

# Magnesium diffusion from implant into bone tissue observed by $\mu XRF$

imaging

A. Turyanskaya<sup>1</sup>, T.A. Gruenewald<sup>2</sup>, M. Meischel<sup>2</sup>, M. Rauwolf<sup>1</sup>, J. Prost<sup>1</sup>, H. Lichtenegger<sup>2</sup>, S.E. Stanzl-Tschegg<sup>2</sup>, A.M. Weinberg<sup>3</sup>, P. Wobrauschek<sup>1</sup>, C. Streli<sup>1</sup>



ATOMINSTITUT

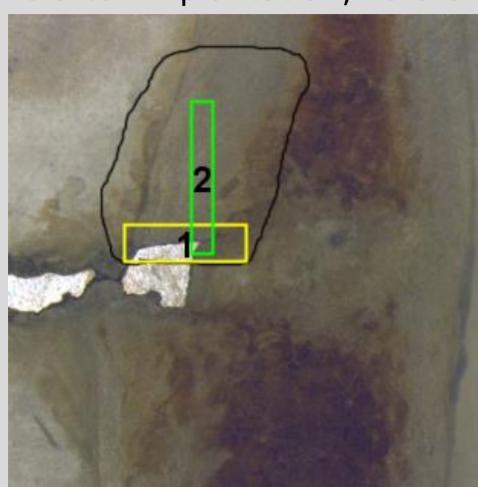
<sup>1</sup>Atominstitut, Technische Universitaet Wien, Stadionallee 2, 1020 Vienna, Austria <sup>2</sup>University of Natural Resources and Life Sciences (BOKU), Peter-Jordan-Straße 82, 1190 Vienna, Austria <sup>3</sup>Department of Orthopaedics and Orthopaedic Surgery, Medical University Graz, 8036 Graz, Austria

#### **Motivation**

Biodegradable orthopedic implants based on magnesium alloys (Mg) are of considerable interest, especially in pediatric surgery, as children's bones are in dynamic state of growth and remodelling. The process of degradation is being studied more explicitly in rat model, and the purpose of the study was to observe, how far the components of implant, Mg being the main element of interest, will penetrate into the bone.

Samples: six thin sections of rat bones containing Mg-implants collected at time given time points between 1 and 18 months after implantation; reference rat bone sample





Two areas per sample were analyzed – one horizontal stripe (Nº1, marked yellow) and one vertical stripe (Nº2, marked green), the stripes overlap each other in T- or L-shape depending on the region of interest with the focus on interface bone/implant and cortical bone. Setting of a scan area was done with taking into account the identified region of interest, by finding the prominent structural elements with the microscope and then adjusting XYZ values. Before scanning pictures at each corner and at the center of the planned scan area were taken (Fig.1).

Figure 1: View of mounted sample and regions chosen for scanning (exemplary sample 4820)

#### Method

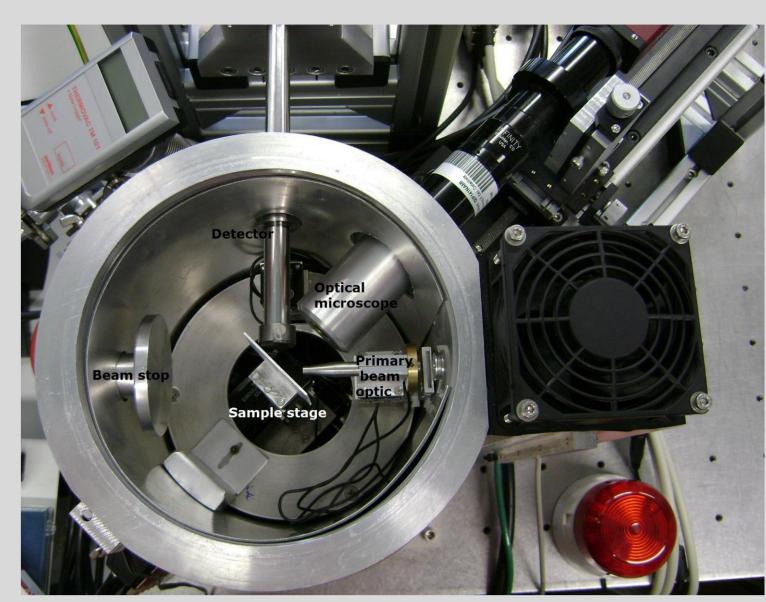
The measurements were performed at µXRF setup of Atominstitut as shown in Fig.2. Sufficient counting time (200 seconds per pixel), as well as ultrathin polymer window and vacuum conditions, are applicable for detection of low-Z

