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IDENTIFYING EXPERIMENTAL TOOL USE THROUGH CONFOCAL MICROSCOPY

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TITLE PAGE

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Abstract

Characterizing use-wear traces quantitatively is a valid way to improve the capacity of use-wear analysis. This aim has been on specialists' agenda since the beginning of the discipline. Micropolish quantification is especially important, as this type of trace allows the identification of worked materials. During the last decade, confocal microscopy has been used as a promising approach to address this question. Following previous efforts in plant microwear characterization (Ibáñez et al., 2014 and 2016), here we test the capacity of the method for correctly grouping experimental tools used for working eight types of materials: bone, antler, wood, fresh hide, dry hide, wild cereals, domestic cereals and reeds. We demonstrate, for the first time, that quantitative texture analysis of use-wear micropolish based on confocal microscopy can consistently identify tools used for working different contact materials. In this way, we are able to move towards using texture analysis as part of the standard functional analysis of Prehistoric instruments.

Keywords : use-wear, confocal microscopy, lithic tools, experimentation

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INTRODUCTION

Pioneering research on use-wear analysis of Prehistoric tools by S. Semenov (1964), based on the comparison of use traces on experimental tools with those observed on archaeological instruments, succeeded in opening a new way to achieve a better understanding of Prehistoric technology. The range of types of wear on lithic tools produced by their use is wide: microscarring, striae, edge rounding and micropolish (Semenov, 1964 ; Keeley, 1980). In exceptional circumstances of preservation, residues can play a complementary role in tool use identification (Kononenko, 2007, Monnier et al., 2012). Use-wear traces, which are the result of the fatigue or redeposition of materials in contact by friction and/or shock, are studied by tribology which is mostly applied to the analysis of industrial components from the 1950s (Burwell, 1950 ; Kruschov & Babichev, 1960). In our case, the traces of the lithic instruments depend, above all, on the characteristics of the material worked (hardness, flexibility, grain, homogeneity, chemical composition, humidity) and the type of contact kinematics ; percussion / pressure, transversal or longitudinal positioning of the edge in relation to the worked material. The characteristics of the rock from which the tool is made (crystallinity and general structure, chemical composition) also play an important role in the development and aspect of traces (Clemente et al., 2015)

The relationship between the wear on the tools and their function is a rather old perception (Nilsson, 1843; Curwen, 1930). In the second half of 20th century, first S. Semenov and later L.H. Keeley made the first general systematizations of the functional method. During the 1980s and 90s, an analytical procedure was built to overcome the previous contentious low vs. high power approaches by gathering a reliable set of available evidence for functional diagnosis (Vaughan, 1981 ; Mansur, 1983 ; Plisson, 1985 ; van Gijn, 1989; González Urquijo & Ibáñez, 1994 ; Gassin, 1996; Stemp et al., 2016).).

Since then, microscarring is considered a footprint to recognize the kinematics or the relative hardness of the materials worked and the use of tools on percussion tasks such as projectiles or adzes (Lazuén, 2015, Claud et al., 2015) but it is not reliable to specify the exact worked material (i.e., antler, bone, wood). Striation marks (Mansur, 1982) are also effective to determine the movement of the tools, to detect the presence of additives in some tasks or for fine distinctions in the work of vegetal matter. Micro-rounding is a good indicator of the type of movement of the tool and of some characteristics of the worked material, such as its abrasive qualities (Kononenko, 2007). The most diagnostic trace to determine the material worked is micropolish (Keeley, 1980). Even so, the core of the functional determinations -the type of activity and the matter worked- are conventionally carried out using the combination of the full range of evidence, evaluating the coherence of the information provided by the different traces (see references above).

