gamma ray Emissions (PIGE), which allows mapping of multiple trace elements at micron resolutions. Compared to other available techniques, the Commonwealth Scientific and Industrial Research Organisation and the Australian Research Council's National Key for Geochemical Evolution and Metallogeny of Continents Nuclear Microprobe (CSIRO-GEMOC NMP) effectively combines superior trace element spatial (resolution of 1-2 μm) and quantitative analysis. The technique is particularly suited to samples where trace elements are spatially inhomogeneous. However, this technology does not lend itself well to bulk sample analysis, due to the time required to scan specimens and the costs involved.

The aim of this study was to analyse the element composition and distribution in a human tooth root and an OIIRR crater. In addition a methodology was developed using the CSIRO-GEMOC NMP to study human root resorption craters.

6.3 Materials and Methods

6.3.1 Sample

Human maxillary first premolar teeth were used in this project (CSAHS Human Ethics Review Committee, United Dental Hospital, Sydney, Australia, Project: 12-2005/2/8782). The sample pool comprised of 20 teeth, from which one tooth was eventually used for scanning, met the following criteria:

1. Bilateral maxillary first premolar teeth to be extracted for orthodontic purposes
2. Complete apexification
3. No history of trauma, dental restorations, pathology or developmental abnormalities
4. No history of bruxism
5. No medical history that may affect dental development
6. Knowledge of birth place and residence to present
7. Knowledge of fluoride consumption history (community water supply fluoridated to 1.0 ppm)

6.3.2 Clinical Procedure

The maxillary premolar teeth received 225 g buccally directed force applied by a 0.017" x 0.025" beta-titanium-molybdenum alloy (TMA®) (Ormco, CA) spring. The spring used was a segment of archwire engaging 0.022" SPEED brackets (Strite Industries, Canada) bonded to the first permanent molars and the experimental teeth (Figure 1). The force magnitude was measured to the nearest gram using a strain gauge (Dentarum, Germany). Glass ionomer cement (Transbond, 3M Unitek™) was bonded on the occlusal surfaces of the mandibular first molar teeth to minimise occlusal trauma.[41]

6.3.3 Sample Preparation

6.3.3.1 Extraction of teeth

After the 12 week experimental period, the maxillary premolar teeth were extracted. Instructions were given to the oral surgeons to avoid forceps contact below the cervical cementum. The teeth were stored in 5 ml of Milli-Q® and then underwent ultrasonic cleaning for 10 minutes and manual

cleaning with damp sterile gauze, to remove remaining periodontal ligament and biological debris.[42] The teeth were then re-stored in Milli-Q® at ambient room temperature (23° ± 1°).[43]

6.3.3.2 Selection of representative OIIRR crater

A single tooth presenting with the crater deemed typical of OIIRR was chosen from the sample pool (Figure 2). The inclusion criterion was a well-defined and unambiguous lesion margin. This was verified by a second researcher (Professor MA Darendeliler) experienced in the field of orthodontic root resorption, compared with the other samples.

6.3.3.3 Locating root resorption craters

Reference points and co-ordinates were established and recorded to enable re-location of the root crater of interest, under microscopic view (WILD M3B®, Heerbrugg Switzerland).

6.3.3.4 Specimen sectioning

The "Wax Marker System" developed was used to indicate the point at which the tooth required sectioning. A sheet of wax (Moyco Union Broach™ Dental wax) softened in the centre point with a hot water delivered via a pipette. The wax was pushed over the tooth root to the point where the tooth was to be cut to the co-ordinated previously established.

The tooth was then floated in Milli-Q® crown-down in an ice-cube tray. This was frozen for 24 hours. The wax was then removed, leaving the exposed root portion to be cut. The specimen was then sectioned transversely, in layers from the apex, through to the identified mid-point of the root resorption crater. Initially, gross sectioning was begun using a diamond disc bur, followed by Fine and Superfine Sof-Lex Discs™ (3M). The final 1 mm to cut and polish was done by hand with 1600 grit-grade sandpaper fixed to a heavy weighted glass slab. The crown of the tooth was then sectioned parallel to the cross-section of root (Figure 3). The tooth was then irrigated with Milli-Q®.

6.3.3.5 Sample preparation for NMP

The specimen was mounted on a glass slide and stabilised using carbon adhesive tape. The slide and specimen was carbon coated (evaporated) in a

vacuum at 10^{-4} Torr with an approximately 20-30 nm layer. The glass slide was placed in a metal stub designed for the nuclear microprobe machine.

6.3.4 Analysis and statistics

6.3.4.1 NMP

The spatial distribution of multiple elements was measured in the resorption crater and non-resorbed tooth structure distant to the crater of the sample tooth-root using CSIRO-GEMOC NMP (Melbourne, Victoria, Australia) (Figure 4).

The analysis was performed with 3.0 MeV protons and the beam focused at 1 x 1.8 μm^2. Electrostatic scanning was conducted in the Y-axis over distances of 800-1500 μm and the sample stage was stepped in the x-axis with a step-size of 2.5 μm. The beam current was maintained at 4 nA. The total accumulated charge for average size area was approximately 20-25 μC. An aluminium absorber of 100 μm used between target and Germanium (Ge) detector (Canberra Ultra-Ge Detector©). Software to evaluate spectra was Geo-PIXE II™ Version 3.8.[44] The elements detectable with gamma rays are sodium, fluorine, magnesium, boron, aluminium and silicon. Whilst under x-rays calcium, iron, nickel, copper, zinc, bromide, rubidium, strontium, barium and lead are measurable.

Final results were presented as a quantitative spectral distribution map PIGE and PIXE Spectrum Component graphs and Dynamic Analysis. These represent images of the scanned tooth structure highlighting the presence of each element.

6.3.4.2 Spectral Deconvolution of Element Distribution Maps and statistical analysis

Geo-PIXE II™ Version 3.8 Computer Program was used to analyse the scanned tooth. A manual deconstruction of regions was conducted by a function that allowed shapes to be drawn over the downloaded scanned image. The regions analysed were a traverse through the middle of the root resorption crater and also distant unaffected tooth. Then separate analyses were made of the cementum surrounding the periphery of the crater and the dentine in the mid-crater region. Cementum and dentine of unaffected tooth structure was also determined. Information generated from this Program's functions included average concentrations of the 500 plus readings per extracted region drawn and minimum detection limits (MDL) of the presence of elements. This was repeated for each slice generated from both the x-ray and gamma ray scans. In addition to the quantitative data, the information was also used to process Spectral Graphs and Picture Plots.

Spectral graphs are traverse concentration profiles of each element, showing the pattern of distribution through the tooth structure. Picture Plots are qualitative representations (maps) of relative concentrations, distributed across the scanned region, for each element.

Error of the measurement was determined by triplicate readings for each region and element. Standard error of the measurement and coefficient of variation was calculated using SPSS Version 14 (Statistical package for social sciences, SPSS Inc., Chicago, Ill, USA.) software program.

6.4 Results

6.4.1 Normal cementum versus normal dentine

Elements above the mean detection limit were fluorine, sodium, magnesium, aluminium, calcium, iron, zinc and strontium. Error of the measurement was found to be minimal, except for iron, which demonstrated moderately more variability between the readings (Table 1). In the tooth structure distant from the root resorption crater, the concentration of fluorine, iron and zinc was higher in cementum (Figure 5 and 6). In the corresponding dentine sodium, magnesium, aluminium, strontium and calcium had higher concentrations (Table 2).

6.4.2 Root resorption crater cementum versus root resorption dentine

The mineral distribution of the root resorption crater followed a similar trend to normal tooth dentine and cementum (Figures 7 to 10). Fluorine and zinc was higher in cementum of the root resorption crater circumference

(Figure 11 and 12). In contrast magnesium, aluminium, iron, strontium and calcium was higher in dentine.

6.4.3 Root resorption crater cementum versus normal cementum

All minerals in normal cementum were in higher concentration compared to the corresponding root resorption crater tooth structure (Table 2).

6.4.4 Root resorption dentine versus normal dentine

In unaffected tooth structure, sodium, magnesium, aluminium and strontium had higher concentrations. In the root resorption crater dentine there were elements in higher concentration compared to normal dentine. These were fluorine (1591 ppm higher), iron (17 ppm higher) and zinc (29 ppm higher).

6.5 Discussion

Cementum and dentine of the root resorption crater maintained similar trends to normal (unaffected) tooth structure. This may be due to the ability for cementum to resist root resorption to a limited degree.[9] However, although the pattern of minerals remained comparable, the mean concentrations associated with the root resorption crater were reduced. Damage in the form of dissolution of crystallite occurs as a part of the resorptive process.

In contrast to the general decrease in mineral concentration, of note was the increase in concentration of fluorine and zinc within the dentine of root resorption craters. This may be considered as the result of processes occurring after the initial breach of superficial cementum, as these concentrations are dissimilar to normal dentine. Interpretation of how an increase in mineralisation, of these elements, could occur may reflect the role of cementum as an important dynamic interface between the tooth and the periodontal environment.

Resorption is usually followed by remineralization. A dynamic exchange of minerals occurs superficially and this limits the extent of more minor resorptive defects. Subjacent unaffected tissue provides a reservoir for diffuse transition of elements.[2] The minerals in the circulating fluid can also

react with cementum. A relative time-frame for re-mineralisation can be extrapolated from that measured for fluorine, which is incorporated into enamel within one hour from the microcirculation.[45] When the root surface is breeched, repair matrices become attached to the resorbed surface.[3] Following the detachment of odontoclasts the cementogenic cells re-populate. This is followed by electron-dense globular accumulations indicating re-mineralisation. This biomineralisation process together with a new paradigm has been more recently established suggesting fluoride is an active participant in the precipitation process and nature of biogenic apatites.[46] The role of fluoride was suggested as being vital in calcium phosphate formation *in vivo*, effecting both the process and characteristic of the final products observed in tooth structure. Fluoride was seen to accelerate the hydrolysis of acidic precursors and increase apatite growth rates via precipitation.[46] Therefore, this study supports the proposal that human cementum may have an inherent ability to resist resorption. Furthermore, this could mean that pre-treatment cementum quality impacts on the ability for tooth roots to resist damage, as the outcome of root resorption reflects the original mineral concentration. Secondly, that the presence of fluorine may increase "repair" (or limit destruction) by being an active participant in accelerating calcium phosphate precipitation. Therefore, elements, such as fluorine, may be extrapolated as a potential preventive agent in limiting the extent of orthodontically induced root resorption craters.

Zinc and fluorine followed similar trends. This concurs with the chemical observation that these elements are taken-up in a similar manner.[21] Furthermore, it has been suggested that surface adsorption of fluorine occurs when calcium ions are exposed on the surface of hydroxyapatite.[47] This also supports similar findings in Part 1 of this Thesis (see Manuscript One).

Fluorine and zinc being in higher concentrations in root resorption lesions may be extrapolated to potentially contribute to limiting the extent of destruction. Studies examining the role of fluoride and its influence on root resorption have been concentrated in the field of endodontics and dental trauma. Research has mainly focused on the protocol following tooth avulsion. It may be beneficial to treat teeth with fluoride to minimise future potential resorption.[25] The effect of fluoride on mechanical injury to the periodontium has also been investigated.[27] A conclusion was made that fluoride suppressed the root resorption induced by the injuries to the periodontal tissues.

The mechanism by which fluorine achieves this effect is not known. However, although fluoride does not increase the physical hardness of cementum *per se,*[28] there have been suggestions on how fluoride may impart a protective effect: direct effect on osteoclasts, alteration of shape of osteoclastic resorption pits and the mineralisation of cementum. These effects may depend on the dosage level. Sodium fluoride at 0.5-1.0 mM on a

local level reduces the number of resorption lacunae made by individual osteoclasts and reduces the resorbed area. A single high dose of fluoride was found to decrease osteoclast density and reduce the number of active osteoclasts whilst increasing inactive ones not attached to the bone surface.[40]

Zinc may also play a vital role in the dynamic processes affecting cementum. Modulation of osteoclastic resorption of bone and dental tissue in the presence of zinc has been examined.[15] It was established that the lacunae developed on tooth cementum, in the presence of extracellular zinc, were fewer in number and had smaller surface areas.

Therefore, although root resorption craters generally have a reduced mineral content, the finding that certain minerals were actually in higher concentrations in the mid-crater region, may be an important part of the tooth's "protective" process.

A limitation of this study was that a single sample was used. This was due to cost and time limitations related to the use of the CSIRO-GEMOC NMP. Future studies may incorporate a greater sample size and examine resorption craters from different regions of the tooth root. However, analysis of multiple resorption craters on a single tooth is limited, because the machine requires a flat smoothed surface to scan, therefore tooth sectioning is needed

through the lesion of interest. Nevertheless, the present study sought to provide a detailed examination of a representative OIIRR crater. Such a qualitative and quantitative elemental description or root resorption craters appears unique in the dental literature.

6.6 Conclusions

1. Elemental distribution within an orthodontically induced root resorption crater was qualitatively and quantitatively described.
2. Root resorption craters and normal tooth structure seem to follow the same pattern of element distribution.
3. There was a general reduction of elemental content in the root resorption crater, which may be the result of the dissolution process associated with OIIRR.
4. However, within the root resorption crater there was an increase in fluorine and zinc concentrations. This may reflect the remineralisation process and could influence the extent of the resorptive lesion by imparting a protective effect on the tooth root surface.

6.7 References

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6.8 Figures

Figure 1: Intraoral view of force application using SPEED brackets (Strite Industries, Canada) and orthodontic wire (*courtesy of MA Darendeliler*).

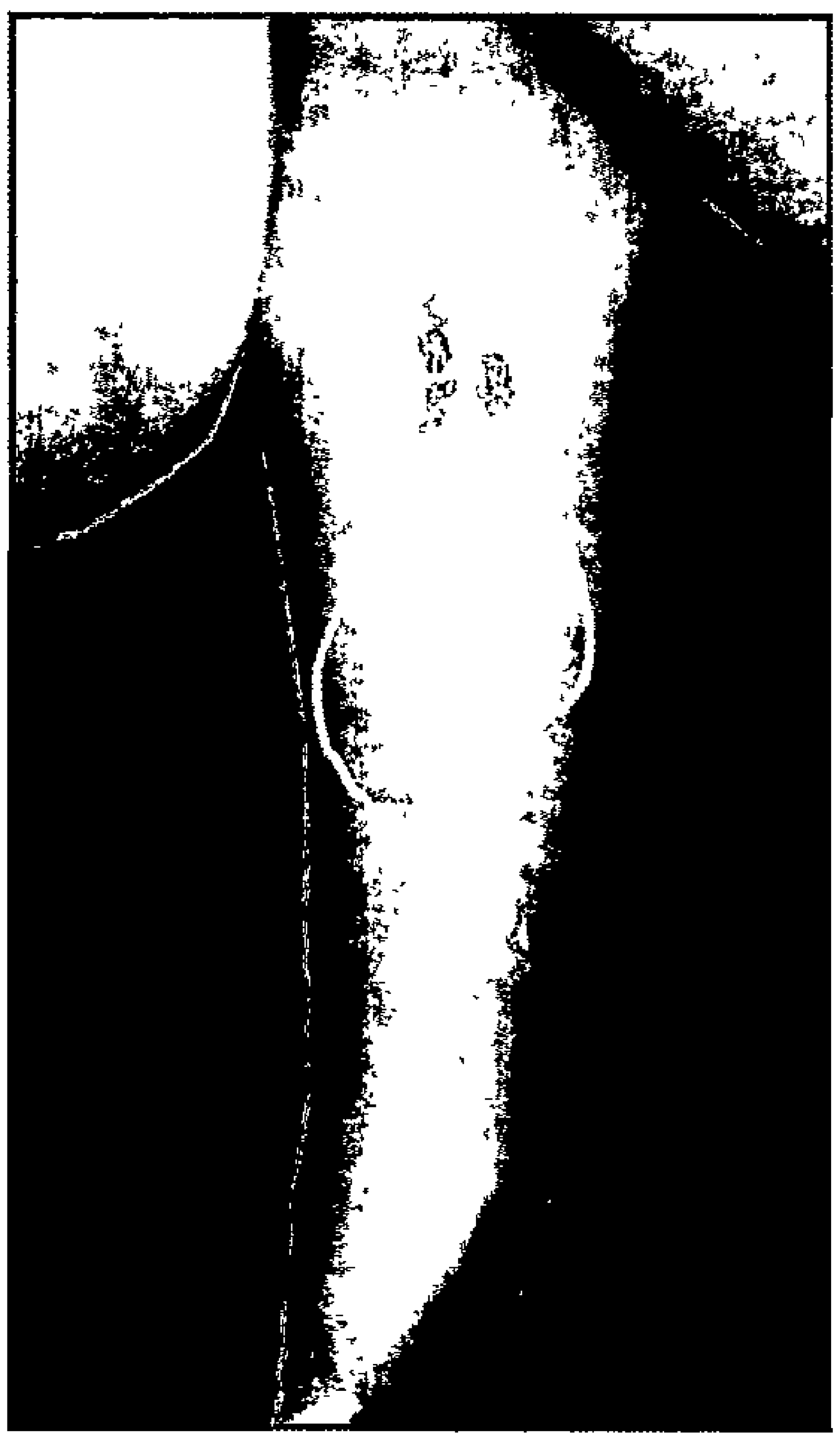


Figure 2: Human OIIRR crater identified for CSIRO-GEMOC NMP analysis indicated by the circle drawn.

Figure 3: Cross-sectioned sample demonstrating location of root resorption crater indicated by the circle drawn.

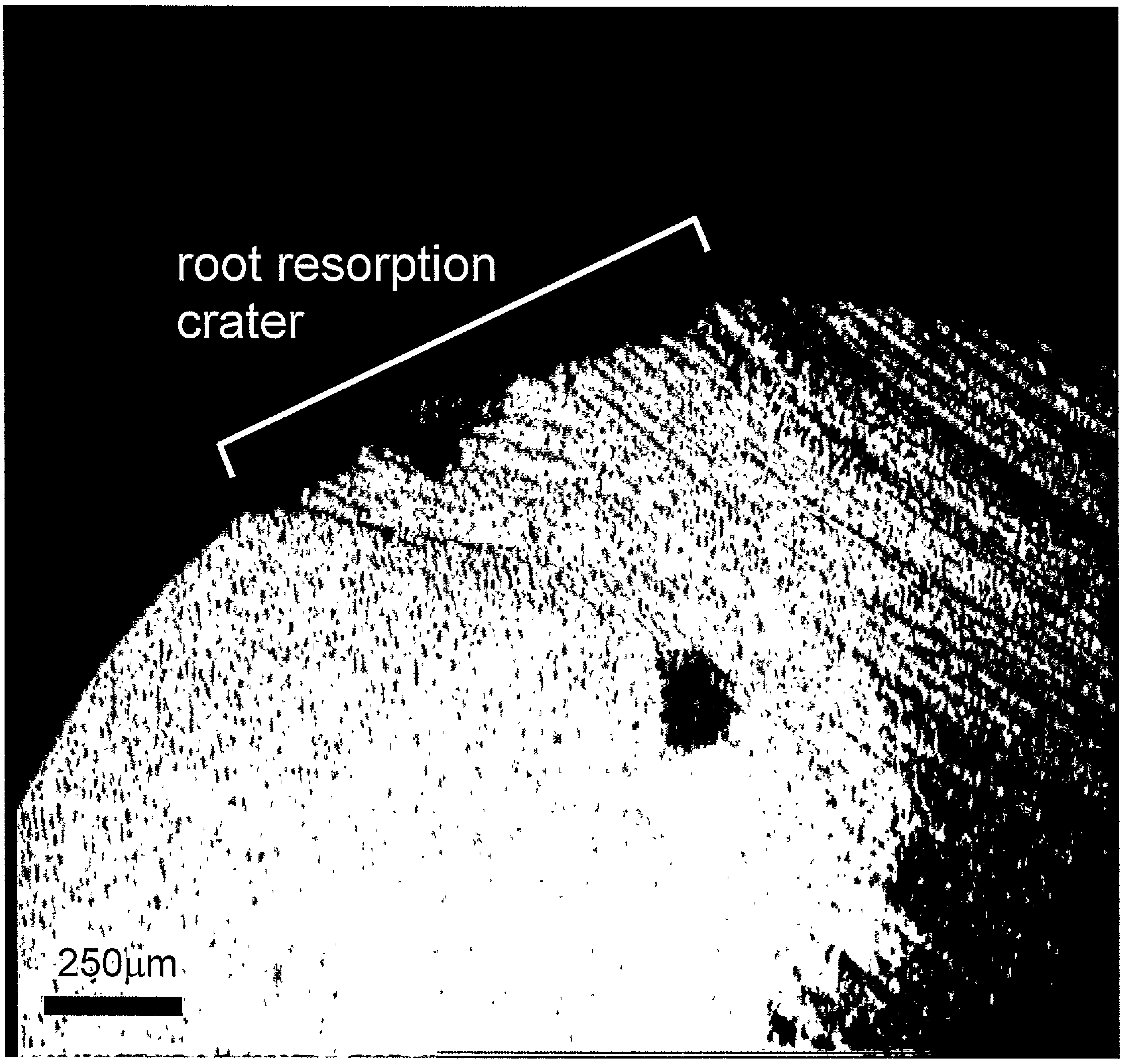


Figure 4: Cross-sectioned root resorption crater of sample tooth, prepared for analysis in the CSIRO-GEMOC NMP machine.

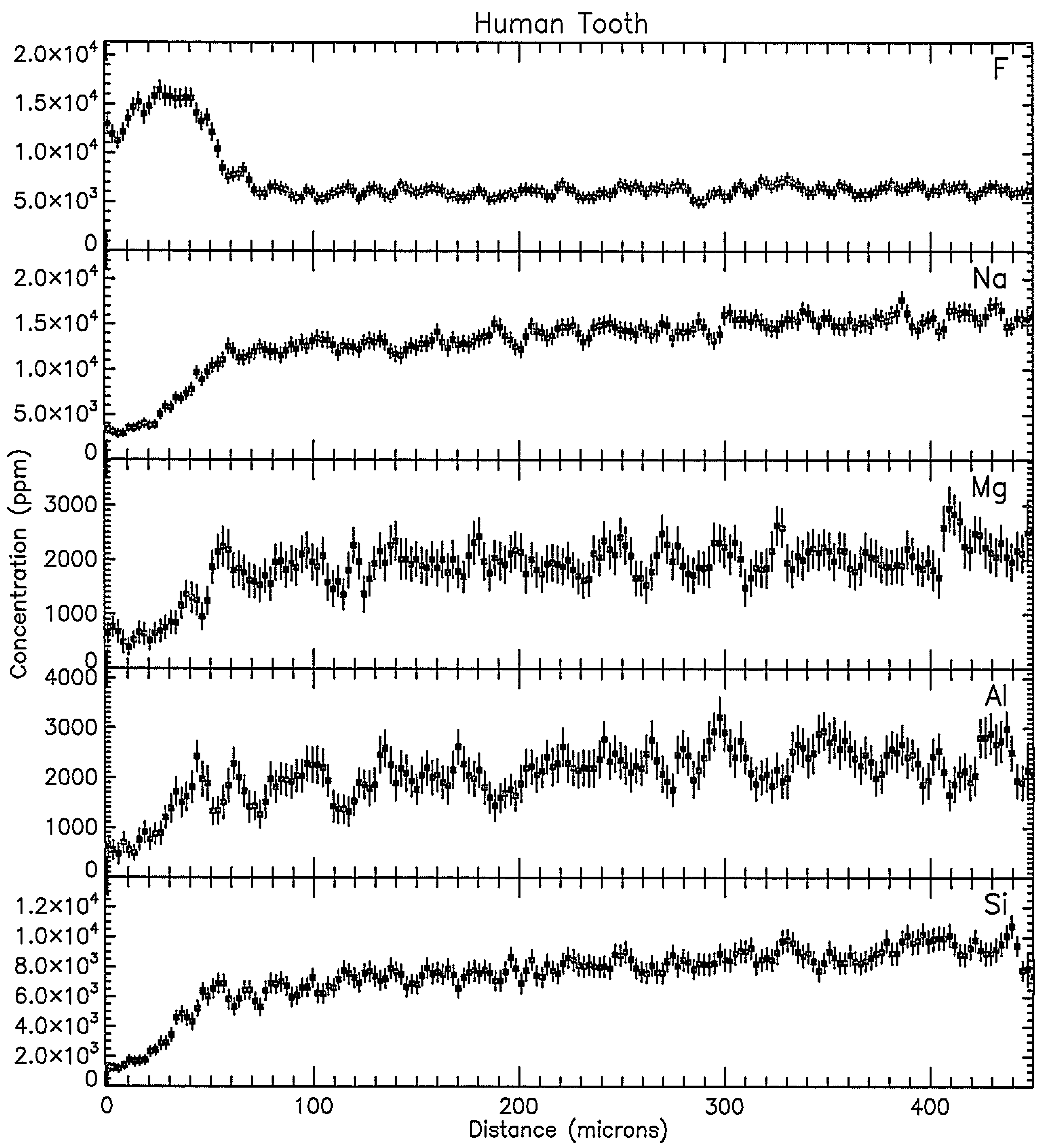


Figure 5: PIGE Spectral Plot (traverse concentration profile) demonstrating element concentrations from cementum to pulp through normal tooth structure (left to right of graph). Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

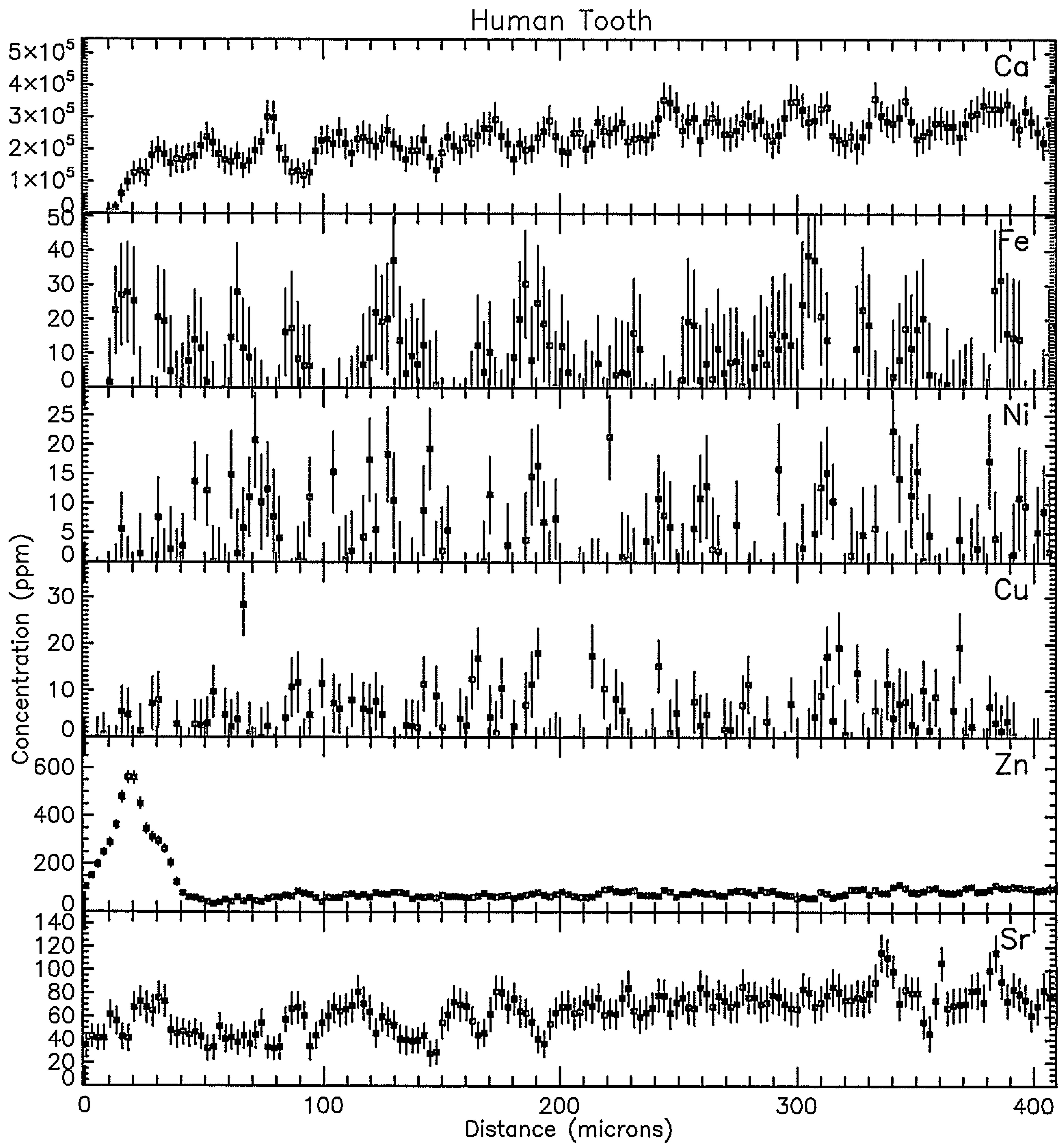


Figure 6: PIXE Spectral Plot (traverse concentration profile) demonstrating element concentrations from cementum to pulp through normal tooth structure (left to right of graph). Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

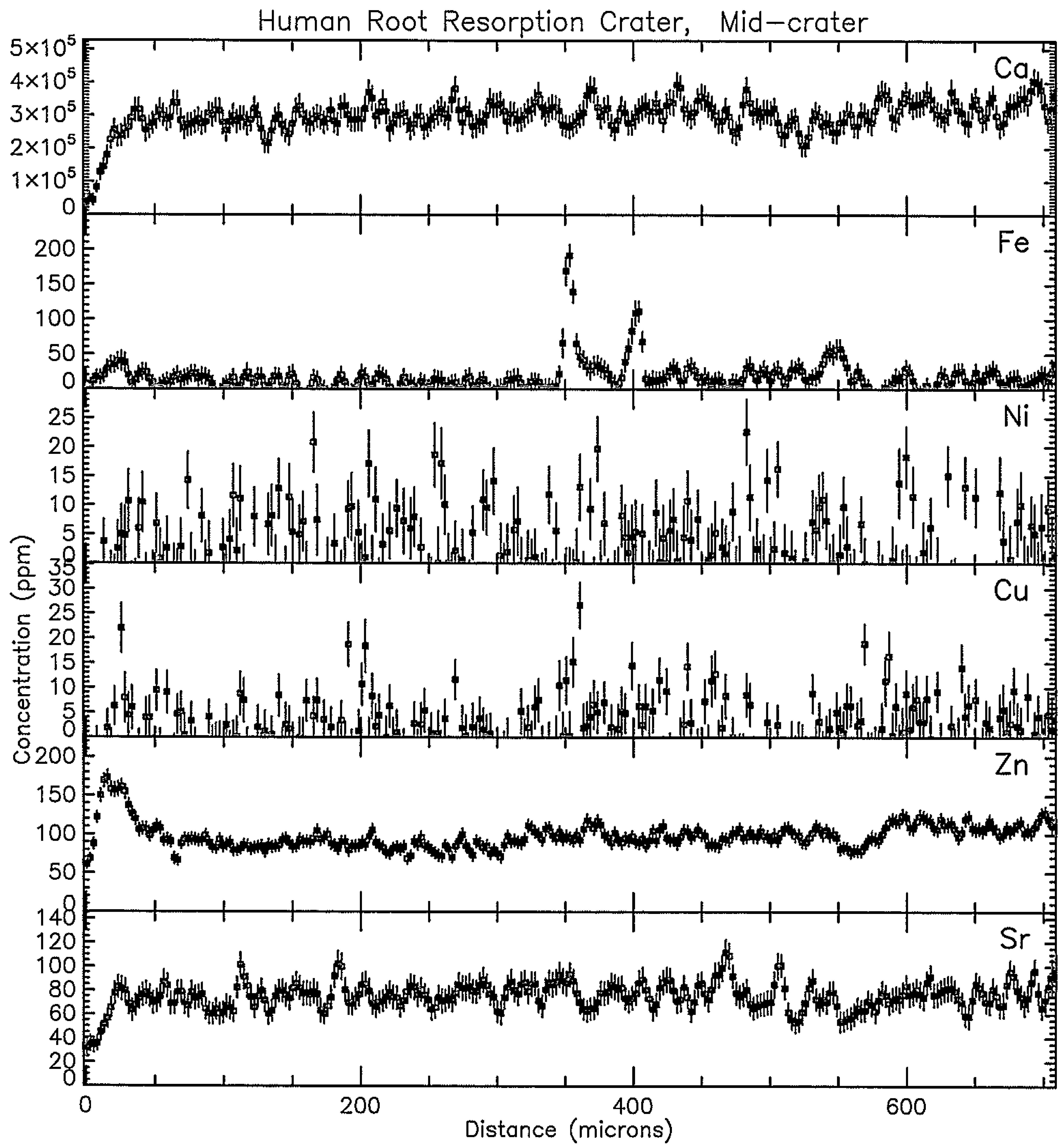


Figure 7: PIXE Spectral Plot (traverse concentration profile) demonstrating element concentrations from superficial to deep through the middle of the sample tooth root resorption crater (left to right of graph). Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

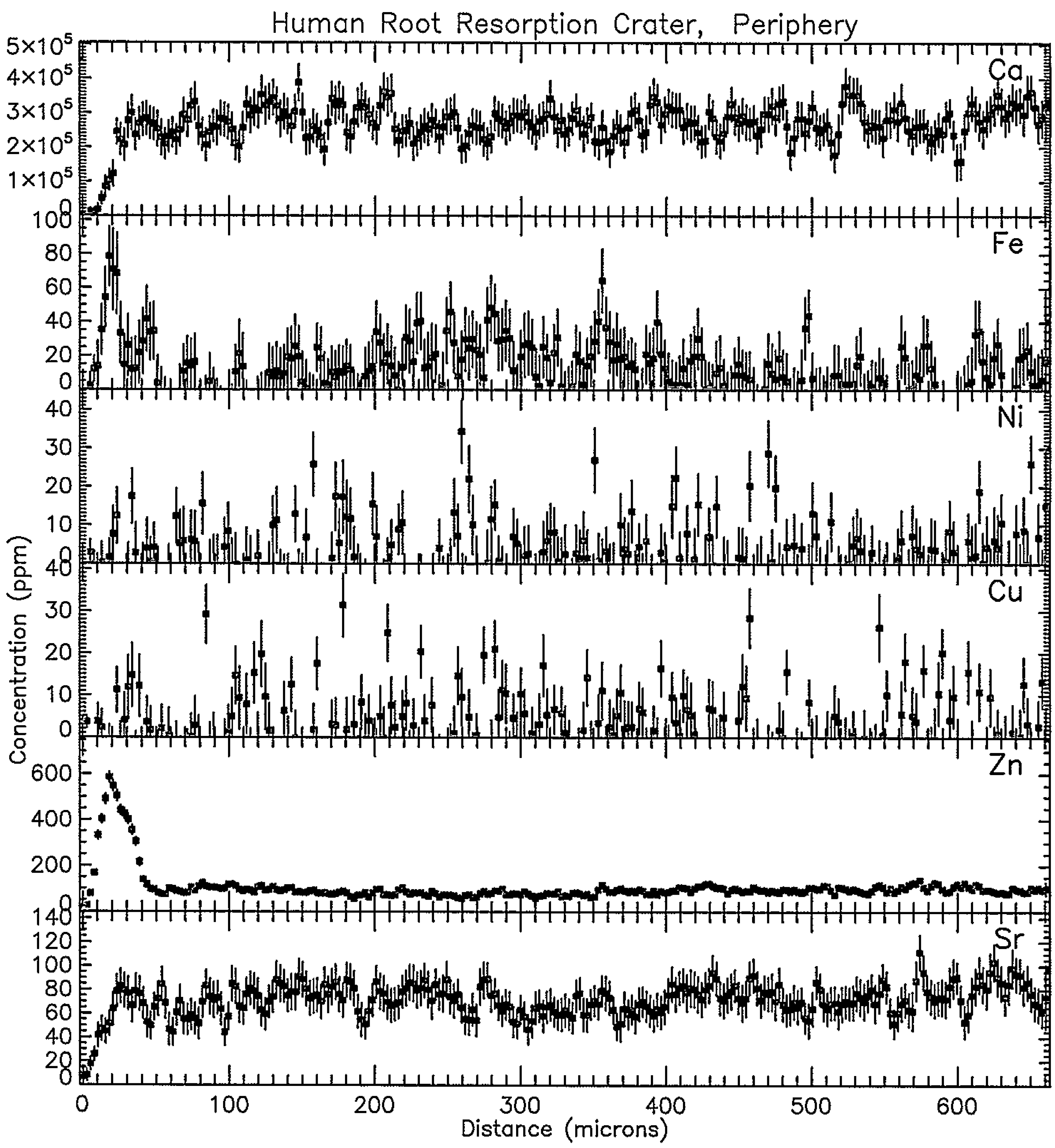


Figure 8: PIXE Spectral Plot (traverse concentration profile) demonstrating element concentrations from superficial to deep through the peripheral margin of the sample tooth root resorption crater (left to right of graph). Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

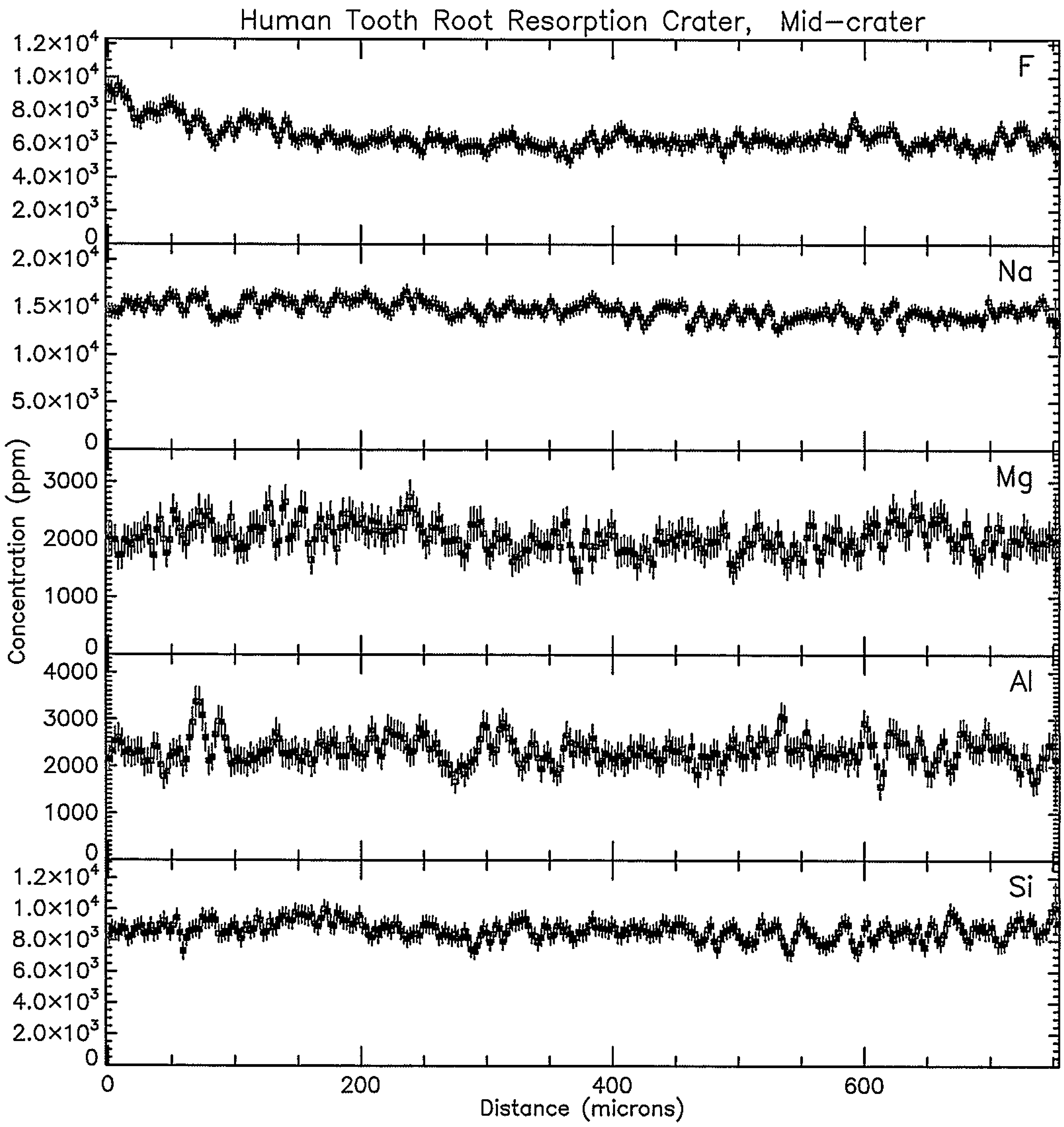


Figure 9: PIGE Spectral Plot (traverse concentration profile) demonstrating element concentrations from superficial to deep through the middle of the sample tooth root resorption crater (left to right of graph). Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

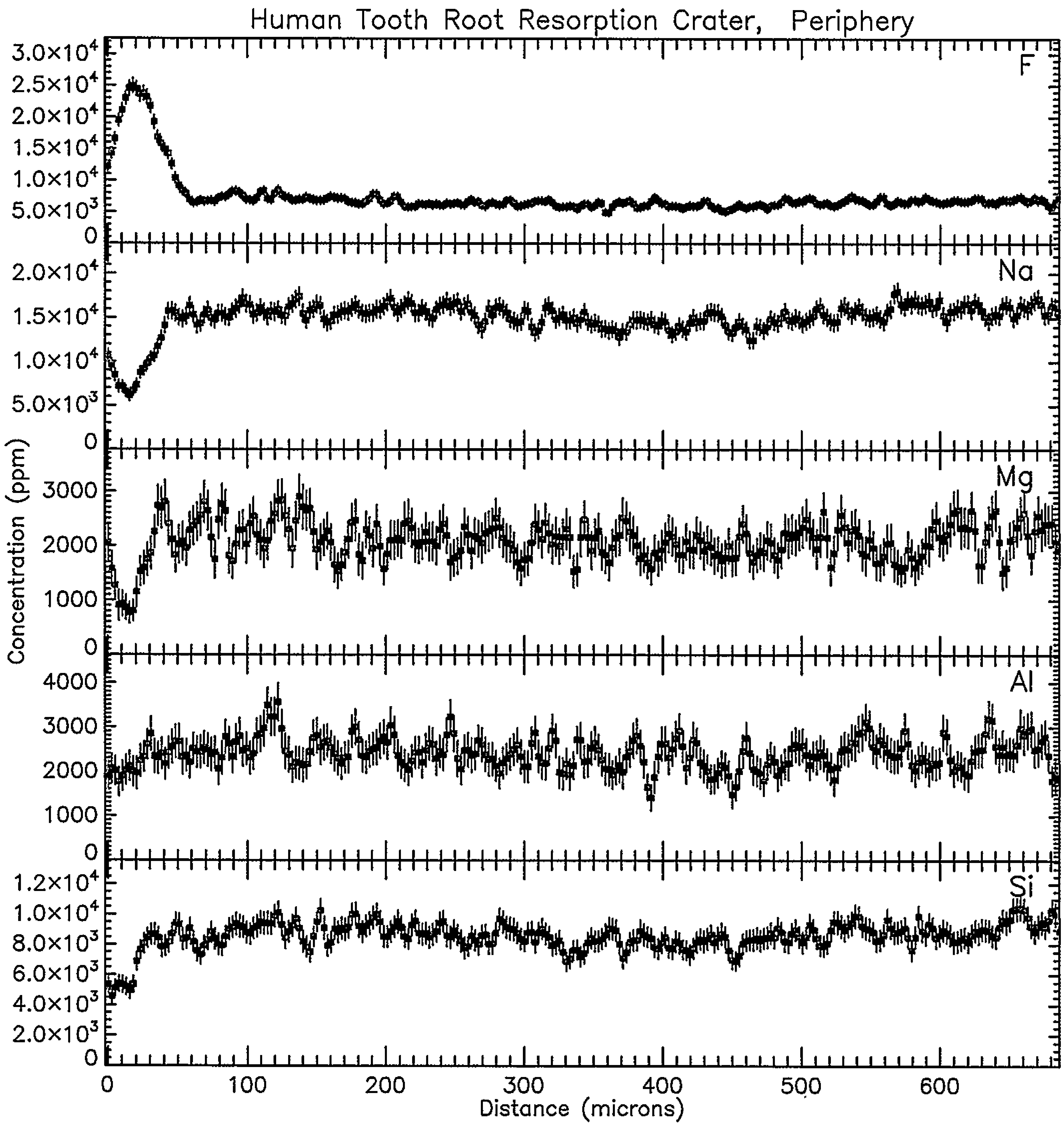


Figure 10: PIGE Spectral Plot (traverse concentration profile) demonstrating element concentrations from superficial to deep through the peripheral margin of the sample tooth root resorption crater (left to right of graph). Generated by the Geo-PIXE II™ Version 3.8 Computer Program.