#### elements, in our case - magnesium. **Setup properties**

- excitation source: Rh tube (voltage 50,00 kV, current 0,40 mA)
- detector: 30mm2 Si(Li) detector (N2 cooled) with ultrathin polymer window (UTW)
- focusing polycapillary (spot size: app. 80µm for Mg-Ka)
- measuring time: 200 sec/pixel real time

Measurements were performed in vacuum conditions.

Figure 2: Experimental setup of the microXRF spectrometer at Atominstitut



## Results and data interpretation

The data analysis was performed using QXAS-AXIL software package. The elemental maps for eight elements were produced: Mg, Y, Zn, Ca, P, Cu, Fe, Mn with the software of X-ray Lab (Fig.3). With the step size of 50  $\mu$ m the approximate size of area 1 accounts to 2.75x0.9 mm, area 2 – 0.55x4.05 mm.

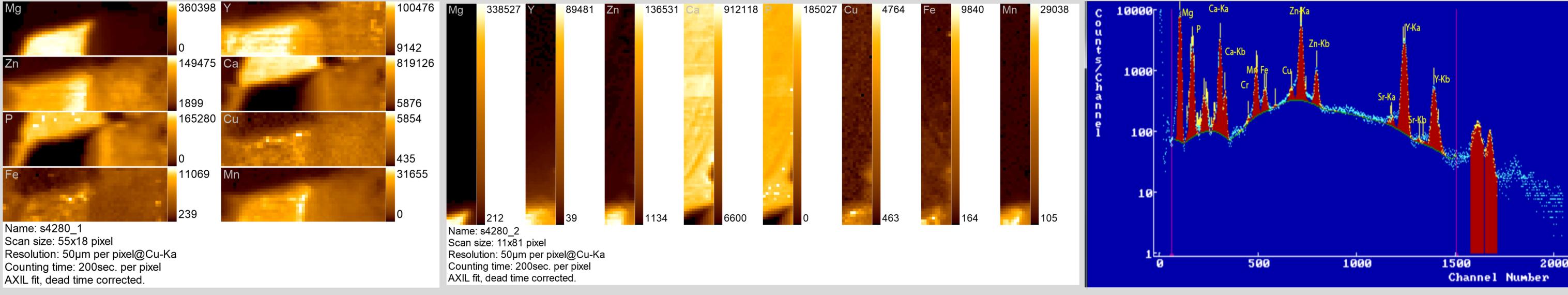
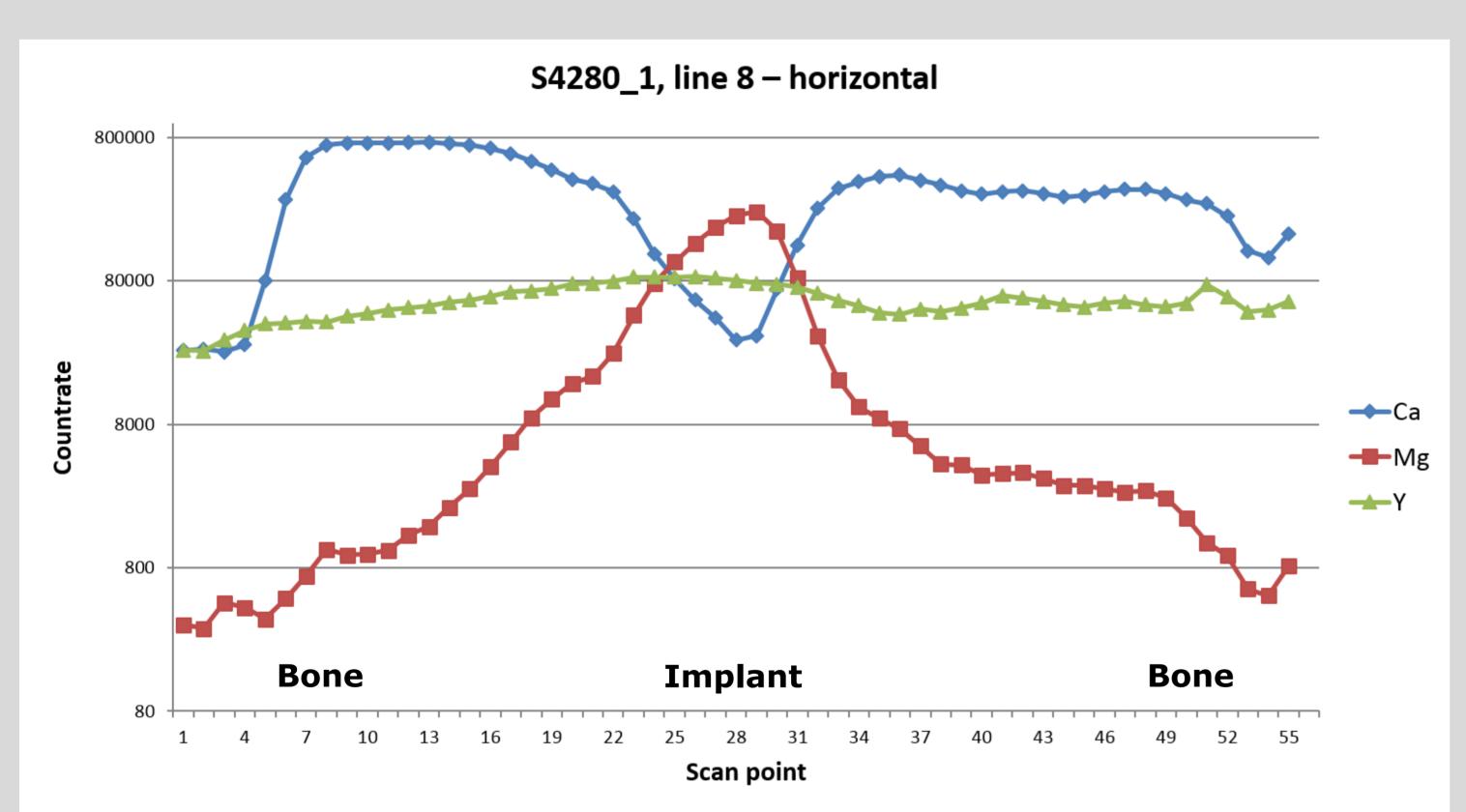
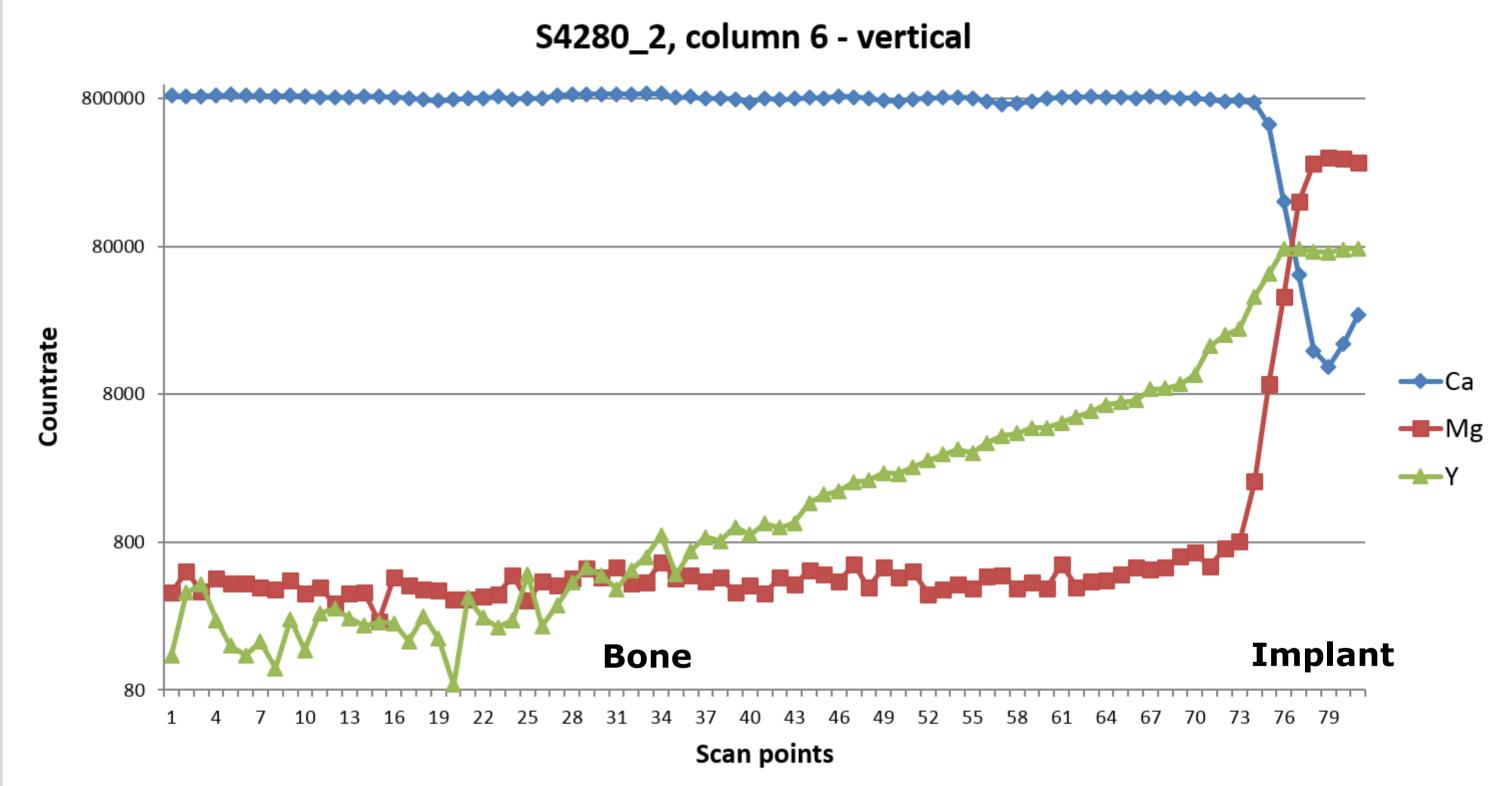
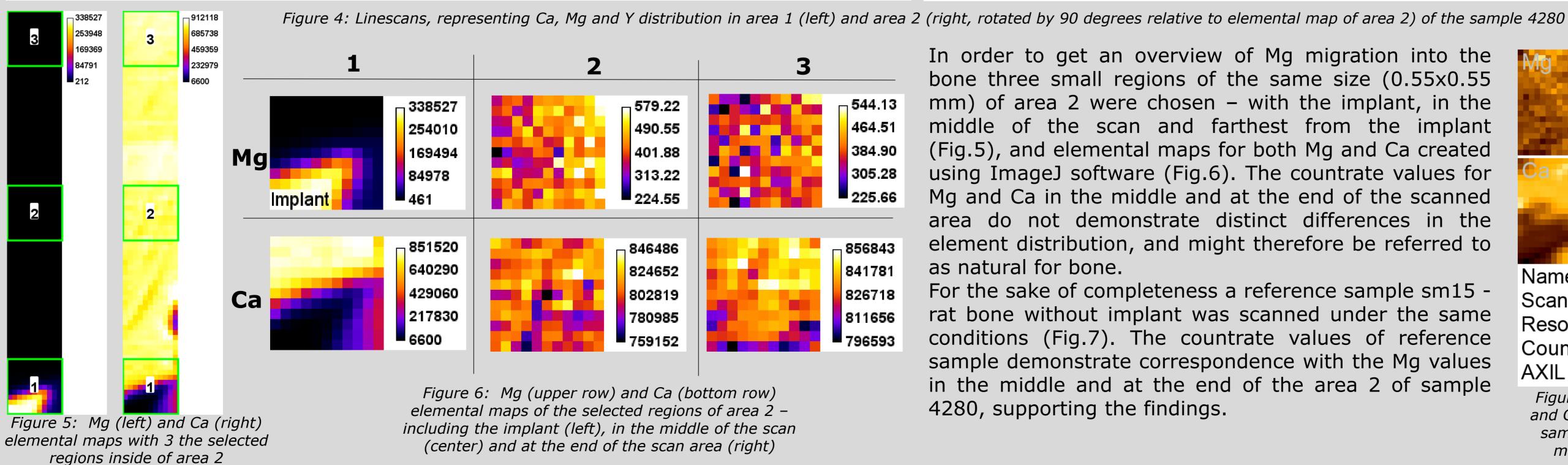