Most use-wear traces are relatively easy to categorize and quantify, including many features of the polish (extension at the edges, invasiveness on the faces). Those that are related to the texture of the polished surfaces, a key feature for the identification of the worked material, have been classified in several approaches (Plisson, 1985; González Urquijio & Ibáñez, 1994; Gassin, 1996). However, their quantitative description, tested several times (see below), has resulted elusive. For this reason, characterizing the textures of polishes continues to depend on the visual analogy between polishes on the experimental pieces and those observed on the archaeological ones. As this characterization is based on visual analogy, it suffers from limitations with respect to the reliability and precision of the analysis.

Because of this, as a way to gain objectivity, precision and transmissibility in the method, quantification of use-wear traces, and more specifically of microwear polish, has been tested from the beginning of of modern use-wear studies (Keeley, 1980). Different methods have been used for this task, such as interferometry (Dumont, 1982), rugosimetry (Beyries et al., 1988), atomic force microscopy (Kimball et al., 1995), laser profilometry (Stemp et al., 2009), image analysis (Bietti et al., 1994, 1998; González-Urquijo and Ibáñez, 2003; Grace et al., 1987; Knutsson, 1988; Vila and Gallart, 1993) or optical interferometry (Anderson et al., 2006; Astruc et al., 2003) among others. However, these methods, though they demonstrate that polish from different contact materials shows distinctive quantitative signatures, are not precise enough to identify tool uses.

During the last decade, confocal microscopy has been applied as a promising approach to solve this problem. First, it was used to analyze wear on tooth surfaces of primates, hominids and ancient Homo, to obtain information on diet (Scott et al., 2006, 2005) and later for use-wear analysis of lithic tools (Evans and Donahue, 2008, Stemp and Chung, 2011, Stevens et al., 2010~~,~~Stemp et al., 2015, 2018). However, even if texture analysis of polishes (antler, wood, dry hide, fresh hide and greasy hide) showed quantitative differences, the method was not utilized for discriminating between experimental tools according to the worked material.

After preliminary essays (Ibáñez et al., 2014), in a previous paper two of the authors with other colleagues promoted a relevant advance in use-wear polish quantification, as we were able to discriminate between four different types of plant polish generated when reaping three types of cereals: wild cereals cut in natural stands (*Hordeum spontaneum* and *T. diccocoides*), cultivated wild cereals (*T. boeticum*) and domestic cereals (*Triticum spelta, T. aestivum, T. monococcum* and *T. dicoccum*), and reeds (*Phragmites communis*). This was possible because of the different degree of moisture in cereal stems when harvested, as wild cereals in natural stands were cut while green, cultivated wild cereals in a semi-green state and domestic cereals were reaped when they were fully mature. Texture analyses of 20 experimental tools using multiple parameters succeeded in correctly discriminating 73% of the 3D images of plant cutting microwear polish. To test the identification capacity of the discriminant function, each experimental tool was classified against the rest of the experimental tools other than the one being tested. The rate of success was high, with 16 out of 20 being correctly classified. Three tools could not be grouped and one tool used for cutting domestic cereals in a semi-ripe condition was wrongly classified in the group of "wild cultivated cereals" (Ibáñez et al., 2016). This wrong classification is most probably explained because, in this experiment, domestic cereals were reaped in a semi-green state. This was, to our knowledge, the first time that quantitative analysis of microwear polish was able to identifying the material worked with an ensemble of experimental tools.

The application of this quantitative method to a collection of archaeological sickles from several archaeological sites dating from the Natufian to the Late Pre-Pottery Neolithic B periods in the Near East indicates that cereals were reaped in semi-green state in the Middle Euphrates during the 13th millennium BP, suggesting that wild cereals were being cultivated in that place and period. Our data also suggest that cultivation of wild cereals took place during two millennia before the first phenotypic changes related to the loss of indehiscent structures for seed dispersal appeared, in about 10,500 BP. At that moment, micropolish from ripe cereal cutting started to be dominant on sickle blades. The process towards cutting cereals in a riper state was an in situ and continuous process in the Middle Euphrates, pointing to this area as one zone where cereal domestication was being accomplished. We also showed that harvesting unripe (green) cereals persisted up to the 10th millennium BP, most probably indicating that there was occasional collection of cereals from wild stands, probably at times of crop failure.