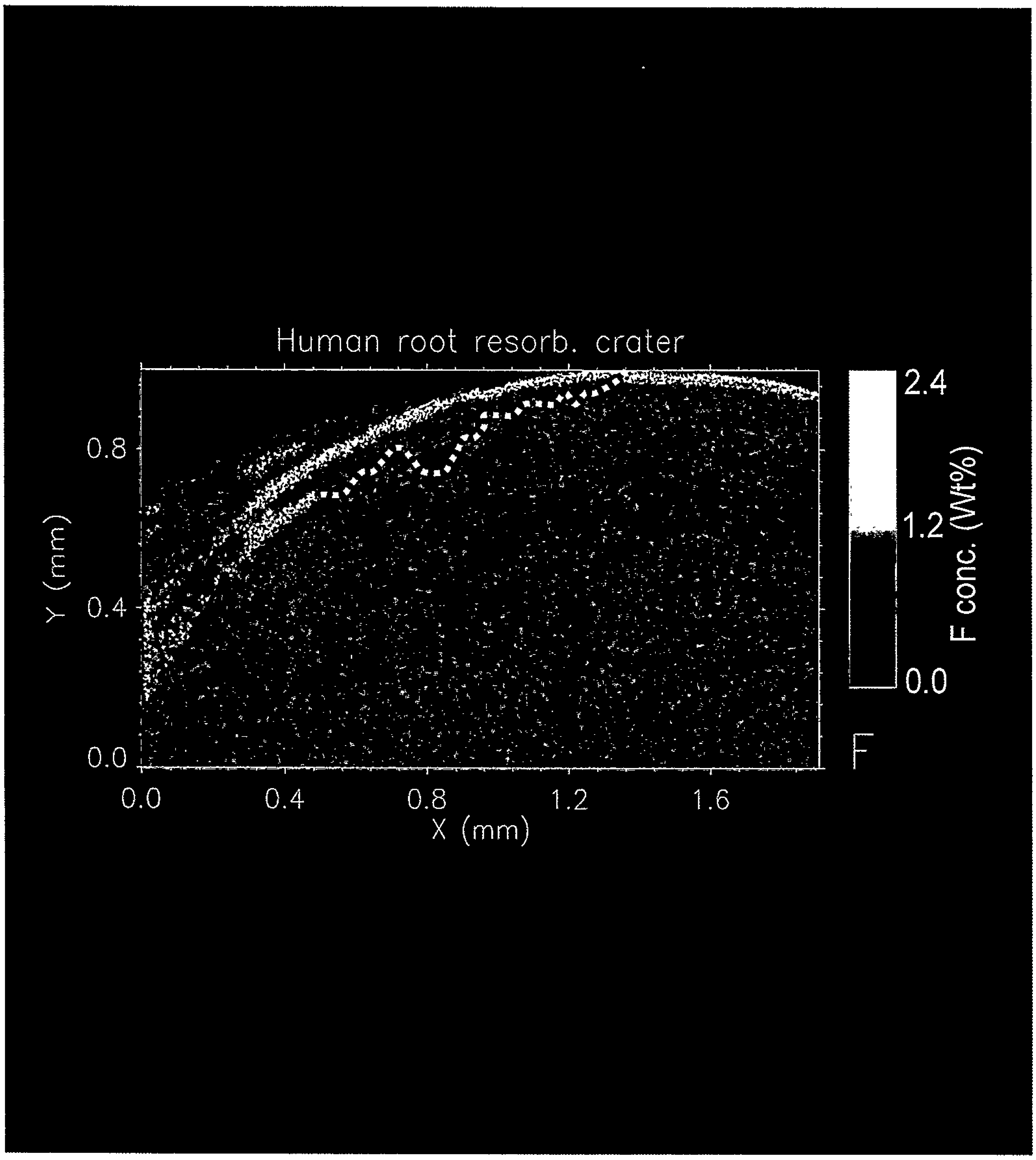


Figure 11: Picture Plot of the distribution of fluorine concentration in radicular dentine and cementum generated using the Geo-PIXE II™ Version 3.8 Computer Program. Surface of root resorption crater indicated by dotted white line.

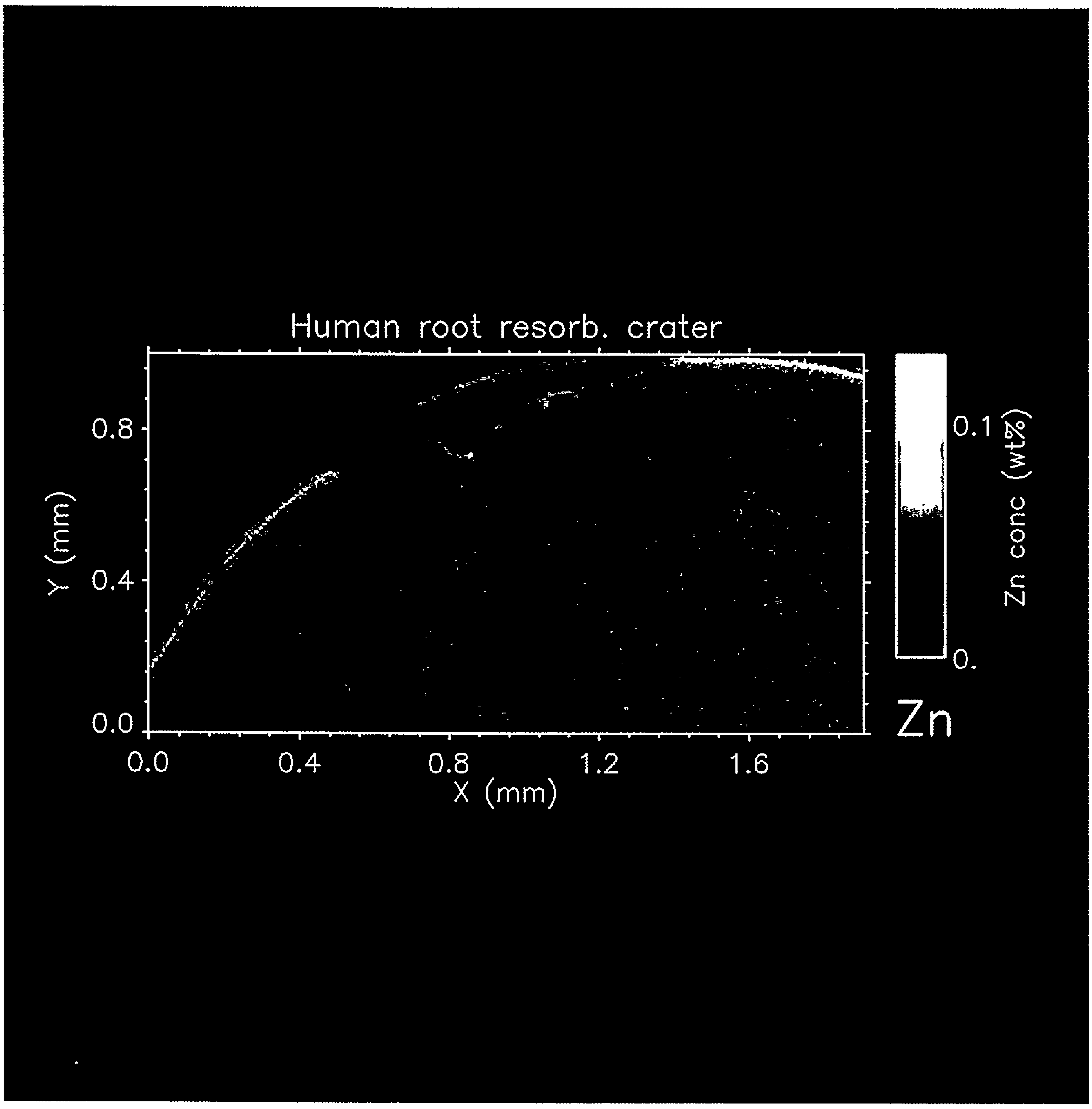


Figure 12: Picture Plot of the distribution of zinc concentration in radicular dentine and cementum, generated by the Geo-PIXE II™ Version 3.8 Computer Program.

6.9 Tables

Error of Measurement	F	Na	Mg	Al	Ca	Fe	Zn	Sr
MSE*	521.8	385.6	65.1	57.9	0.52	3.2	13.8	1.4
CV†	3.59	3.21	3.59	2.86	3.01	27.14	9.39	2.45

Table 1: Standard Error of Measurement and Coefficient of Variation for elements recorded

* Standard Error of Measurement

† Coefficient of Variation (%)

Area of Tooth	F†§	Na†§	Mg†§	Al†§	Ca‡§	Fe†§	Zn†§	Sr†§
RR* Cementum	19561 ± 207	9042 ± 142	1520 ± 58	1525 ± 58	4.8 ± 0.04	12 ± 2	145 ± 2	33 ± 2
RR* Dentine	8578 ± 133	13666 ± 168	1760 ± 60	2126 ± 66	25.3 ± 0.8	24 ± 3	116 ± 2	66 ± 2
Normal Cementum	24283 ± 391	9959 ± 254	1714 ± 106	2158 ± 118	12.1 ± 0.8	14 ± 3	283 ± 4	49 ± 3
Normal Dentine	6987 ± 106	16248 ± 162	2329 ± 61	2439 ± 63	27.1 ± 0.5	7 ± 2	87 ± 1	77 ± 1

Table 2: Mean element concentrations in cementum and dentine of human tooth structure and within root resorption craters

* Root resorption crater

† ppm

‡ %

§ Standard Deviation

7. Future Directions

This Thesis has presented information exploring the role of elemental composition on OIIRR craters and the impact of orthodontic force. It is hoped that this may form a basis from which future studies can develop. Limitations of currently available technology meant only selective root resorption craters could be examined and that the sample teeth required sectioning, which risks the loss of structural detail from the specimens. With the development of new technologies, there may be the ability to scan a tooth's surface in three-dimensions, and gather quantitative and qualitative elemental data from the entire intact craters and root surfaces.

Complementing laboratory and clinical based data are population-based studies. There may be two different approaches to increasing our knowledge regarding the impact of elements on OIIRR risk and prevention. Firstly, demographic surveys of those who have suffered severe root resorption investigating their history of exposure to elements such as fluorine. Alternatively, prospective studies examining teeth from areas of varied community water fluoridation protocols. Such studies would contribute to the knowledge base as to whether patients from non-fluoridated communities are at a risk of suffering more severe forms of OIIRR.

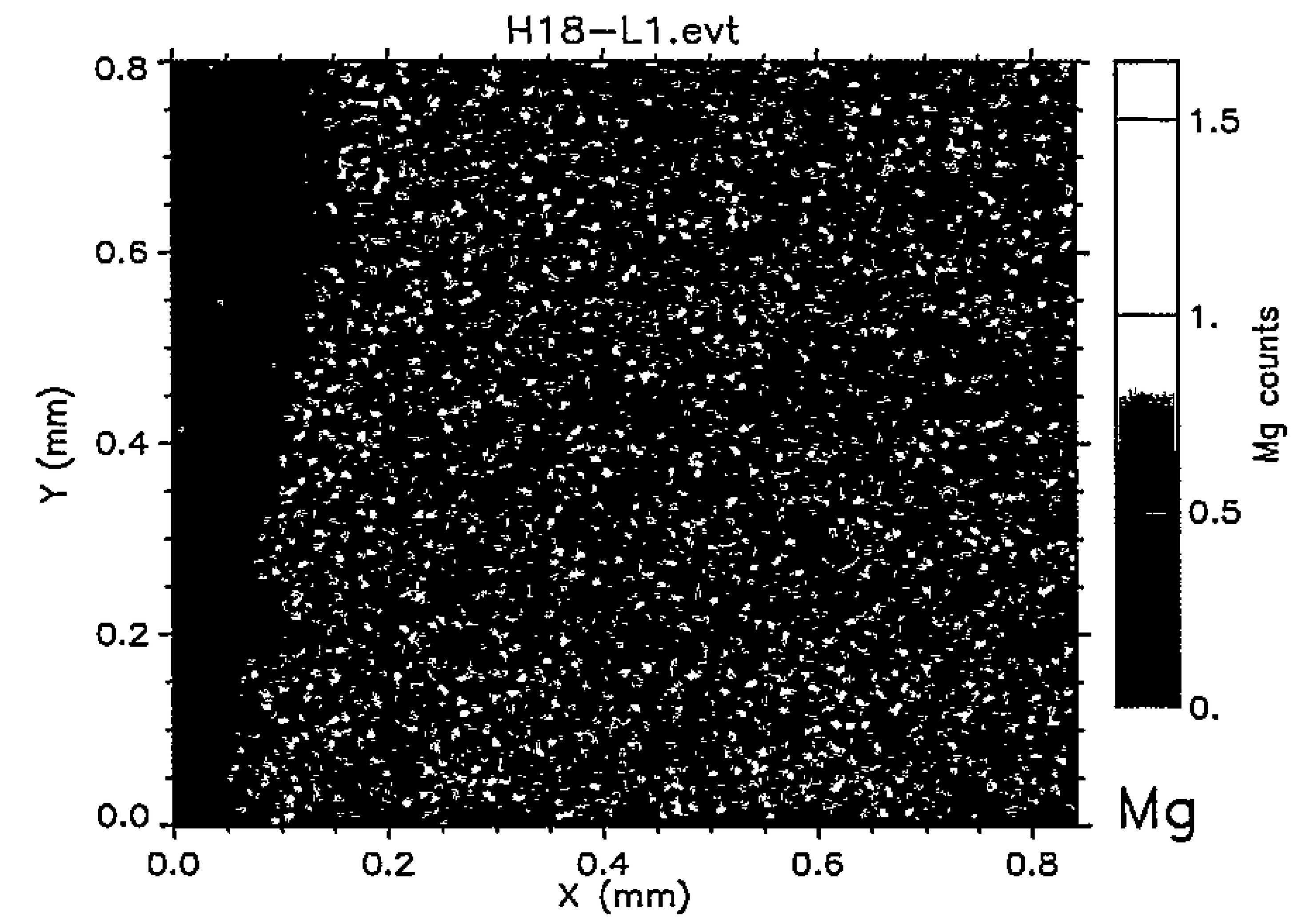
If such a link is established and fluoride is found to minimise OIIRR, then studies could be undertaken to examine whether it can prevent these lesions from developing. A future challenge would be the targeted delivery of fluoride directly to a tooth root *in vivo*.

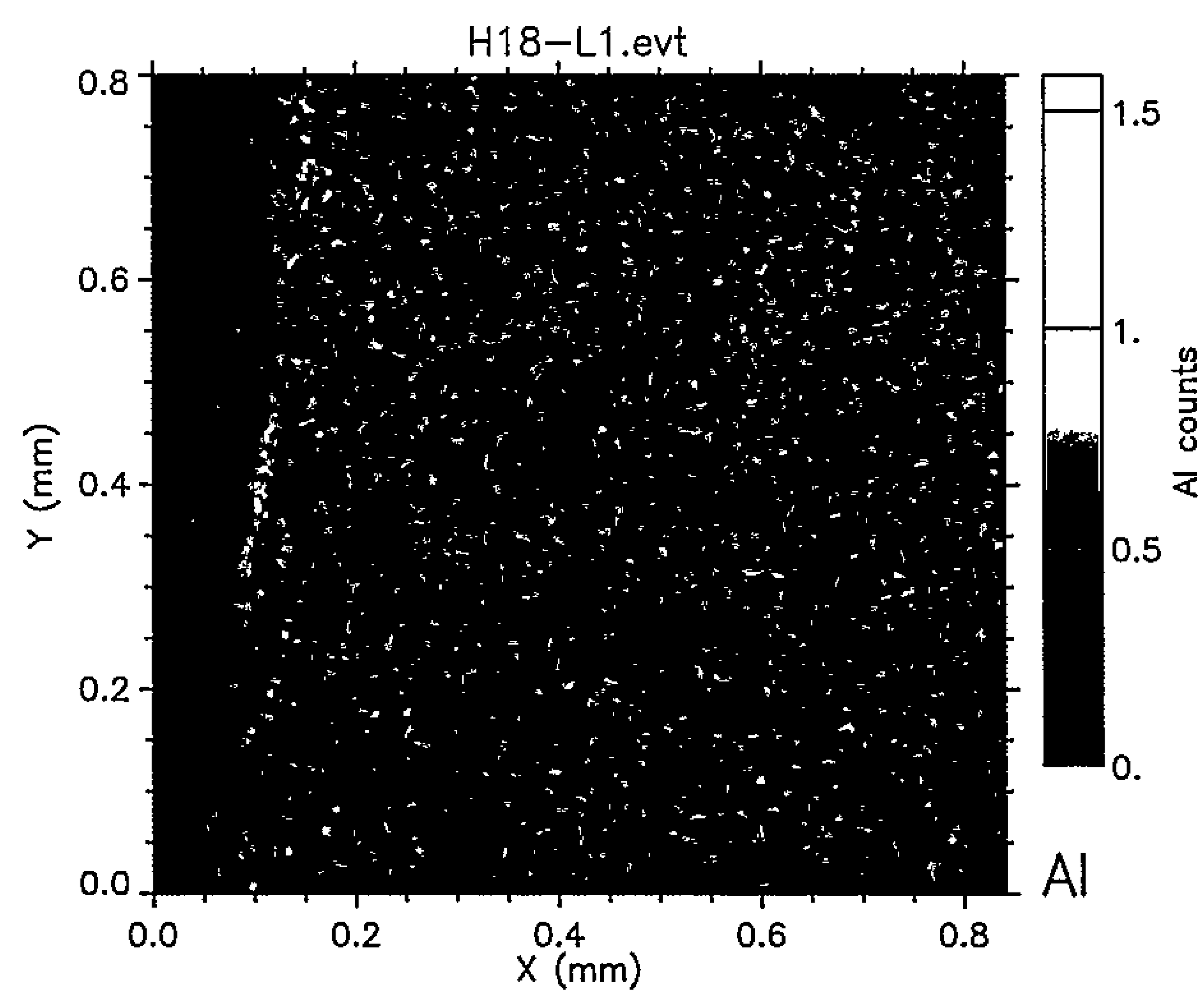
An initial step that the orthodontic profession would be able to implement is the inclusion of, as part of their medical history taking, questions regarding whether a patient grew up exposed to systemic fluoride, likelihood of fluoride exposure during treatment and factors that may affect uptake of other trace elements. Building on the current study it may be established that factors affecting elements at the level of the tooth root surface could influence whether an individual has an increased susceptibility to OIIRR.

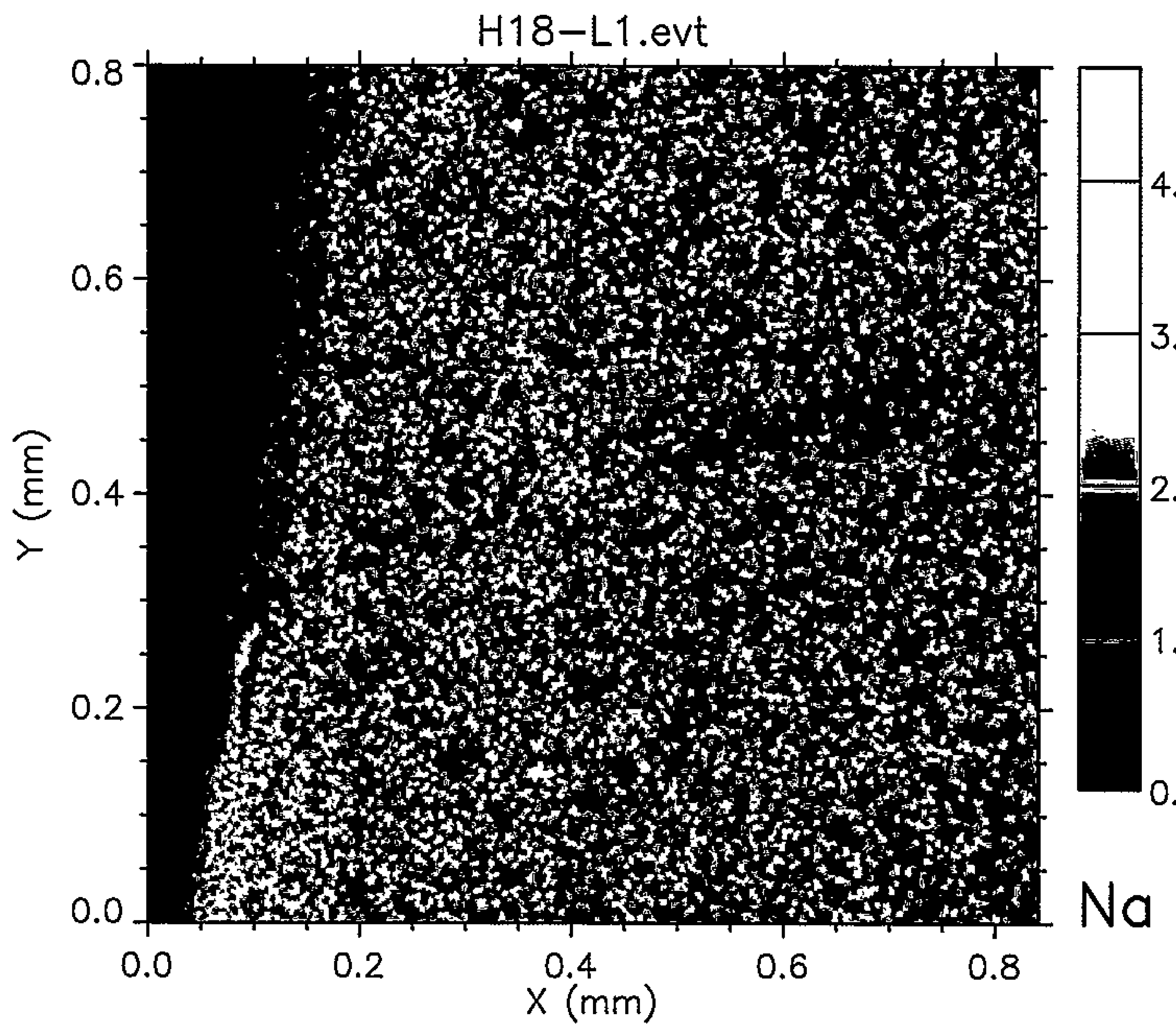
8. Appendices

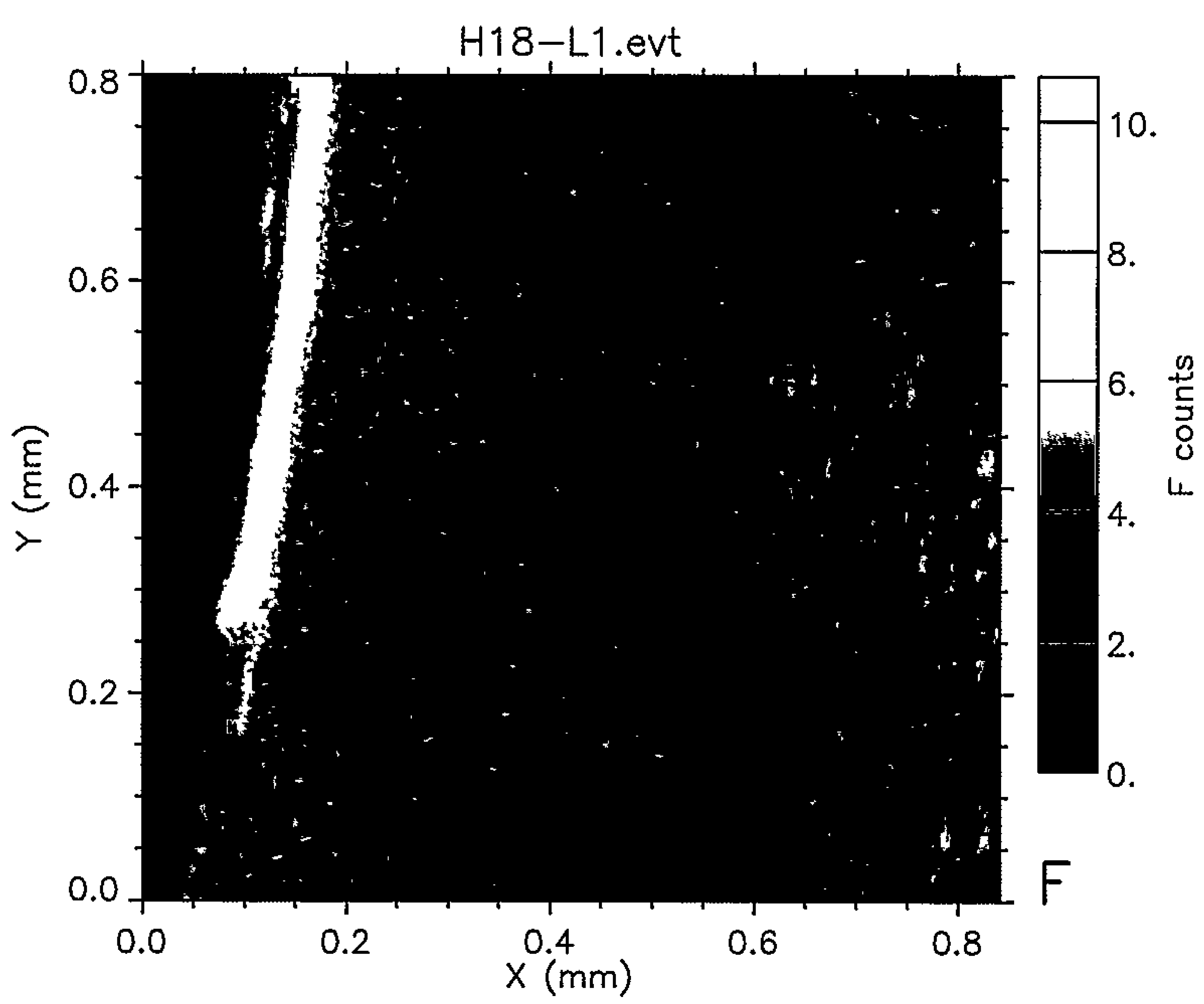
8.1 Example of selected data generated by CSIRO-GEMOC NMP for one tooth (Manuscript Two, Heavy Control Tooth)

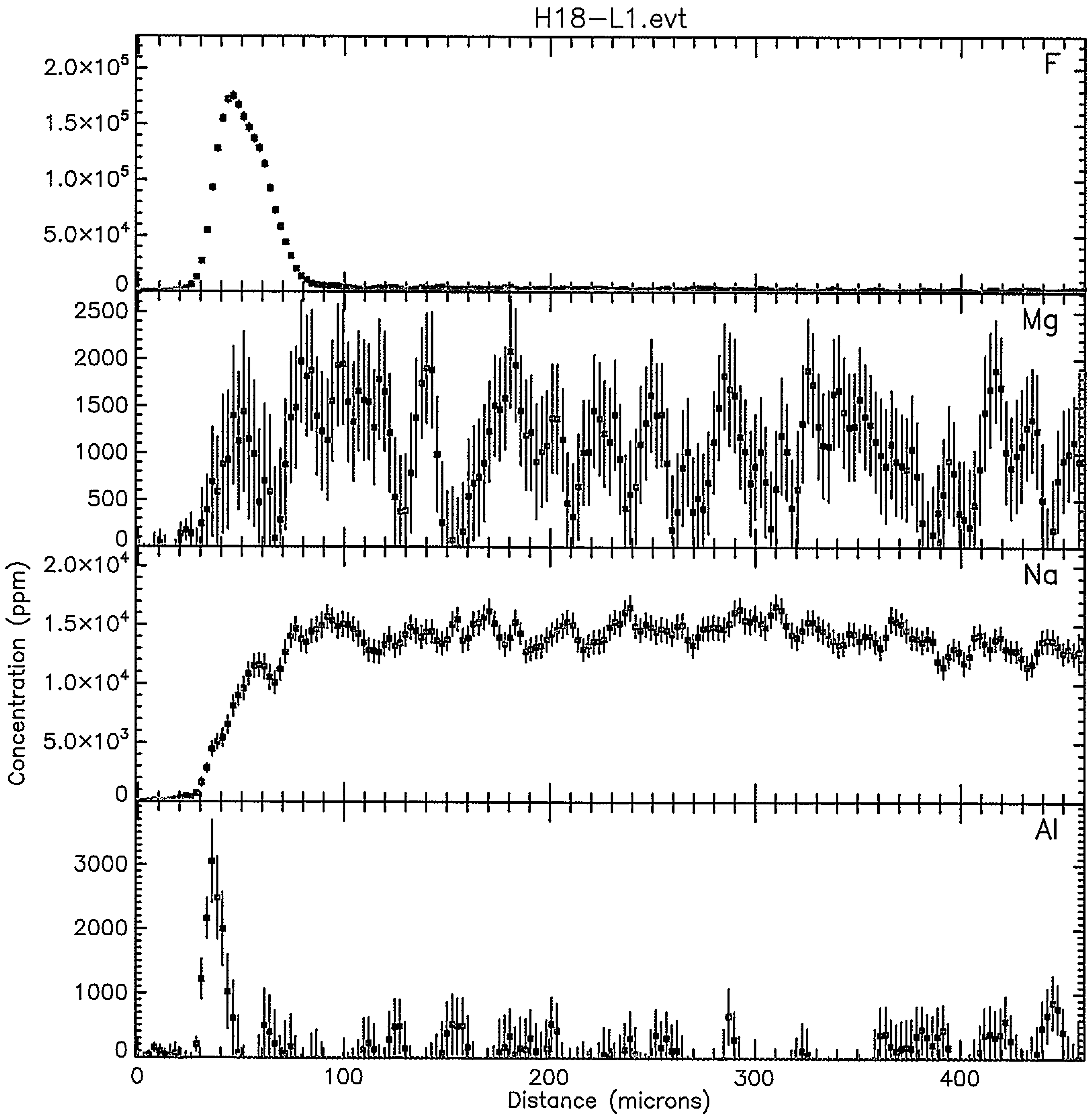
8.1.1 H18-L1 (Heavy-Control Tooth, Cementoenamel junction, Buccal) PIGE Mode






H18–L1.evt
0.8
0.6
0.4
0.2
0.0
Y (mm)
0.0
0.2
0.4
0.6
0.8
X (mm)
4.
3.
2.
1.
0.
Na counts
Na


H18–L1.evt
0.8
0.6
0.4
0.2
0.0
Y (mm)
0.0
0.2
0.4
0.6
0.8
X (mm)
10.
8.
6.
4.
2.
0.
F counts
F



H18−L1.evt
F
Mg
Na
Al
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
2500
2000
1500
1000
500
0
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
3000
2000
1000
0
Concentration (ppm)
0
100
200
300
400
Distance (microns)

microns	F	e_F	Mg	e_Mg	B	e_B	Na
0	-132.814	247.3926	-49.9056	119.3182	-18.8481	103.3326	-39.0568
2.540786	-176.865	247.3926	-94.2928	119.3182	7.659052	103.3326	-7.69156
5.081571	-53.0126	268.377	-141.015	162.7755	283.1366	123.0469	45.43492
7.622356	-115.351	268.377	-20.1707	162.7755	362.6696	123.0469	115.3553
10.16314	-153.8	338.6937	38.92624	133.4016	273.4304	178.9773	99.96766
12.70393	46.8681	338.6937	-16.7025	133.4016	15.05959	178.9773	54.69784
15.24471	361.458	520.6408	-95.71	103.3326	-18.754	133.4018	123.0469
17.7855	853.6341	520.6408	-34.9957	103.3326	5.547455	133.4018	253.7853
20.32628	1546.891	876.4279	143.8481	106.5617	138.4161	194.5542	367.1864
22.86707	3053.17	876.4279	178.4147	106.5617	42.85507	194.5542	522.9424
25.40786	6644.576	1379.165	143.2192	215.1035	-171.249	215.1039	453.7343
27.94864	13508.73	1379.165	-25.322	215.1035	-371.397	215.1039	779.9648
30.48943	27855.03	2017.914	248.6359	372.5708	-115.481	337.4828	1691.87
33.03021	55156.06	2017.914	391.3967	372.5708	517.3054	337.4828	2907.021
35.571	93638.63	2696.307	694.2433	583.662	521.8069	563.8716	4506.558
38.11178	128691.2	2696.307	587.676	583.662	133.2764	563.8716	5121.793
40.65257	155723.6	3184	883.1838	735.7126	212.3932	693.3339	5483.318
43.19336	173077.5	3184	928.315	735.7126	-61.6132	693.3339	6578.129
45.73414	176095.4	3391.39	1403.402	733.1026	-541.749	752.2725	8159.53
48.27493	168127.8	3391.39	1130.38	733.1026	-427.343	752.2725	9051.616
50.81571	157354.2	3470.711	1445.44	852.4931	770.0414	780.6449	9628.465
53.35649	147763.8	3470.711	1151.272	852.4931	768.8885	780.6449	10889.6
55.89728	137735.6	3255.263	994.7847	775.5676	360.6942	756.989	11558.72
58.43807	129176.3	3255.263	476.2787	775.5676	-25.4253	756.989	11635.63
60.97885	114956	2996.997	708.3181	813.8779	242.687	704.1679	11481.81
63.51964	93069.15	2996.997	590.9545	813.8779	-66.5615	704.1679	10593.35
66.06042	73351.55	2604.764	95.65388	753.5045	441.5294	671.1415	10140.74
68.60121	58485.72	2604.764	290.082	753.5045	899.9309	671.1415	11258.75
71.142	44243.14	2136.947	879.4587	693.1755	625.6991	543.5202	12750.75
73.68278	32268.99	2136.947	1384.522	693.1755	131.1648	543.5202	14096.54
76.22356	21002.65	1718.287	1488.619	648.0634	-102.704	516.6629	14696.34
78.76435	14234.53	1718.287	1982.422	648.0634	-43.7388	516.6629	13828.17
81.30514	10812.83	1385.479	1824.312	636.9843	96.74002	530.2616	13607.16
83.84592	7675.278	1385.479	1885.589	636.9843	196.0443	530.2616	14496.38
86.38671	6836.664	1157.558	1395.054	627.4175	223.8107	532.8086	14681.04
88.9275	6156.328	1157.558	1236.998	627.4175	185.7696	532.8086	15015.66
91.46828	5614.027	996.1324	1141.73	642.5476	805.0372	491.9615	15742.25
94.00906	5921.363	996.1324	1559.304	642.5476	1082.815	491.9615	15424.4
96.54985	5606.33	944.4169	1940.001	642.323	769.3472	532.8086	14927.17
99.09064	4960.301	944.4169	1954.826	642.323	-143.912	532.8086	15096.26
101.6314	4083.624	903.3083	1547.286	634.184	-777.006	462.1173	15042.49
104.1722	3506.881	903.3083	1335.894	634.184	-930.997	462.1173	14688.7
106.713	2906.91	909.8864	1662.441	636.4031	-490.369	507.3352	14304.18
109.2538	1776.558	909.8864	1568.518	636.4031	254.6473	507.3352	13519.78