Figure 3: Elemental maps of area 1 (left), area 2 (middle) and exemplary spectrum of a point on the implant-bone border fitted with QXAS-AXIL (right) of the sample 4280

Mg is the element of interest; the implant also contains Y and Zn in the amounts of 2% and 1 %, respectively, and 0.15% of Mn. Traces of Fe and Cu were also detected. Ca and P are the main elements of the bone. Linescans (single line or column taken from the whole map) allow for more distinct comprehension of the migration of the elements (Fig.4). A drop on Ca countrate marks the bone-implant border, and for the area 2 it can be seen that Mg exhibits homogeneous distribution ~350 µm off the implant border.

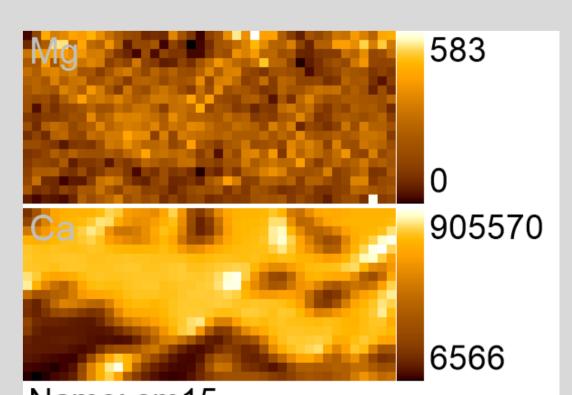






In order to get an overview of Mg migration into the bone three small regions of the same size (0.55x0.55 mm) of area 2 were chosen - with the implant, in the middle of the scan and farthest from the implant (Fig.5), and elemental maps for both Mg and Ca created using ImageJ software (Fig.6). The countrate values for Mg and Ca in the middle and at the end of the scanned area do not demonstrate distinct differences in the element distribution, and might therefore be referred to as natural for bone.

For the sake of completeness a reference sample sm15 rat bone without implant was scanned under the same conditions (Fig.7). The countrate values of reference sample demonstrate correspondence with the Mg values in the middle and at the end of the area 2 of sample 4280, supporting the findings.



Name: sm15 Scan size: 41x19 pixel Resolution: 50µm per pixel@Cu-Ka Counting time: 200sec. per pixel AXIL fit, dead time corrected.

Figure 7: Elemental maps of Mg (above) and Ca (below) for the reference rat bone sample, showing natural distribution of magnesium in calcified bone matrix

## **Conclusions and Outlook**

The analysis of the sample pool allows the following conclusions:

- 1. The diffusion of the components into the bone tissue is different depending on a sample;
- 2. Estimated Mg migration is in the range  $\sim 300 700 \, \mu m$ ;
- 3. Analysis of reference sample gives us the information on natural elemental distribution in bone, which is to be used for the further analysis;
- 4. Samples with visible implant parts: Mg migration is limited, while Y spreads out further;
- 5. Samples with no visible parts of implant: show correlation between Ca and Mg;
- 6. In some samples traces of other metals were detected.

Further investigations of the biodegradation of magnesium based implants and the migration of elements into the bone tissue will be conducted.

### References

[1] P. Wobrauschek, B. Frank, N. Zoeger, C. Streli, N. Cernohlawek, C. Jokubonis, H. Hoefler, "Micro XRF of light elements using a polycapillary lens and an ultra thin window silicon drift detector inside a vacuum chamber," Adv. X-ray Anal., vol. 48, pp. 229-235, 2005.

[2] S. Smolek, C. Streli, N. Zoeger, P. Wobrauschek, "Improved micro x-ray fluorescence spectrometer for light element analysis.," Rev. Sci. Instrum., vol. 81, no. 5, p. 053707, May 2010.

[3] T. Kraus, S.F. Fischerauer, A.C. Haenzi, P.J. Uggowitzer, J.F. Loeffler, A.M. Weinberg, "Magnesium alloys for temporary implants in osteosynthesis: in vivo studies of their degradation and interaction with bone," Acta Biomater.; 8(3):1230-8, Mar 2012

Corresponding author: Anna Turyanskaya; anna.turyanskaya@ati.ac.at