In this way, our study demonstrated that texture analysis of 3D images obtained through confocal microscopy is useful for discriminating between tools showing microwear polish generated by variants of similar worked materials. Thus, the method permits greater precision in the study of tool use beyond the discriminating capacity based on the specialist's visual memory.

In this paper, we continue exploring the discriminating capacity of texture analysis and confocal microscopy. Here we test the method for correctly grouping experimental tools used for working eight types of worked materials: bone, antler, wood, fresh hide, dry hide, wild cereals, domestic cereals and reeds. This offers the opportunity to determine whether the method is valuable for correctly identifying worked materials between a wider array of possibilities (eight), distinguishing between microwear polishes that are known to be similar (i.e. bone and antler) while others are more distant (i.e. hide and plants). In this way, we aim to advance in a direction which in the future could allow the use of texture analysis as part of the standard functional analysis of Prehistoric artifacts.

MATERIALS AND METHODS

Thirty experiments were carried out for eight different types of contact materials: wood (oak and pine), bone (goat and cow), antler (deer), fresh hide (goat), dry hide (goat and horse), domestic cereal (wheat), wild cereal (wheat and barley) and non-woody vegetal (reed) (Table 1). Meat was not included in the analysis because this worked material generates faint use wear polish. Butchering activities provoke mixed use wear polish caused by contact with meat, cartilages and bone. We decided to deal with these two worked material in future work in a more advanced step of our research. Wood was worked in fresh or in a drier state. Antler was immersed several hours and regularly soaked during work in four of the experiments, as this material is much more easily modified when it is soaked (Owen, 1983; Osipowicz, 2007). Bone was worked fresh, without the addition of water. As control experiments, bone was soaked in one activity (PE 215), while antler was kept natural (without soaking) in another one (PE 209). Experiments were, in general, carried out during long periods in order to ensure the presence of well-developed microwear polishes. Scraping, cutting and engraving activities were carried out with tools made of fine-grained flint collected in the outcrops of Barrika (Spain), Treviño (Spain) and Charente (France). The variability in the natural texture of different varieties of fine-grained flints does not significantly affect the measurements of microwear polish (Ibáñez et al., 2014).

Some experiments were carried out by two of the authors (JG-U and JJI) in the late 1980s and early 1990s as part of our PhD theses. These tools were cleaned following the protocol proposed by L.H. Keeley, in a solution of ClH and another one of KOH. However, in the following years we realized that it is not necessary to use such aggressive cleaning procedures in most of the cases (González Urquijo & Ibáñez, 2001). ClH is useful for eliminating basic mineral residues, which are not present in our experimental tools. Organic residues from the worked materials can be eliminated in most of the cases by just cleaning the tool with soapy water, gently rubbing the edge with the fingers and using an ultrasonic tank with soapy water. Because of this, some of the experimental tools have been cleaned just with soapy water . This difference in the cleaning method does not affect the texture of microwear polish, as weak solutions of ClH and KOH (20%) during short periods of time (half an hour) do not affect the structure of the micropolish surface.