111.7946	2242.221	901.4776	1547.591	611.3233	397.6367	499.1438	12906.28
114.3354	3422.179	901.4776	1276.83	611.3233	-14.6239	499.1438	12819.93
116.8761	3745.277	905.6198	1790.279	634.184	-91.0573	499.1438	12735.34
119.4169	3845.18	905.6198	1658.255	634.184	-58.4318	499.1438	13373.7
121.9577	4114.4	920.7812	1217.991	630.4271	259.8524	472.5705	13881.11
124.4985	4183.528	920.7812	532.2418	630.4271	832.7742	472.5705	13281.46
127.0393	3283.837	899.6885	378.0199	593.6001	1428.825	543.5202	13504.41
129.5801	2248.906	899.6885	390.0948	593.6001	969.0336	543.5202	14227.96
132.1208	2114.928	903.9748	790.0497	630.4268	492.8176	507.3352	14842.58
134.6616	3117.189	903.9748	1378.97	630.4268	384.7223	507.3352	14546.78
137.2024	3998.967	901.2738	1748.116	583.662	668.4902	484.436	14012.08
139.7432	3837.568	901.2738	1908.506	583.662	604.1394	484.436	14481
142.284	3491.441	875.6749	1891.4	612.8022	887.9706	455.9398	14504.12
144.8248	4195.347	875.6749	990.5533	612.8022	813.7938	455.9398	13703.19
147.3656	4614.15	890.4739	261.6792	645.3107	887.2764	465.9524	13473.57
149.9063	3668.393	890.4739	-48.0215	645.3107	585.3563	465.9524	13819.78
152.4471	2839.542	892.7345	74.90117	563.8707	650.6645	488.3271	15098.78
154.9879	2722.45	875.1773	0.901352	522.0431	452.6611	525.6564	15534.51
157.5287	3117.147	875.1773	164.5776	522.0431	657.8748	525.6564	13742.35
160.0695	3081.889	850.8821	543.688	608.4052	612.6271	438.403	13940.21
162.6103	3322.256	850.8821	682.9191	608.4052	316.7793	438.403	15127.07
165.1511	3537.552	851.5806	746.1757	619.9948	-66.7558	421.8535	15242.45
167.6918	2953.191	851.5806	898.2552	619.9948	-209.926	421.8535	15703.17
170.2326	3283.76	853.0578	1235.852	536.9314	133.4476	491.9615	16196
172.7734	3491.482	853.0578	1509.223	536.9314	860.6049	491.9615	15180.88
175.3142	3453.002	865.0684	1468.706	543.3599	977.7037	492.1875	14012.05
177.855	4275.983	865.0684	1591.059	543.3599	489.3527	492.1875	13435.09
180.3958	4906.035	863.683	2089.627	599.6556	148.6046	529.2446	13984.53
182.9366	3248.543	863.683	1944.736	599.6556	309.3117	529.2446	15272.79
185.4773	2276.383	847.8823	1458.418	581.4841	29.24788	442.4437	14342.68
188.0181	2914.68	847.8823	1196.175	581.4841	355.8701	442.4437	12796.96
190.5589	3237.649	857.9783	1225.652	612.1496	649.3705	460.3993	12989.09
193.0997	2830.094	857.9783	915.98	612.1496	396.6775	460.3993	13196.79
195.6405	2991.616	839.647	1019.606	584.5369	-541.084	450.4163	13273.69
198.1813	3491.364	839.647	1082.896	584.5369	-555.615	450.4163	13827.38
200.7221	2783.999	837.2521	1376.434	578.4158	33.97889	491.9615	14319.59
203.2628	2742.226	837.2521	1373.864	578.4158	569.9901	491.9615	14632.81
205.8036	3822.079	836.81	1150.282	540.2356	986.8871	488.3307	14996.35
208.3444	3376.116	836.81	471.1266	540.2356	783.4482	488.3307	15319.32
210.8852	3091.6	857.1886	328.3092	563.8708	405.7832	492.1875	15073.22
213.426	3106.862	857.1886	648.2163	563.8708	206.4451	492.1875	13819.7
215.9668	3076.212	845.6194	1013.706	553.2552	282.7072	450.4163	12966.09
218.5076	3059.116	845.6194	1018.12	553.2552	338.3357	450.4163	13311.74
221.0483	3837.546	855.0936	1458.014	599.6558	405.5537	468.5485	13642.83
223.5891	3837.455	855.0936	1374.851	599.6558	524.1481	468.5485	13665.87
226.1299	3234.443	835.9128	1214.718	565.9752	409.6424	462.1173	13835.99
228.6707	2937.693	835.9128	1127.77	565.9752	645.2836	462.1173	14865.6

231.2115	2837.815	831.7137	1416.146	581.4846	624.1105	491.9615	15334.65
233.7523	3242.186	831.7137	947.2472	581.4846	455.9333	491.9615	15195.43
236.2931	3229.917	845.3248	419.3648	567.2175	-67.1565	460.3993	16142.14
238.8338	2137.966	845.3248	568.9767	567.2175	-273.03	460.3993	16542.06
241.3746	2044.503	851.6399	646.3498	618.3023	-59.9777	472.5705	14962.54
243.9154	2653.181	851.6399	1100.521	618.3023	1.417463	472.5705	14627.27
246.4562	2668.56	848.6254	1330.285	596.5905	857.9994	516.6629	15119.29
248.997	2368.65	848.6254	1624.236	596.5905	1458.395	516.6629	14865.67
251.5378	2714.743	870.69	1410.704	550.282	1529.496	503.591	14496.41
254.0786	3360.707	870.69	1419.582	550.282	903.0885	503.591	14727.23
256.6194	3656.218	863.0351	902.3385	578.4158	380.432	516.6629	14585.84
259.1601	2960.7	863.0351	188.2207	578.4158	457.439	516.6629	14311.38
261.7009	2484.043	858.8762	382.7826	617.1179	720.6862	509.7275	14973.24
264.2417	2553.209	858.8762	850.8766	617.1179	695.6265	509.7275	15034.7
266.7825	3260.753	867.0987	1023.167	573.8514	517.9355	480.5134	13858.22
269.3233	4085.904	867.0987	383.8722	573.8514	773.0436	480.5134	13359.37
271.864	4222.033	846.3892	524.2119	587.5734	975.7924	473.5294	14081.22
274.4048	4052.902	846.3892	411.7705	587.5734	778.6241	473.5294	14773.24
276.9456	4187.314	841.873	692.6953	543.5197	470.0192	499.1438	14826.26
279.4864	3796.937	841.873	1125.005	543.5197	172.2292	499.1438	14890.59
282.0272	3260.678	856.9553	1495.615	557.1179	528.6298	456.27	14827.16
284.568	2491.296	856.9553	1831.649	557.1179	1306.46	456.27	14735.34
287.1088	2699.373	853.4692	1690.442	602.8037	1491.157	460.3993	15203.98
289.6496	3352.969	853.4692	1625.563	602.8037	1337.303	460.3993	16119.15
292.1903	3039.1	824.8322	1183.898	550.0292	686.6487	434.3247	16374.96
294.7311	2722.398	824.8322	1030.67	550.0292	-94.9869	434.3247	15480.84
297.2719	2530.182	824.7295	689.3889	557.1177	-611.276	456.27	15380.89
299.8127	2876.234	824.7295	864.3683	557.1177	-285.742	456.27	15688.44
302.3535	3578.095	810.4483	1022.111	584.5369	126.2365	477.2727	15226.56
304.8943	3383.759	810.4483	705.4025	584.5369	312.9567	477.2727	14888.73
307.4351	2354.95	829.0048	208.2506	599.6558	568.444	468.5485	15946.83
309.9758	1861.127	827.8799	628.505	615.2336	622.3704	525.6564	16634.4
312.5166	2445.52	827.8799	1195.02	615.2336	665.0836	525.6564	16357.49
315.0574	2745.494	806.9733	1025.819	509.7269	346.1984	520.0959	15050.22
317.5982	2722.398	806.9733	425.9606	509.7269	98.48109	520.0959	14258.05
320.139	2537.835	799.4492	624.023	619.9949	2.311907	454.3501	14011.97
322.6798	2176.361	799.4492	1327.602	619.9949	459.5037	454.3501	14619.53
325.2206	1367.235	813.9679	1890.973	546.8319	673.0587	480.5134	15320.3
327.7613	1315.103	813.9679	1740.491	546.8319	469.4747	480.5134	15334.69
330.3021	1637.997	804.3853	1296.162	556.4622	24.5309	438.403	14834.85
332.8429	1799.606	804.3853	1092.481	556.4622	-83.5985	438.403	14557.99
335.3837	2814.701	799.1466	1084.945	587.5735	467.7639	434.3247	14273.39
337.9245	3837.444	799.1466	1641.376	587.5735	457.2849	434.3247	13773.61
340.4653	2660.925	805.2614	1678.883	586.8956	33.08442	468.5485	13404.39
343.006	1787.044	805.2614	1447.389	586.8956	-209.217	468.5485	13478.42
345.5468	1791.88	792.6625	1288.477	565.9753	-141.136	499.1438	14381.05
348.0876	2070.283	792.6625	1294.478	565.9753	55.36718	499.1438	14328.1

350.6284	1599.623	811.6313	1584.989	553.7104	212.6867	480.5134	13750.59
353.1692	1584.267	811.6313	1401.492	553.7104	303.7731	480.5134	14173.39
355.71	2499.382	815.8721	1313.236	532.8082	290.3954	460.3993	14173.46
358.2508	3156.207	815.8721	1132.021	532.8082	489.6377	460.3993	13656.25
360.7915	2768.552	805.7542	988.3374	608.4052	459.4746	430.2078	13173.71
363.3323	1614.985	805.7542	872.9509	608.4052	-16.4129	430.2078	14081.25
365.8731	1098.013	819.5514	1107.432	570.5443	-582.751	492.1875	15583.3
368.4139	1399.613	819.5514	921.1542	570.5443	-860.605	492.1875	15396.3
370.9547	1585.968	815.5441	876.4738	546.832	-708.377	443.6518	15187.47
373.4955	1362.936	815.5441	836.8094	546.832	-390.604	443.6518	14652.05
376.0363	1253.591	794.7065	1052.086	575.3307	185.6086	477.2727	14012.01
378.5771	1937.993	794.7065	763.7742	575.3307	495.4871	477.2727	13958.07
381.1178	2710.884	784.5739	269.7921	530.261	830.2284	421.8535	13664.12
383.6586	2284.072	784.5739	-29.9354	530.261	771.8594	421.8535	13965.82
386.1994	1899.567	781.1912	144.4409	509.7272	626.6228	469.7561	13727.31
388.7402	2076.373	781.1912	376.2809	509.7272	251.6703	469.7561	12004.83
391.281	1734.384	783.0049	570.6331	593.5999	161.6633	465.9524	11546.93
393.8217	1684.282	783.0049	924.8516	593.5999	280.8891	465.9524	12489.18
396.3625	2688.046	797.1272	798.1187	546.8317	179.5387	472.5705	13077.13
398.9033	2753.142	797.1272	373.3071	546.8317	-88.0512	472.5705	12819.76
401.4441	1945.739	790.327	307.0145	612.15	-180.726	430.6641	11866.49
403.9849	1538.025	790.327	219.9509	612.15	23.60721	430.6641	12443.07
406.5257	846.0016	769.1102	456.0381	581.4844	342.2978	499.1438	14088.82
409.0665	553.7018	769.1102	841.627	581.4844	285.4198	499.1438	14211.92
411.6073	1584.272	783.8265	1446.023	605.9351	-71.8095	408.1003	13535.15
414.148	2976.494	783.8265	1690.173	605.9351	42.85975	408.1003	13125.07
416.6888	2999.254	791.0621	1891.57	539.8652	253.0295	452.1031	13842.73
419.2296	1853.4	791.0621	1710.472	539.8652	416.6487	452.1031	14035
421.7704	1461.279	786.595	1025.524	543.5197	23.90076	477.2727	13058.38
424.3112	2483.953	786.595	850.9617	543.5197	-261.212	477.2727	12904.52
426.852	2922.361	804.6512	985.0737	599.6555	-103.57	476.5585	12881.51
429.3928	2960.828	804.6512	1087.457	599.6555	505.394	476.5585	12320
431.9335	3255.989	783.4207	1282.54	549.3288	563.1503	494.7355	11540
434.4743	3206.935	783.4207	1364.619	549.3288	202.0216	494.7355	11774.02
437.0151	2726.527	808.0186	1246.72	602.8032	-41.8919	464.4917	12859.42
439.5559	1976.341	808.0186	509.7484	602.8032	32.15227	464.4917	13705.42
442.0967	1384.275	805.8911	-108.679	532.808	-149.46	514.742	13789.01
444.6375	1491.959	805.8911	188.5919	532.808	-151.972	514.742	13735.07
447.1783	1953.123	800.4946	717.837	540.2356	83.07848	469.7561	13335.94
449.7191	2507.101	800.4946	927.9952	540.2356	239.1289	469.7561	12712.33
452.2598	2676.243	816.2518	1000.62	491.9611	478.2868	473.5294	13012.17
454.8006	2599.391	816.2518	1123.866	491.9611	376.3699	473.5294	12627.68
457.3414	2607.03	1296.549	919.3047	957.8044	413.1487	786.9172	12812.33
459.8822	3501.32	1296.549	926.9195	957.8044	353.2484	786.9172	13792.32

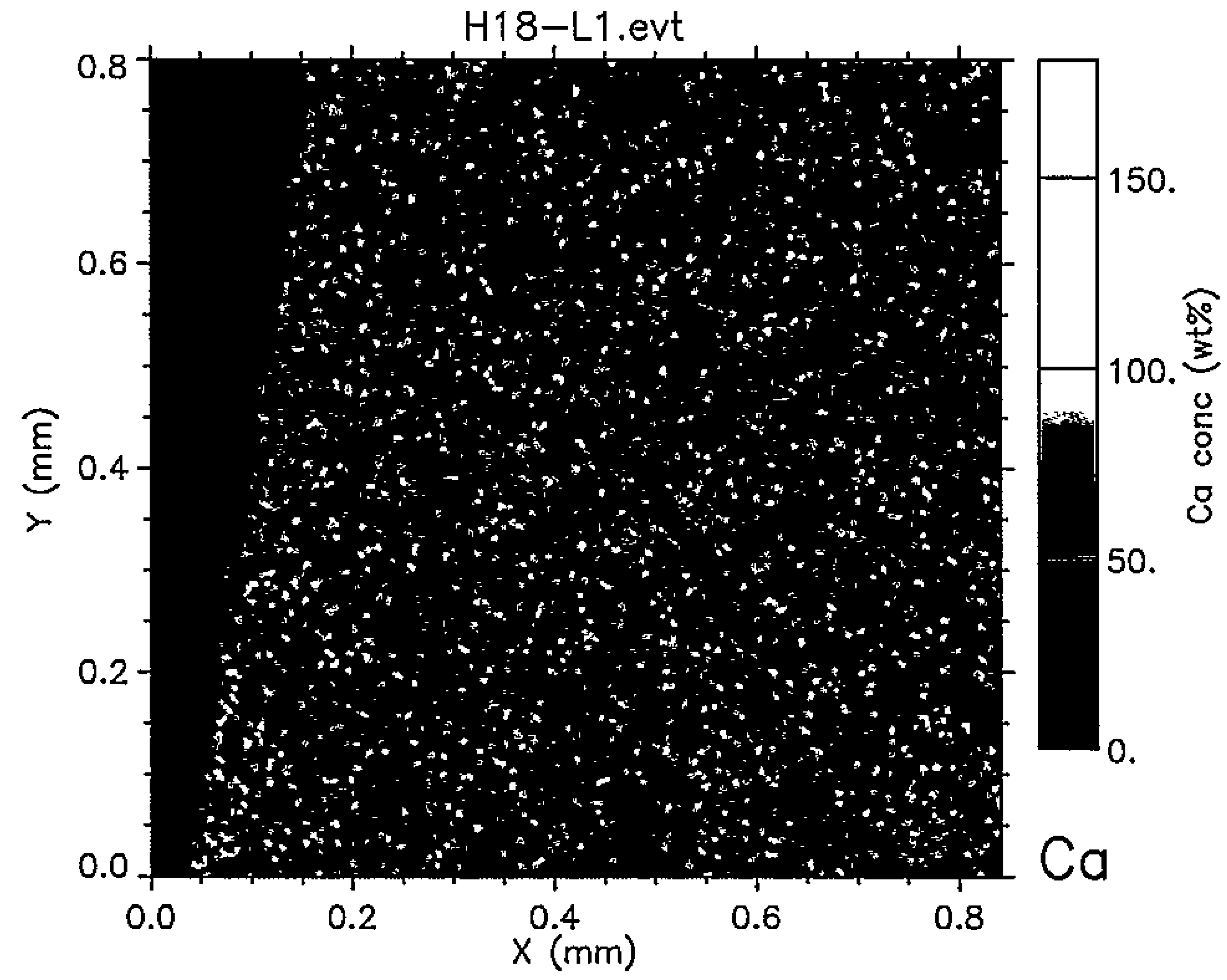
microns	e_Na	Al	e_Al	Si	e_Si	P	e_P
0	119.3182	-26.1271	103.3326	-61.6783	59.65909	-17.9476	21.15628
2.540786	119.3182	-38.9254	103.3326	-25.7189	59.65909	23.62961	21.15628
5.081571	0	39.91941	61.52344	0	0	49.0535	61.52344
7.622356	0	158.0426	61.52344	25.71887	0	36.61346	61.52344
10.16314	103.3326	106.6048	84.3707	34.99569	59.65909	0	0
12.70393	103.3326	46.8222	84.3707	26.1271	59.65909	0	0
15.24471	119.3182	31.066	157.8431	0	0	0	0
17.7855	119.3182	73.92107	157.8431	-36.6135	0	0	0
20.32628	137.5706	-24.4837	162.7757	-50.6108	61.52344	0	0
22.86707	137.5706	-75.5388	162.7757	-47.5081	61.52344	73.22691	0
25.40786	197.8668	-41.9606	103.3326	43.57835	103.3326	136.2534	103.3326
27.94864	197.8668	210.8389	103.3326	56.79197	103.3326	129.5787	103.3326
30.48943	352.948	1226.045	309.9977	95.01608	146.1343	52.85693	99.01487
33.03021	352.948	2170.635	309.9977	342.7276	146.1343	140.9622	99.01487
35.571	618.3029	3060.16	642.3235	735.9402	358.7402	339.4015	195.832
38.11178	618.3029	2490.126	642.3235	720.0212	358.7402	505.8703	195.832
40.65257	748.4649	2005.822	573.8524	716.0273	403.4361	529.7914	210.9324
43.19336	748.4649	1031.828	573.8524	1173.233	403.4361	657.6315	210.9324
45.73414	854.1882	621.2116	575.3315	1548.866	450.4163	664.766	223.272
48.27493	854.1882	84.81565	575.3315	1140.106	450.4163	615.2388	223.272
50.81571	955.1006	-464.186	645.2632	696.3206	443.6518	536.1889	245.1714
53.35649	955.1006	-1147.01	645.2632	1147.3	443.6518	586.9772	245.1714
55.89728	958.2668	-1108.81	596.5909	1895.294	465.9524	523.4526	218.252
58.43807	958.2668	-248.141	596.5909	1953.897	465.9524	434.8699	218.252
60.97885	1029.484	506.0242	563.8716	1199.432	384.2137	400.2657	159.8962
63.51964	1029.484	406.6296	563.8716	1123.475	384.2137	314.4161	159.8962
66.06042	906.2968	223.3712	511.052	1561.445	348.0291	259.9819	139.2899
68.60121	906.2968	-168.214	511.052	1547.448	348.0291	206.9195	139.2899
71.142	939.5123	73.92105	491.9615	1187.843	342.7154	259.3101	135.069
73.68278	939.5123	179.3087	491.9615	1196.861	342.7154	185.7102	135.069
76.22356	1014.205	-96.1109	430.2078	1276.359	352.948	45.49482	96.72826
78.76435	1014.205	-381.137	430.2078	1246.211	352.948	-46.1199	96.72826
81.30514	963.8221	-431.693	442.4437	1471.234	367.7633	-37.6808	70.01408
83.84592	963.8221	-66.9561	442.4437	1659.801	367.7633	38.1388	70.01408
86.38671	1029.484	-13.436	452.1031	1646.223	336.9778	47.73071	65.27735
88.9275	1029.484	-212.602	452.1031	1604.508	336.9778	160.9501	65.27735
91.46828	987.5338	-474.328	442.4437	1453.156	315.6862	324.8905	168.7414
94.00906	987.5338	-460.885	442.4437	1414.836	315.6862	333.557	168.7414
96.54985	1018.394	-515.795	488.3271	1530.112	384.2137	157.3484	0
99.09064	1018.394	-420.149	488.3271	1842.668	384.2137	36.61346	0
101.6314	992.9251	-328.133	400.2054	1763.199	352.948	73.44956	59.65909
104.1722	992.9251	-255.342	400.2054	1355.627	352.948	178.6067	59.65909
106.713	997.7425	-207.168	488.3271	1188.537	336.9778	173.0895	124.9661
109.2538	997.7425	129.2884	488.3271	938.4556	336.9778	105.9769	124.9661
111.7946	939.5123	231.1519	395.7336	1117.954	309.9977	-14.6056	0

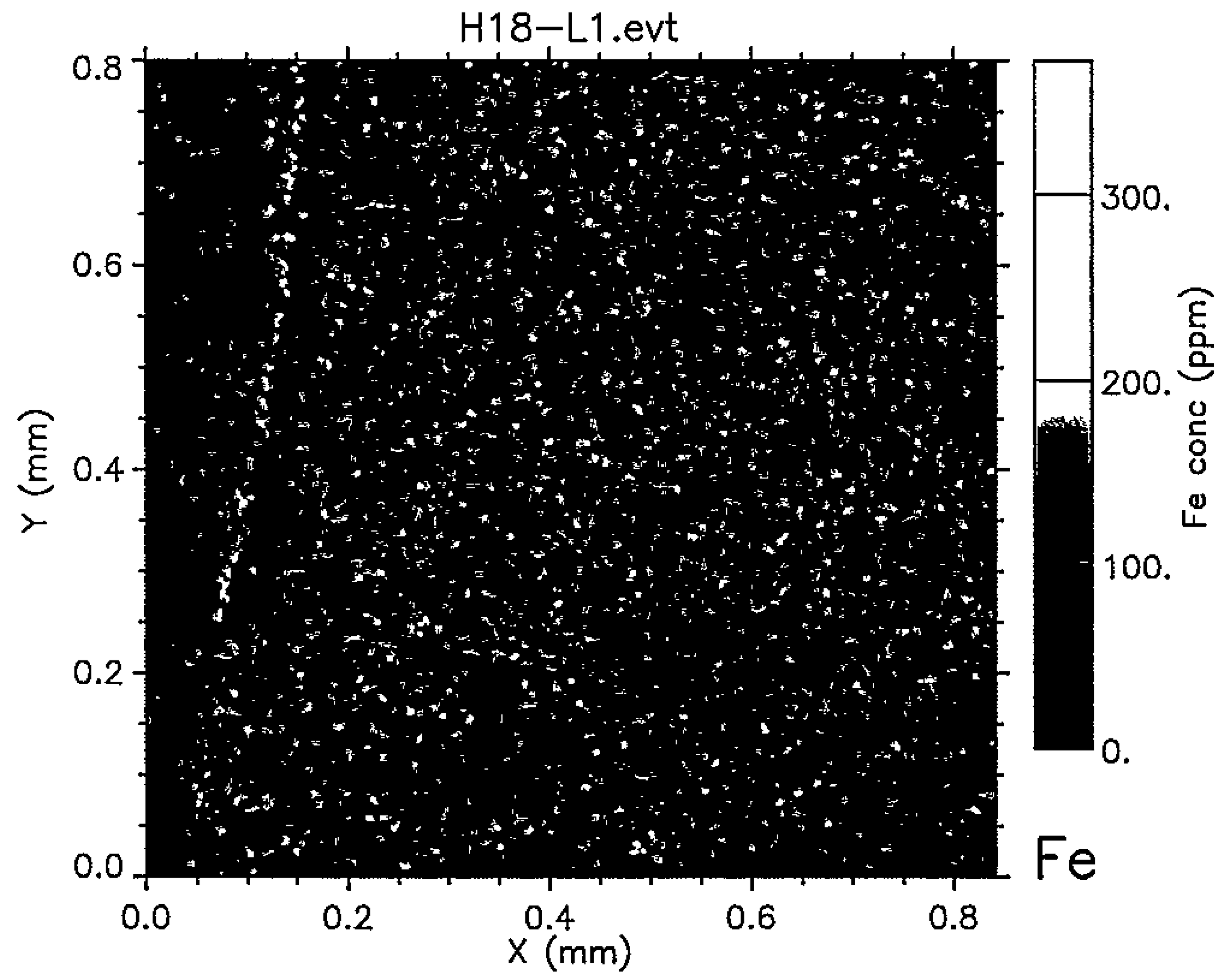
114.3354	939.5123	132.8175	395.7336	1143.112	309.9977	20.33987	0
116.8761	916.5004	-186.073	382.0046	1230.669	326.7663	40.69955	63.29926
119.4169	916.5004	-227.834	382.0046	1249.746	326.7663	73.22691	63.29926
121.9577	964.9574	286.2363	430.6641	1295.807	342.548	101.2577	87.00728
124.4985	964.9574	487.5345	430.6641	1301.584	342.548	108.2226	87.00728
127.0393	947.0587	489.3818	413.3303	1258.299	352.948	133.9415	59.65909
129.5801	947.0587	149.4369	413.3303	1269.043	352.948	123.4302	59.65909
132.1208	988.2127	-243.953	435.0364	1236.016	336.9778	73.22691	87.00728
134.6616	988.2127	-631.872	435.0364	1162.9	336.9778	37.19462	87.00728
137.2024	972.7709	-637.918	447.8974	1048.325	348.0291	86.43342	87.00728
139.7432	972.7709	-385.382	447.8974	984.1747	348.0291	73.44957	87.00728
142.284	946.1659	-205.751	440.9868	979.0279	295.2557	29.84091	20.53404
144.8248	946.1659	-78.883	440.9868	1071.306	295.2557	65.19137	20.53404
147.3656	929.9932	75.53882	480.987	1299.766	304.2029	119.3398	84.3707
149.9063	929.9932	389.312	480.987	1238.822	304.2029	141.9932	84.3707
152.4471	1025.801	525.7332	464.4917	987.0128	295.056	133.9122	110.9387
154.9879	976.6543	495.5942	435.0364	767.0353	336.9778	117.8921	123.0469
157.5287	976.6543	496.9463	435.0364	1120.506	336.9778	168.1479	123.0469
160.0695	987.5338	171.377	484.6728	1348.458	332.1678	144.6392	29.9195
162.6103	987.5338	-231.563	484.6728	1550.913	332.1678	43.14962	29.9195
165.1511	989.3341	-605.635	480.987	1424.201	362.8921	52.96307	86.98277
167.6918	989.3341	-712.399	480.987	1449.186	362.8921	79.28188	86.98277
170.2326	996.5033	-650.03	386.6351	1245.493	337.4828	49.34848	0
172.7734	996.5033	-194.856	386.6351	1246.911	337.4828	25.71887	0
175.3142	970.8234	101.7807	499.8188	1054.366	319.6852	45.89027	87.00728
177.855	970.8234	170.5258	499.8188	1113.693	319.6852	77.1566	87.00728
180.3958	1036.811	338.242	426.2469	1143.113	307.6172	61.67827	0
182.9366	1036.811	56.56605	426.2469	1276.098	307.6172	36.05017	0
185.4773	894.8864	153.9708	480.987	1139.182	321.274	0	0
188.0181	894.8864	135.0071	480.987	1319.243	321.274	0	0
190.5589	924.9001	310.738	439.3652	1477.457	379.2559	25.71887	87.00728
193.0997	924.9001	107.1278	439.3652	1456.885	379.2559	93.39831	87.00728
195.6405	948.9359	-35.5187	438.403	1278.9	347.8693	132.6804	63.29926
198.1813	948.9359	153.4187	438.403	1468.903	347.8693	66.23013	63.29926
200.7221	941.4046	530.9126	417.6136	1553.49	337.4828	-14.6262	29.9195
203.2628	941.4046	428.6646	417.6136	1453.411	337.4828	-2.62526	29.9195
205.8036	992.9251	-71.3797	315.6862	1363.687	367.7633	23.85227	59.65909
208.3444	992.9251	-407.372	315.6862	1555.136	367.7633	47.50805	59.65909
210.8852	974.7145	-389.312	398.7174	1612.816	325.5514	58.91578	92.31612
213.426	974.7145	-226.617	398.7174	1671.218	325.5514	66.4528	92.31612
215.9668	926.1581	-176.132	434.3247	1588.915	372.5709	35.54478	0
218.5076	926.1581	-317.565	434.3247	1682.467	372.5709	-0.245	0
221.0483	959.0554	-428.932	447.8974	1793.342	369.1406	64.8366	89.70098
223.5891	959.0554	-202.544	447.8974	1519.418	369.1406	83.01688	89.70098
226.1299	1022.94	57.88973	426.0511	1238.962	321.274	126.5195	86.98277
228.6707	1022.94	29.4482	426.0511	1273.324	321.274	138.184	86.98277
231.2115	987.5338	-167.52	409.0021	1382.964	377.3172	68.36105	66.74117

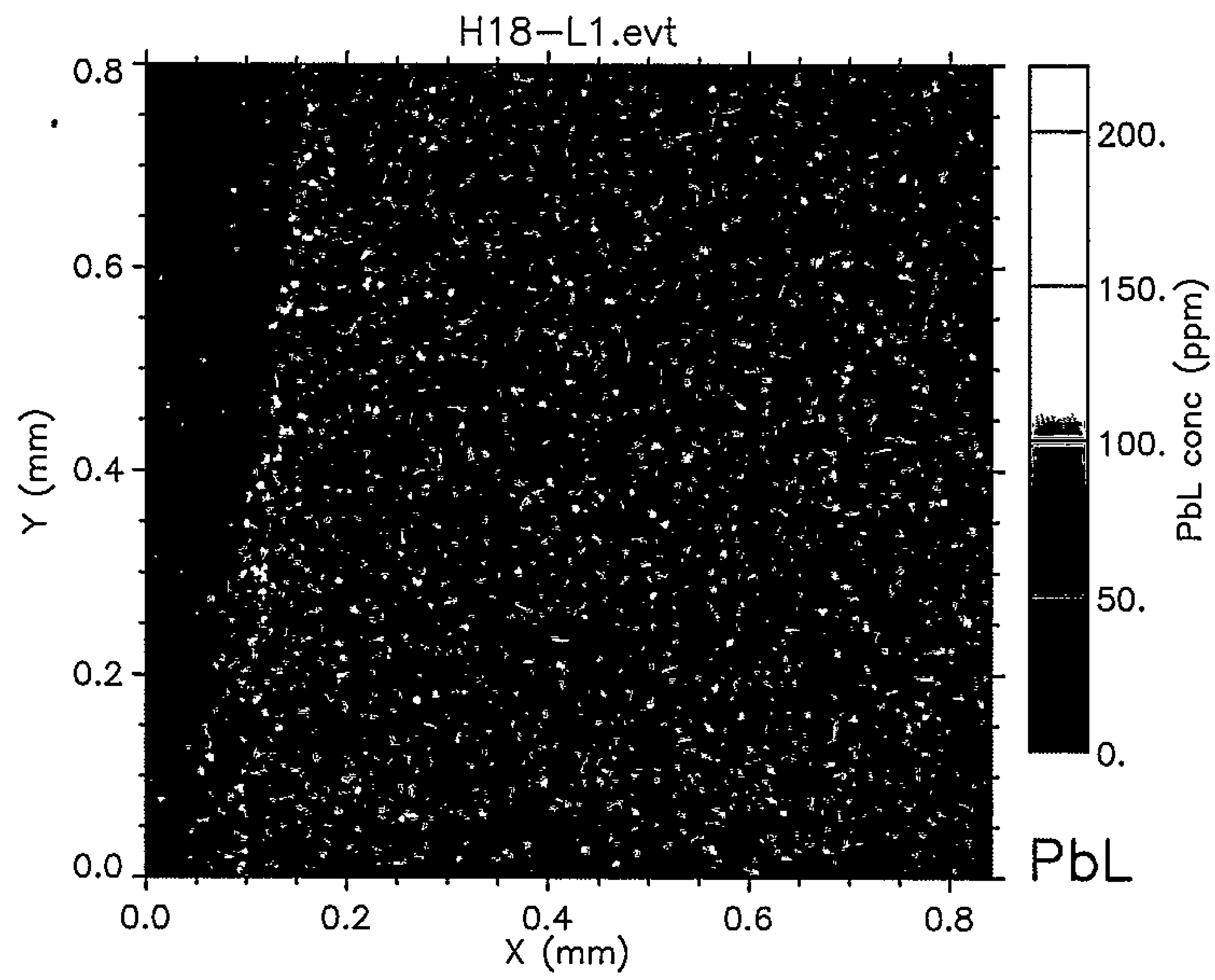
233.7523	987.5338	-43.3318	409.0021	1558.093	377.3172	-26.1172	66.74117
236.2931	1033.154	134.6356	412.7117	1483.821	374.2325	6.40936	68.82683
238.8338	1033.154	311.6616	412.7117	1233.382	374.2325	57.17598	68.82683
241.3746	982.4505	70.28153	412.7117	1086.15	353.4252	76.12357	61.52344
243.9154	982.4505	-323.021	412.7117	1200.991	353.4252	47.50805	61.52344
246.4562	985.7299	-367.523	442.4437	1296.931	347.8693	40.69955	84.3707
248.997	985.7299	-2.54138	442.4437	1405.476	347.8693	46.05873	84.3707
251.5378	980.5222	362.4052	398.7174	1762.276	374.2325	31.51288	21.81741
254.0786	980.5222	174.0547	398.7174	1481.186	374.2325	36.67971	21.81741
256.6194	971.1796	312.3183	413.3303	1106.181	362.8921	11.06752	59.65909
259.1601	971.1796	118.0598	413.3303	1157.903	362.8921	46.77715	59.65909
261.7009	1003.621	121.1356	469.7561	1553.519	321.274	126.9766	84.3707
264.2417	1003.621	-112.876	469.7561	1783.571	321.274	132.3237	84.3707
266.7825	962.9941	-398.066	439.3652	1736.357	325.5514	88.05119	61.52344
269.3233	962.9941	-466.594	439.3652	1555.541	325.5514	46.61869	61.52344
271.864	952.6793	-436.126	409.0021	1387.817	326.7663	27.5593	21.15628
274.4048	952.6793	-476.84	409.0021	1471.909	326.7663	-6.77255	21.15628
276.9456	1003.621	-495.342	377.3172	1590.308	337.4828	33.99305	103.3326
279.4864	1003.621	-639.354	377.3172	1534.816	337.4828	140.0596	103.3326
282.0272	964.9574	-469.274	476.5585	1424.23	325.5514	220.3749	137.5706
284.568	964.9574	-15.5055	476.5585	1331.297	325.5514	298.219	137.5706
287.1088	997.7425	658.8128	430.6641	1572.273	342.548	316.2855	108.7722
289.6496	997.7425	290.3372	430.6641	1653.359	342.548	216.6679	108.7722
292.1903	1022.94	-85.9288	434.3247	1555.338	372.5709	82.56879	0
294.7311	1022.94	-472.94	434.3247	1316.902	372.5709	-12.9839	0
297.2719	1025.801	-410.178	363.9776	1112.969	307.6172	0	0
299.8127	1025.801	-783.678	363.9776	1130.628	307.6172	25.71887	0
302.3535	996.5033	-764.827	465.9524	1322.949	326.7663	46.61869	84.3707
304.8943	996.5033	-739.899	465.9524	1634.605	326.7663	113.7701	84.3707
307.4351	1038.635	-475.284	412.7117	1637.74	342.548	96.0499	108.7722
309.9758	1010.933	-774.401	447.8974	1328.72	353.4252	99.20438	72.20203
312.5166	1010.933	-674.102	447.8974	1138.688	353.4252	57.04918	72.20203
315.0574	996.5033	-502.617	377.3172	1430.472	332.1678	45.72015	84.3707
317.5982	996.5033	-238.205	377.3172	1590.826	332.1678	69.49528	84.3707
320.139	973.0104	-108.223	434.3247	1567.126	367.7633	132.39	86.98277
322.6798	973.0104	121.429	434.3247	1598.021	367.7633	123.0469	86.98277
325.2206	993.9415	71.10236	393.9422	1637.681	389.1084	65.12407	0
327.7613	993.9415	-368.447	393.9422	1635.529	389.1084	33.54638	0
330.3021	994.7159	-720.916	413.3303	1705.52	372.5709	47.95493	63.29926
332.8429	994.7159	-604.34	413.3303	1951.385	372.5709	29.043	63.29926
335.3837	958.2668	-391.853	426.0511	1849.633	367.7633	83.11907	86.98277
337.9245	958.2668	-450.921	426.0511	1697.861	367.7633	79.88354	86.98277
340.4653	980.5222	-592.551	439.3652	1582.444	389.1084	60.24306	21.81741
343.006	980.5222	-644.293	439.3652	1739.971	389.1084	-3.804	21.81741
345.5468	941.4046	-589.115	446.4478	1699.943	367.7633	-34.5144	21.15628
348.0876	941.4046	-508.188	446.4478	1707.373	367.7633	-32.5532	21.15628
350.6284	1031.321	-404.136	476.5585	1602.645	358.7402	-16.8473	0