The formation of use-wear polish is a dynamic process (Grace, 1989), so its degree of development affects the texture measurements. Three successive phases in the process of use-wear polish development have been distinguished: generic weak polish, smooth-pitted polish, and well developed polish (Vaughan, 1985). Use-wear polish reaches a phase of stability in its development after a certain time of use (Ibáñez & González Urquijo, 2003 ; Evans, 2014) that corresponds to phase three in Vaughan's classification. Other variables being constant (type and degree of humidity of the contact material, texture of the rock of which the tool is made, time of use…), the degree of development of the polish depends on the intensity of the friction between the microsurface of the active zone of the tool and the worked material. Thus, various degrees of polish development can be observed on the same used edge, as the different parts of the edge inevitably come into contact with the worked material with different intensities (Plisson, 1985). In order to control the degree of development of the polish, we chose visually those areas which showed a similar degree of polish development, where polished areas cover more than 90% of the sampled surface. Six areas within the zones of well-developed polish of 650x500 microns were measured on the experimental tools with the Sensofar Plu Neox white-light scanning confocal microscope, using a 20X (0.45 NA) objective, with a spatial sampling of 0.83 micron, an optical resolution of 0.31 micron, a vertical resolution of 20 nm and a z-step interval of 1 micron. . The selection of 20X objective is a compromise to maximize details in texture avoiding the loss of areal information associated to the use of higher magnifications. This magnification is the most commonly used by use wear analysts for use wear polish identification. Several samples of 50x50 microns were selected from the areas of 650x500 microns. The size of the samples was chosen because bone working tools do not show extended polished surfaces, so it was not possible to choose more extensive areas for this contact material and we aimed to maintain the size of the analyzed surface constant for all the contact materials. In our previous study of plant polish quantification we measured zones of 200x200 microns (Ibáñez et al., 2016). The quantity of samples for each tool varies from 12 to 76. The samples were chosen in the areas where microwear polish was homogenous and well developed and not showing irregularities caused by the natural surface of flint.

These samples were processed and later measured with the Mountain 7 software, from Digital Surf. The processing of samples before measuring tried, first, to correct for the lack of horizontality of the surface. For this, a leveling operator using the Least Squares

(LS) Plane Method was used. Processing was also used to separate polish texture from the irregularities of the flint surface, which can be considered as background noise. For this, we have resorted to spatial filtering, which is done by moving a small filtering matrix (called a kernel matrix) over the surface (Milanfar, 2013). The arithmetic mean operator consists in averaging each point with its 13x13 neighboring points. The texture, which is the surface measured in our analysis, is calculated by subtracting the filtered surface from the source surface. For texture measurement we have chosen the combination of parameters offering better discriminatory capacity through discriminant function analysis (Le Goïc et al., 2016 and see below). These parameters include: 1) amplitude parameters, a class of surface finish parameters characterizing the distribution of heights (Sq, the square root mean height; Sz, the distance between the highest peak and the deepest valley; Sp, the maximum peak height and Sv, maximum valley depth area); 2) spatial parameters, which quantify the lateral information present on the X and Y-axes of the surface based upon spectral analysis (Sal, expressing the content in wavelength of the surface; Str, which measures whether the surface is isotropic), 3) hybrid parameters considering both the amplitude and the spacing (Sdq, the root mean-square value of the surface slope; Sds, density of summits expressed in peaks/mm²; 4) feature parameters (S5p, average value of the heights of the five peaks with the largest global peak height, within the definition area; Spc, arithmetic mean peak curvature, which determines the mean form of the peaks: either pointed or rounded; Spd, density of peaks; 5) functional parameters, which are calculated from the Abbott-Firestone curve obtained by the integration of height distribution on the whole surface (Sdc, difference in height between q=80% and p=10% material ratio); 6) functional indices (Sbi, the ratio of the RMS deviation over the surface height at 5% bearing area, where the higher the Sbi index, the higher the number of wear shelves on the surface; Sci, the core fluid retention index; Svi, the valley fluid retention index; 7) parameters measuring the micro-valley network, obtained after the vectorization of the surface, searching for all the furrows contained in a surface and measuring their mean depth (MDF) and mean density (MDenF).

Quadratic discriminant function analysis, a common variant of discriminant analysis (Lix and Sajobi, 2010) was used for treating the data, building a predictive model for group membership, which is composed of discriminant functions based on quadratic combinations of predictor variables when these variables show different variance-covariance matrices. The classification rule of the predictive analysis is based on Bayes' theorem. This type of statistics is very sensitive to the presence of outliers, which can distort the final result of the classification. Because of this, the outliers for the seventeen parameters used in the analyses were eliminated by resorting to the box diagram of each variable, eliminating the cases greater than 3 times the Interquartile Range. Missing values were replaced with the mean of the group. First, we tested the statistical analysis of all the analyzed samples by grouping them according to worked material. Later, we checked the capacity of the Bayesian prediction using the discriminant function for correctly identifying the worked material of each experimental tool. For this, we asked for all the samples of each tool, without providing the actual worked material, to be grouped within the eight worked materials. As a result, the samples could be distributed among the eight worked materials. When more than 35% of the samples were correctly grouped and the distance between the proportion of well identified samples and the following group in proportion of attributed samples is higher than 15 percentage points, we consider that the tool can be considered as correctly classified. If these conditions are accomplished for a wrong group, the tool can be regarded as wrongly classified. If sample classification is in between the two cases, the tool can be considered as unclassified. As we shall see, we have tested two strategies of inference of the worked material. First, we tested the correct grouping capacity for all the tools among the eight worked materials. Later, a progressive procedure was tested, using a decision tree strategy in which each tool was grouped first into three potential groups: wood/antler/bone, hide and plants. Tools identified as belonging to the first group were then classified as wood or antler/bone. If the tool was classified in the second group, the last classification tried to discriminate between bone and antler working tools. Experiments classified as hide working tools were then discriminated between dry hide and fresh hide groups. Experiments classified as plant working tools were then discriminated between domestic cereal, wild cereal and reed working tools.

RESULTS

The discriminant function analysis shows consistent discrimination between the samples of use-wear polish resulting from working the eight types of materials. Significant mean differences (Wilks' Lambda) were observed for all the predictors mentioned in the previous section and for discriminant functions (Everitt and Dunn, 2001). The contribution of the discriminating variables to the standardized canonical discriminant functions can be observed in Table 2. While the log determinants were quite similar, Box's M indicated that the assumption of equality of covariance matrices was violated, so a quadratic discriminant analysis was chosen. Sixty-seven per cent of the samples were correctly classified (Table 3). Wood samples show 71.9% correct classification, while the wrongly classified samples are distributed among the rest of the worked materials regularly. Bone samples are better classified (78.8%) and wrong grouping correspond to samples attributed to wood (9.1%) and antler (6.1%). Accordingly, antler, which shows a rate of correct classification of 63.9%, is mixed with wood (10.7%) and bone (6.5%). Fresh and dry hide are well classified in the group of hide (90.5% of correct classification for fresh hide and 91.2% for dry hide) but the degree of overlapping between samples from both groups is important as 30.6% of the samples from fresh hide are wrongly classified as dry hide and 23.7% of dry hide samples are attributed to the fresh hide group. Samples from cutting domestic and wild cereals and reeds are well classified as plant microwear polish (91.9%, 98.5% and 83.5% classified as plant polish respectively). Domestic cereal work is well defined on its own (72.8% of correct classification) but for wild cereal and reed polish the degree of admixture with respect to the other types of plant polish is important (38.4% and 24.7% respectively).

As mentioned in the previous section, in order to test the potential of the discriminant function not only to correctly classify sample images of microwear polishes but whole tools as well, we have blindly grouped the samples of each tool against the rest of the samples of the experimental tools (Table 4). The results are similar to those already observed. The seven tools used for working wood are correctly identified with more than 40% of the samples well classified and potential alternative classification showing much lower proportions. Only PE 179, with 27.6% of the samples misidentified as bone and 10.3% as antler, shows less clear results but the relatively high proportion of correct classification of samples (48.3%) permits scoring this tool as correctly classified. The four tools used for working bone are also correctly identified with more than 50%