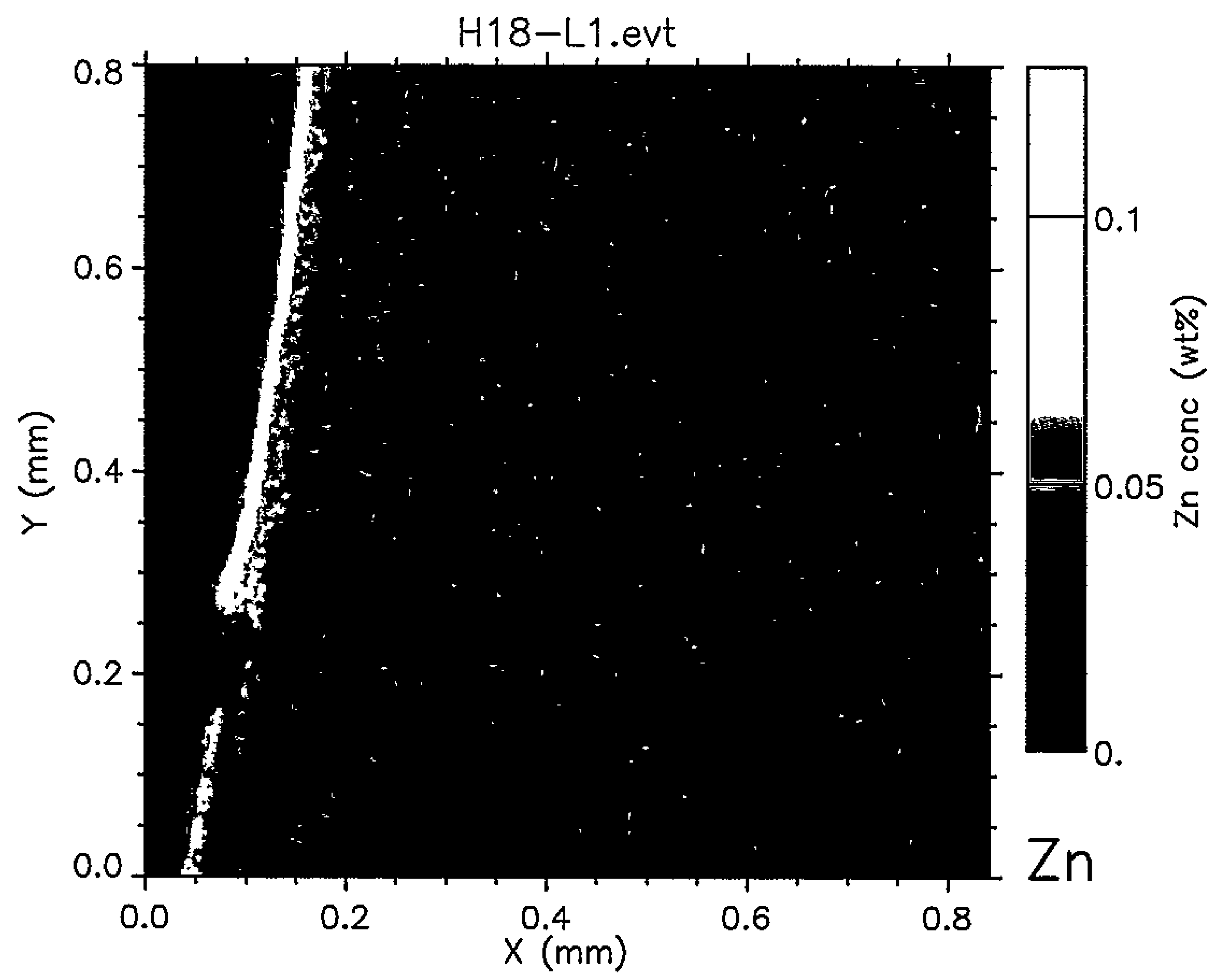
353.1692	1031.321	-475.051	476.5585	1437.408	358.7402	0	0
355.71	910.4637	-466.963	468.5485	1455.203	313.7092	36.61346	87.00728
358.2508	910.4637	-5.10426	468.5485	1416.688	313.7092	87.80538	87.00728
360.7915	1003.621	365.8759	430.2078	1445.296	362.8921	86.43341	59.65909
363.3323	1003.621	384.8885	430.2078	1409.807	362.8921	36.61346	59.65909
365.8731	1040.456	197.1235	412.7117	1689.296	353.4252	12.5391	21.81741
368.4139	1040.456	123.0469	412.7117	1771.553	353.4252	28.22314	21.81741
370.9547	937.097	156.5591	426.2469	1548.997	403.4361	24.07199	65.27735
373.4955	937.097	179.5387	426.2469	1715.726	403.4361	-1.68234	65.27735
376.0363	926.1581	161.0777	454.3501	2113.156	337.4828	31.3007	107.5769
378.5771	926.1581	357.5519	454.3501	1911.242	337.4828	126.6615	107.5769
381.1178	969.3455	452.6465	362.8921	1287.224	332.1678	131.2833	42.31256
383.6586	969.3455	339.2918	362.8921	1067.773	332.1678	43.50408	42.31256
386.1994	866.5983	216.6455	450.4163	1316.208	347.8693	8.061514	86.98277
388.7402	866.5983	350.5871	450.4163	1328.291	347.8693	18.47327	86.98277
391.281	965.6668	446.604	386.6351	1627.785	352.948	54.51052	66.74117
393.8217	965.6668	174.4846	386.6351	1676.336	352.948	27.52743	66.74117
396.3625	897.905	-448.763	439.3652	1650.286	325.5514	26.82507	89.70098
398.9033	897.905	-533.225	439.3652	1267.776	325.5514	68.74168	89.70098
401.4441	964.9574	-458.809	412.7117	1288.378	358.7402	131.1992	65.27735
403.9849	964.9574	-337.874	412.7117	1547.971	358.7402	111.9936	65.27735
406.5257	969.3455	-104.293	413.3303	1887.141	332.1678	33.7706	59.65909
409.0665	969.3455	108.0223	413.3303	1839.261	332.1678	-12.9839	59.65909
411.6073	961.0268	363.9938	435.0364	1576.202	288.5705	36.61346	61.52344
414.148	961.0268	388.9178	435.0364	1220.084	288.5705	50.61076	61.52344
416.6888	949.1374	333.4508	412.7117	1190.849	331.3138	109.8404	61.52344
419.2296	949.1374	376.1056	412.7117	1244.37	331.3138	99.63993	61.52344
421.7704	894.8864	583.2448	395.7336	1320.138	332.1678	120.7349	84.3707
424.3112	894.8864	286.6369	395.7336	885.923	332.1678	90.36311	84.3707
426.852	883.0274	-54.4438	443.6518	704.9324	348.0291	119.1172	61.52344
429.3928	883.0274	-275.048	443.6518	890.2535	348.0291	75.53883	61.52344
431.9335	921.026	-272.184	409.446	1147.692	370.7691	32.24618	104.4129
434.4743	921.026	-55.1671	409.446	1333.544	370.7691	45.86567	104.4129
437.0151	949.1374	82.14028	426.2469	1338.307	295.056	77.80956	65.27735
439.5559	949.1374	480.0914	426.2469	1311.238	295.056	88.19843	65.27735
442.0967	984.375	677.5375	412.7117	1216.568	384.2137	39.11773	106.5617
444.6375	984.375	876.8466	412.7117	1528.694	384.2137	126.5051	106.5617
447.1783	886.8962	780.1487	377.3172	1588.51	309.9977	185.0348	59.65909
449.7191	886.8962	418.7311	377.3172	1466.592	309.9977	148.7657	59.65909
452.2598	926.1581	-9.04737	372.5709	1507.629	382.0046	36.61345	0
454.8006	926.1581	-126.776	372.5709	1841.05	382.0046	0	0
457.3414	1588.34	4.423468	605.7692	1801.23	428.3435	73.22691	53.7044
459.8822	1588.34	-83.3144	605.7692	1317.529	428.3435	24.23957	53.7044

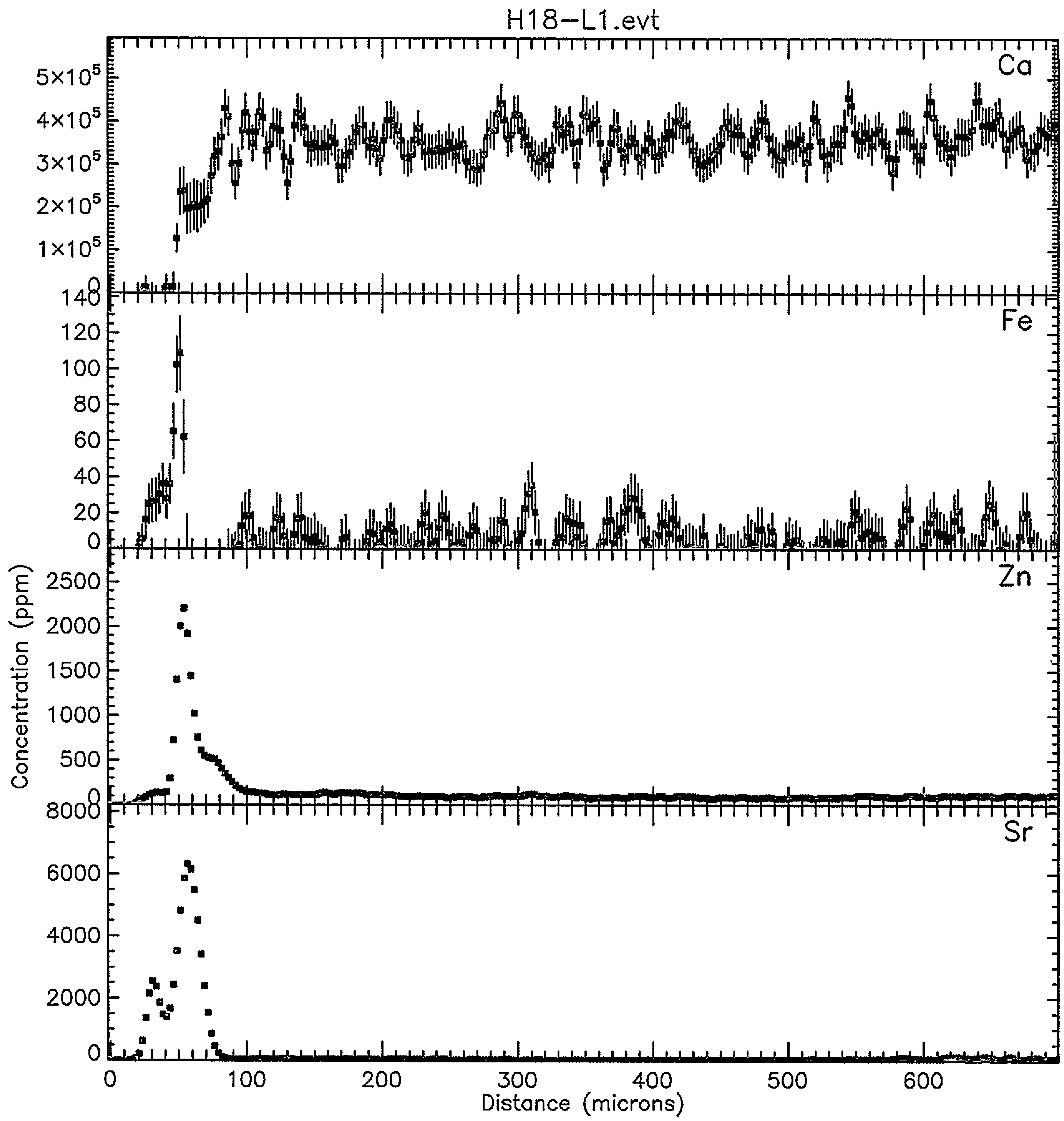
8.1.2 H18-L1 (Heavy-Control Tooth, Cementoenamel junction, Buccal) PIXE Mode






H18–L1.evt
0.8
0.6
0.4
0.2
0.0
Y (mm)
0.0
0.2
0.4
0.6
0.8
X (mm)
200.
150.
100.
50.
0.
PbL conc (ppm)
PbL


H18–L1.evt
0.8
0.6
0.4
0.2
0.0
Y (mm)
0.0
0.2
0.4
0.6
0.8
X (mm)
0.1
0.05
0.
Zn conc (wt%)
Zn


H18–L1.evt
Ca
Fe
Zn
Sr
Concentration (ppm)
Distance (microns)

microns	Ca	e_Ca	Fe	e_Fe	Ni	e_Ni
0	-15868.4	5393.034	-4.31532	5.951441	-6.72125	2.356964
2.540786	-17189.2	5393.034	-5.42449	5.951441	-5.16128	2.356964
5.081571	-18734.5	2426.234	-4.93796	6.023342	-6.96519	2.492585
7.622356	-20081.3	2426.234	-4.24933	6.023342	-6.24628	2.492585
10.16314	-19620.5	3496.91	-7.40878	5.536309	-6.63989	2.535828
12.70393	-16932.8	3496.91	-9.64106	5.536309	-6.24311	2.535828
15.24471	-17582.7	6226.491	-8.1744	5.694747	-4.64772	2.201864
17.7855	-20166.2	6226.491	-6.80747	5.694747	-1.08135	2.201864
20.32628	-9442.24	11884.92	0.964321	7.57982	5.373357	3.550245
22.86707	7380.99	11884.92	5.868396	7.57982	9.628016	3.550245
25.40786	14105.79	24380.99	16.30693	10.57548	16.31375	5.617091
27.94864	-6133.13	24380.99	25.03133	10.57548	22.06436	5.617091
30.48943	-12448.5	29378.82	26.94125	11.67088	30.26682	6.853447
33.03021	-14912.8	29378.82	27.32238	11.67088	39.08566	6.853447
35.571	-24979.6	24616.3	30.72239	10.85991	44.18919	7.067015
38.11178	-6968.74	24616.3	36.42005	10.85991	50.51926	7.067015
40.65257	15705.6	26155.66	28.1288	10.74061	53.21485	7.857294
43.19336	-4841	26155.66	36.20984	10.74061	56.28975	7.857294
45.73414	15907.14	31067.98	65.4963	15.22727	65.10637	8.603649
48.27493	128261.5	31067.98	102.489	15.22727	99.63517	8.603649
50.81571	235982.9	52572.51	108.798	20.09519	137.6741	12.55319
53.35649	238993.6	52572.51	62.31331	20.09519	170.5437	12.55319
55.89728	196576	57048.86	-1.12759	20.15298	175.987	15.2573
58.43807	198777.2	57048.86	-55.2913	20.15298	144.9607	15.2573
60.97885	206456.1	58033.91	-69.5167	15.78104	86.03806	11.92946
63.51964	201722.5	58033.91	-81.5707	15.78104	36.4733	11.92946
66.06042	204478.3	49703.33	-80.0459	14.64021	1.039236	8.513933
68.60121	213271.7	49703.33	-79.5905	14.64021	-19.3946	8.513933
71.142	218496.3	41576.01	-68.5481	12.11159	-21.7945	6.473442
73.68278	272926.9	41576.01	-54.1458	12.11159	-20.7469	6.473442
76.22356	318692.3	43024.11	-29.5908	12.58102	-15.4082	5.747659
78.76435	330356.8	43024.11	-23.392	12.58102	-10.5198	5.747659
81.30514	362839.1	40312.26	-19.8971	12.09811	-0.17368	6.806312
83.84592	431035.7	40312.26	-12.2779	12.09811	0.96063	6.806312
86.38671	412011.1	43740.02	-1.73267	12.57373	-0.29703	6.123689
88.9275	301946.5	43740.02	-5.15371	12.57373	-9.87708	6.123689
91.46828	256510.8	35787.7	-2.66539	11.78879	-14.2524	4.81641
94.00906	302659.5	35787.7	2.70084	11.78879	-15.2808	4.81641
96.54985	380082.6	43304.91	13.01622	12.76532	-9.1037	5.576614
99.09064	420358.1	43304.91	18.35671	12.76532	-3.1737	5.576614
101.6314	375400.2	40288.06	18.41527	14.35735	3.633648	6.053403
104.1722	349476.7	40288.06	6.384393	14.35735	6.394989	6.053403
106.713	375808.8	41408.26	-3.46864	10.90999	3.430733	5.794706
109.2538	422955	41408.26	0.747647	10.90999	0.30822	5.794706
111.7946	408701.6	42976.93	-0.01781	11.17875	2.052068	5.561303

114.3354	331720.3	42976.93	-1.64044	11.17875	2.136548	5.561303
116.8761	346690.7	39782.57	-3.3792	12.22196	-0.92777	6.330185
119.4169	389091	39782.57	11.0782	12.22196	-4.91682	6.330185
121.9577	385251.4	43151.89	17.21583	13.67252	-6.16053	5.480503
124.4985	378824.5	43151.89	16.40811	13.67252	-7.64889	5.480503
127.0393	317538.1	37540.39	7.158248	12.4842	-4.88709	5.735332
129.5801	256272.1	37540.39	-1.48077	12.4842	-3.66192	5.735332
132.1208	306747.8	37220.39	-1.64109	11.65871	-4.18927	5.902873
134.6616	390475.6	37220.39	8.010378	11.65871	-4.36093	5.902873
137.2024	420188.1	43207.61	16.89807	13.23875	-0.58446	5.956968
139.7432	411821.2	43207.61	17.69487	13.23875	6.315059	5.956968
142.284	386290.6	42421.73	6.461998	11.76325	8.167233	6.366953
144.8248	346940.7	42421.73	5.563478	11.76325	5.266106	6.366953
147.3656	336421.7	39074.41	3.98997	12.48295	-3.21268	5.754388
149.9063	350402.2	39074.41	7.139234	12.48295	-5.6949	5.754388
152.4471	339091.7	39218.43	3.525007	11.58502	-2.91813	5.830784
154.9879	338944.8	39218.43	1.847752	11.58502	3.325556	5.830784
157.5287	348545.8	39593.79	0.524578	11.08589	5.236251	6.128189
160.0695	341731.4	39593.79	-3.78544	11.08589	0.893836	6.128189
162.6103	363005.3	40592.28	-12.8638	11.71385	-5.8487	5.891944
165.1511	350276.4	40592.28	-16.2874	11.71385	-4.85572	5.891944
167.6918	296388	37569.13	-8.13572	10.69805	-1.66005	6.000494
170.2326	296543	37569.13	5.749742	10.69805	-0.67628	6.000494
172.7734	320950.7	37138.81	6.901964	12.21224	-4.46021	5.284279
175.3142	328581.6	37138.81	-1.87581	12.21224	-3.92992	5.284279
177.855	351919.9	39085.66	-11.8891	11.55749	-0.08497	5.996898
180.3958	375582.9	39085.66	-12.692	11.55749	0.490159	5.996898
182.9366	390731.9	42048.88	-6.73149	11.69537	-4.10542	6.051419
185.4773	391635.1	42048.88	-3.43782	11.69537	-6.12828	6.051419
188.0181	356121.4	38765.04	4.383158	11.81984	1.854945	5.902467
190.5589	339330.2	38765.04	9.686998	11.81984	7.451829	5.902467
193.0997	358091	39831.98	8.819577	12.71093	6.035163	6.09895
195.6405	336748.7	39831.98	2.228998	12.71093	-0.66308	6.09895
198.1813	313769.9	37744.84	3.588236	11.56161	-3.75181	5.592512
200.7221	356697.7	37744.84	1.536487	11.56161	-4.86499	5.592512
203.2628	403493.9	42307.46	11.24542	11.16513	-4.58295	5.364396
205.8036	403746.7	42307.46	14.1613	11.16513	-2.34432	5.364396
208.3444	390732.7	42270.56	9.927252	12.57286	-1.80244	5.469584
210.8852	379403	42270.56	-2.49193	12.57286	-0.69149	5.469584
213.426	356080.5	37753.28	0.797189	12.08522	-1.70583	5.712572
215.9668	318259.8	37753.28	1.378143	12.08522	-4.42232	5.712572
218.5076	314947.5	39646.33	0.614977	11.56504	-5.75525	5.170771
221.0483	322936.8	39646.33	-3.10295	11.56504	-4.67721	5.170771
223.5891	357760.7	39416.47	-3.42307	12.97241	0.740844	5.564167
226.1299	384846.7	39416.47	3.410463	12.97241	3.942559	5.564167
228.6707	353491.9	40582.07	13.80828	12.2009	0.805848	6.192112
231.2115	329438	40582.07	20.47826	12.2009	-5.31401	6.192112

233.7523	333237.1	38031.21	12.51165	13.23737	-6.20085	5.657133
236.2931	330226.9	37770.25	3.281043	11.73608	-1.79556	5.801269
238.8338	332204.1	37770.25	4.866548	11.73608	-0.05821	5.801269
241.3746	339836.7	38591.04	12.17422	13.39069	1.877675	5.978956
243.9154	330140.2	38591.04	18.92211	13.39069	2.634701	5.978956
246.4562	334681.8	40431.7	17.26569	11.5478	3.855737	5.943758
248.997	353119	40431.7	9.323716	11.5478	2.327619	5.943758
251.5378	337783.5	37868.75	2.308349	11.75985	-3.6938	5.489492
254.0786	320533.7	37868.75	0.244141	11.75985	-2.91681	5.489492
256.6194	343768.2	39641.76	4.338215	10.77789	1.791772	6.306241
259.1601	348926.7	39641.76	1.55025	10.77789	3.001636	6.306241
261.7009	308856.2	36988.12	-2.18085	12.23071	-3.41941	4.869796
264.2417	294564.5	36988.12	7.856173	12.23071	-8.03952	4.869796
266.7825	295994.2	36989.81	12.71882	12.93936	-1.86434	6.393589
269.3233	289250.4	36989.81	10.57607	12.93936	-3.25561	6.393589
271.864	296565.2	38575.56	-2.72319	11.66018	-6.84192	5.080658
274.4048	324422	38575.56	-2.8329	11.66018	-12.0143	5.080658
276.9456	364167.3	41296.11	-1.24775	11.63628	-11.8141	4.546496
279.4864	382483.3	41296.11	6.046221	11.63628	-10.9861	4.546496
282.0272	379605.2	41881.38	5.259922	12.03031	-8.01225	5.261314
284.568	418855.5	41881.38	6.217101	12.03031	-1.55835	5.261314
287.1088	443103.8	43782.64	16.22166	12.61053	1.505862	6.148228
289.6496	405156.2	43782.64	15.29125	12.61053	5.830368	6.148228
292.1903	360304.5	39150.28	1.548526	11.86696	6.995182	6.346773
294.7311	370015.8	39150.28	-7.07903	11.86696	6.167986	6.346773
297.2719	416632.6	42794.81	-1.87688	12.37723	5.399334	6.125914
299.8127	417347.2	42794.81	5.462084	12.37723	4.374201	6.125914
302.3535	380219.2	39644.36	9.100189	13.60779	2.80139	6.187221
304.8943	365004.2	39644.36	23.23486	13.60779	4.287329	6.187221
307.4351	346299.4	38176.74	31.01052	12.56965	6.741142	5.977137
309.9758	326260.3	38176.74	35.62663	12.56965	3.503972	5.977137
312.5166	315687.9	39184.89	20.78958	11.90501	-3.51183	5.081243
315.0574	306340.9	39184.89	4.327284	11.90501	-7.16344	5.081243
317.5982	314633.2	37579.56	-12.7555	9.86048	-5.72526	4.938904
320.139	322930.1	37579.56	-22.7201	9.86048	-9.2367	4.938904
322.6798	300735.3	39829.96	-24.4877	11.37363	-9.61413	5.997935
325.2206	334396.2	39829.96	-10.219	11.37363	-9.09882	5.997935
327.7613	394363.9	42052.96	4.038476	13.24693	-1.51297	5.836681
330.3021	388006.1	42052.96	7.566543	13.24693	0.533539	5.836681
332.8429	369839.9	40411.01	6.757728	13.33577	-1.3322	5.349778
335.3837	376116.1	40411.01	17.37792	13.33577	-4.66521	5.349778
337.9245	395373.9	40007.06	15.7085	12.64486	-3.48709	6.031184
340.4653	351759.4	40007.06	14.84425	12.64486	-1.39958	6.031184
343.006	299752.6	38892.55	7.197324	12.55177	-7.63716	4.320115
345.5468	354340.4	38892.55	13.90704	12.55177	-11.0674	4.320115
348.0876	418379.3	42735.82	3.230007	11.81435	-9.18769	6.359272
350.6284	414244.3	42735.82	-3.81607	11.81435	-2.722	6.359272

353.1692	386342.1	41844.68	-14.0007	10.9074	2.17453	5.882033
355.71	396309.9	41844.68	-10.1605	10.9074	5.263435	5.882033
358.2508	406040.9	40253.67	-7.91813	11.66952	7.20583	6.11342
360.7915	351928.2	40253.67	-3.03119	11.66952	6.477721	6.11342
363.3323	289830.8	36066.82	4.979657	12.79107	0.662491	5.036268
365.8731	304777.6	36066.82	15.80401	12.79107	-9.40136	5.036268
368.4139	351601.6	42739.4	16.82712	12.58119	-12.6978	5.597175
370.9547	385775.5	42739.4	4.108221	12.58119	-11.7974	5.597175
373.4955	384178.5	37908.47	8.21578	12.50305	-6.53195	5.41475
376.0363	335943.9	37908.47	12.29108	12.50305	-2.95302	5.41475
378.5771	318594.3	39886.74	21.27	12.59172	0.624088	5.480085
381.1178	345926.9	39886.74	23.08137	12.59172	-3.01073	5.480085
383.6586	365174.6	37809.7	28.95833	12.98106	-5.00351	5.247043
386.1994	351881	37809.7	28.36267	12.98106	-8.73944	5.247043
388.7402	318366.7	39283.79	22.66078	14.04085	-7.3003	5.775372
391.281	307422.6	39283.79	19.31457	14.04085	-7.50983	5.775372
393.8217	335746.3	40408.09	5.785842	11.09434	-10.0333	4.799857
396.3625	363097.7	40408.09	2.105042	11.09434	-12.281	4.799857
398.9033	352906.8	37034.84	-6.13785	11.65816	-7.52361	6.327872
401.4441	319593.6	37034.84	-1.01246	11.65816	-0.15373	6.327872
403.9849	322737.4	38396.52	8.159792	12.17116	5.283543	5.797655
406.5257	336993.8	38396.52	15.40291	12.17116	3.832236	5.797655
409.0665	362964.7	43264.25	14.12365	12.45402	1.331672	5.371519
411.6073	377457.2	43264.25	9.374359	12.45402	-1.34734	5.371519
414.148	370677.9	39657.93	17.68435	12.87006	0.902928	5.224785
416.6888	401222.9	39657.93	14.18449	12.87006	-0.61379	5.224785
419.2296	405225.4	41334.96	6.618277	11.41013	2.30886	5.932589
421.7704	392670.4	41334.96	-0.04983	11.41013	1.93069	5.932589
424.3112	391503.5	41352.64	1.401569	12.23386	1.550645	5.412332
426.852	361235.5	41352.64	2.142116	12.23386	-4.86636	5.412332
429.3928	333807.4	38346.62	0.724786	12.54995	-7.06662	5.372198
431.9335	314493.3	38346.62	-1.07187	12.54995	-7.66321	5.372198
434.4743	301557.4	37012.39	0.977957	12.2094	-6.01675	5.555404
437.0151	299380.8	37012.39	7.858952	12.2094	-6.03547	5.555404
439.5559	306984.4	37529.36	-1.20817	10.5943	-5.34059	5.267775
442.0967	313469.7	37529.36	-11.9139	10.5943	-2.30356	5.267775
444.6375	325173.6	39024	-12.714	11.89574	-1.21432	5.197607
447.1783	334375.7	39024	-3.61364	11.89574	-4.02607	5.197607
449.7191	348245.1	42429.56	2.318163	12.02438	-3.83089	6.148806
452.2598	388082	42429.56	0.538681	12.02438	-4.10196	6.148806
454.8006	401441.3	41724.92	-3.4574	11.40147	-2.16132	5.552291
457.3414	374599.3	41724.92	-2.75906	11.40147	0.251134	5.552291
459.8822	370937.7	41733.68	-3.13941	11.69466	-0.88392	5.687661
462.423	389443.7	41733.68	-1.22943	11.69466	-3.60893	5.687661
464.9637	369827	38446.72	-6.63484	12.75721	-7.25086	5.759983
467.5045	327252.6	39831.15	1.203016	11.92393	-1.28085	6.082287
470.0453	320580.5	39831.15	7.665587	11.92393	1.675447	6.082287

472.5861	348185	40610.6	4.147235	12.69721	1.352901	5.509769
475.1269	364126.2	40610.6	2.346387	12.69721	-2.72772	5.509769
477.6677	380371	44120.07	11.64948	12.00441	-3.71139	6.196443
480.2085	406758.2	44120.07	11.46124	12.00441	-2.34283	6.196443
482.7493	403420.4	38114.36	-2.67739	12.41831	-4.18798	5.212353
485.29	362315.8	38114.36	2.018743	12.41831	-4.15502	5.212353
487.8308	335322.4	38751.37	10.58218	9.978128	-3.31474	5.769636
490.3716	324516.2	38751.37	-0.78513	9.978128	-1.04004	5.769636
492.9124	312647.1	38615.55	-19.8607	12.58873	-2.65304	5.074093
495.4532	311569.1	38615.55	-13.3439	12.58873	-6.63366	5.074093
497.994	340765.3	39469.05	2.199658	12.73013	-12.1221	5.913476
500.5348	352814.8	39469.05	5.350524	12.73013	-9.61165	5.913476
503.0755	344242.9	39746.7	2.986768	11.00533	1.322992	5.517362
505.6163	349638.1	39746.7	5.4125	11.00533	1.039477	5.517362
508.1571	360946.2	38355.04	0.750949	11.43439	-4.90058	5.971859
510.6979	337317.7	38355.04	-7.09681	11.43439	-5.72922	5.971859
513.2387	306592.8	43714.31	-10.4499	12.02648	-4.27127	5.096902
515.7795	344798.9	43714.31	-7.58745	12.02648	-9.93171	5.096902
518.3203	409822.2	39324.06	-9.12726	12.61131	-14.5041	6.125521
520.861	402973.7	39324.06	-4.97398	12.61131	-7.39003	6.125521
523.4018	355564.8	38252.32	1.063021	10.99042	-3.61172	5.577517
525.9426	321753.7	38252.32	6.243108	10.99042	-3.17074	5.577517
528.4834	302000.7	38889.07	4.941073	11.32449	-5.7566	5.341248
531.0242	327776.3	38889.07	0.49783	11.32449	-5.27	5.341248
533.5649	349318.1	41189.71	-2.20639	12.58049	-5.51943	5.711146
536.1058	351405.2	41189.71	4.13381	12.58049	-7.30889	5.711146
538.6465	347982.5	43845.08	5.134829	10.98614	1.35269	6.13099
541.1873	384823.2	43845.08	3.89918	10.98614	11.1885	6.13099
543.7281	456580	39324.41	-1.19919	14.38625	13.12835	5.14732
546.2689	438434.8	39324.41	14.34098	14.38625	-0.80291	5.14732
548.8097	374156.3	40184.99	21.38682	11.66472	-10.3119	6.055882
551.3505	358874.6	40184.99	17.45532	11.66472	-8.27707	6.055882
553.8912	357649.5	40699.32	6.949251	13.22915	1.282531	5.730983
556.432	376484.8	40699.32	9.266273	13.22915	4.081618	5.730983
558.9728	364355.4	41663.23	10.79754	12.201	-1.42441	5.455466
561.5136	344778.8	41663.23	5.477776	12.201	-8.58515	5.455466
564.0544	374947.3	39114.44	8.899661	11.20058	-10.0716	5.953835
566.5952	384232.2	39114.44	6.354637	11.20058	-6.063	5.953835
569.136	357651.4	39853.98	6.522803	11.22036	0.804816	4.825464
571.6768	345631.8	39853.98	-5.29223	11.22036	-3.80302	4.825464
574.2175	318445.2	37843.31	-15.7522	11.44717	-12.8514	5.748004
576.7583	281925.1	37843.31	-19.2716	11.44717	-14.904	5.748004
579.2991	315500.2	41532.63	-8.27331	12.98547	-7.78371	5.489037
581.8399	379216.8	41532.63	4.48161	12.98547	-4.59869	5.489037
584.3807	384651.9	41120.72	13.475	13.34998	-7.2238	5.538181
586.9214	380357.1	41120.72	22.85037	13.34998	-9.32831	5.538181
589.4622	375706.3	40341.11	17.5195	11.64985	-10.2585	5.820911

592.0031	344966.4	40341.11	-3.79778	11.64985	-5.30778	5.820911
594.5438	322273.8	39488.82	-10.8618	12.74132	-1.04787	5.50777
597.0846	312907.5	39488.82	0.077721	12.74132	-1.50317	5.50777
599.6254	346490.8	43603.25	2.64733	13.58422	-4.12181	6.460107
602.1662	420150	43603.25	10.31834	13.58422	-1.56745	6.460107
604.707	448746.5	41283.25	15.46319	12.38488	-0.25559	5.306184
607.2477	411702.7	41283.25	19.7928	12.38488	-5.72495	5.306184
609.7885	368379.2	39692.48	10.18099	13.1166	-6.42739	6.370654
612.3293	351522.1	39692.48	8.036009	13.1166	0.416697	6.370654
614.8701	352779.5	39651.36	9.219358	10.94262	9.657384	6.023067
617.4109	340225.6	39651.36	5.252574	10.94262	7.304768	6.023067
619.9517	319841.8	41122.5	7.406641	14.38886	5.432649	5.845306
622.4924	341782.2	41122.5	16.37944	14.38886	2.156019	5.845306
625.0333	367740.8	41305.03	21.86839	11.80969	0.11968	5.636249
627.574	366540.4	41305.03	11.77213	11.80969	-7.41216	5.636249
630.1148	364466	40453.68	-5.68016	12.37008	-8.95176	5.667106
632.6556	366921.5	40453.68	-8.51722	12.37008	-5.40306	5.667106
635.1964	382321.6	44402.64	-1.37847	10.81432	-1.79002	5.555936
637.7372	448289.1	44402.64	-1.95738	10.81432	-5.22318	5.555936
640.278	450427.3	41915.32	-5.20711	13.49503	-7.81292	5.268695
642.8187	391980.4	41915.32	4.479131	13.49503	-5.06333	5.268695
645.3596	391997.8	40438.13	18.41069	13.16939	-0.61463	6.175849
647.9003	395793.1	40438.13	25.50068	13.16939	0.512835	6.175849
650.4411	387833.4	43795.92	23.56002	11.59359	1.303749	5.812054
652.9819	402561.6	43795.92	15.50571	11.59359	2.875404	5.812054
655.5226	418804.2	37842.5	0.388819	12.52911	2.687133	5.706182
658.0635	373585.4	37842.5	-2.9171	12.52911	0.595699	5.706182
660.6042	338500.5	42250.34	3.13884	10.51714	1.046191	5.746524
663.145	362098.3	42250.34	-1.82966	10.51714	0.969936	5.746524
665.6858	372441.1	41144.04	-7.25349	12.84555	0.175753	6.250278
668.2266	380884.3	41144.04	-8.5835	12.84555	-3.35237	6.250278
670.7674	388202.4	37982.26	7.73394	13.73555	-2.54946	5.017168
673.3082	349785.8	37982.26	18.27082	13.73555	-7.00608	5.017168
675.8489	313194.6	39356.04	20.26818	11.5899	-8.37884	5.689609
678.3898	332115.6	39356.04	6.235471	11.5899	-7.43686	5.689609
680.9305	332911.6	43195.93	-1.1692	12.33462	-3.5865	5.785729
683.4713	347134.6	43195.93	-2.16108	12.33462	-1.57451	5.785729
686.0121	383845.8	40067.98	-4.4723	10.91755	-1.4603	6.664878
688.5529	375534.4	40067.98	-15.1448	10.91755	2.313282	6.664878
691.0937	366805.8	41326.33	-15.7228	12.19941	5.503754	6.143447
693.6345	387365.6	41326.33	-3.66418	12.19941	8.601483	6.143447
696.1752	395593.1	180597	4.899788	58.34895	2.815087	17.79226
698.716	365931.8	180597	1.322489	58.34895	1.930211	17.79226

microns	Cu	e_Cu	Zn	e_Zn	Br	e_Br
0	-2.81779	2.10892	-8.57509	1.495657	-0.94433	1.297587
2.540786	-1.59624	2.10892	-8.4839	1.495657	-1.96626	1.297587
5.081571	0.462097	2.971561	-8.37056	1.841587	-2.33437	0.3226
7.622356	1.253149	2.971561	-6.77335	1.841587	-2.65583	0.3226
10.16314	3.210627	2.852441	-7.09538	1.955823	-1.38239	0.628103
12.70393	6.504203	2.852441	-5.84151	1.955823	-0.64419	0.628103
15.24471	8.321267	3.24876	2.732401	2.962369	-0.10086	1.702356
17.7855	6.91904	3.24876	19.0702	2.962369	-0.8622	1.702356
20.32628	9.829566	3.992451	46.13782	5.44596	-1.50212	0.665108
22.86707	6.695012	3.992451	71.87443	5.44596	-1.96266	0.665108
25.40786	3.704609	3.524568	91.0672	7.402143	0.692442	1.681106
27.94864	0.134184	3.524568	113.1029	7.402143	3.468652	1.681106
30.48943	3.375588	4.045582	129.526	9.188087	3.287035	3.447319
33.03021	4.06675	4.045582	140.6951	9.188087	1.319083	3.447319
35.571	4.603572	4.149383	137.5033	8.946226	-0.04745	1.798774
38.11178	3.078305	4.149383	136.6906	8.946226	0.020887	1.798774
40.65257	-1.37917	3.642879	146.9209	9.195309	0.572624	2.000315
43.19336	-2.14331	3.642879	301.6357	9.195309	3.343401	2.000315
45.73414	-0.96494	4.796246	727.1929	19.77423	3.090873	3.107262
48.27493	1.080161	4.796246	1404.734	19.77423	2.223552	3.107262
50.81571	-7.67889	5.69107	2007.759	31.95234	-1.13041	3.220332
53.35649	-14.2048	5.69107	2208.079	31.95234	-0.56188	3.220332
55.89728	-19.1663	7.110757	1923.227	31.62144	-4.11027	4.42335
58.43807	-20.1874	7.110757	1446.962	31.62144	-5.33819	4.42335
60.97885	-21.5814	6.366977	1027.926	23.56272	-5.42136	4.21987
63.51964	-21.4371	6.366977	758.3734	23.56272	1.305942	4.21987
66.06042	-20.8483	6.069089	613.5495	18.38861	2.786052	4.469855
68.60121	-20.2659	6.069089	552.6927	18.38861	0.534461	4.469855
71.142	-15.3296	5.33506	534.1615	17.38383	1.730238	3.541979
73.68278	-12.5573	5.33506	523.4014	17.38383	6.75909	3.541979
76.22356	-9.52066	5.401152	513.4449	16.94472	8.103836	4.684719
78.76435	-7.78326	5.401152	473.7671	16.94472	1.253999	4.684719
81.30514	-1.81347	4.871543	414.1307	15.03063	-1.67073	2.16821
83.84592	0.98472	4.871543	356.7377	15.03063	-3.88765	2.16821
86.38671	0.859093	5.146275	308.3848	13.43503	-4.85206	1.991918
88.9275	-4.05721	5.146275	258.4258	13.43503	-6.81137	1.991918
91.46828	-3.14162	4.449362	219.3253	11.43691	-6.88575	2.261271
94.00906	2.634511	4.449362	192.1316	11.43691	-5.87652	2.261271
96.54985	3.501188	5.443769	169.6864	10.28814	-4.24641	2.41719
99.09064	0.477837	5.443769	154.6058	10.28814	-1.89598	2.41719
101.6314	-1.84812	4.649797	146.0375	9.754038	0.594848	3.111725
104.1722	2.848754	4.649797	145.4841	9.754038	0.019522	3.111725
106.713	0.765457	5.055817	140.8197	9.559362	0.918411	3.006444
109.2538	-3.21366	5.055817	137.2123	9.559362	1.440119	3.006444
111.7946	-3.32773	4.537853	132.2315	9.370204	3.308462	3.776691
114.3354	1.213504	4.537853	126.6535	9.370204	0.171175	3.776691

116.8761	0.45308	4.852034	116.3575	8.926163	-2.17369	2.356518
119.4169	-4.68243	4.852034	111.7735	8.926163	-1.77531	2.356518
121.9577	-2.38245	4.862851	111.5138	8.749193	0.652466	3.156309
124.4985	0.567668	4.862851	119.8013	8.749193	2.682168	3.156309
127.0393	3.085346	5.198246	123.6095	9.099607	0.584175	3.490483
129.5801	1.812863	5.198246	122.1601	9.099607	-0.29734	3.490483
132.1208	3.348459	5.005962	119.4088	9.060357	-0.95221	2.63687
134.6616	2.50706	5.005962	119.5711	9.060357	2.656723	2.63687
137.2024	1.268472	5.118099	117.599	9.020082	3.998371	3.777762
139.7432	-0.27326	5.118099	116.3451	9.020082	4.42531	3.777762
142.284	-5.53143	4.582886	113.9137	8.610322	0.750569	3.021172
144.8248	-8.00389	4.582886	119.2331	8.610322	-3.05626	3.021172
147.3656	-3.98962	4.876905	120.2735	9.337265	-5.40401	2.304058
149.9063	0.688814	4.876905	120.9291	9.337265	-6.18549	2.304058
152.4471	1.313547	4.655447	125.0635	9.064846	-5.03625	2.126412
154.9879	-2.39045	4.655447	139.5343	9.064846	-1.64802	2.126412
157.5287	-5.83464	4.46212	144.8773	9.431653	1.399787	2.896055
160.0695	-13.6384	4.46212	137.382	9.431653	1.105978	2.896055
162.6103	-17.3485	3.473777	123.1147	9.389012	-1.62834	3.102835
165.1511	-13.9891	3.473777	123.1947	9.389012	-3.08112	3.102835
167.6918	-7.68768	4.337354	133.8566	9.101558	-1.8452	2.540269
170.2326	-1.78574	4.337354	141.9634	9.101558	5.924567	2.540269
172.7734	3.47775	4.885095	139.3639	9.183393	11.1868	4.116425
175.3142	7.27912	4.885095	139.221	9.183393	7.96848	4.116425
177.855	3.298164	5.251526	132.5518	9.365934	1.715949	3.072441
180.3958	1.812003	5.251526	138.1417	9.365934	0.069364	3.072441
182.9366	0.545053	5.484107	138.2071	9.59231	0.400797	2.790632
185.4773	0.19152	5.484107	127.8108	9.59231	-2.13256	2.790632
188.0181	0.903659	4.442537	112.6599	8.688818	-1.29175	3.13173
190.5589	7.689916	4.442537	114.9557	8.688818	-1.64218	3.13173
193.0997	8.559957	5.192683	122.4641	8.99354	-1.39111	2.61587
195.6405	6.301425	5.192683	117.6963	8.99354	-3.08561	2.61587
198.1813	2.707986	5.219611	115.1219	8.758601	-2.59608	2.132695
200.7221	0.984083	5.219611	114.0667	8.758601	-3.60114	2.132695
203.2628	-0.97744	4.862264	117.3574	8.630258	-1.61524	2.808833
205.8036	-3.48745	4.862264	118.7754	8.630258	-1.03389	2.808833
208.3444	-5.6895	4.446153	111.3154	8.644443	-0.68551	2.86424
210.8852	-5.6729	4.446153	106.2511	8.644443	-1.06504	2.86424
213.426	1.377065	4.855173	102.818	8.399913	-0.16825	2.786624
215.9668	5.987404	4.855173	101.8824	8.399913	-0.89836	2.786624
218.5076	5.04865	4.919525	98.09683	8.310938	-3.49675	2.46614
221.0483	-0.56417	4.919525	98.38951	8.310938	-4.26076	2.46614
223.5891	-8.37235	4.48279	104.688	8.511903	-3.88157	2.501868
226.1299	-5.08649	4.48279	106.2771	8.511903	-1.06268	2.501868
228.6707	-2.13358	4.491925	103.4593	8.518983	-1.13316	2.665764
231.2115	1.209174	4.491925	98.2771	8.518983	-1.92379	2.665764
233.7523	2.002668	5.121238	99.57231	8.429049	-2.6492	2.938948

236.2931	3.994404	4.665018	99.31519	8.318222	-2.87753	1.925268
238.8338	1.936825	4.665018	102.6323	8.318222	-2.36978	1.925268
241.3746	0.007598	5.335842	101.0785	8.2479	-2.59004	3.034774
243.9154	-1.42231	5.335842	95.46686	8.2479	-0.5181	3.034774
246.4562	-2.21229	4.09199	89.81013	7.885403	-0.27147	2.583594
248.997	-2.84373	4.09199	87.20434	7.885403	-0.02465	2.583594
251.5378	-4.06781	4.48274	93.18889	8.383711	-1.76693	3.066765
254.0786	-5.32983	4.48274	96.24229	8.383711	0.013248	3.066765
256.6194	-6.29784	4.312201	100.3645	7.941393	0.943187	2.628487
259.1601	-2.29869	4.312201	96.05433	7.941393	2.190189	2.628487
261.7009	-0.47869	4.362051	97.17676	8.188584	-0.42484	2.920895
264.2417	-1.94663	4.362051	99.6791	8.188584	0.191445	2.920895
266.7825	-6.06066	4.459854	94.43144	7.956881	0.095436	3.002298
269.3233	-6.28285	4.459854	90.05579	7.956881	2.711418	3.002298
271.864	-2.64018	4.959179	90.98132	8.338062	2.041777	3.418967
274.4048	-0.93263	4.959179	96.41873	8.338062	0.342879	3.418967
276.9456	-1.02135	4.543835	97.78135	8.412186	-3.29476	2.753783
279.4864	-4.41336	4.543835	105.5553	8.412186	-0.96814	2.753783
282.0272	-7.44973	4.297367	111.9508	8.793477	1.202869	2.484931
284.568	-3.64425	4.297367	113.1545	8.793477	0.98284	2.484931
287.1088	-1.75941	5.008182	109.2805	8.374389	-1.48323	2.810706
289.6496	0.847274	5.008182	108.202	8.374389	-2.18234	2.810706
292.1903	-0.98125	4.775446	105.86	8.684221	-3.5837	2.185951
294.7311	-1.88548	4.775446	101.8411	8.684221	-6.21764	2.185951
297.2719	0.847566	5.325747	101.4357	8.515665	-4.82096	2.671278
299.8127	3.637477	5.325747	108.7511	8.515665	0.598608	2.671278
302.3535	3.075155	4.496192	111.2837	8.667738	4.240445	3.543282
304.8943	-0.74955	4.496192	116.6133	8.667738	7.330572	3.543282
307.4351	0.929061	4.735836	127.8977	9.058689	5.250906	3.493948
309.9758	3.549214	4.735836	133.2658	9.058689	1.244452	3.493948
312.5166	2.17013	4.640401	120.342	8.89092	-2.19979	2.945147
315.0574	-1.22755	4.640401	112.0064	8.89092	-0.0861	2.945147
317.5982	-6.84762	4.020993	111.8548	8.654345	1.434407	3.562277
320.139	-10.2358	4.020993	111.4316	8.654345	1.341524	3.562277
322.6798	-9.60938	4.413009	100.4551	8.184266	-0.04577	2.801729
325.2206	-4.87041	4.413009	96.731	8.184266	-2.52255	2.801729
327.7613	-0.97076	5.136636	97.11176	8.309375	-1.30709	2.755231
330.3021	-1.14261	5.136636	99.49812	8.309375	0.14603	2.755231
332.8429	-3.16951	4.505021	102.8446	8.764009	-1.37726	1.816451
335.3837	-4.66181	4.505021	114.0051	8.764009	-4.38197	1.816451
337.9245	-7.46447	4.22688	112.0024	8.328519	-1.27599	3.836459
340.4653	-8.02495	4.22688	99.32677	8.328519	1.952107	3.836459
343.006	-6.1786	4.687725	91.69939	8.484133	0.521843	2.294147
345.5468	0.565592	4.687725	98.96398	8.484133	0.951428	2.294147
348.0876	0.855626	4.569482	97.19594	7.826405	1.269799	3.29851
350.6284	-5.96049	4.569482	86.94997	7.826405	0.996872	3.29851
353.1692	-7.96888	5.122508	80.55853	8.006825	-3.12273	2.382573

355.71	-1.28208	5.122508	85.49029	8.006825	-3.31465	2.382573
358.2508	2.354641	4.497094	88.05518	8.199415	-1.42792	2.884964
360.7915	-2.84604	4.497094	93.27575	8.199415	-0.23344	2.884964
363.3323	-4.7866	4.190224	89.08862	7.989076	-2.33852	2.18581
365.8731	-4.458	4.190224	90.0607	7.989076	-4.31573	2.18581
368.4139	-1.37261	4.948337	90.14043	8.291501	-3.19849	3.011389
370.9547	-1.03742	4.948337	97.13847	8.291501	-1.15082	3.011389
373.4955	1.592744	4.676005	98.01887	8.025354	-0.68109	2.654378
376.0363	1.686582	4.676005	89.39518	8.025354	-1.64502	2.654378
378.5771	1.619701	4.745293	85.94776	8.161353	1.328307	4.242081
381.1178	-4.07209	4.745293	91.03279	8.161353	3.630254	4.242081
383.6586	-4.62592	4.442605	102.5166	8.299104	3.224189	2.61006
386.1994	-2.13932	4.442605	102.258	8.299104	-0.51906	2.61006
388.7402	-0.83442	4.468221	108.4155	9.010161	-2.44923	2.717072
391.281	-8.35038	4.468221	109.5363	9.010161	-0.24003	2.717072
393.8217	-7.38181	4.755424	108.0036	8.288093	1.318277	3.236803
396.3625	-1.63747	4.755424	100.4786	8.288093	2.203678	3.236803
398.9033	1.442156	4.712203	97.24885	8.4793	-1.78434	2.813526
401.4441	-0.72762	4.712203	101.3127	8.4793	-1.6873	2.813526
403.9849	-0.08018	4.786829	107.6045	8.330565	-1.47419	1.927067
406.5257	1.876417	4.786829	106.204	8.330565	1.805832	1.927067
409.0665	1.152957	4.601486	91.90856	7.934378	2.45755	3.396973
411.6073	1.896303	4.601486	85.21399	7.934378	1.646123	3.396973
414.148	2.571017	4.646147	92.61318	8.400705	0.472706	3.250071
416.6888	5.329311	4.646147	104.0251	8.400705	0.743376	3.250071
419.2296	5.051804	5.685721	109.7283	8.456676	1.901509	2.410784
421.7704	5.949268	5.685721	106.6807	8.456676	-0.14122	2.410784
424.3112	1.770222	4.283166	100.6067	8.383708	-1.2237	3.1402
426.852	-3.95158	4.283166	103.5199	8.383708	-2.04566	3.1402
429.3928	-9.54919	4.36639	104.9622	8.188343	-1.32109	2.884726
431.9335	-7.87119	4.36639	97.25589	8.188343	-0.18767	2.884726
434.4743	-7.28208	4.141533	87.946	8.100866	1.23877	3.385404
437.0151	-5.47941	4.141533	92.37901	8.100866	3.166033	3.385404
439.5559	-2.47321	5.180257	91.06544	7.757442	4.645136	3.255395
442.0967	2.830681	5.180257	79.61432	7.757442	2.47267	3.255395
444.6375	1.503963	4.383726	76.59749	7.929619	-2.13059	1.566437
447.1783	-4.16506	4.383726	87.15057	7.929619	-4.48524	1.566437
449.7191	-5.91052	4.274524	95.0134	8.21982	-1.83348	3.010041
452.2598	-8.08482	4.274524	95.61684	8.21982	0.788096	3.010041
454.8006	-2.68945	5.165545	92.12192	8.279881	0.83816	3.406645
457.3414	0.205474	5.165545	89.01685	8.279881	0.132531	3.406645
459.8822	2.251223	4.083127	84.11059	8.20629	-0.2217	2.786729
462.423	-6.06322	4.083127	95.53207	8.20629	0.010094	2.786729
464.9637	-10.8547	3.88388	102.2497	8.353274	-1.7259	2.638033
467.5045	-7.64132	5.669202	100.268	7.955015	-1.33016	2.901714
470.0453	1.192465	5.669202	88.20641	7.955015	0.681522	2.901714
472.5861	5.647614	5.172598	87.31352	8.069535	1.965231	3.170849

475.1269	5.073791	5.172598	87.91562	8.069535	0.945072	3.170849
477.6677	0.636157	4.706457	82.65359	8.12394	-0.26003	2.418909
480.2085	-1.799	4.706457	84.80074	8.12394	-2.0392	2.418909
482.7493	-6.60452	4.663145	90.626	8.125939	-3.2677	2.802974
485.29	-3.24821	4.663145	96.64103	8.125939	-3.17649	2.802974
487.8308	0.075199	4.540146	89.50699	7.759543	-2.02272	2.618887
490.3716	2.462497	4.540146	84.09641	7.759543	-1.42376	2.618887
492.9124	-1.87471	4.562699	81.01725	7.960481	-2.15952	2.113502
495.4532	-5.38172	4.562699	81.84663	7.960481	-3.02528	2.113502
497.994	-4.78965	5.039793	82.76568	8.300813	-4.52443	2.710442
500.5348	-1.49557	5.039793	86.82478	8.300813	-3.79739	2.710442
503.0755	0.059967	4.429955	93.53568	8.036663	-1.19517	3.679845
505.6163	-2.42822	4.429955	93.71857	8.036663	2.421771	3.679845
508.1571	-5.42428	5.17853	95.18405	8.356475	5.076647	3.319158
510.6979	-0.79641	5.17853	94.97476	8.356475	3.167884	3.319158
513.2387	0.114024	4.484628	96.79609	8.076311	1.308047	3.09532
515.7795	-3.66743	4.484628	85.59963	8.076311	0.047548	3.09532
518.3203	-9.54939	5.293144	83.12254	8.280771	-1.077	2.025537
520.861	-3.81126	5.293144	84.46001	8.280771	-3.11999	2.025537
523.4018	1.468568	4.781115	94.19498	8.043548	-4.33489	2.689751
525.9426	0.708502	4.781115	88.65741	8.043548	-3.70454	2.689751
528.4834	-3.58487	4.854124	91.47939	7.842711	-2.14997	2.778699
531.0242	-0.99008	4.854124	86.68165	7.842711	0.078508	2.778699
533.5649	1.908818	4.663528	88.10436	8.485502	1.574986	3.316281
536.1058	1.573192	4.663528	86.15385	8.485502	1.139571	3.316281
538.6465	-0.54682	4.897497	97.23369	8.074674	0.109509	2.835212
541.1873	-2.07332	4.897497	102.1809	8.074674	-0.70513	2.835212
543.7281	-2.26069	4.597146	95.46463	8.37143	0.089129	3.286986
546.2689	-3.78352	4.597146	90.58223	8.37143	1.244332	3.286986
548.8097	-2.19991	4.655746	101.4949	8.608283	0.212513	2.268529
551.3505	-3.5826	4.655746	110.912	8.608283	-2.32082	2.268529
553.8912	-2.25196	4.50151	112.8114	8.598987	-2.73643	2.715601
556.432	-6.15067	4.50151	112.1315	8.598987	-2.637	2.715601
558.9728	-4.44645	4.700204	115.1371	8.740307	-1.89766	2.872845
561.5136	0.133954	4.700204	111.0065	8.740307	-2.63795	2.872845
564.0544	3.237356	4.785421	103.1811	8.607257	0.360636	3.052524
566.5952	1.99931	4.785421	102.719	8.607257	0.745556	3.052524
569.136	-2.48126	4.460499	105.3148	8.262575	1.672013	2.763906
571.6768	-6.97923	4.460499	102.5738	8.262575	-1.74873	2.763906
574.2175	-11.0298	4.747356	94.95161	7.943345	-2.59128	3.177897
576.7583	-5.76662	4.747356	88.95659	7.943345	-0.8284	3.177897
579.2991	-0.77081	5.292155	89.16451	8.481043	1.560001	2.724428
581.8399	2.902365	5.292155	91.07988	8.481043	0.634676	2.724428
584.3807	3.352021	5.058642	100.7495	8.930431	-2.14434	2.777948
586.9214	2.931783	5.058642	110.1357	8.930431	-3.61561	2.777948
589.4622	-2.28193	4.428137	115.9876	8.734418	-3.61334	3.106724
592.0031	-4.49698	4.428137	115.0117	8.734418	-1.51702	3.106724

594.5438	-4.60138	4.642457	108.2507	8.723751	0.236347	2.544999
597.0846	-5.10794	4.642457	108.5793	8.723751	-0.17876	2.544999
599.6254	-9.23552	4.852163	108.7984	8.360067	-2.53631	2.344285
602.1662	-8.73136	4.852163	102.3971	8.360067	-3.54111	2.344285
604.707	-4.58782	4.830762	91.04963	8.186823	-3.11016	3.369863
607.2477	-2.56434	4.830762	91.04366	8.186823	-1.25613	3.369863
609.7885	-2.83372	4.555068	100.5163	8.60807	-1.33244	2.82519
612.3293	-4.041	4.555068	108.6905	8.60807	-0.01263	2.82519
614.8701	-2.7793	5.030732	113.7631	8.671308	-0.34606	2.92549
617.4109	-2.20598	5.030732	108.9275	8.671308	-0.87024	2.92549
619.9517	1.036056	4.570079	109.4526	8.753896	-0.87012	2.807309
622.4924	-0.92134	4.570079	110.6117	8.753896	-0.28308	2.807309
625.0333	-3.92881	4.948331	110.6807	8.438069	-1.8251	2.761509
627.574	-5.48942	4.948331	106.6069	8.438069	-3.14094	2.761509
630.1148	-3.87988	4.832538	102.005	8.792506	-2.18677	3.097735
632.6556	-2.03388	4.832538	108.8102	8.792506	0.851613	3.097735
635.1964	0.538136	4.758248	118.055	8.583659	1.822793	2.997937
637.7372	-0.70377	4.758248	119.0026	8.583659	1.023178	2.997937
640.278	-5.08712	4.06467	111.6578	8.754166	-0.53079	3.158267
642.8187	-5.70971	4.06467	107.9366	8.754166	1.478498	3.158267
645.3596	-5.75432	4.811511	112.882	8.176909	3.951554	3.027154
647.9003	-2.42175	4.811511	109.3777	8.176909	3.014321	3.027154
650.4411	-0.63582	5.590116	103.4823	8.202605	1.721155	3.04071
652.9819	8.070662	5.590116	98.15869	8.202605	1.031358	3.04071
655.5226	9.732541	4.676315	99.98559	8.693604	1.906139	2.72371
658.0635	6.953547	4.676315	103.7998	8.693604	-0.2695	2.72371
660.6042	-0.48629	4.945051	114.1129	9.020442	-1.53941	2.221879
663.145	-3.21733	4.945051	119.0384	9.020442	-4.47091	2.221879
665.6858	-0.58289	5.103384	117.663	8.473723	-4.30866	2.745123
668.2266	-1.03643	5.103384	106.5466	8.473723	-3.5715	2.745123
670.7674	-0.94277	4.704288	102.7665	8.873322	-0.90648	3.22618
673.3082	-1.27181	4.704288	113.5198	8.873322	0.448545	3.22618
675.8489	1.461155	4.975359	117.0636	8.463422	2.090924	2.497815
678.3898	0.72357	4.975359	106.5999	8.463422	0.187285	2.497815
680.9305	-1.80114	5.305032	97.62126	8.735271	-1.99945	2.284096
683.4713	0.934402	5.305032	105.0775	8.735271	-3.98693	2.284096
686.0121	2.032075	4.962597	109.6651	8.776769	-2.84481	2.676006
688.5529	-1.42153	4.962597	107.6644	8.776769	-4.09511	2.676006
691.0937	-0.17502	5.10957	106.6706	9.029506	-1.962	3.218045
693.6345	0.457392	5.10957	113.4363	9.029506	-0.71365	3.218045
696.1752	3.479291	19.01975	116.1942	35.10939	0.995029	18.07064
698.716	7.418686	19.01975	115.6647	35.10939	0.384172	18.07064

microns	Rb	e_Rb	Sr	e_Sr	Sn	e_Sn
0	-2.19131	0.545396	2.100975	3.381573	9.184198	17.73786
2.540786	-1.83068	0.545396	2.324169	3.381573	7.357966	17.73786
5.081571	-1.79953	0.325554	1.679529	2.604368	-4.59066	1.183915
7.622356	-1.7135	0.325554	1.082948	2.604368	2.35193	1.183915
10.16314	-1.18854	1.385779	4.071424	3.637346	7.574461	16.45804
12.70393	-1.17384	1.385779	6.192393	3.637346	19.25718	16.45804
15.24471	-1.41542	0.448759	27.40206	5.412115	14.30195	16.39888
17.7855	-0.8787	0.448759	71.19398	5.412115	7.996526	16.39888
20.32628	1.442132	2.240444	216.9488	17.27252	-5.11724	1.91926
22.86707	6.967828	2.240444	634.2532	17.27252	5.552314	1.91926
25.40786	14.16433	4.453322	1365.238	40.96407	16.51795	15.34761
27.94864	16.58504	4.453322	2157.797	40.96407	13.90843	15.34761
30.48943	17.85652	4.446536	2560.8	53.46878	-0.88507	12.14192
33.03021	24.46536	4.446536	2377.149	53.46878	0.601521	12.14192
35.571	28.32212	6.11768	1877.17	44.402	6.111567	13.1653
38.11178	19.85529	6.11768	1482.397	44.402	23.84885	13.1653
40.65257	11.5963	4.120538	1415.907	43.21218	31.84326	26.78562
43.19336	16.49874	4.120538	1676.376	43.21218	47.20277	26.78562
45.73414	24.57375	5.649735	2443.318	52.20846	36.26119	21.74494
48.27493	34.03204	5.649735	3527.076	52.20846	62.88154	21.74494
50.81571	38.06133	6.510148	4818.768	72.66116	82.60194	34.09781
53.35649	50.92548	6.510148	5861.992	72.66116	100.979	34.09781
55.89728	70.61119	9.733004	6325.297	84.94777	99.77077	40.21824
58.43807	83.00433	9.733004	6157.881	84.94777	86.92276	40.21824
60.97885	70.23974	9.022176	5480.345	79.13288	86.32379	43.02474
63.51964	51.63864	9.022176	4506.189	79.13288	105.1656	43.02474
66.06042	41.11081	8.330642	3421.936	62.57835	130.7316	48.3606
68.60121	32.58712	8.330642	2409.449	62.57835	100.2308	48.3606
71.142	18.14205	6.441604	1552.083	41.03718	52.7727	28.8741
73.68278	6.598062	6.441604	874.5634	41.03718	24.43051	28.8741
76.22356	5.008584	3.666622	473.8386	24.01523	69.01596	25.45027
78.76435	5.624474	3.666622	247.6234	24.01523	77.32849	25.45027
81.30514	5.327876	4.174391	130.9654	13.4982	60.39875	37.05899
83.84592	1.0926	4.174391	80.64422	13.4982	16.18796	37.05899
86.38671	0.542725	3.059745	61.87386	10.47961	28.88902	21.50399
88.9275	1.92289	3.059745	44.74796	10.47961	18.64008	21.50399
91.46828	3.735038	3.655532	43.09176	9.102608	9.277302	21.50561
94.00906	2.023163	3.655532	40.90228	9.102608	-5.63821	21.50561
96.54985	-0.56862	3.142927	38.14872	8.001856	-14.624	8.036913
99.09064	1.211104	3.142927	47.30264	8.001856	-7.51183	8.036913
101.6314	2.379179	3.373428	53.36969	9.042108	4.97635	12.77943
104.1722	4.132206	3.373428	53.30222	9.042108	7.981358	12.77943
106.713	2.013538	4.112541	52.5391	9.995871	-3.69919	16.64456
109.2538	1.64413	4.112541	63.56601	9.995871	-0.961	16.64456
111.7946	-0.47982	3.80232	67.19458	10.04863	0.711979	12.25789
114.3354	-0.04469	3.80232	63.63817	10.04863	-4.50358	12.25789
116.8761	-1.08582	2.802343	51.20447	9.624685	-7.36804	11.62702
119.4169	-1.59772	2.802343	47.76436	9.624685	-5.06629	11.62702
121.9577	-3.46537	2.807421	58.97107	9.735392	-11.39	3.961267

124.4985	-6.51554	2.807421	65.68776	9.735392	-15.3292	3.961267
127.0393	-7.69415	1.724305	70.14075	10.31825	-12.5244	13.75862
129.5801	-5.26053	1.724305	66.99443	10.31825	-3.46438	13.75862
132.1208	-1.34075	2.377218	61.31461	9.669584	1.341364	15.83757
134.6616	0.357663	2.377218	48.25195	9.669584	23.43184	15.83757
137.2024	-1.931	3.679175	40.16916	8.960644	24.08955	26.6415
139.7432	-3.96553	3.679175	41.37307	8.960644	12.35361	26.6415
142.284	-1.19345	3.400068	50.05232	8.819153	-6.45771	5.642936
144.8248	-0.25662	3.400068	54.4985	8.819153	-4.31652	5.642936
147.3656	-1.91152	2.395676	53.43114	8.952403	-1.47047	13.13654
149.9063	-5.00691	2.395676	49.26698	8.952403	10.59201	13.13654
152.4471	-5.05776	1.638156	48.32979	8.912011	9.185894	22.19987
154.9879	-4.50753	1.638156	46.56696	8.912011	5.673578	22.19987
157.5287	-2.93724	2.523122	49.7756	8.789171	11.34316	18.38449
160.0695	-1.33575	2.523122	56.7915	8.789171	34.2701	18.38449
162.6103	-1.10146	3.65605	54.59683	9.557287	27.55737	27.52159
165.1511	-1.86517	3.65605	48.45472	9.557287	14.21226	27.52159
167.6918	-1.61874	3.563218	48.58168	8.906458	1.54346	19.30356
170.2326	-4.35448	3.563218	55.77016	8.906458	16.36767	19.30356
172.7734	-6.62993	2.172408	61.11717	9.78268	13.86318	21.55014
175.3142	-8.15902	2.172408	57.27958	9.78268	8.07291	21.55014
177.855	-5.304	2.059926	50.72745	9.123936	-14.0391	4.787594
180.3958	-4.98763	2.059926	51.31844	9.123936	-18.7964	4.787594
182.9366	-2.20405	3.613425	54.09396	9.722714	-20.3034	2.211344
185.4773	0.813961	3.613425	56.49741	9.722714	-0.26321	2.211344
188.0181	2.340693	2.954195	52.43842	9.138536	8.214706	16.04681
190.5589	-1.09206	2.954195	53.01217	9.138536	17.6439	16.04681
193.0997	-3.69423	2.764517	49.97766	9.151917	3.016682	22.73526
195.6405	-4.45586	2.764517	43.56112	9.151917	10.30219	22.73526
198.1813	-3.99347	2.735519	36.5	7.97586	9.165266	19.14089
200.7221	-3.8291	2.735519	35.17259	7.97586	15.44761	19.14089
203.2628	-3.26014	1.891752	46.24509	8.896979	16.00813	21.12468
205.8036	-3.01558	1.891752	61.03642	8.896979	12.43003	21.12468
208.3444	-4.06704	2.282411	65.47512	9.827558	8.951276	14.84461
210.8852	-5.89149	2.282411	64.80779	9.827558	-4.70937	14.84461
213.426	-6.2464	1.660678	64.40173	10.18556	10.24799	19.60415
215.9668	-5.56607	1.660678	61.10181	10.18556	22.0416	19.60415
218.5076	-2.94338	1.807802	49.77356	8.584044	21.37247	22.79695
221.0483	0.656541	1.807802	49.23057	8.584044	8.837888	22.79695
223.5891	1.8482	4.050801	51.57734	9.441021	16.66803	15.94341
226.1299	-0.70223	4.050801	51.32558	9.441021	36.91607	15.94341
228.6707	-3.73523	2.446672	40.6175	8.534076	30.33436	27.32775
231.2115	-1.97826	2.446672	42.26399	8.534076	20.8794	27.32775
233.7523	0.567333	3.525433	42.67012	9.000751	7.356399	20.37736
236.2931	1.733777	3.397286	52.29814	9.549933	11.57716	13.84566
238.8338	2.447269	3.397286	63.90021	9.549933	8.509192	13.84566
241.3746	0.622892	3.070857	69.50292	9.834818	-3.72741	19.19661
243.9154	-1.92718	3.070857	64.96207	9.834818	-4.33575	19.19661
246.4562	-3.12407	3.020424	52.02105	8.247132	5.476446	14.27726
248.997	1.134116	3.020424	40.28061	8.247132	20.80956	14.27726
251.5378	1.193281	4.04636	33.24692	8.144621	17.31838	22.51487
254.0786	1.552847	4.04636	35.08505	8.144621	11.55003	22.51487

256.6194	2.047667	3.179496	39.17557	8.232007	4.835848	15.28509
259.1601	4.171675	3.179496	40.55077	8.232007	-6.33882	15.28509
261.7009	2.226741	4.228705	48.64542	9.087219	-15.3302	2.754738
264.2417	0.419312	4.228705	57.07042	9.087219	-12.6632	2.754738
266.7825	-1.21782	3.008688	56.46413	9.059856	-1.74408	13.3813
269.3233	-3.28509	3.008688	53.59065	9.059856	-0.58117	13.3813
271.864	-2.49794	3.36153	47.7	9.621856	0.876263	15.32238
274.4048	-1.55494	3.36153	48.34193	9.621856	-1.05123	15.32238
276.9456	2.049735	3.705476	44.72921	8.77262	-5.33346	4.835272
279.4864	0.606547	3.705476	50.42765	8.77262	-17.6596	4.835272
282.0272	-1.87858	3.065483	44.70889	8.514516	-21.8742	25.79911
284.568	-3.95939	3.065483	44.86962	8.514516	7.382914	25.79911
287.1088	-2.1399	2.736183	55.37568	10.06552	26.40522	19.56428
289.6496	-0.66654	2.736183	65.24629	10.06552	39.61714	19.56428
292.1903	1.668693	4.684762	60.88466	9.082639	14.8099	10.12139
294.7311	5.453724	4.684762	46.85337	9.082639	1.977357	10.12139
297.2719	3.089462	2.262655	32.59645	7.566292	-10.2257	14.07297
299.8127	-3.00324	2.262655	27.43301	7.566292	-10.3684	14.07297
302.3535	-7.32454	2.801014	33.60023	8.68183	-15.1429	1.861029
304.8943	-3.07374	2.801014	43.13076	8.68183	-21.9965	1.861029
307.4351	0.710687	3.393396	45.72312	8.829183	-11.7351	15.20821
309.9758	2.163503	3.393396	48.14162	8.829183	-8.1244	15.20821
312.5166	2.799768	3.955919	52.02015	9.478951	-0.47584	17.00456
315.0574	1.638343	3.955919	54.95308	9.478951	0.396497	17.00456
317.5982	-1.09346	2.450927	46.90144	8.88716	-1.77073	21.28482
320.139	-5.04216	2.450927	46.84539	8.88716	2.206001	21.28482
322.6798	-2.54857	3.251743	39.88399	7.819912	21.69317	19.79691
325.2206	1.00474	3.251743	39.42024	7.819912	21.87946	19.79691
327.7613	1.090245	3.026598	30.36119	7.874028	-2.51527	9.072756
330.3021	-1.86055	3.026598	30.17352	7.874028	-17.2633	9.072756
332.8429	-2.30378	2.185706	34.82476	9.014434	-1.65605	23.11348
335.3837	-0.17663	2.185706	40.79094	9.014434	9.22537	23.11348
337.9245	-0.64681	3.083043	47.38963	8.929523	4.782761	2.832191
340.4653	-1.86299	3.083043	48.25777	8.929523	-10.5878	2.832191
343.006	-2.35729	3.072265	52.65343	9.002095	-6.01138	14.526
345.5468	-1.11876	3.072265	48.26395	9.002095	-0.39864	14.526
348.0876	-1.25223	2.962191	40.02526	8.044984	12.7623	22.80955
350.6284	-3.53196	2.962191	34.08514	8.044984	9.220693	22.80955
353.1692	-2.59553	3.309761	40.76413	9.128382	0.505727	1.913589
355.71	-1.8275	3.309761	48.02519	9.128382	-18.0991	1.913589
358.2508	-2.24159	1.607679	46.69404	8.968246	-13.699	15.32529
360.7915	-5.17325	1.607679	46.54416	8.968246	-9.45038	15.32529
363.3323	-1.40716	3.125209	44.71655	8.634915	-0.07878	17.16503
365.8731	-1.31427	3.125209	41.88528	8.634915	1.49975	17.16503
368.4139	-0.1657	3.706663	46.02387	8.949497	2.955915	16.58138
370.9547	-0.27518	3.706663	49.46904	8.949497	6.202604	16.58138
373.4955	3.771402	3.647841	47.68524	8.72407	13.21863	13.20746
376.0363	2.448946	3.647841	38.50144	8.72407	8.36781	13.20746
378.5771	-0.02441	2.965512	40.22189	8.408396	-4.54832	6.144917
381.1178	-2.16276	2.965512	43.18155	8.408396	-7.23595	6.144917
383.6586	-2.93177	2.23823	47.00586	8.823701	-3.29708	17.35667
386.1994	-3.82754	2.23823	44.93133	8.823701	4.823668	17.35667

388.7402	-4.78018	2.92737	44.99315	9.090304	10.97213	12.45914
391.281	-4.11379	2.92737	47.10967	9.090304	8.399187	12.45914
393.8217	-5.69055	2.207473	49.11848	9.272099	2.159715	16.08768
396.3625	-2.86136	2.207473	53.25087	9.272099	-0.55225	16.08768
398.9033	0.248705	3.521517	50.91018	8.123692	-2.31977	22.11167
401.4441	0.65735	3.521517	43.21835	8.123692	4.537462	22.11167
403.9849	-1.18746	2.956422	40.47816	9.269869	14.91916	18.95868
406.5257	-0.28572	2.956422	49.02062	9.269869	17.07737	18.95868
409.0665	-0.35322	3.223966	56.66607	9.448102	18.62002	14.22418
411.6073	-2.80604	3.223966	54.26019	9.448102	3.15796	14.22418
414.148	-3.0675	2.829492	47.67923	7.803559	-7.33257	3.190705
416.6888	-2.64523	2.829492	37.52246	7.803559	-18.2567	3.190705
419.2296	-1.48958	2.737468	32.32707	8.286479	-19.3624	6.258175
421.7704	-1.69434	2.737468	32.81351	8.286479	-17.3533	6.258175
424.3112	-1.39818	2.304534	35.26467	8.346135	-8.22764	15.37464
426.852	-0.11179	2.304534	41.27454	8.346135	15.64538	15.37464
429.3928	0.223222	3.254977	51.9778	10.05864	15.12092	23.6356
431.9335	-2.11922	3.254977	57.71109	10.05864	-0.14405	23.6356
434.4743	-4.78838	2.11236	53.98009	8.425347	-18.8953	3.232882
437.0151	-5.5418	2.11236	55.08348	8.425347	-17.4774	3.232882
439.5559	-3.57988	3.071024	61.71173	9.660295	-16.0183	4.878931
442.0967	-1.19127	3.071024	56.74462	9.660295	-15.7693	4.878931
444.6375	-0.54511	2.684758	47.51881	8.923326	-17.7822	3.610727
447.1783	-3.23552	2.684758	48.31595	8.923326	-21.7556	3.610727
449.7191	-2.5205	3.915622	52.62923	9.063963	-21.606	2.828688
452.2598	1.62095	3.915622	45.37136	9.063963	-22.0595	2.828688
454.8006	4.633247	4.097698	38.50406	8.765099	-20.6697	13.18124
457.3414	2.763422	4.097698	39.11744	8.765099	-15.3062	13.18124
459.8822	-1.55375	2.978534	40.20608	8.35742	-10.8748	4.230196
462.423	-2.21145	2.978534	33.43691	8.35742	-11.8885	4.230196
464.9637	-2.94629	2.552687	33.11092	8.343559	3.16012	20.3624
467.5045	-3.25454	2.189914	39.35837	9.332768	7.449995	10.76942
470.0453	-4.00702	2.189914	50.48837	9.332768	6.759562	10.76942
472.5861	-3.91088	2.662005	50.27364	8.400933	-7.51322	4.933089
475.1269	-3.55891	2.662005	44.31575	8.400933	-7.34358	4.933089
477.6677	-1.11217	3.388492	36.75777	9.644849	-14.1377	23.91626
480.2085	-0.95064	3.388492	41.73717	9.644849	-4.25852	23.91626
482.7493	-3.93081	2.308871	52.92059	8.950394	12.60557	15.74574
485.29	-6.55884	2.308871	55.09902	8.950394	29.01344	15.74574
487.8308	-4.22468	2.638908	57.45564	9.019187	22.64463	15.63984
490.3716	-1.73531	2.638908	55.58562	9.019187	4.37678	15.63984
492.9124	-0.99649	3.82159	59.54939	9.941139	-0.73328	23.29027
495.4532	-0.2213	3.82159	58.4307	9.941139	5.265437	23.29027
497.994	1.559972	2.879429	55.77839	9.163309	3.457455	9.122513
500.5348	1.582174	2.879429	54.71439	9.163309	-14.6835	9.122513
503.0755	-1.52097	2.805689	53.61015	9.162248	-13.2301	15.85814
505.6163	-4.83696	2.805689	53.00008	9.162248	-8.22103	15.85814
508.1571	-5.29011	3.918304	50.13178	9.502555	0.662727	4.932528
510.6979	-1.97277	3.918304	49.14516	9.502555	-7.08923	4.932528
513.2387	-1.03965	3.49426	55.56175	10.46352	-11.336	15.45335
515.7795	-1.83186	3.49426	67.63994	10.46352	-12.2789	15.45335
518.3203	-2.23393	3.528298	70.24132	9.747767	-9.61544	1.881377

520.861	-1.37341	3.528298	63.53613	9.747767	-15.1488	1.881377
523.4018	-0.87217	2.290515	57.38125	9.775679	-26.3349	12.73701
525.9426	-1.61768	2.290515	59.16026	9.775679	-18.3967	12.73701
528.4834	-0.76944	3.700798	58.55801	8.828285	-12.7584	16.00218
531.0242	-1.53469	3.700798	58.04376	8.828285	-14.8204	16.00218
533.5649	0.133597	4.079889	54.6074	9.890701	-3.16866	17.16384
536.1058	-0.20645	4.079889	50.80206	9.890701	15.41179	17.16384
538.6465	3.046978	2.962375	53.85689	9.971595	13.06157	19.46026
541.1873	2.072802	2.962375	65.45493	9.971595	-0.91702	19.46026
543.7281	1.525693	2.506293	73.22093	9.859089	4.868464	10.92546
546.2689	-3.29006	2.506293	71.62289	9.859089	5.425274	10.92546
548.8097	-4.78194	1.976626	62.2993	10.21734	4.292081	16.06443
551.3505	-6.62841	1.976626	66.79422	10.21734	5.545536	16.06443
553.8912	-5.50226	3.21151	64.68669	9.175906	28.64911	24.089
556.432	-2.81222	3.21151	65.2611	9.175906	21.71631	24.089
558.9728	-0.70374	3.80565	52.02394	9.520036	9.236953	12.72259
561.5136	0.04429	3.80565	55.47858	9.520036	-3.32192	12.72259
564.0544	-0.66557	3.55852	62.04418	10.49376	-4.99674	8.28365
566.5952	-0.34014	3.55852	73.72808	10.49376	-4.70211	8.28365
569.136	-0.43879	1.66196	68.89398	9.871458	-7.33398	2.175896
571.6768	-2.74936	1.66196	65.70893	9.871458	-15.2947	2.175896
574.2175	-6.46358	2.372112	65.84344	10.97385	-18.4768	9.30713
576.7583	-7.36842	2.372112	74.98995	10.97385	-18.5373	9.30713
579.2991	-4.9277	4.237253	87.65507	13.04509	2.249156	21.77893
581.8399	1.506653	4.237253	115.2088	13.04509	16.88058	21.77893
584.3807	3.072824	3.093521	128.7365	12.03405	17.6158	20.888
586.9214	2.332104	3.093521	116.8002	12.03405	2.065497	20.888
589.4622	-0.56143	2.796255	97.46147	11.28373	11.07338	24.15173
592.0031	-1.50479	2.796255	89.84507	11.28373	27.66426	24.15173
594.5438	-3.30465	2.156312	90.78318	10.57505	19.33668	1.952133
597.0846	-4.27072	2.156312	86.78023	10.57505	-7.70232	1.952133
599.6254	-4.98807	3.00187	79.52674	10.68554	-24.1617	20.34884
602.1662	-3.58239	3.00187	74.72226	10.68554	-12.2014	20.34884
604.707	-0.92783	2.248501	76.9239	11.28816	4.970498	17.63294
607.2477	-1.74136	2.248501	70.03305	11.28816	4.51193	17.63294
609.7885	-5.91075	1.258608	71.05753	11.75634	10.47282	13.97082
612.3293	-8.76276	1.258608	82.72878	11.75634	11.27286	13.97082
614.8701	-6.8282	3.222299	122.5728	13.2339	6.135348	12.67286
617.4109	-3.544	3.222299	137.8491	13.2339	-5.43659	12.67286
619.9517	-0.26284	3.786901	138.1741	13.20836	2.375506	9.879775
622.4924	0.644877	3.786901	129.6794	13.20836	9.660996	9.879775
625.0333	-0.4489	2.090257	138.47	12.35038	2.065793	9.710767
627.574	-3.52765	2.090257	130.4484	12.35038	-2.12181	9.710767
630.1148	-4.94436	3.453099	111.1972	11.60614	3.605447	21.84347
632.6556	-4.74126	3.453099	97.70074	11.60614	2.350815	21.84347
635.1964	-0.7021	2.540957	88.83927	12.22494	3.135778	20.62854
637.7372	0.390615	2.540957	92.54828	12.22494	9.513082	20.62854
640.278	-0.51937	2.441752	102.4659	13.48255	15.31479	21.46496
642.8187	-4.88576	2.441752	130.83	13.48255	20.45215	21.46496
645.3596	-5.97974	3.41817	150.702	11.52257	15.64251	11.96188
647.9003	-2.15936	3.41817	134.4094	11.52257	16.8257	11.96188
650.4411	0.194368	3.194096	92.46618	9.665837	0.760032	20.48297