correct classification of samples. Among the five tools used for working antler, four show a clearly higher rate of correct classification as antler than for alternative materials. For PE 309 the score of correct classification (37.5%) is not significantly higher than the ones obtained for wood (31.3%) and bone (25%) so this tool could be considered unclassified rather than correctly classified. Tools used for working fresh and dry hide are well grouped as hide working tools, with more than 79% of samples correctly classified as hide working polish, but the admixture of fresh and dry hide results indicates poor discrimination capacity for distinguishing both variants of hide working. Only two tools can be considered as well grouped (PE 537 and 507), while the results for the rest of the hide working tools are ambiguous. Regarding plant polish, all the tools are well identified as plant working tools except R17 (reed cutting tool) which displays ambiguous results. At the level of identification of type of plant polish, the two tools used for cutting domestic cereals are well discriminated, while reed and wild cereal cutting tools are not.

A progressive strategy of classification, a decision-making tree, has been tested. First the samples were classified in three groups: 1 wood/bone/antler, 2 fresh and dry hide, 3 plants (Table 5). This classificatory step enables the correct grouping of 29 experimental tools, while PE 352, an antler-working tool, shows ambiguous results, with a similar quantity of samples classified in the first group (the correct one) and in the group of plant working experiments.

In a second step, tools used for wood working were separated from those used on bone and antler (Table 6). Fourteen of the sixteen tools can be regarded as correctly classified, with more than 65% of correctly classified samples. Exceptions are PE 221, which is wrongly classified as a wood working tool when it was used to work with bone, and PE 309, for which only 56.3% of samples are correctly classified, so it can be considered an ambiguous result.

In a third step, bone and antler tools were discriminated quite successfully as eight out of nine artifacts were correctly classified, except PE 215, which is wrongly grouped as an antler-working tool (Table 7).

The discrimination of fresh and dry hide working tools was not successful, as only four tools are correctly classified while the other three are incorrectly grouped (Table 8).

As regards the identification of the three types of plant polish (Table 9), cutting domestic cereals is well characterized and both tools used for this activity are well grouped, while microwear polish from wild cereal cutting experiments is mixed with both domestic cereal and reeds, and reed polish overlaps with the wild cereal harvesting polish. Using this research protocol, none of the four tools used for cutting wild cereals and reeds could be correctly classified at the level of type of plant being worked.

DISCUSSION

Our research shows that confocal microscopy allows a good rate of discrimination of 3D images of tools used to work with six different types of materials (wood, bone, antler, hide, domestic cereals, and wild cereals/reeds). These results confirm the potential of confocal microscopy for correctly grouping flint surfaces which have been modified by working different materials, what had already been tested in other studies (Evans adn Donahue, 2008; Evans and Macdonald, 2011; Stemp et al., 2013). However, while in previous papers the identified materials varied from two to five, in this research we have increased the number of worked materials. Moreover, classifying each tool against the rest of the experimental artifacts we have blind tested, for the first time, the capacity of the method for correctly grouping tools depending on the worked material.

The partial overlapping between some contact materials in our quantitative analysis is similar to that observed visually by experts in use-wear analysis during decades and to that inferred from misidentifications of worked material in blind tests carried out by different scholars (Evans, 2014). There is a relative degree of overlapping of bone with wood and antler micropolish and of antler with bone and wood, while fresh and dry hide micropolish are difficult to distinguish and the same can be said for the discrimination of micropolishes from working different fresh siliceous plants.

These limitations in the capacity of discriminating fresh and dry hide and wild cereals and reeds should not be understood in absolute terms, as if this identification were always impossible using texture analysis and confocal microscopy, but in the context of the parameters we have used in this specific research. In fact in previously published research (Ibáñez et al., 2016) we have shown that it is possible to distinguish between tools used for reaping wild cereals in natural stands, cultivated wild cereals, domestic cereals and reeds (Ibáñez et al., 2016). In that study the analyzed surfaces were larger (200x200 microns=40.000 sq microns) and the set of measured variables were different, including one based on the fractal analysis of surfaces (Sfd), which could not be used in this study as it does not work for small surfaces like those used in this research (50x50 microns=2.500 sq microns), a surface area that is a sixteenth of the one analyzed in the previous study. Moreover, in another study, which is under way, although a significant degree of overlapping is observed between polish generated by tools used on hide in different states, the results seem to be more promising than those obtained in the current study.