652.9819	0.242225	3.194096	67.82502	9.665837	11.54903	20.48297
655.5226	-0.83656	3.504984	62.03699	12.78476	7.585985	20.8876
658.0635	1.808376	3.504984	75.62151	12.78476	-2.4546	20.8876
660.6042	1.682223	3.476631	122.2644	12.50789	-5.8243	4.31532
663.145	1.030299	3.476631	144.4024	12.50789	3.138187	4.31532
665.6858	-0.37649	2.586411	116.358	9.738227	-0.90862	17.32714
668.2266	-3.40794	2.586411	67.45206	9.738227	-14.0303	17.32714
670.7674	-4.27839	3.507179	56.25497	9.677311	-0.40472	17.87007
673.3082	-2.92573	3.507179	54.78417	9.677311	10.97698	17.87007
675.8489	0.08063	2.863848	69.60536	13.34818	12.32042	7.475504
678.3898	-0.20858	2.863848	100.4025	13.34818	-0.55718	7.475504
680.9305	-0.40675	3.473985	115.3003	10.3005	-10.2005	6.830248
683.4713	-0.6707	3.473985	108.3528	10.3005	-13.9546	6.830248
686.0121	0.270221	3.663801	84.19151	10.6743	-13.0476	15.02021
688.5529	0.334406	3.663801	71.59254	10.6743	-7.22656	15.02021
691.0937	0.99273	3.384748	66.98	10.07698	5.291212	21.5785
693.6345	1.973147	3.384748	65.47321	10.07698	18.1799	21.5785
696.1752	0.517589	23.39335	59.82729	41.95021	15.86002	5.889045
698.716	-2.67999	23.39335	83.76683	41.95021	-15.9711	5.889045

microns	Ba	e_Ba	PbL	e_PbL
0	5.379338	6.148907	-5.54063	3.195085
2.540786	-15.9222	6.148907	-5.96388	3.195085
5.081571	-17.7754	4.46938	-7.03438	1.245055
7.622356	1.96598	4.46938	-7.6504	1.245055
10.16314	11.93006	34.47876	-6.81223	1.851847
12.70393	43.88	34.47876	-6.25838	1.851847
15.24471	73.95874	59.67363	-7.30416	1.349965
17.7855	72.11032	59.67363	-7.675	1.349965
20.32628	52.2484	27.02623	-5.20314	3.266764
22.86707	50.34157	27.02623	-1.89434	3.266764
25.40786	75.56425	73.33183	1.457846	3.698596
27.94864	54.3697	73.33183	-0.01837	3.698596
30.48943	53.43079	48.48712	-0.20592	4.347731
33.03021	63.05222	48.48712	-0.31264	4.347731
35.571	72.56274	63.85808	2.624743	3.742522
38.11178	52.78659	63.85808	2.552281	3.742522
40.65257	37.31823	58.33769	3.811836	4.291862
43.19336	17.2745	58.33769	4.221087	4.291862
45.73414	12.05152	28.01232	2.805837	4.051414
48.27493	78.16669	28.01232	-2.1926	4.051414
50.81571	78.47765	81.86855	6.275958	7.437361
53.35649	139.962	81.86855	14.23507	7.437361
55.89728	102.2633	102.2921	19.95382	9.714489
58.43807	238.3894	102.2921	18.95172	9.714489

60.97885	252.3587	127.6264	21.89215	8.580309
63.51964	234.0608	127.6264	27.08231	8.580309
66.06042	33.23213	47.49154	22.42712	9.668899
68.60121	21.8707	47.49154	16.90143	9.668899
71.142	60.63656	80.67937	7.088931	7.951515
73.68278	112.1234	80.67937	8.722145	7.951515
76.22356	164.1369	99.97276	4.48557	7.515483
78.76435	212.1113	99.97276	7.102588	7.515483
81.30514	175.6619	86.52177	13.41642	8.270504
83.84592	194.7996	86.52177	16.14134	8.270504
86.38671	174.2396	92.21203	14.63194	6.874774
88.9275	98.36502	92.21203	10.92381	6.874774
91.46828	-14.0617	61.76967	2.982275	7.082266
94.00906	-2.91973	61.76967	-0.57387	7.082266
96.54985	-17.0637	18.75915	-0.96438	5.696843
99.09064	-11.962	18.75915	1.314604	5.696843
101.6314	21.32261	65.49406	-2.90944	5.228708
104.1722	33.42007	65.49406	3.423446	5.228708
106.713	10.42495	50.77117	3.576359	6.817689
109.2538	0.66794	50.77117	2.211812	6.817689
111.7946	0.306394	61.62292	0.006667	5.45735
114.3354	5.648437	61.62292	-0.67174	5.45735
116.8761	1.889727	50.85226	-2.6247	6.226158
119.4169	-21.3969	50.85226	-2.3858	6.226158
121.9577	-22.5316	16.63283	-0.97088	5.99425
124.4985	-6.36094	16.63283	0.376837	5.99425
127.0393	-33.4569	55.20918	1.259597	7.148238
129.5801	-31.4074	55.20918	10.11531	7.148238
132.1208	19.53411	54.79113	12.11066	7.581442
134.6616	38.20671	54.79113	8.931734	7.581442
137.2024	-7.92091	50.05762	4.011564	6.539835
139.7432	-20.0608	50.05762	3.175124	6.539835
142.284	-11.1675	54.8665	-1.67574	5.2804
144.8248	-33.1149	54.8665	-3.7341	5.2804
147.3656	-79.2338	5.914483	-0.93133	6.286231
149.9063	-80.2529	5.914483	3.967428	6.286231
152.4471	-74.7229	12.77556	4.635173	6.517572
154.9879	-63.5503	12.77556	4.212222	6.517572
157.5287	-29.9502	25.41511	4.606495	6.206259
160.0695	-4.57738	25.41511	2.979634	6.206259
162.6103	27.97394	76.94497	0.654638	6.721188
165.1511	52.88194	76.94497	1.655939	6.721188
167.6918	71.0627	56.19874	2.090125	6.782096
170.2326	46.52942	56.19874	4.461905	6.782096
172.7734	4.857185	65.42877	1.869236	6.2245
175.3142	-41.503	65.42877	1.502521	6.2245
177.855	-57.9346	20.7557	1.137452	6.515658

180.3958	11.17687	20.7557	8.490192	6.515658
182.9366	57.87889	79.14034	12.45167	7.263721
185.4773	28.53241	79.14034	5.836874	7.263721
188.0181	-35.2075	22.57945	0.21249	6.385017
190.5589	15.18521	22.57945	2.209017	6.385017
193.0997	62.61943	64.27438	10.47292	6.120271
195.6405	77.55498	64.27438	6.242377	6.120271
198.1813	65.28391	70.47607	1.278318	6.257991
200.7221	44.54731	70.47607	-0.71217	6.257991
203.2628	0.259631	49.87219	-0.00489	5.606015
205.8036	-8.37559	49.87219	-4.30338	5.606015
208.3444	71.3271	58.98861	-6.8407	5.784515
210.8852	130.5538	58.98861	-3.5065	5.784515
213.426	120.0141	98.46912	1.539934	6.259863
215.9668	103.8586	98.46912	5.143041	6.259863
218.5076	128.1197	69.86378	1.975396	6.162001
221.0483	99.8833	69.86378	0.335783	6.162001
223.5891	47.44234	69.36875	2.851545	5.966621
226.1299	1.565379	69.36875	7.425478	5.966621
228.6707	14.80669	61.81934	-0.47882	6.280424
231.2115	11.15449	61.81934	-5.94224	6.280424
233.7523	42.29124	61.21967	-8.96138	5.211288
236.2931	36.18151	62.86203	-4.84639	6.206104
238.8338	23.39567	62.86203	-1.18791	6.206104
241.3746	6.650593	48.814	2.663785	6.021253
243.9154	-5.29877	48.814	1.968158	6.021253
246.4562	-25.1501	27.88144	-3.41941	5.141079
248.997	-50.6295	27.88144	-4.48434	5.141079
251.5378	-44.9588	34.94819	0.234158	6.996117
254.0786	-46.3136	34.94819	6.666537	6.996117
256.6194	-11.085	64.85115	10.39439	6.289654
259.1601	7.206675	64.85115	8.459468	6.289654
261.7009	19.03199	20.92115	5.097533	6.331185
264.2417	-7.16513	20.92115	0.372541	6.331185
266.7825	13.99314	52.44302	0.216523	5.86975
269.3233	32.54767	52.44302	-3.25272	5.86975
271.864	24.35442	66.11057	-5.49072	5.079992
274.4048	35.60259	66.11057	-1.90497	5.079992
276.9456	39.74099	52.23327	0.48208	6.284448
279.4864	34.8885	52.23327	-1.09682	6.284448
282.0272	-18.655	49.65027	-8.2356	4.103285
284.568	-0.31853	49.65027	-8.23459	4.103285
287.1088	48.69544	96.93228	-5.32172	6.05303
289.6496	97.3201	96.93228	1.31552	6.05303
292.1903	85.68047	49.33422	3.39045	6.274386
294.7311	38.51668	49.33422	0.943958	6.274386
297.2719	4.083219	36.84431	-2.42424	5.7897

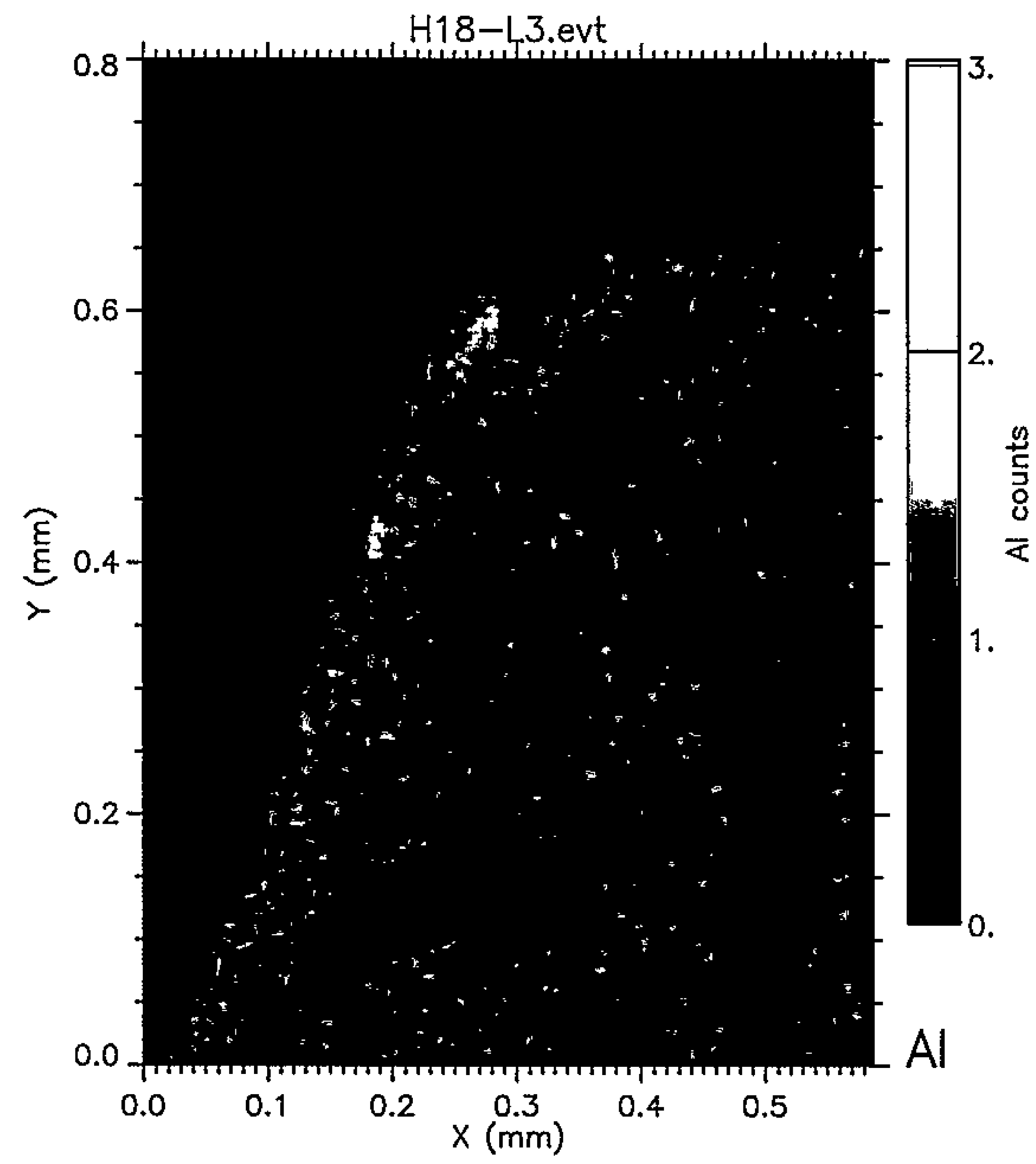
299.8127	-15.3676	36.84431	-2.5591	5.7897
302.3535	-14.3501	28.81142	-2.11951	5.928833
304.8943	-15.3397	28.81142	0.655692	5.928833
307.4351	0.198901	58.16604	1.122784	5.810186
309.9758	32.06392	58.16604	-0.32694	5.810186
312.5166	25.35135	60.03338	1.030849	7.046454
315.0574	33.0275	60.03338	4.728965	7.046454
317.5982	25.09291	44.53861	8.768983	6.246034
320.139	0.930536	44.53861	6.184134	6.246034
322.6798	-58.9974	22.22355	3.875583	5.656323
325.2206	-38.6946	22.22355	-1.13067	5.656323
327.7613	14.3737	60.46386	0.658174	6.377245
330.3021	44.25034	60.46386	0.451762	6.377245
332.8429	7.89044	46.05964	2.289623	5.826028
335.3837	3.421939	46.05964	2.312325	5.826028
337.9245	-44.0963	13.30616	-1.83111	5.140851
340.4653	-68.6155	13.30616	-5.72458	5.140851
343.006	-77.4577	40.827	-5.51331	5.593632
345.5468	-10.6888	40.827	-0.08104	5.593632
348.0876	45.40782	66.32067	-0.16347	6.263679
350.6284	33.37475	66.32067	0.353424	6.263679
353.1692	-40.4782	33.24022	1.293467	6.478171
355.71	-55.6959	33.24022	3.790817	6.478171
358.2508	-17.0578	7.113543	4.517048	6.231241
360.7915	18.06686	7.113543	3.549882	6.231241
363.3323	16.95646	81.5772	1.277909	5.473668
365.8731	18.81628	81.5772	-1.179	5.473668
368.4139	-10.8933	38.66323	-2.93438	5.859169
370.9547	15.12412	38.66323	-1.19301	5.859169
373.4955	18.97234	46.43085	0.416291	6.083154
376.0363	19.94708	46.43085	1.664108	6.083154
378.5771	-39.3401	23.08484	6.039242	6.417976
381.1178	-40.9437	23.08484	11.4827	6.417976
383.6586	-17.0283	48.26615	10.93946	6.329984
386.1994	7.887272	48.26615	2.846534	6.329984
388.7402	-6.47974	28.28026	-3.08997	6.547517
391.281	-18.8184	28.28026	-0.53548	6.547517
393.8217	-27.7598	55.60114	5.646916	6.212913
396.3625	-14.168	55.60114	9.509022	6.212913
398.9033	-6.31927	44.15032	2.594101	5.144608
401.4441	4.804944	44.15032	-3.24278	5.144608
403.9849	-20.0757	48.83316	1.439433	6.684804
406.5257	-22.1819	48.83316	9.516889	6.684804
409.0665	9.910899	62.96476	7.056668	6.794033
411.6073	60.592	62.96476	2.168978	6.794033
414.148	42.86356	73.79678	-0.77811	5.19297
416.6888	42.52803	73.79678	-1.64515	5.19297

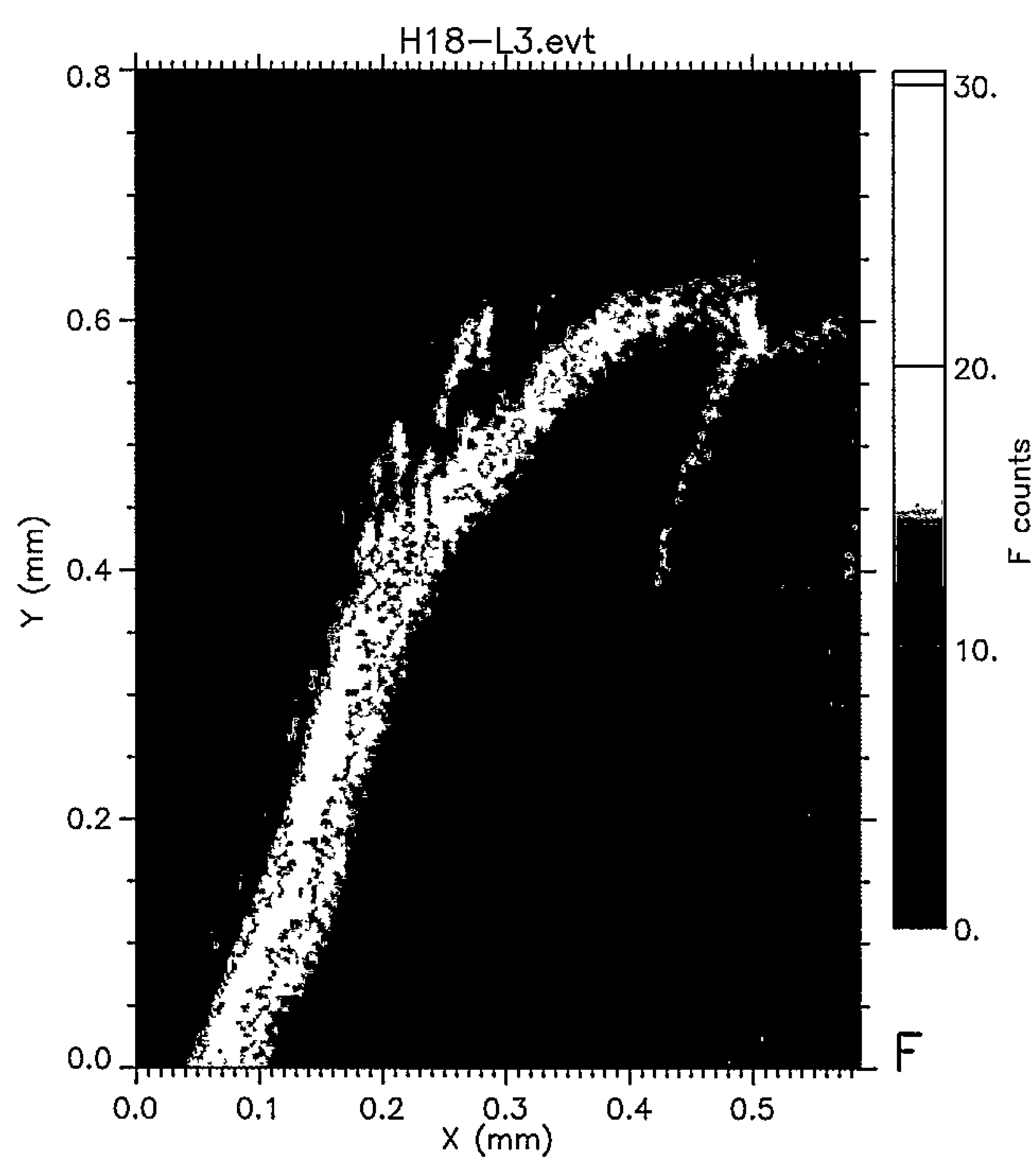
419.2296	18.28737	34.57328	2.447984	6.550463
421.7704	2.224906	34.57328	6.862485	6.550463
424.3112	33.62166	80.34174	5.383282	5.711079
426.852	59.72816	80.34174	0.487741	5.711079
429.3928	42.54815	49.37503	0.692889	5.503999
431.9335	13.43959	49.37503	0.752253	5.503999
434.4743	46.3422	57.48585	-1.02836	5.283904
437.0151	9.742349	57.48585	-3.10369	5.283904
439.5559	0.573399	60.22164	-1.21981	6.22508
442.0967	23.46023	60.22164	0.30642	6.22508
444.6375	53.60001	54.11647	3.536368	6.273122
447.1783	9.271139	54.11647	-1.58505	6.273122
449.7191	5.41118	46.09668	-2.07911	5.518392
452.2598	-26.699	46.09668	-6.9421	5.518392
454.8006	-14.5719	58.28576	-5.14522	5.509486
457.3414	-10.3553	58.28576	-2.30948	5.509486
459.8822	0.897415	53.69058	3.674193	6.386113
462.423	28.97506	53.69058	9.345517	6.386113
464.9637	55.01918	55.13994	10.71633	7.597863
467.5045	39.58714	40.3233	11.43088	7.010581
470.0453	-9.93719	40.3233	9.60261	7.010581
472.5861	-28.7402	75.71629	4.474785	6.18531
475.1269	-18.6189	75.71629	-1.62209	6.18531
477.6677	42.61952	33.88767	1.668013	6.328978
480.2085	51.7603	33.88767	4.603065	6.328978
482.7493	12.82097	23.35326	3.29838	6.482237
485.29	-44.0763	23.35326	2.475409	6.482237
487.8308	-20.7234	37.34232	2.426755	5.570796
490.3716	-14.1895	37.34232	-1.33125	5.570796
492.9124	-21.7533	37.76149	-6.97657	5.570736
495.4532	-19.2697	37.76149	-6.64343	5.570736
497.994	-16.6658	70.37236	-0.64082	5.337127
500.5348	35.15783	70.37236	-1.2887	5.337127
503.0755	60.3	50.45563	-0.99673	5.381189
505.6163	59.88328	50.45563	-5.47983	5.381189
508.1571	17.0161	96.89197	-1.76267	6.097667
510.6979	22.17569	96.89197	-1.09785	6.097667
513.2387	61.11321	25.65333	-5.43565	4.847846
515.7795	35.63558	25.65333	-14.4071	4.847846
518.3203	-3.15207	36.46795	-15.1143	6.205682
520.861	-52.2496	36.46795	-6.85804	6.205682
523.4018	-38.09	7.299331	-1.40374	5.261882
525.9426	-49.3871	7.299331	-0.12135	5.261882
528.4834	-63.5552	24.82468	-1.86218	5.5817
531.0242	-82.6991	24.82468	-6.42643	5.5817
533.5649	-27.5449	63.79394	-3.78495	5.489589
536.1058	3.4112	63.79394	1.80748	5.489589

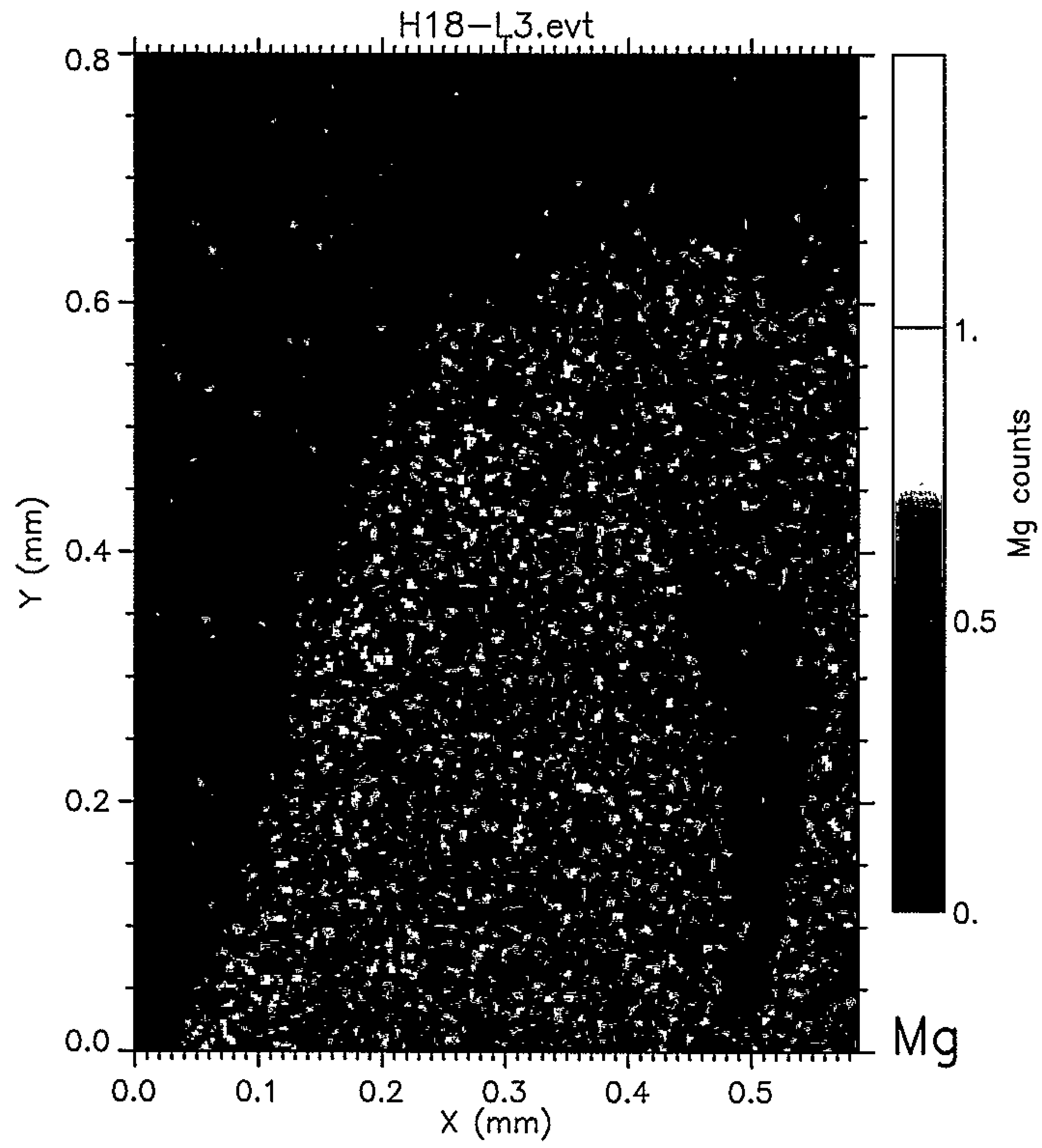
538.6465	27.87565	41.51447	2.521726	6.131083
541.1873	-13.6025	41.51447	0.897877	6.131083
543.7281	18.43635	62.98789	0.51683	5.837982
546.2689	18.60423	62.98789	1.757556	5.837982
548.8097	0.648482	41.39573	0.585658	5.549496
551.3505	-21.7003	41.39573	0.129989	5.549496
553.8912	-30.6576	28.64077	0.281968	6.646443
556.432	-38.7189	28.64077	0.553044	6.646443
558.9728	-59.3232	60.64569	2.268459	5.181215
561.5136	-39.1989	60.64569	1.767024	5.181215
564.0544	29.84928	56.98137	-3.14705	4.785253
566.5952	70.38319	56.98137	-6.50711	4.785253
569.136	39.58999	52.47701	-7.25087	6.03229
571.6768	-44.1556	52.47701	-6.93363	6.03229
574.2175	-0.73386	77.42979	-4.74975	6.742329
576.7583	39.86593	77.42979	-1.26425	6.742329
579.2991	49.33181	9.530113	3.0059	6.496948
581.8399	-25.5346	9.530113	0.968475	6.496948
584.3807	-33.7963	73.54875	-2.19434	6.188787
586.9214	-12.8043	73.54875	-5.75604	6.188787
589.4622	25.78707	81.74524	-4.82815	5.136315
592.0031	82.05465	81.74524	-3.67367	5.136315
594.5438	116.4228	74.22435	-4.44259	6.657154
597.0846	114.0113	74.22435	-0.89817	6.657154
599.6254	69.48477	50.03324	2.720466	6.828898
602.1662	25.21909	50.03324	7.417014	6.828898
604.707	13.60034	67.43512	5.046299	6.232478
607.2477	56.77401	67.43512	2.985622	6.232478
609.7885	71.08282	23.87689	-2.10851	5.502659
612.3293	14.86974	23.87689	-5.66549	5.502659
614.8701	-53.3077	64.00584	-3.52196	4.475358
617.4109	3.347964	64.00584	-3.81973	4.475358
619.9517	26.5737	86.90347	-6.23086	6.684464
622.4924	84.46907	86.90347	-5.32665	6.684464
625.0333	89.59874	49.12074	7.390909	6.969045
627.574	78.83865	49.12074	14.25636	6.969045
630.1148	9.241252	90.89663	6.702336	5.024251
632.6556	29.67604	90.89663	-4.67523	5.024251
635.1964	81.34806	108.3157	-7.34146	5.780634
637.7372	180.7155	108.3157	-6.02277	5.780634
640.278	172.5852	12.40954	-0.38953	6.383749
642.8187	87.67395	12.40954	1.598424	6.383749
645.3596	-26.0565	34.18554	2.668628	5.880131
647.9003	-42.5338	34.18554	-0.45973	5.880131
650.4411	-32.4961	69.50109	2.124997	5.661864
652.9819	-20.9351	69.50109	0.272394	5.661864
655.5226	5.210475	58.55571	-2.61759	6.713151

658.0635	35.10235	58.55571	0.021	6.713151
660.6042	31.79248	62.03918	7.061606	4.924283
663.145	39.1781	62.03918	2.956875	4.924283
665.6858	82.07787	78.48676	-5.64584	7.149442
668.2266	86.19073	78.48676	-4.28434	7.149442
670.7674	58.17536	47.91851	7.111274	6.78012
673.3082	-13.7252	47.91851	9.899841	6.78012
675.8489	0.428	71.14851	13.76308	7.189588
678.3898	-5.08985	71.14851	13.63084	7.189588
680.9305	4.125305	73.26745	10.97948	6.191844
683.4713	3.746769	73.26745	3.492281	6.191844
686.0121	36.24007	67.24827	1.757702	5.928287
688.5529	100.4795	67.24827	1.899091	5.928287
691.0937	70.59396	40.232	1.609998	6.515285
693.6345	24.27109	40.232	-1.02421	6.515285
696.1752	-20.5671	22.06297	1.897048	55.28088
698.716	-75.7849	22.06297	4.859533	55.28088

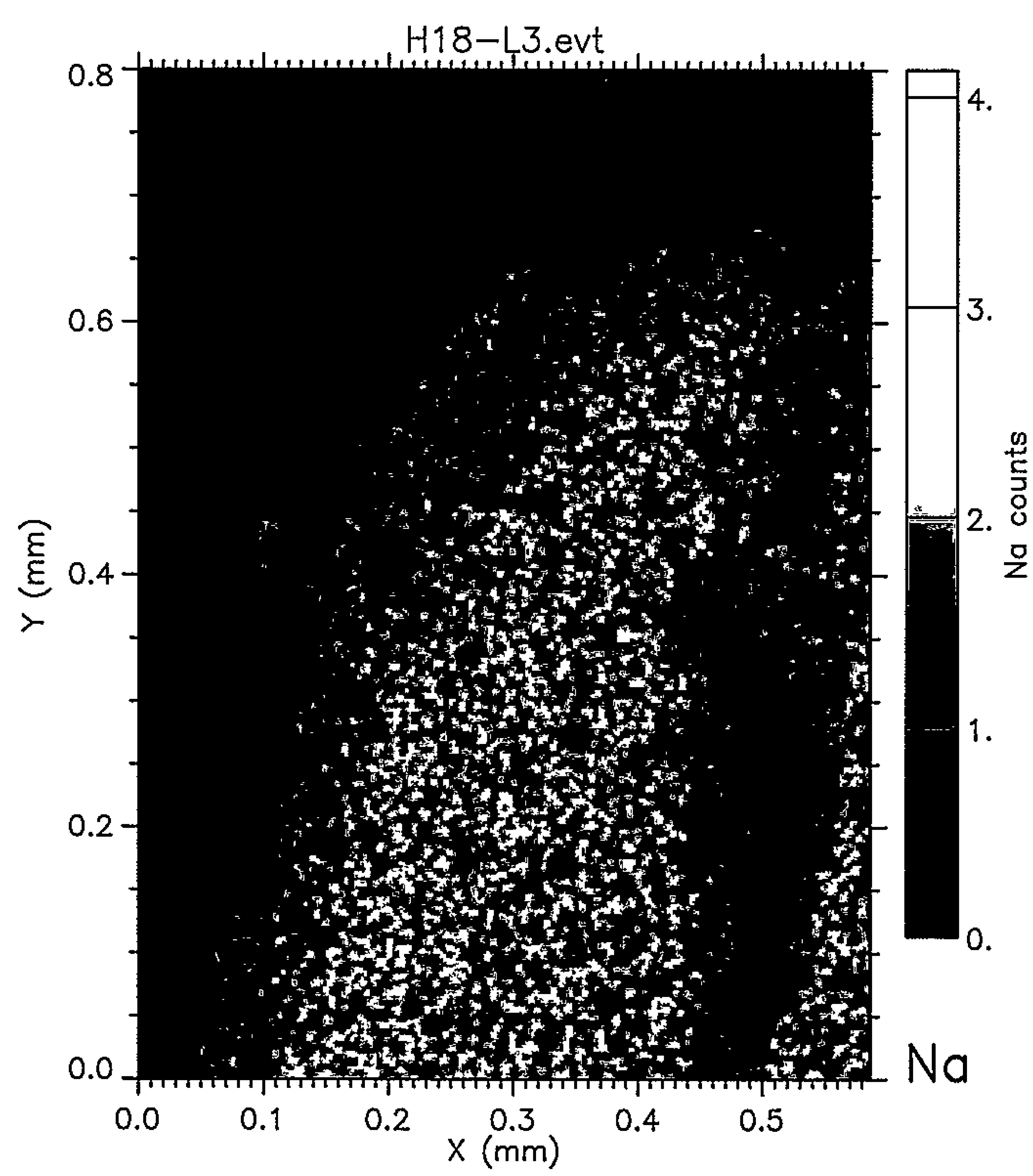
8.1.3 H18-L3 (Heavy-Control Tooth, Apical-third, Buccal) PIGE Mode



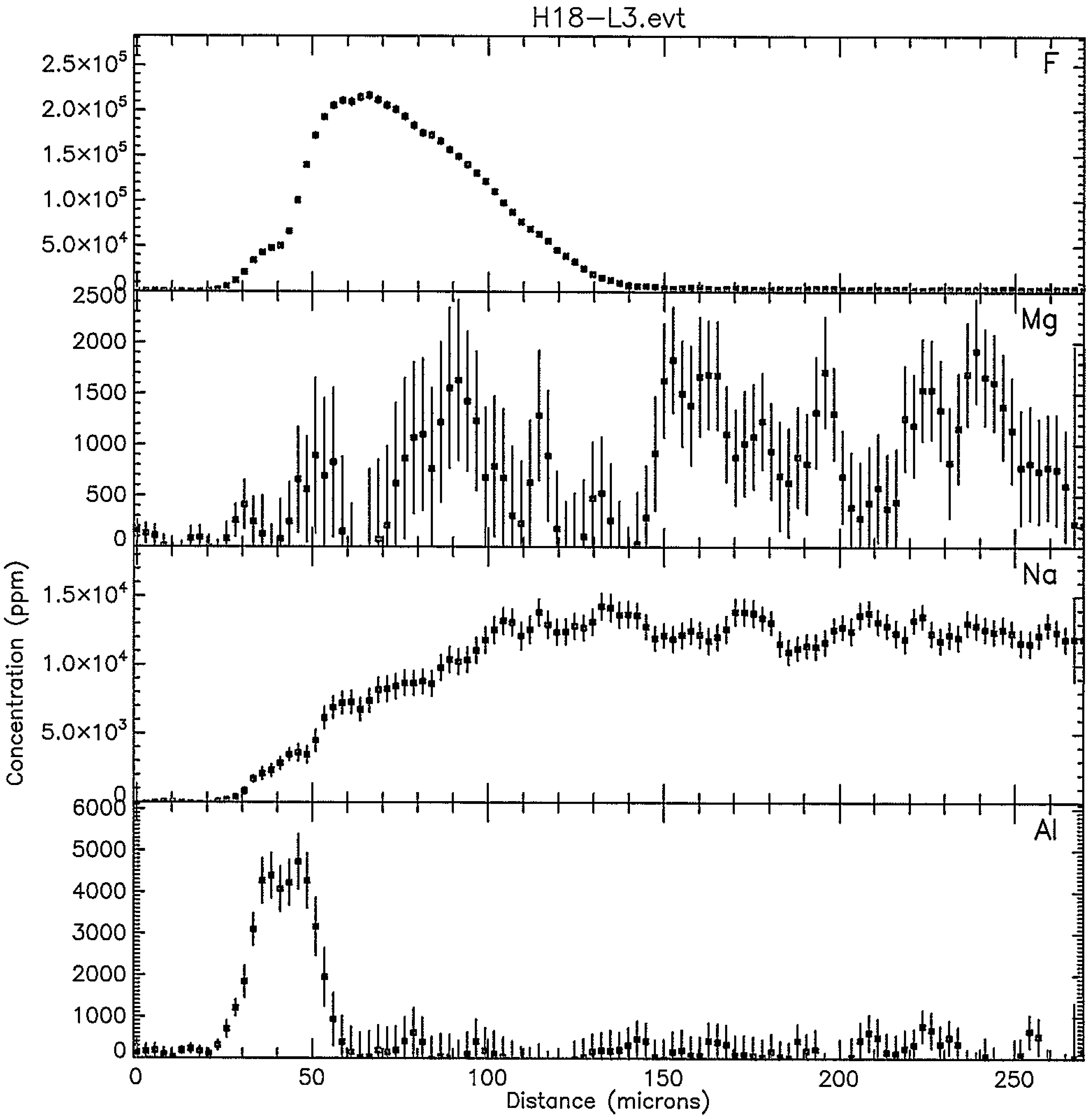




H18–L3.evt
Y (mm)
X (mm)
Mg counts
Mg



H18–L3.evt
Y (mm)
X (mm)
Na counts
Na


H18–L3.evt
F
Mg
Na
Al
Concentration (ppm)
Distance (microns)
2.5×10⁵
2.0×10⁵
1.5×10⁵
1.0×10⁵
5.0×10⁴
2500
2000
1500
1000
500
0
1.5×10⁴
1.0×10⁴
5.0×10³
6000
5000
4000
3000
2000
1000
0
50
100
150
200
250

microns	F	e_F	Mg	e_Mg
0	238.8525	246.896	158.9997	97.42786
2.541117	201.3505	246.896	129.8826	97.42786
5.082234	253.5555	269.7128	108.7537	103.3326
7.623351	323.2146	269.7128	8.861657	103.3326
10.16447	80.81019	323.569	-66.857	100.2934
12.70558	-178.984	323.569	-49.8787	100.2934
15.2467	-260.988	438.7673	83.81432	112.4997
17.78782	-14.6879	438.7673	91.42469	112.4997
20.32894	663.7195	681.4758	-5.18445	115.8085
22.87005	2152.427	681.4758	-55.0958	115.8085
25.41117	5921.247	1015.011	80.19852	157.8429
27.95229	12414.91	1015.011	259.4506	157.8429
30.4934	21477.34	1404.232	414.0803	238.6364
33.03452	34320.91	1404.232	247.9989	238.6364
35.57564	43043.79	1777.714	125.9555	377.3361
38.11675	48114.92	1777.714	-165.071	377.3361
40.65787	50512.02	2310.857	78.34097	384.0938
43.19899	66688.09	2310.857	246.1476	384.0938
45.7401	100831.5	2886.596	660.1768	516.6627
48.28122	140027.1	2886.596	562.9478	516.6627
50.82234	172559.3	3372.423	895.7806	761.6755
53.36346	193055	3372.423	694.8535	761.6755
55.90457	205943	3621.146	828.675	731.2495
58.44569	211289.8	3621.146	149.9021	731.2495
60.98681	209958.7	3852.48	-380.866	800.254
63.52792	215174	3852.48	-790.1	800.254
66.06904	217203.4	3954.03	-80.964	841.5943
68.61016	212132.9	3857.204	74.03709	776.8683
71.15128	206307.4	3857.204	209.091	776.8683
73.69239	201568.9	3708.827	622.8352	785.4879
76.23351	193757.7	3708.827	867.5129	785.4879
78.77463	183929	3689.763	1069.959	742.7489
81.31574	175424.7	3689.763	1101.874	742.7489
83.85686	173242.5	3543.662	768.4302	784.692
86.39798	166263.7	3543.662	1222.618	784.692
88.93909	156903.6	3327.333	1557.842	785.4528
91.48021	149309.1	3327.333	1634.681	785.4528
94.02132	140213.8	3094.48	1427.628	681.9945
96.56245	130943.7	3094.48	1235.279	681.9945
99.10356	121645	2956.569	678.8746	685.4299
101.6447	110496	2956.569	788.7809	685.4299
104.1858	97938.06	2657.551	675.7501	677.7529
106.7269	87770.91	2657.551	306.5487	677.7529
109.268	76937.98	2393.63	228.1352	607.3062
111.8091	69241.77	2393.63	630.7256	607.3062

114.3503	63433.46	2152.729	1289.632	636.9842
116.8914	56013.69	2152.729	894.0419	636.9842
119.4325	45922.84	1837.212	178.8118	561.4034
121.9736	39494.23	1837.212	-117.456	561.4034
124.5147	32998.66	1564.238	-25.9137	552.3719
127.0558	25667.24	1564.238	102.7203	552.3719
129.597	19389.27	1336.154	477.0553	549.3289
132.1381	15429.37	1336.154	527.8593	549.3289
134.6792	12745.4	1170.846	260.0041	553.2551
137.2203	9784.949	1006.437	-113.661	562.4996
139.7614	6995.101	1006.437	-369.279	562.4996
142.3026	6018.119	946.402	29.93615	504.7979
144.8437	6009.119	946.402	290.6514	504.7979
147.3848	5697.375	913.7697	917.4183	558.4094
149.9259	4429.713	913.7697	1631.839	558.4094
152.467	3587.054	913.7026	1834.922	516.6622
155.0081	4334.177	913.7026	1504.805	516.6622
157.5493	5011.355	882.131	1387.997	581.9315
160.0904	5061.378	882.131	1671.332	581.9315
162.6315	3616.892	853.3646	1690.333	527.5336
165.1726	2915.865	853.3646	1682.565	527.5336
167.7137	3643.665	823.6641	1107.858	466.8399
170.2548	4488.414	823.6641	880.0998	466.8399
172.796	3862.91	817.3899	1015.666	513.2067
175.3371	2938.234	817.3899	1082.863	513.2067
177.8782	2593.19	796.5228	1233.091	470.6208
180.4193	3122.086	796.5228	940.3624	470.6208
182.9604	3542.244	811.5831	696.5749	530.7022
185.5015	3206.667	811.5831	631.4264	530.7022
188.0426	3129.439	814.7178	882.7508	487.9105
190.5838	3717.084	814.7178	817.0224	487.9105
193.1249	3892.791	826.3232	1321.889	540.2356
195.666	4071.728	826.3232	1717.264	540.2356
198.2071	3937.445	795.6483	1308.177	449.9997
200.7482	3041.322	795.6483	692.5845	449.9997
203.2894	2789.06	809.0887	391.025	536.9826
205.8305	2953.106	822.5878	285.2907	543.5193
208.3716	3467.374	822.5878	436.3437	543.5193
210.9127	3534.77	811.8557	582.7026	527.5338
213.4538	3136.834	811.8557	379.1153	527.5338
215.9949	3519.869	797.764	442.7612	515.5393
218.5361	3364.466	797.764	1262.767	515.5393
221.0772	2423.71	800.9333	1193.665	498.1121
223.6183	2225.849	800.9333	1543.223	498.1121
226.1594	2960.621	804.308	1543.297	484.6724
228.7005	3594.372	804.308	1345.452	484.6724
231.2416	3438.005	790.5927	830.5803	536.9831

233.7828	3173.479	790.5927	1165.189	536.9831
236.3239	3169.436	794.3725	1697.417	504.7982
238.865	3370.713	794.3725	1923.47	504.7982
241.4061	3313.077	804.9564	1668.858	470.4173
243.9472	2872.384	804.9564	1614.881	470.4173
246.4883	3944.973	817.2894	1377.744	513.2064
249.0295	4176.044	817.2894	1145.742	513.2064
251.5706	2982.556	806.9705	780.0913	555.399
254.1117	2659.268	806.9705	821.6025	555.399
256.6528	2818.905	802.0508	745.8437	511.3976
259.1939	3191.777	802.0508	783.3054	511.3976
261.735	3320.418	797.3113	759.6619	540.0959
264.2762	3621.632	797.3113	602.7947	540.0959
266.8173	3937.452	2628.39	230.929	1736.272
269.3584	3072.487	2628.39	216.9571	1736.272

microns	B	e_B	Na	e_Na	Al	e_Al
0	48.60054	159.099	-130.279	112.5	132.6177	168.75
2.541117	55.06411	159.099	-82.0302	112.5	158.6328	168.75
5.082234	108.7537	103.3326	-7.46287	59.65909	182.0035	157.8431
7.623351	-59.5413	103.3326	36.73149	59.65909	89.21629	157.8431
10.16447	-105.585	163.7784	44.07215	115.8088	26.1126	81.8892
12.70558	-24.9395	163.7784	-22.3667	115.8088	188.7574	81.8892
15.2467	138.8783	159.099	-44.7465	79.54951	230.3138	112.5
17.78782	189.6938	159.099	-95.498	79.54951	173.3249	112.5
20.32894	160.2015	129.4782	-89.4864	81.8892	101.9999	115.8088
22.87005	110.0298	129.4782	80.8123	81.8892	314.7664	115.8088
25.41117	212.1281	188.6586	178.9663	168.7414	711.3972	197.8668
27.95229	42.48151	188.6586	389.3693	168.7414	1210.847	197.8668
30.4934	-68.5435	286.115	842.6748	253.1121	1844.045	382.0046
33.03452	-52.2252	286.115	1726.32	253.1121	3103.676	382.0046
35.57564	398.1647	346.7483	2110.437	432.0644	4274.999	536.5908
38.11675	446.9256	346.7483	2356.545	432.0644	4401.431	536.5908
40.65787	420.8511	448.5256	2864.966	433.3169	4077.151	543.1915
43.19899	71.15739	448.5256	3496.729	433.3169	4231.035	543.1915
45.7401	-151.566	546.7846	3624.271	596.5909	4734.37	658.9562
48.28122	-241.357	546.7846	3482.638	596.5909	4275.388	658.9562
50.82234	134.5414	768.6536	4517.877	780.1438	3168.236	695.7386
53.36346	311.0126	768.6536	6170.635	780.1438	1955.433	695.7386
55.90457	219.7776	713.7325	6927.929	787.5	937.2838	626.3735
58.44569	452.1107	713.7325	7256.03	787.5	394.9989	626.3735
60.98681	566.8729	785.4536	7316.675	820.9367	146.7126	612.8026
63.52792	548.6041	785.4536	6780.465	820.9367	18.2502	612.8026
66.06904	840.6823	804.8452	7420.082	837.3552	25.29975	625.7098
68.61016	436.0009	772.5412	8210.571	895.1805	193.9424	584.8058
71.15128	182.569	772.5412	8279.043	895.1805	148.3749	584.8058
73.69239	-27.1584	726.9102	8470.026	892.941	196.6406	576.391

76.23351	-160.709	726.9102	8717.702	892.941	409.8054	576.391
78.77463	-32.3382	745.1418	8695.294	866.5983	616.5112	590.5949
81.31574	13.94134	745.1418	8822.638	866.5983	393.767	590.5949
83.85686	86.08435	768.6536	8658.05	902.8058	-23.7875	540.2361
86.39798	177.4613	768.6536	9829.042	902.8058	42.03757	540.2361
88.93909	132.888	727.8471	10410.43	915.5491	34.19157	536.9834
91.48021	-12.5128	727.8471	10262.58	915.5491	-107.574	536.9834
94.02132	-615.867	651.1408	10403.01	907.004	103.0614	527.6718
96.56245	-320.701	651.1408	11085.22	907.004	408.6799	527.6718
99.10356	222.2138	634.1849	11834.91	941.4046	185.8424	546.7846
101.6447	627.5828	634.1849	12580.59	941.4046	104.436	546.7846
104.1858	722.4749	662.7463	13237.68	944.3924	36.13663	477.492
106.7269	920.1479	662.7463	13127.35	944.3924	-64.2663	477.492
109.268	593.9324	657.6677	12133.25	974.1029	-242.836	521.1396
111.8091	86.30692	657.6677	12602.99	974.1029	-266.131	521.1396
114.3503	-124.881	546.7846	13862	952.6793	-182.733	526.8948
116.8914	-36.2112	546.7846	12965.83	952.6793	-362.192	526.8948
119.4325	-121.172	558.4099	12424.07	911.8795	-451.215	448.5256
121.9736	-51.2536	558.4099	12453.79	911.8795	-433.669	448.5256
124.5147	-146.078	491.3352	12862.98	906.3474	-22.8306	437.1687
127.0558	224.224	491.3352	12738.11	906.3474	34.78268	437.1687
129.597	217.5696	425.5088	13162.34	935.4744	167.8227	421.5504
132.1381	443.2473	425.5088	14310.65	935.4744	193.0751	421.5504
134.6792	447.6267	477.2727	14199.97	965.6668	180.8045	495.5656
137.2203	829.3862	470.6212	13678.45	917.4098	206.9728	413.3514
139.7614	571.4288	470.6212	13729.04	917.4098	318.6118	413.3514
142.3026	-206.721	448.5256	13632.07	880.0708	472.5947	429.4306
144.8437	-441.446	448.5256	12826.25	880.0708	417.4522	429.4306
147.3848	104.5829	437.1687	11969.14	852.9852	36.1488	405.3309
149.9259	763.5748	437.1687	12187.12	852.9852	-20.7579	405.3309
152.467	609.0087	438.403	11931.84	904.7749	161.5478	484.6728
155.0081	-6.65303	438.403	12216.53	904.7749	202.3089	484.6728
157.5493	-416.128	473.968	12528.38	900.7812	81.76664	448.5256
160.0904	-690.4	473.968	12238.58	900.7812	63.60322	448.5256
162.6315	-510.118	421.5504	11805.07	919.204	429.1567	437.1687
165.1726	-215.46	421.5504	12080.95	919.204	397.0467	437.1687
167.7137	276.8931	466.8403	12650.01	942.6154	338.4792	463.2353
170.2548	744.4235	466.8403	13906.05	942.6154	81.87233	463.2353
172.796	921.6717	446.4478	13900.63	935.7163	96.14169	454.3501
175.3371	784.9598	446.4478	13811.03	935.7163	67.87044	454.3501
177.8782	393.3567	420.9365	13450.72	824.7869	33.45659	424.6782
180.4193	407.4561	420.9365	13120.04	824.7869	169.5433	424.6782
182.9604	529.484	444.7722	11603.74	874.3373	47.83143	366.2196
185.5015	604.4064	444.7722	10999.64	874.3373	12.61206	366.2196
188.0426	406.8542	437.1687	11254.2	841.1101	427.0046	396.9726
190.5838	394.239	437.1687	11445.2	841.1101	190.3291	396.9726
193.1249	375.946	404.6277	11372.54	878.8333	224.678	477.2727

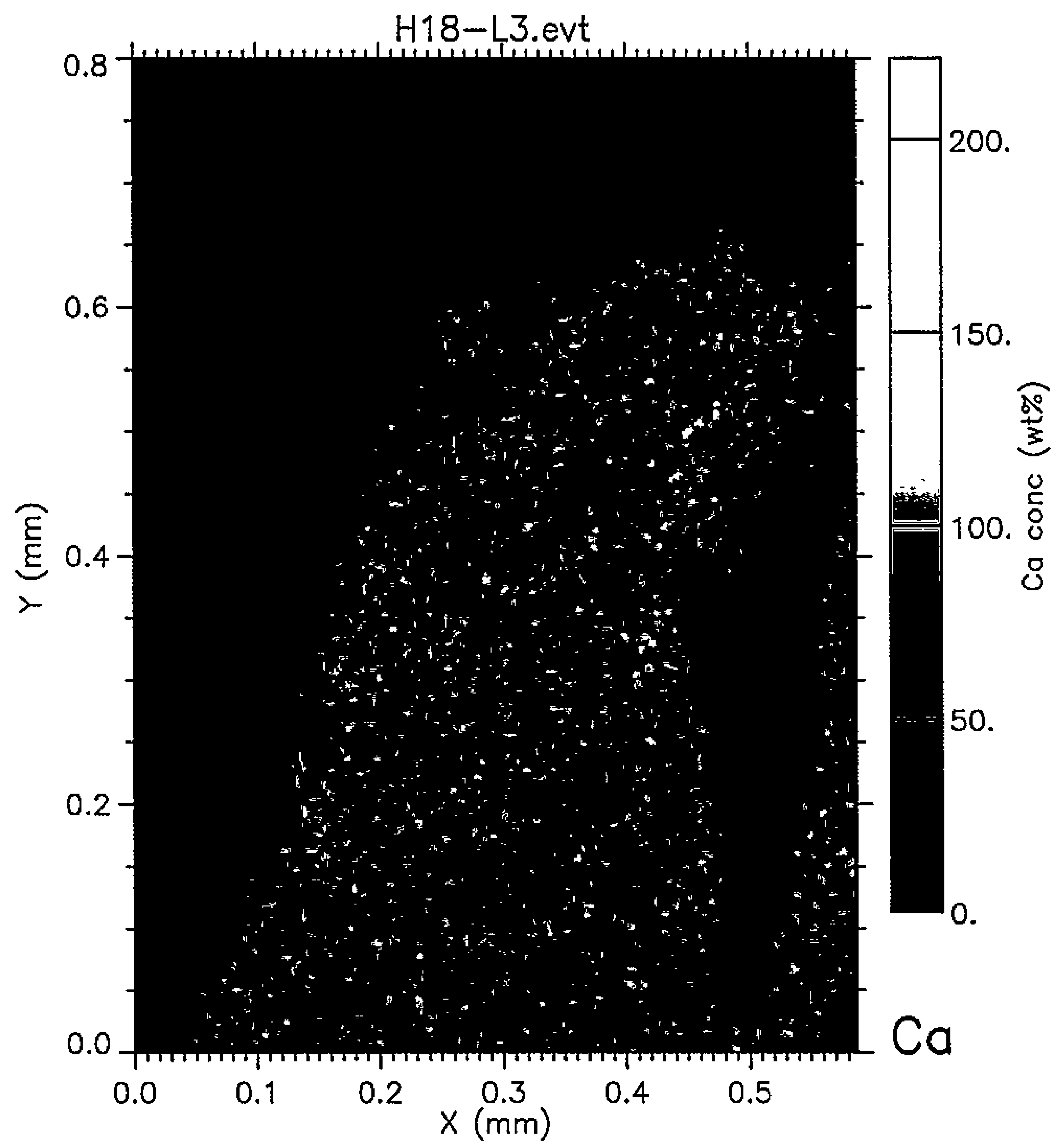
195.666	421.3412	404.6277	11693.17	878.8333	-345.371	477.2727
198.2071	574.5718	424.6782	12605.92	858.619	-796.621	409.5062
200.7482	783.842	424.6782	12804.11	858.619	-665.805	409.5062
203.2894	716.5823	425.5088	12506.15	935.4744	37.04444	466.8403
205.8305	280.4153	442.4437	13646.95	894.8864	440.9014	430.2078
208.3716	-76.7925	442.4437	13817.97	894.8864	625.0604	430.2078
210.9127	81.09354	396.9726	13177.22	868.5661	512.0753	452.2479
213.4538	13.96909	396.9726	12899.71	868.5661	156.5732	452.2479
215.9949	555.9019	453.502	12356.88	924.2818	122.1428	442.9129
218.5361	598.5651	453.502	11922.71	924.2818	242.6989	442.9129
221.0772	210.0522	437.1687	13304	849.0453	332.5362	379.7046
223.6183	-142.931	437.1687	13582.75	849.0453	786.6244	379.7046
226.1594	-98.8907	434.3247	12334.66	888.9005	689.6855	430.2078
228.7005	374.7657	434.3247	11812.45	888.9005	352.992	430.2078
231.2416	231.1295	437.1687	12238.57	913.7161	509.54	409.446
233.7828	168.0258	437.1687	12040.24	913.7161	357.6918	409.446
236.3239	321.0761	405.3309	13087.7	880.0708	-226.475	444.7722
238.865	608.5299	405.3309	12901.22	880.0708	-280.193	444.7722
241.4061	478.5112	448.5256	12620.63	874.3373	62.41279	437.1687
243.9472	658.3535	448.5256	12451.58	874.3373	-148.758	437.1687
246.4883	719.6631	421.8535	12632.78	900.8325	-477.946	377.3172
249.0295	612.8476	421.8535	12356.89	900.8325	-518.829	377.3172
251.5706	85.34572	433.3169	11665.61	931.8833	91.14438	388.4346
254.1117	-8.36195	433.3169	11599.47	931.8833	662.1404	388.4346
256.6528	259.7652	448.5256	12207.77	841.1101	537.209	437.1687
259.1939	161.3535	448.5256	12945.91	841.1101	-204	437.1687
261.735	25.64088	429.4306	12429.59	897.0513	-407.326	433.3169
264.2762	135.9511	429.4306	11908.04	897.0513	-301.652	433.3169
266.8173	546.0105	1856.155	11946.67	3078.085	26.70253	1312.5
269.3584	614.5825	1856.155	11924.46	3078.085	185.6198	1312.5

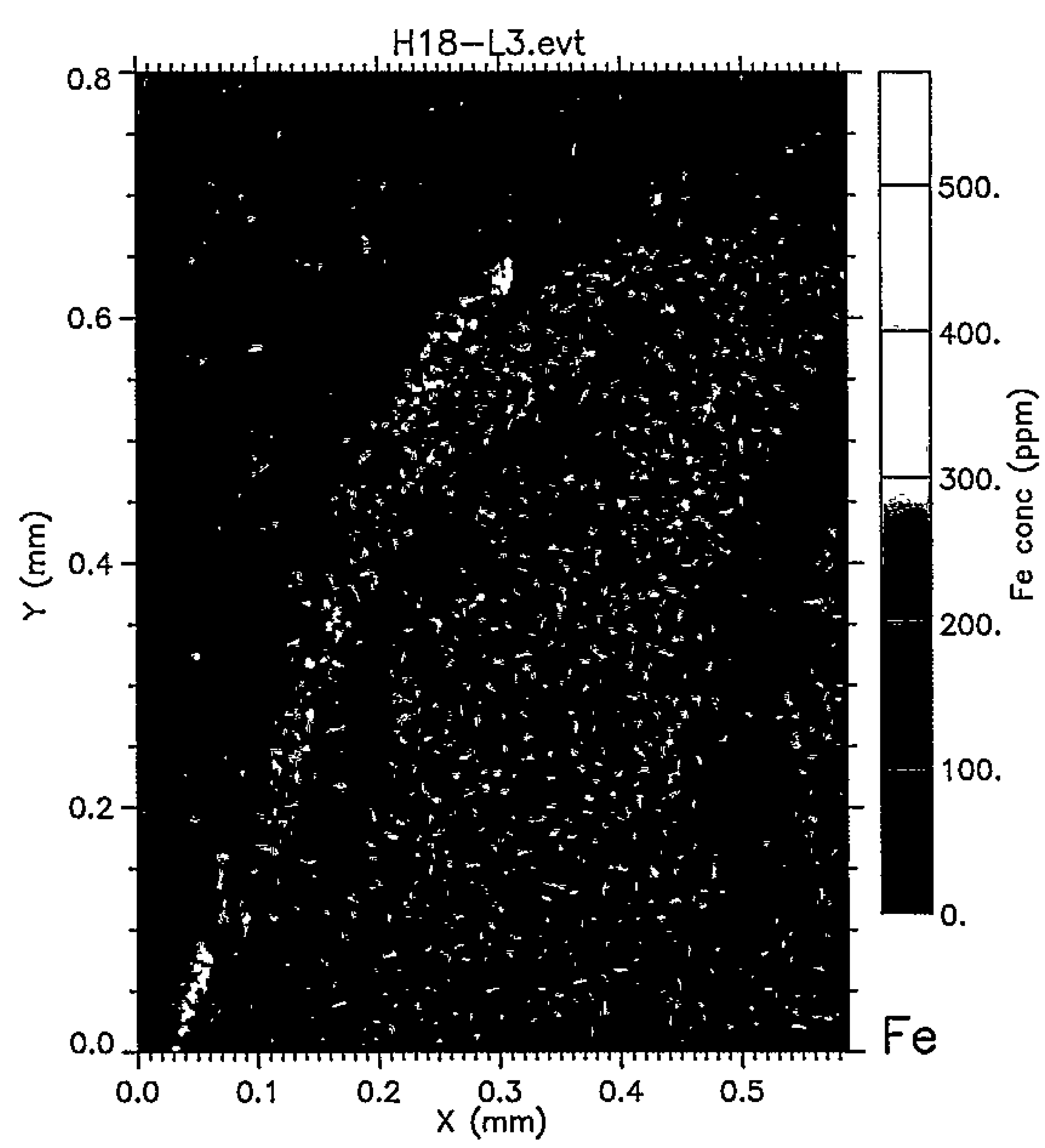
microns	Si	e_Si	P	e_P
0	34.45972	56.25	0	0
2.541117	48.31027	56.25	0	0
5.082234	35.50396	0	0	0
7.623351	49.13455	0	0	0
10.16447	87.67097	81.8892	0	0
12.70558	78.62913	81.8892	0	0
15.2467	21.1289	0	0	0
17.78782	0	0	0	0
20.32894	0	0	10.56445	0
22.87005	0	0	38.72778	0
25.41117	0	0	46.28432	63.29926
27.95229	90.76163	0	-6.4693	63.29926
30.4934	281.7616	133.4018	-0.48257	63.29926
33.03452	458.1971	133.4018	18.80472	63.29926
35.57564	403.8288	186.5602	39.9733	88.99276
38.11675	292.5202	186.5602	62.88134	88.99276
40.65787	313.0298	163.7784	119.9692	121.1471

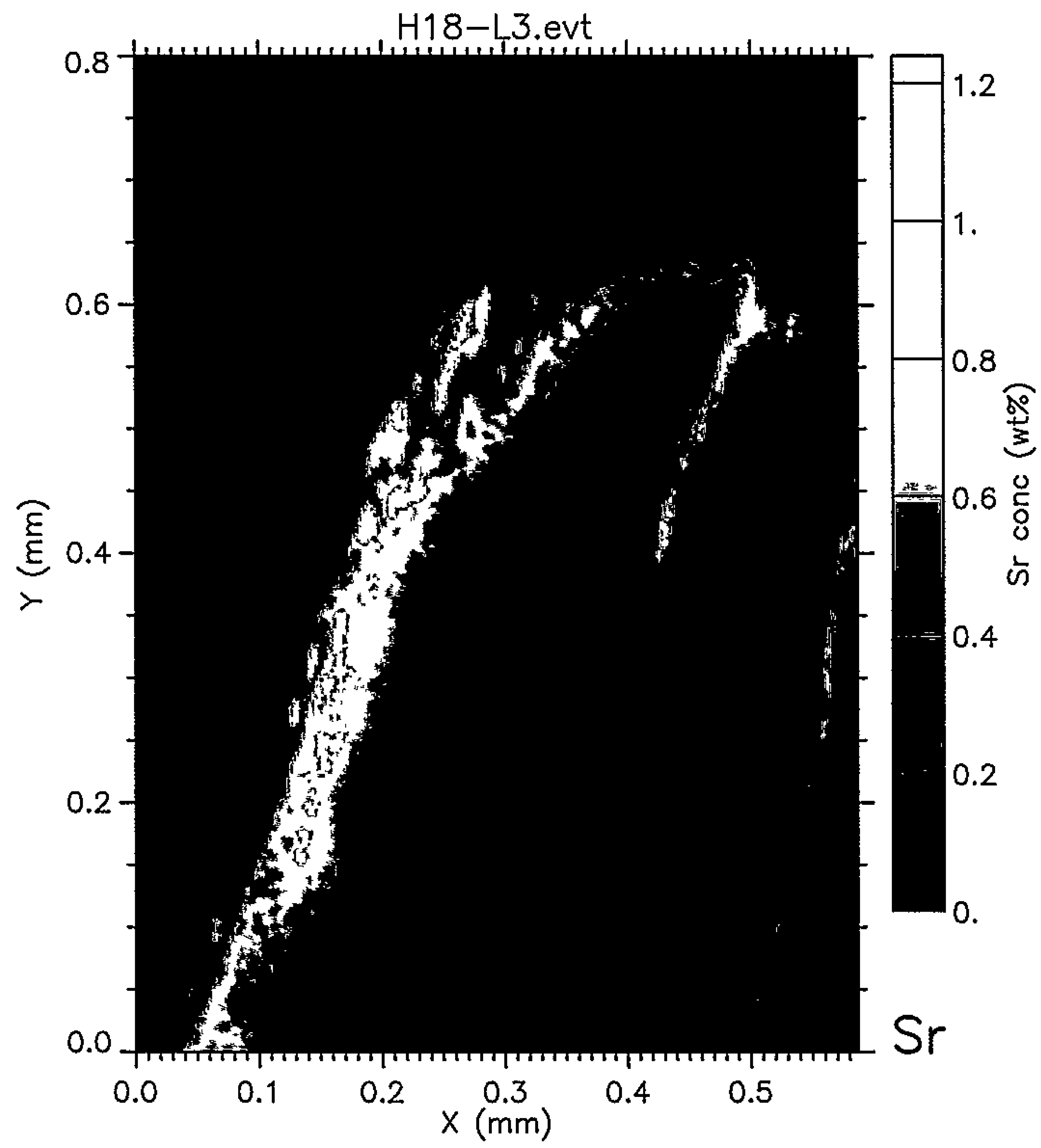
43.19899	782.0163	163.7784	140.3942	121.1471
45.7401	1156.081	304.2029	96.2231	133.4823
48.28122	916.4113	304.2029	115.8433	133.4823
50.82234	625.4708	446.4478	368.4003	172.7366
53.36346	748.6766	446.4478	312.4549	172.7366
55.90457	1214.699	393.75	82.19649	198.9939
58.44569	1375.859	393.75	-9.56605	198.9939
60.98681	1166.129	448.5256	326.3765	202.7279
63.52792	1011.511	448.5256	724.0192	202.7279
66.06904	1195.229	465.9524	836.1855	254.037
68.61016	1471.806	473.968	650.5705	240.5898
71.15128	1465.189	473.968	558.7708	240.5898
73.69239	1297.519	473.9709	487.543	222.4175
76.23351	1274.081	473.9709	500.3512	222.4175
78.77463	1548.866	469.7561	477.6219	201.2847
81.31574	1674.534	469.7561	428.844	201.2847
83.85686	1528.633	434.3247	390.6953	243.3244
86.39798	1601.495	434.3247	556.2884	243.3244
88.93909	1406.177	337.6378	585.3334	196.4408
91.48021	1107.661	337.6378	591.0639	196.4408
94.02132	992.9927	417.1611	517.7007	201.8763
96.56245	1224.008	417.1611	391.2881	201.8763
99.10356	1259.796	473.5294	228.7697	131.7951
101.6447	1449.046	473.5294	112.5398	131.7951
104.1858	1544.135	401.1735	317.3227	177.3167
106.7269	1570.966	401.1735	404.1419	177.3167
109.268	1130.691	337.6378	464.2569	179.6789
111.8091	1123.743	337.6378	422.1987	179.6789
114.3503	1149.26	372.5709	365.9104	141.5414
116.8914	1237.123	372.5709	84.33997	141.5414
119.4325	990.7226	311.8248	92.9902	106.4129
121.9736	996.3243	311.8248	210.0242	106.4129
124.5147	1348.698	392.7268	277.0638	131.0963
127.0558	1975.775	392.7268	213.3036	131.0963
129.597	1621.728	342.5671	108.4831	84.42445
132.1381	1398.494	342.5671	121.1028	84.42445
134.6792	1271.023	332.1678	214.2611	119.3182
137.2203	1423.063	342.1554	205.2083	56.25
139.7614	1194.078	342.1554	89.19358	56.25
142.3026	1414.5	352.2188	56.63286	57.90441
144.8437	1522.495	352.2188	68.40276	57.90441
147.3848	1558.279	332.6355	108.7537	81.8892
149.9259	1724.332	332.6355	107.1305	81.8892
152.467	1576.048	326.7663	80.00362	84.3707
155.0081	1389.662	326.7663	108.6759	84.3707
157.5493	1230.928	342.5671	144.2577	100.2934
160.0904	1617.201	342.5671	200.1006	100.2934
162.6315	1726.865	332.6355	117.7494	20.53404
165.1726	1539.226	332.6355	47.85307	20.53404
167.7137	1494.556	317.1555	-16.8761	20.53404
170.2548	1609.857	317.1555	-24.805	20.53404
172.796	1544.217	326.7663	-29.7222	86.98277

175.3371	1293.613	326.7663	-19.1577	86.98277
177.8782	1464.881	346.7483	48.89686	28.20981
180.4193	1251.755	346.7483	88.70914	28.20981
182.9604	967.5744	277.6998	24.63397	81.8892
185.5015	578.4053	277.6998	44.66301	81.8892
188.0426	810.3374	352.2188	65.28859	20.53404
190.5838	1194.641	352.2188	63.54208	20.53404
193.1249	1195.903	352.948	37.28862	84.3707
195.666	1228.908	352.948	55.06411	84.3707
198.2071	1353.115	286.8199	107.1305	82.01233
200.7482	1575.574	286.8199	80.56755	82.01233
203.2894	1562.568	271.5958	72.06181	0
205.8305	1294.12	309.9977	42.47371	0
208.3716	1002.24	309.9977	24.56727	0
210.9127	811.6622	271.5958	35.50396	57.90441
213.4538	759.6575	271.5958	57.99599	57.90441
215.9949	931.1747	332.7795	49.87902	97.42786
218.5361	1044.338	332.7795	10.40677	97.42786
221.0772	1298.826	327.5568	81.57236	64.77819
223.6183	1347.979	327.5568	109.3389	64.77819
226.1594	1444.847	315.6862	95.64189	59.65909
228.7005	1203.552	315.6862	65.27707	59.65909
231.2416	1312.561	283.6725	52.67342	57.90441
233.7828	1313.532	283.6725	45.4441	57.90441
236.3239	1366.384	283.6725	44.49966	0
238.865	1203.358	283.6725	39.31456	0
241.4061	1035.86	332.6355	10.40677	57.90441
243.9472	1002.548	332.6355	0	57.90441
246.4883	1065.735	304.2029	35.50396	59.65909
249.0295	1183.992	304.2029	48.31027	59.65909
251.5706	1336.937	289.522	45.38082	57.90441
254.1117	1234.914	289.522	38.72778	57.90441
256.6528	1102.42	289.522	44.49966	100.2934
259.1939	922.8521	289.522	85.38297	100.2934
261.735	787.1241	332.6355	214.2611	100.2934
264.2762	914.1858	332.6355	229.7756	100.2934
266.8173	1117.885	656.25	151.3575	232.7191
269.3584	1337.245	656.25	87.59393	232.7191

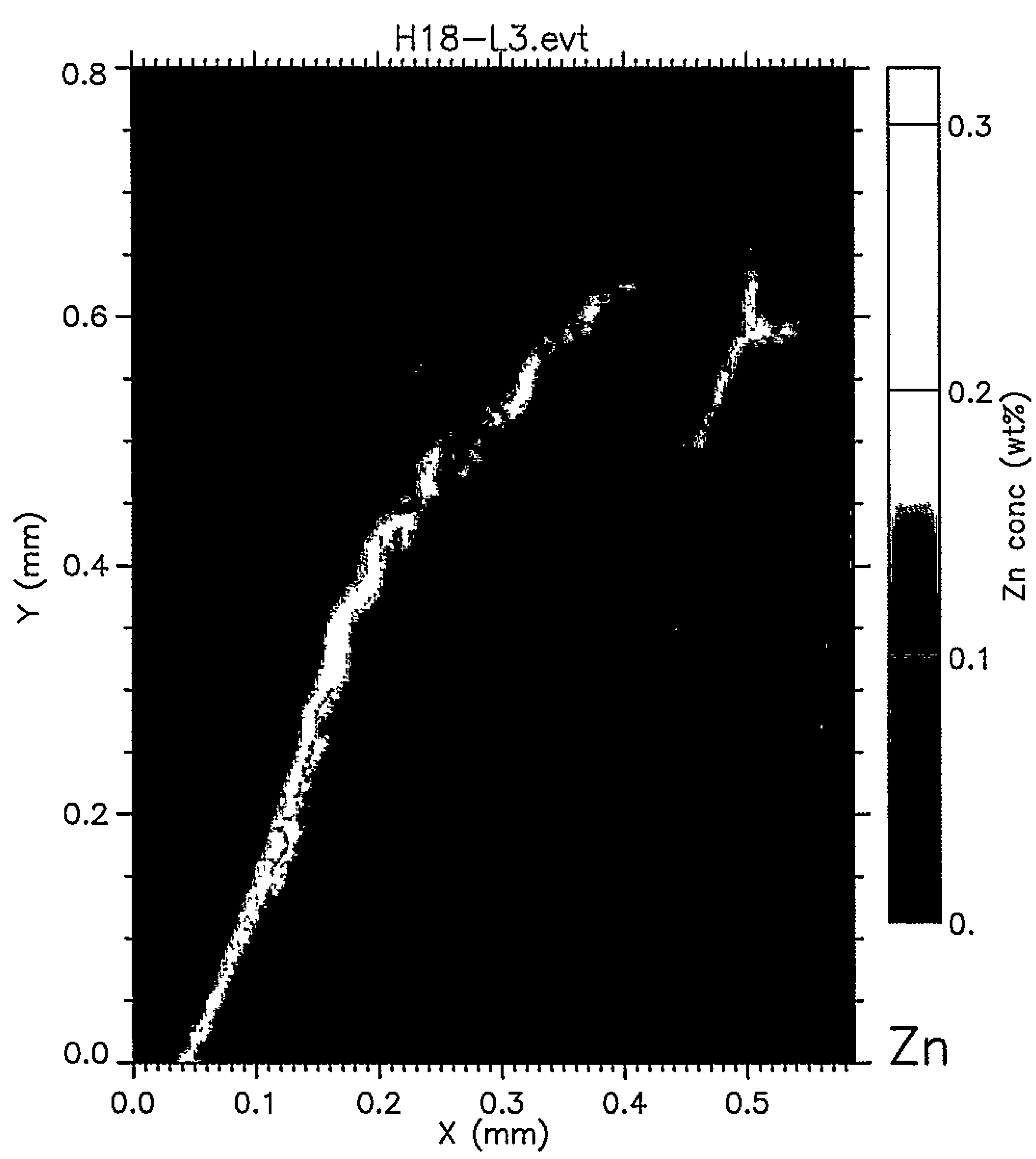
8.1.4 H18-L3 (Heavy-Control Tooth, Apical-third, Buccal) PIXE Mode



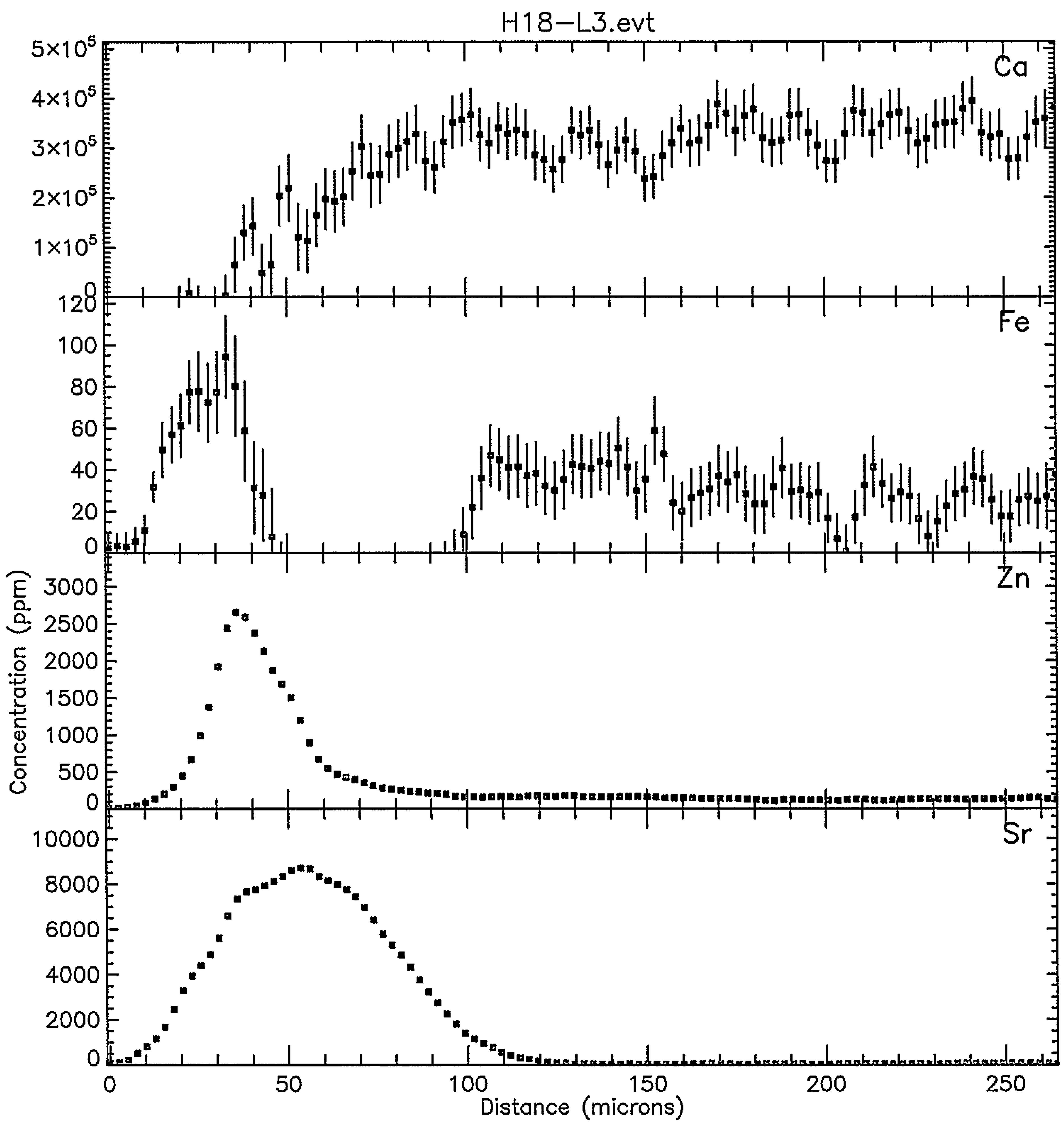




H18–L3.evt
Y (mm)
X (mm)
Sr conc (wt%)
Sr



H18–L3.evt
Y (mm)
X (mm)
Zn conc (wt%)
Zn



H18–L3.evt
Ca
Fe
Zn
Sr
Concentration (ppm)
Distance (microns)

microns	Ca	e_Ca	Fe	e_Fe	Ni	e_Ni
0	-21633.5	5797.084	2.228221	5.713288	-4.19091	2.539535
2.541117	-22753.7	5797.084	3.492549	5.713288	-3.55663	2.539535
5.082234	-27667.3	7201.611	3.073011	6.384635	-4.29176	1.865981
7.623351	-35193	7201.611	5.602333	6.384635	-1.63501	1.865981
10.16447	-42881.2	10461.91	11.05257	7.019848	1.039406	3.673702
12.70558	-48770.8	10461.91	31.85631	7.019848	6.960632	3.673702
15.2467	-58990.8	15108.77	49.86382	13.07485	17.06624	5.648509
17.78782	-43790	15108.77	57.14996	13.07485	32.60403	5.648509
20.32894	-7991.26	28611.34	61.39156	14.93261	49.99701	8.054175
22.87005	7533.108	28611.34	77.46754	14.93261	62.9386	8.054175
25.41117	-14115.9	35602.18	77.8559	18.71654	72.14312	10.34684
27.95229	-47658.9	35602.18	72.5271	18.71654	94.50835	10.34684
30.4934	-39166.1	40076.24	77.4539	19.43663	126.1433	13.13136
33.03452	2631.867	40076.24	94.34113	19.43663	171.3517	13.13136
35.57564	64919.08	54531.21	80.29368	23.77516	210.9859	15.57377
38.11675	129944.4	54531.21	58.83218	23.77516	258.5796	15.57377
40.65787	143016.4	56702.67	31.54292	21.95784	305.813	18.44139
43.19899	48592.64	56702.67	27.9118	21.95784	340.921	18.44139
45.7401	65223.08	59630.3	7.845132	23.1088	346.4705	20.13246
48.28122	203815.4	59630.3	-18.065	23.1088	348.3855	20.13246
50.82234	219968.2	66178.52	-22.8013	19.88241	380.4188	20.8574
53.36346	120778.4	66178.52	-32.5946	19.88241	386.7527	20.8574
55.90457	112472	62751.29	-48.0091	19.40002	342.9086	19.61069
58.44569	164887.6	62751.29	-69.2605	19.40002	291.0624	19.61069
60.98681	197394.5	60641.46	-51.369	16.66705	265.3597	18.0565
63.52792	193114.2	60641.46	-31.806	16.66705	251.7033	18.0565
66.06904	201954.7	57429.13	-29.0893	16.61057	216.4682	16.33534
68.61016	253862.7	57429.13	-42.4702	16.61057	193.4122	16.33534
71.15128	303025	63359.38	-45.9952	15.41381	149.3731	14.41847
73.69239	245027.6	63359.38	-33.6374	15.41381	120.2457	14.41847
76.23351	247023.7	56587.5	-41.0712	13.79053	94.27614	12.23618
78.77463	287864.9	56587.5	-41.8451	13.79053	78.36293	12.23618
81.31574	299636	57024.34	-38.6015	14.25462	41.89368	9.569913
83.85686	313762	57024.34	-33.1957	14.25462	17.46807	9.569913
86.39798	328433.7	57255.9	-27.7515	13.22823	8.46346	7.462622
88.93909	274150.9	57255.9	-25.5912	13.22823	3.751411	7.462622
91.48021	261239.2	50760.52	-20.2404	14.21821	5.582128	7.2568
94.02132	313355.8	50760.52	-8.91174	14.21821	4.075878	7.2568
96.56245	352125.8	51587.24	-1.81781	12.79173	0.268202	6.562963
99.10356	357349.5	51587.24	8.905508	12.79173	-5.38906	6.562963
101.6447	367343.8	52102.32	21.95081	14.99816	-8.08645	5.387922
104.1858	327212.6	52102.32	36.11978	14.99816	-1.45159	5.387922
106.7269	310239	50184	46.94346	14.62069	2.756839	6.506217
109.268	341076.2	50184	44.86111	14.62069	-2.10605	6.506217
111.8091	329040.3	50462.02	41.20126	14.79187	-8.39785	5.935829

114.3503	337061.9	50462.02	41.60649	14.79187	-5.03324	5.935829
116.8914	327724.8	48575.68	37.28571	15.16101	-1.5136	5.828188
119.4325	285971.7	48575.68	38.35676	15.16101	-4.77048	5.828188
121.9736	277291.8	45742.46	32.35493	13.60181	-0.62486	6.251499
124.5147	258178.6	45742.46	30.23022	13.60181	-0.07142	6.251499
127.0558	277158	45401.77	35.41323	13.91141	2.206285	5.741098
129.597	336962.4	45401.77	42.71943	13.91141	7.581728	5.741098
132.1381	326360.4	47298.31	41.66647	14.99002	8.643387	6.186869
134.6792	336301.3	46985.61	40.688	13.69983	10.05671	6.550865
137.2203	306852.4	46985.61	44.26086	13.69983	6.504902	6.550865
139.7614	266882.7	45950.57	43.05122	14.69995	-3.4137	5.582534
142.3026	295781	45950.57	50.52945	14.69995	-1.21109	5.582534
144.8437	316823.3	43136.93	41.45306	13.55839	4.461157	6.179223
147.3848	293881.3	43136.93	30.08872	13.55839	4.64459	6.179223
149.9259	238884.4	43589.48	35.63935	15.9425	3.762496	6.126512
152.467	243060.8	43589.48	58.96398	15.9425	5.685901	6.126512
155.0081	284541.3	48055.73	47.66602	12.7893	7.048105	6.693187
157.5493	311001.6	48055.73	24.21039	12.7893	12.47801	6.693187
160.0904	339361.2	46494.1	19.98013	13.68082	14.2957	6.514145
162.6315	310108.2	46494.1	26.68518	13.68082	8.759706	6.514145
165.1726	316457.8	49878.11	28.91818	12.56403	2.739653	6.24328
167.7137	346412.5	49878.11	30.87901	12.56403	9.751401	6.24328
170.2548	389114.8	46268.32	37.14832	14.45068	14.37947	6.825129
172.796	370856.6	46268.32	34.10468	14.45068	14.42841	6.825129
175.3371	336026.3	49649.25	37.67096	13.09048	5.886773	5.85058
177.8782	366258.4	49649.25	28.45823	13.09048	5.574787	5.85058
180.4193	378596.7	48536.83	23.48437	13.75229	8.973176	6.864264
182.9604	321123.2	48536.83	23.44276	13.75229	9.446234	6.864264
185.5015	311159.8	46369.05	31.82085	14.38053	7.890757	6.567228
188.0426	315776.5	46369.05	40.88246	14.38053	12.07206	6.567228
190.5838	366862.7	50596.7	29.64227	12.82323	14.03254	6.67766
193.1249	368318.8	50596.7	30.27431	12.82323	9.552688	6.67766
195.666	331526.3	47162.73	27.67279	13.93122	3.199346	5.985023
198.2071	306421.2	47162.73	29.20231	13.93122	-1.46725	5.985023
200.7482	274863.3	41472.05	16.76707	11.59806	-3.75578	5.908871
203.2894	273968	41472.05	6.844116	11.59806	2.505096	5.908871
205.8305	329045.2	49725.71	0.719581	12.40967	8.786384	6.484558
208.3716	376121.4	49725.71	17.20512	12.40967	14.86672	6.484558
210.9127	371394.1	47228.42	32.56975	14.35616	13.0575	6.148763
213.4538	331005.3	47228.42	41.49107	14.35616	7.69213	6.148763
215.9949	348428.3	48583.73	33.41709	11.26523	0.618296	5.835817
218.5361	367379.5	48583.73	26.33326	11.26523	5.759542	5.835817
221.0772	372124.3	46749.57	29.20736	13.4057	5.747953	5.859452
223.6183	335385	46749.57	27.38674	13.4057	5.501179	5.859452
226.1594	309785	47939.66	16.43399	11.71829	5.668032	6.223843
228.7005	318602.3	47939.66	7.955318	11.71829	8.238368	6.223843
231.2416	347422.5	48794.25	15.13194	12.21322	6.843791	6.311928

233.7828	351448.9	48794.25	22.61151	12.21322	12.9554	6.311928
236.3239	352779.1	52041.72	28.46774	12.82132	14.80728	6.391227
238.865	379297.8	52041.72	30.50352	12.82132	14.86046	6.391227
241.4061	395761.4	45780.45	36.79139	13.28361	9.792232	6.050419
243.9472	331400.3	45780.45	35.61346	13.28361	10.34469	6.050419
246.4883	322228.9	48104.09	25.66812	11.66913	6.32275	5.919755
249.0295	328132.3	48104.09	17.59957	11.66913	7.178823	5.919755
251.5706	277818.7	41162.64	17.57669	12.32028	13.14064	6.739288
254.1117	279380.3	41162.64	25.54608	12.32028	16.48811	6.739288
256.6528	322801.8	49433.21	27.2606	13.04845	11.88985	5.841893
259.1939	352197.6	49433.21	24.92444	13.04845	6.25595	5.841893
261.735	359800.1	55817.82	27.24901	15.64193	7.666233	7.405077
264.2762	382352.4	55817.82	37.89399	15.64193	10.55194	7.405077

microns	Cu	e_Cu	Zn	e_Zn	Br	e_Br
0	-1.29788	2.750966	6.517485	3.64582	0.358456	0.332861
2.541117	-0.406	2.750966	12.13819	3.64582	2.369964	0.332861
5.082234	-0.52324	2.019984	20.66155	4.345926	3.77889	3.136921
7.623351	-2.96925	2.019984	44.59586	4.345926	5.054227	3.136921
10.16447	-2.49894	2.276964	82.94739	7.401182	2.231708	2.213453
12.70558	1.050093	2.276964	137.0633	7.401182	0.924303	2.213453
15.2467	2.407386	4.024818	201.0235	11.15055	2.314727	1.808996
17.78782	7.724126	4.024818	293.1774	11.15055	1.427103	1.808996
20.32894	8.946591	5.220365	447.5345	16.67234	2.10446	2.851788
22.87005	10.72492	5.220365	669.607	16.67234	1.056466	2.851788
25.41117	3.474718	6.036022	989.5576	23.13212	2.968852	3.804251
27.95229	-1.91539	6.036022	1374.963	23.13212	1.834226	3.804251
30.4934	-6.65053	6.301156	1924.954	34.10405	1.157641	3.648912
33.03452	-5.37539	6.301156	2443.453	34.10405	-0.48439	3.648912
35.57564	-3.49099	7.754825	2655.717	39.35966	-1.49505	4.463551
38.11675	-9.85464	7.754825	2592.235	39.35966	0.194366	4.463551
40.65787	-16.0919	8.46511	2374.578	38.3807	-1.54788	5.363051
43.19899	-18.9291	8.46511	2131.61	38.3807	-2.89976	5.363051
45.7401	-17.7879	8.825418	1874.506	34.52215	-6.93377	4.289023
48.28122	-20.2386	8.825418	1689.308	34.52215	-10.5452	4.289023
50.82234	-24.8242	7.868297	1504.074	31.58736	-13.7272	4.346082
53.36346	-30.7274	7.868297	1200.929	31.58736	-13.7065	4.346082
55.90457	-29.5743	8.110769	898.2382	24.73903	-12.0409	3.011356
58.44569	-33.5369	8.110769	676.2625	24.73903	-4.20679	3.011356
60.98681	-28.8863	7.237904	548.8384	20.04099	-1.83322	5.180279
63.52792	-26.281	7.237904	469.6559	20.04099	-1.18401	5.180279
66.06904	-23.7252	6.807708	427.7242	17.35227	-1.61701	4.161033
68.61016	-28.5769	6.807708	395.1328	17.35227	1.10792	4.161033
71.15128	-26.0643	6.283576	353.2844	16.20543	-1.12378	4.141436
73.69239	-22.4173	6.283576	313.9591	16.20543	-0.8688	4.141436
76.23351	-18.2661	5.836697	284.4707	14.47926	1.904071	4.112594
78.77463	-14.2759	5.836697	268.5348	14.47926	5.225713	4.112594
81.31574	-6.02554	6.079309	253.1115	13.97581	3.899477	4.398458
83.85686	-4.12071	6.079309	240.5143	13.97581	4.233654	4.398458
86.39798	-2.70165	6.321524	227.665	13.18104	4.000003	3.983307

88.93909	-3.60992	6.321524	216.0074	13.18104	-0.85103	3.983307
91.48021	-5.62328	5.357164	210.8885	12.85667	-2.51359	3.386985
94.02132	-4.78229	5.357164	195.2734	12.85667	0.210335	3.386985
96.56245	-4.28192	5.295415	174.079	11.5295	7.720989	4.571868
99.10356	-6.23025	5.295415	160.7005	11.5295	10.45508	4.571868
101.6447	0.911822	5.50623	162.9133	10.90661	8.74747	4.73238
104.1858	6.127069	5.50623	155.5521	10.90661	4.64192	4.73238
106.7269	5.469355	5.567482	160.9424	11.29921	1.806957	3.271516
109.268	-2.8429	5.567482	169.2131	11.29921	3.32591	3.271516
111.8091	-4.441	4.903725	167.7731	11.36842	1.694359	3.885331
114.3503	-1.04232	4.903725	156.1756	11.36842	-1.90386	3.885331
116.8914	4.558199	5.496371	176.269	11.21361	0.476805	3.000641
119.4325	10.7712	5.496371	179.8482	11.21361	7.431203	3.000641
121.9736	12.85218	6.071586	171.8887	11.35457	13.62604	5.162932
124.5147	11.72935	6.071586	168.6208	11.35457	14.41384	5.162932
127.0558	11.31072	5.96219	180.9195	11.5982	11.81499	4.458071
129.597	9.955782	5.96219	181.2274	11.5982	6.709095	4.458071
132.1381	7.436024	5.756379	163.5037	10.81814	4.328311	4.263714
134.6792	5.30304	5.399999	164.0893	10.94431	4.002028	3.479036
137.2203	4.39749	5.399999	161.6899	10.94431	3.527022	3.479036
139.7614	5.584052	5.486451	161.8838	11.00823	3.148518	4.091064
142.3026	6.137392	5.486451	166.0842	11.00823	3.539416	4.091064
144.8437	3.753425	5.2214	169.019	11.31924	3.461257	3.233499
147.3848	-1.71918	5.2214	172.0207	11.31924	-0.40592	3.233499
149.9259	2.064506	4.906703	167.4499	10.90769	-4.63564	2.565081
152.467	6.498663	4.906703	160.4387	10.90769	-2.51813	2.565081
155.0081	8.766166	5.992825	147.671	10.60484	1.294208	3.334608
157.5493	7.511353	5.992825	150.5466	10.60484	-0.01892	3.334608
160.0904	3.463946	5.206057	151.1117	10.68754	-3.05367	2.118075
162.6315	-0.24443	5.206057	146.5605	10.68754	-2.40731	2.118075
165.1726	-0.0565	5.028753	143.3435	10.57051	2.495808	3.514147
167.7137	2.839969	5.028753	144.819	10.57051	4.403411	3.514147
170.2548	8.463621	5.77454	142.2268	10.26063	4.61483	4.26085
172.796	13.29694	5.77454	141.494	10.26063	5.871048	4.26085
175.3371	15.51328	6.664606	141.5055	10.17739	7.618055	3.920584
177.8782	13.96573	6.664606	135.2231	10.17739	5.183779	3.920584
180.4193	11.29583	5.205337	125.3991	9.528446	1.088313	3.05691
182.9604	2.095263	5.205337	116.8855	9.528446	0.366986	3.05691
185.5015	-1.81386	5.005717	112.2679	10.04673	3.043833	3.788979
188.0426	2.752366	5.005717	124.4532	10.04673	5.158023	3.788979
190.5838	4.431574	5.083151	128.3344	9.998081	5.102311	3.913835
193.1249	0.538742	5.083151	121.7396	9.998081	4.796026	3.913835
195.666	-1.92035	5.269804	119.3574	9.742184	0.642739	3.199686
198.2071	1.262893	5.269804	118.8546	9.742184	-1.55759	3.199686
200.7482	7.327139	5.439907	117.1593	9.475951	0.490116	2.750081
203.2894	5.067472	5.439907	115.0223	9.475951	0.725627	2.750081
205.8305	1.989726	4.558323	124.899	10.14585	1.744166	3.416375
208.3716	1.5126	4.558323	129.3012	10.14585	2.750342	3.416375
210.9127	3.756324	5.531874	128.2711	9.460009	4.458365	3.043585
213.4538	4.070053	5.531874	117.1986	9.460009	1.720391	3.043585
215.9949	-0.22486	4.611111	117.0049	9.508361	-0.19609	2.507735
218.5361	1.834433	4.611111	118.5221	9.508361	-1.84117	2.507735

221.0772	4.529041	5.250416	124.4184	10.18148	-2.0163	2.78742
223.6183	4.058824	5.250416	132.2913	10.18148	-1.83535	2.78742
226.1594	-0.56207	4.708844	139.7901	10.01985	-3.48436	2.58753
228.7005	0.415078	4.708844	138.6221	10.01985	-1.78594	2.58753
231.2416	8.024344	5.964928	135.3664	10.44368	-0.12136	2.980077
233.7828	10.59769	5.964928	135.8959	10.44368	1.542263	2.980077
236.3239	11.90176	5.526397	132.2262	10.09654	1.92237	3.507057
238.865	12.19292	5.526397	130.2145	10.09654	-1.03139	3.507057
241.4061	15.34796	5.493015	136.5959	9.830132	-2.06781	2.557388
243.9472	13.63273	5.493015	134.8111	9.830132	-1.90639	2.557388
246.4883	10.77483	5.663781	135.9076	10.20089	2.364331	3.771183
249.0295	10.69653	5.663781	140.0555	10.20089	3.063665	3.771183
251.5706	8.894074	5.254971	140.178	10.23056	2.988495	3.688523
254.1117	8.713076	5.254971	142.2032	10.23056	0.973131	3.688523
256.6528	9.326755	5.714736	151.0737	10.67512	1.423487	2.787061
259.1939	12.57347	5.714736	151.6102	10.67512	2.597881	2.787061
261.735	9.774769	5.917404	139.8186	11.9587	1.632467	4.537934
264.2762	4.494961	5.917404	135.3087	11.9587	3.043643	4.537934

microns	Rb	e_Rb	Sr	e_Sr	Sn	e_Sn
0	-3.98258	0.46971	64.78168	10.40664	27.7564	21.15187
2.541117	-3.12443	0.46971	90.14728	10.40664	34.63295	21.15187
5.082234	2.419196	2.870682	198.8428	17.57534	15.69042	17.39995
7.623351	5.620761	2.870682	510.9839	17.57534	-5.94141	17.39995
10.16447	6.911215	3.922804	803.9334	33.45527	-0.80726	1.909828
12.70558	10.25264	3.922804	1159.097	33.45527	-1.10808	1.909828
15.2467	15.3702	5.377291	1679.497	46.04204	-4.677	10.75121
17.78782	26.68813	5.377291	2452.039	46.04204	43.94408	10.75121
20.32894	37.64494	7.732924	3292.108	65.78608	107.4652	46.99485
22.87005	40.40707	7.732924	3946.716	65.78608	139.5276	46.99485
25.41117	36.34666	8.355602	4397.146	75.33036	112.9209	40.53952
27.95229	36.61192	8.355602	4892.505	75.33036	75.79688	40.53952
30.4934	40.89596	9.474824	5609.513	86.34894	12.42453	31.38692
33.03452	53.40232	9.474824	6610.392	86.34894	-21.1796	31.38692
35.57564	63.82775	11.60423	7340.326	97.75407	-10.0388	30.33919
38.11675	57.25581	11.60423	7659.931	97.75407	12.05535	30.33919
40.65787	50.46572	9.857507	7749.555	101.436	27.17462	35.07928
43.19899	65.45769	9.857507	7940.357	101.436	17.01599	35.07928
45.7401	83.35409	13.05503	8128.208	104.1048	10.20269	34.47687
48.28122	86.32365	13.05503	8351.045	104.1048	2.556283	34.47687
50.82234	76.59974	12.50732	8608.397	108.6405	5.844787	32.33485
53.36346	64.84872	12.50732	8710.622	108.6405	19.25932	32.33485
55.90457	60.62309	11.18523	8680.008	106.5619	24.04151	34.89672
58.44569	61.94201	11.18523	8340.476	106.5619	41.14191	34.89672
60.98681	63.04842	11.82402	8153.595	104.3409	86.15325	38.68776
63.52792	65.48956	11.82402	7975.528	104.3409	108.0147	38.68776
66.06904	63.71797	10.54766	7759.23	100.3057	89.76372	49.9576
68.61016	62.87812	10.54766	7441.416	100.3057	52.50633	49.9576
71.15128	57.74281	10.68073	6977.832	98.77026	41.48786	37.55479
73.69239	53.47845	10.68073	6420.128	98.77026	43.22887	37.55479
76.23351	48.21547	9.855053	5783.722	87.36414	59.13334	41.89359

78.77463	41.39403	9.855053	5311.11	87.36414	48.24915	41.89359
81.31574	35.74512	9.053612	4859.236	80.69272	34.62207	30.30486
83.85686	24.0444	9.053612	4328.548	80.69272	12.76821	30.30486
86.39798	15.01646	7.926865	3743.774	71.94833	10.28879	24.08646
88.93909	5.776627	7.926865	3222.814	71.94833	22.67373	24.08646
91.48021	1.89646	6.113218	2741.197	62.87376	46.31142	31.34767
94.02132	-4.89125	6.113218	2243.46	62.87376	71.85982	31.34767
96.56245	-7.32127	5.638096	1794.519	50.04414	72.96023	41.7512
99.10356	-4.88562	5.638096	1391.651	50.04414	58.03787	41.7512
101.6447	-1.40992	5.556952	1136.849	39.57285	31.77058	33.63033
104.1858	-1.40109	5.556952	940.8427	39.57285	23.29634	33.63033
106.7269	-7.55898	4.814107	762.0667	33.37349	7.41007	21.85357
109.268	-15.7452	4.814107	556.0783	33.37349	-18.7469	21.85357
111.8091	-12.6217	4.210153	406.3941	26.28788	-33.4889	5.094123
114.3503	-7.92519	4.210153	297.6037	26.28788	-22.6165	5.094123
116.8914	-7.75613	3.863586	234.1407	22.20371	-8.17388	15.24451
119.4325	-13.7419	3.863586	160.7968	22.20371	-5.64176	15.24451
121.9736	-18.2106	3.292108	105.5502	16.49855	-10.3951	18.49099
124.5147	-18.5934	3.292108	71.4082	16.49855	9.726456	18.49099
127.0558	-16.4956	3.828466	64.30496	14.25188	26.12575	29.44784
129.597	-14.4741	3.828466	42.21727	14.25188	25.39083	29.44784
132.1381	-13.6827	3.289911	35.33342	12.74364	3.706613	26.9252
134.6792	-13.8392	2.649929	36.02456	12.92338	-3.55473	19.8957
137.2203	-14.8214	2.649929	29.90226	12.92338	-4.2847	19.8957
139.7614	-14.1088	3.284033	22.01458	12.61898	-0.09044	17.59872
142.3026	-12.1349	3.284033	32.24504	12.61898	4.969144	17.59872
144.8437	-12.3305	4.273179	39.87714	13.27254	-2.16313	20.22533
147.3848	-10.7461	4.273179	27.35859	13.27254	9.131015	20.22533
149.9259	-8.57314	3.589787	22.67709	12.2604	9.513796	24.95613
152.467	-7.94976	3.589787	21.88269	12.2604	12.40771	24.95613
155.0081	-10.5246	3.92835	29.7487	13.3638	6.375378	19.39812
157.5493	-10.2238	3.92835	27.28278	13.3638	-1.77658	19.39812
160.0904	-7.83039	3.994094	31.65113	13.35596	-27.8734	5.448132
162.6315	-5.21195	3.994094	34.79087	13.35596	-31.3821	5.448132
165.1726	-4.65491	5.203208	45.1126	13.4358	-29.7967	5.008405
167.7137	-8.59055	5.203208	46.30744	13.4358	-22.0266	5.008405
170.2548	-12.663	2.93907	45.4793	12.52348	-7.48468	20.18095
172.796	-15.0568	2.93907	32.92823	12.52348	8.236524	20.18095
175.3371	-15.5255	2.800854	23.46099	12.39138	-13.1047	16.83699
177.8782	-14.4029	2.800854	19.60747	12.39138	-19.8911	16.83699
180.4193	-10.0655	3.951725	36.55807	13.65108	-20.2192	7.823067
182.9604	-10.6808	3.951725	44.1655	13.65108	-23.9549	7.823067
185.5015	-13.8681	3.732355	45.40921	13.34738	-33.0597	6.221171
188.0426	-14.8488	3.732355	41.53849	13.34738	-27.3768	6.221171
190.5838	-13.6588	3.539961	39.21357	13.5588	-17.2469	9.037422
193.1249	-12.6491	3.539961	46.04311	13.5588	-12.5302	9.037422
195.666	-13.026	2.834145	32.30239	12.24565	-3.43473	18.40464
198.2071	-13.0588	2.834145	16.62632	12.24565	-4.41034	18.40464
200.7482	-15.0579	2.069204	20.72391	13.31781	-16.4954	5.237613
203.2894	-14.3046	2.069204	41.71678	13.31781	-20.8224	5.237613
205.8305	-14.5021	2.110692	48.90636	13.82611	-9.49315	19.43827
208.3716	-13.129	2.110692	47.57264	13.82611	5.007958	19.43827

210.9127	-12.0384	2.674072	51.20363	12.73281	3.133578	23.95452
213.4538	-11.9601	2.674072	51.05612	12.73281	0.60877	23.95452
215.9949	-10.9478	3.843305	43.79138	12.89197	-0.63156	15.17321
218.5361	-8.50482	3.843305	36.41283	12.89197	12.88612	15.17321
221.0772	-10.595	3.469509	34.70376	13.42947	25.99001	30.28239
223.6183	-12.4413	3.469509	39.52298	13.42947	44.18513	30.28239
226.1594	-10.8105	2.512598	49.78844	13.53879	33.28608	27.10915
228.7005	-11.4692	2.512598	42.76323	13.53879	18.24417	27.10915
231.2416	-13.1137	3.246021	41.24617	13.00594	-2.26379	12.27564
233.7828	-10.449	3.246021	46.77059	13.00594	-13.3759	12.27564
236.3239	-10.5294	4.047776	60.88885	13.69947	-6.22017	24.6225
238.865	-8.05166	4.047776	63.37339	13.69947	1.370289	24.6225
241.4061	-8.28429	4.142685	60.77148	13.4787	4.969	14.42339
243.9472	-6.4834	4.142685	54.84148	13.4787	-2.11257	14.42339
246.4883	-2.84776	5.696119	61.97044	14.82194	-8.85268	10.59472
249.0295	0.660919	5.696119	69.23898	14.82194	-12.4899	10.59472
251.5706	-2.88513	4.033416	72.01804	14.16153	-6.86221	15.60281
254.1117	-10.294	4.033416	64.97554	14.16153	-11.0007	15.60281
256.6528	-13.6598	2.701549	65.81734	13.46034	-10.2182	18.40125
259.1939	-13.7842	2.701549	55.93998	13.46034	-2.58688	18.40125
261.735	-12.1483	3.83338	49.86186	15.58528	0.648658	8.623165
264.2762	-10.5819	3.83338	52.60297	15.58528	1.042806	8.623165

microns	Ba	e_Ba	PbL	e_PbL
0	15.99794	27.75605	-5.91985	0.778198
2.541117	26.1488	27.75605	-5.68938	0.778198
5.082234	12.58208	36.79833	-4.03513	0.924736
7.623351	0.781193	36.79833	0.196791	0.924736
10.16447	2.67099	5.080974	-0.16779	4.419752
12.70558	25.14491	5.080974	-2.20485	4.419752
15.2467	2.127671	44.58522	-4.07867	3.283718
17.78782	-27.7056	44.58522	-0.5411	3.283718
20.32894	-0.25675	55.05506	4.790866	6.13218
22.87005	33.31924	55.05506	11.79596	6.13218
25.41117	30.67621	58.33962	7.380956	6.566175
27.95229	33.86208	58.33962	0.149845	6.566175
30.4934	39.67723	105.3346	2.317315	8.155629
33.03452	52.96988	105.3346	9.750898	8.155629
35.57564	19.88956	89.7185	16.48211	8.474775
38.11675	22.99034	89.7185	30.14343	8.474775
40.65787	125.7892	121.0885	22.51721	11.22363
43.19899	224.2492	121.0885	10.95291	11.22363
45.7401	219.686	151.6384	8.601405	10.69253
48.28122	177.1417	151.6384	21.25641	10.69253
50.82234	97.71424	153.3386	13.68303	10.90817
53.36346	133.938	153.3386	-2.43035	10.90817
55.90457	174.2761	148.6832	-0.1565	9.365277
58.44569	143.5846	148.6832	3.202169	9.365277
60.98681	31.6033	117.2281	3.698731	8.889561
63.52792	-9.75963	117.2281	9.766006	8.889561
66.06904	69.47965	98.39037	24.21546	10.91053

68.61016	193.0155	98.39037	18.66995	10.91053
71.15128	119.0222	112.3767	11.03366	9.505359
73.69239	60.43872	112.3767	11.13352	9.505359
76.23351	54.92	102.7958	14.25861	9.137246
78.77463	108.7557	102.7958	10.4409	9.137246
81.31574	202.0391	117.0451	2.027147	7.366268
83.85686	141.176	117.0451	-1.31664	7.366268
86.39798	66.41541	81.97865	2.958343	8.02257
88.93909	-55.9384	81.97865	3.934573	8.02257
91.48021	-59.1948	66.40344	0.87891	7.454666
94.02132	22.87448	66.40344	-1.94973	7.454666
96.56245	15.2426	87.56147	2.887367	6.743083
99.10356	2.12922	87.56147	14.48614	6.743083
101.6447	-22.3751	63.50132	15.71528	8.272595
104.1858	-11.3377	63.50132	11.63258	8.272595
106.7269	7.626597	50.63698	7.476844	6.989644
109.268	34.01507	50.63698	9.124206	6.989644
111.8091	77.67112	58.50954	9.101843	7.495701
114.3503	19.73625	58.50954	11.21683	7.495701
116.8914	15.78894	92.14217	10.78387	7.561902
119.4325	-14.0344	92.14217	3.473844	7.561902
121.9736	-26.6032	81.32698	-1.09297	6.845857
124.5147	-53.2216	81.32698	0.000481	6.845857
127.0558	-9.97891	65.02624	2.693553	6.254724
129.597	4.515613	65.02624	5.225647	6.254724
132.1381	1.073413	57.36073	5.614827	7.076046
134.6792	-34.6209	75.03163	1.386577	6.07363
137.2203	-2.92525	75.03163	-3.062	6.07363
139.7614	19.39247	62.33062	5.782825	8.334692
142.3026	54.29564	62.33062	15.92954	8.334692
144.8437	20.51175	77.71971	11.77127	5.572546
147.3848	53.01398	77.71971	4.353075	5.572546
149.9259	8.428331	55.63089	10.27493	8.157919
152.467	-6.68062	55.63089	14.84344	8.157919
155.0081	-39.9348	53.53953	8.681662	6.901864
157.5493	-16.4079	53.53953	6.003621	6.901864
160.0904	-49.0971	32.45177	8.742166	7.558617
162.6315	-78.8211	32.45177	10.40847	7.558617
165.1726	-78.448	28.79568	10.06187	7.287585
167.7137	-64.0106	28.79568	8.165571	7.287585
170.2548	-45.0354	39.67014	6.019163	6.356879
172.796	-48.0781	39.67014	1.737926	6.356879
175.3371	-45.4802	79.81883	1.596984	6.252877
177.8782	-47.9492	79.81883	3.026381	6.252877
180.4193	-56.1237	11.94446	0.242784	6.509774
182.9604	-77.297	11.94446	4.026192	6.509774
185.5015	-63.4535	55.15958	5.823172	8.066669
188.0426	8.610026	55.15958	13.03015	8.066669
190.5838	1.118976	97.07926	10.77593	5.7857
193.1249	11.22081	97.07926	6.005651	5.7857
195.666	9.023257	52.38998	0.833711	6.363081
198.2071	-1.22442	52.38998	4.278331	6.363081

200.7482	-40.7816	14.58878	10.44893	8.286639
203.2894	-84.9339	14.58878	11.33033	8.286639
205.8305	-81.7454	20.319	6.129922	6.230435
208.3716	-54.2299	20.319	10.45228	6.230435
210.9127	-5.53677	72.98061	9.018137	6.416723
213.4538	41.09421	72.98061	3.217573	6.416723
215.9949	-4.17984	68.19473	-0.27124	5.941767
218.5361	-21.2832	68.19473	0.976532	5.941767
221.0772	-37.5111	31.73351	2.101776	6.983222
223.6183	-4.2785	31.73351	4.039286	6.983222
226.1594	13.13555	84.33386	3.538115	6.454826
228.7005	8.724204	84.33386	5.697459	6.454826
231.2416	-48.0389	24.50293	8.50894	6.474878
233.7828	-39.1315	24.50293	6.183097	6.474878
236.3239	43.94	95.09935	-0.1634	5.953248
238.865	67.84721	95.09935	-0.82951	5.953248
241.4061	42.2331	35.70246	0.36347	5.936057
243.9472	-7.32961	35.70246	0.16584	5.936057
246.4883	13.958	57.30552	-0.54234	5.772977
249.0295	-22.2234	57.30552	4.398745	5.772977
251.5706	-66.123	49.86364	-0.87666	5.188788
254.1117	-39.99	49.86364	2.535838	5.188788
256.6528	20.21421	64.78002	7.231888	6.92611
259.1939	42.3257	64.78002	8.521438	6.92611
261.735	73.39171	129.453	4.590912	8.35709
264.2762	85.09808	129.453	1.45498	8.35709

8.2 Manuscript Two Z-Scores

				z-diff	p	z-diff	p	z-diff	p	z-diff	p	z-diff	p	z-diff	p	z-diff
Comp 17H and 7L	Bu	CEJ	C	35.90	0.00	-3.57	0.00	-0.22	0.41	-2.28	0.01	-4.77	0.00	31.29	0.00	-0.03
(17-7)	Bu	CEJ	D	-17.52	0.00	-6.21	0.00	4.46	0.00	-9.19	0.00	2.24	0.01	5.46	0.00	0.10
	Bu	Mid	C	154.01	0.00	3.10	0.00	15.26	0.00	0.53	0.30	-4.83	0.00	96.64	0.00	-0.03
	Bu	Mid	D	-21.58	0.00	-7.92	0.00	-11.61	0.00	-0.87	0.19	2.65	0.00	12.80	0.00	0.26
	Bu	Apex	C	22.87	0.00	-1.15	0.12	-5.78	0.00	-4.24	0.00	-3.92	0.00	14.64	0.00	0.00
	Bu	Apex	D	11.24	0.00	-2.16	0.02	-21.96	0.00	-0.54	0.29	-1.57	0.06	91.68	0.00	0.03
	Li	CEJ	C	26.37	0.00	3.64	0.00	-1.20	0.12	5.49	0.00	0.88	0.19	89.52	0.00	0.01
	Li	CEJ	D	-1.18	0.12	2.12	0.02	10.77	0.00	10.14	0.00	1.83	0.03	32.00	0.00	-0.27
	Li	Mid	C	35.86	0.00	-3.18	0.00	-25.64	0.00	-2.37	0.01	0.80	0.21	27.11	0.00	-0.08
	Li	Mid	D	-31.48	0.00	-8.36	0.00	-55.10	0.00	-24.60	0.00	1.34	0.09	-9.69	0.00	0.21
	Li	Apex	C	81.27	0.00	1.75	0.04	0.00	0.50	4.50	0.00	3.54	0.00	71.69	0.00	0.01
	Li	Apex	D	-56.07	0.00	2.45	0.01	-7.02	0.00	1.41	0.08	2.21	0.01	-12.52	0.00	0.03
Comp 17H and 18C	Bu	CEJ	C	-20.40	0.00	0.17	0.43	-14.94	0.00	-7.31	0.00	-7.78	0.00	-38.54	0.00	0.00
(17-18)	Bu	CEJ	D	-9.52	0.00	0.95	0.17	-13.32	0.00	-8.80	0.00	0.49	0.31	-23.54	0.00	-0.04
	Bu	Mid	C	-39.25	0.00	-2.77	0.00	15.74	0.00	-0.65	0.26	-2.22	0.01	-39.00	0.00	-0.01
	Bu	Mid	D	-6.43	0.00	-7.97	0.00	3.20	0.00	-1.11	0.13	1.66	0.05	2.06	0.02	0.12
	Bu	Apex	C	-21.29	0.00	2.71	0.00	-4.17	0.00	-9.21	0.00	-4.12	0.00	-0.53	0.30	-0.01
	Bu	Apex	D	16.75	0.00	-2.44	0.01	-14.45	0.00	0.22	0.41	-0.71	0.24	74.24	0.00	-0.15
	Li	CEJ	C	-3.43	0.00	1.29	0.10	-5.89	0.00	1.80	0.04	6.93	0.00	46.30	0.00	0.01
	Li	CEJ	D	0.89	0.19	0.92	0.18	-9.03	0.00	-12.96	0.00	0.23	0.41	-18.55	0.00	-0.38
	Li	Mid	C	-39.15	0.00	1.71	0.04	-7.81	0.00	0.88	0.19	16.92	0.00	12.26	0.00	-0.02
	Li	Mid	D	1.85	0.03	2.12	0.02	8.48	0.00	-1.40	0.08	-4.24	0.00	-6.11	0.00	0.05
	Li	Apex	C	-5.38	0.00	6.10	0.00	-8.39	0.00	8.06	0.00	18.40	0.00	46.38	0.00	-0.02
	Li	Apex	D	4.86	0.00	2.90	0.00	1.64	0.05	1.52	0.06	-2.85	0.00	44.72	0.00	-0.06
Comp 7L and 8C	Bu	CEJ	C	-76.10	0.00	0.61	0.27	-15.75	0.00	2.90	0.00	-4.12	0.00	-23.16	0.00	0.02
(7-8)	Bu	CEJ	D	-5.76	0.00	-2.85	0.00	-44.85	0.00	-15.20	0.00	0.71	0.24	-18.40	0.00	-0.31
	Bu	Mid	C	35.99	0.00	-6.96	0.00	-32.87	0.00	0.14	0.44	-5.09	0.00	-60.67	0.00	0.00
	Bu	Mid	D	-14.12	0.00	-8.89	0.00	-60 86	0.00	-2.39	0.01	-0.28	0.39	-13.97	0.00	-0.53
	Bu	Apex	C	-24.83	0.00	-1.14	0.13	4.29	0.00	0.00	0.50	-6.20	0.00	-26.47	0.00	-0.01
	Bu	Apex	D	-25.33	0.00	-11.35	0.00	-2.46	0.01	10.60	0.00	-0.67	0.25	-155.27	0.00	-0.02
	Li	CEJ	C	-47.25	0.00	-2.53	0.01	-12.39	0.00	-5.10	0.00	-13.90	0.00	-143.31	0.00	-0.01
	Li	CEJ	D	-5.83	0.00	-4.64	0.00	-25.58	0.00	-24.40	0.00	-0.28	0.39	-27.33	0.00	-0.06
	Li	Mid	C	-80.37	0.00	-2.83	0.00	-23.50	0.00	15.07	0.00	-13.08	0.00	-79.75	0.00	0.04
	Li	Mid	D	10.96	0.00	-1.64	0.05	4.61	0.00	1.29	0.10	-0.35	0.36	5.76	0.00	-0.53
	Li	Apex	C	-32.84	0.00	0.86	0.20	8.27	0.00	3.94	0.00	-6.66	0.00	-19.17	0.00	-0.01
	Li	Apex	D	-0.53	0.30	-3.31	0.00	9.61	0.00	9.00	0.00	-6.38	0.00	-87.33	0.00	-0.04