Two strategies of tool use identification based on texture analysis of microwear polish have been tested in this study. First we tried discriminating the eight types of contact materials in one step; second, we tested a step by step approach, as a progressive decision-making tree. Both strategies seem to be useful for the research goal. In fact, when the identification of the worked material from a defined set of potential worked materials is intended the first strategy seems more useful, whereas, in the second strategy, the degree of incertitude or error resulting from each step of analysis is accumulated. The second exploratory strategy may be useful when a kind of microwear polish of unknown origin, which does not exactly match the characteristics of known and well defined experimental polishes, needs to be related to a group of polishes of similar characteristics (e.g. plant polish vs. wood/bone/antler polish) rather than to a specific type (e.g. bone). The second step-by-step strategy can also be used for identifying use-wear polish of similar characteristics, which would be useful for example to discriminate bone and antler working tools. We show in this research that bone and antler polishes can be distinguished. However, a note of caution has to be expressed as regards this. In most of the experiments, antler was soaked when worked, while bone was in most cases modified while fresh, without the addition of water. Thus, new research has to be carried out in order to identify whether it is the nature of the worked material -bone vs. antler), very similar but with some differences in structure and composition (Chen et al., 2009)- or the degree of humidity of the material (soaked or not) that is at the origin of the discriminant capacity of the method. Suspiciously, it was the tool used on soaked bone that was classified as an antler working tool (PE 215).

What are the keys of this research allowing the correct classification of experimental tools depending on the type of material they modified? We think that these keys are:

1. The analysis of relatively large surfaces (2500 sq microns or more). In previous studies, sampled surfaces had been smaller (e.g. in Evans & MacDonald, 2011). Our research suggests that analyzing larger areas improves the discriminant capacity of the method on condition that the analyzed micropolish is well developed and compact.
2. This is exactly the second key element in our analyses: polished surfaces were in an advanced stage of development, with more than 90% of the measured surface completely polished. In fact, as we will discuss later, dealing with the variability in the degree of development of the polish is one of the most important challenges of use-wear quantification studies (González Urquijo & Ibáñez, 2003 ; Bietti et al., 1994)
3. Filtering is an important step in the analysis (Dobrzański & Pawlus, 2011) as the characteristics of the polished surface have to be discriminated from the original flint surface topography. We have used a quite strong filtering algorithm for isolating the smaller wavelength components of topography (Sullivan, 2001). Moreover, original surfaces were placed in a horizontal position before filtering.
4. We have used a multi-parameter approach for texture analysis. In an inductive research strategy we have measured texture in the samples using as many parameters as possible. Later, we have chosen those parameters which are significant for the discrimination of groups.
5. Despite filtering, some measured samples for all or for certain parameters display aberrant results. These outliers were eliminated from the analysis (Motulsky, 2014), which resulted in a more coherent definition of the discriminant algorithm. This then showed more consistent ability to correctly classify new micropolish surfaces.

This study represents an important step forward towards integrating quantitative texture analysis into the methodology for use-wear analysis. However, it is necessary to stress that use-wear analysis is only a part of the methodology employed for the study of tool use. Moreover, micropolish analysis is only a part of use-wear analysis. We are trying to build a methodology to improve the specialist's ability to discriminate micropolishes. In the current state of the art, we aspire to offer a method allowing more precise identifications. This is what we have done, for example when we distinguished different plant polishes in order to shed light on the topic of the origins of cereal domestication (Ibáñez et al., 2016). Surely, new studies will follow this one, distinguishing micropolishes from working different hard animal materials (bone, antler, ivory and horn) or micropolishes generated from working hide in different states (soaked, dry, fresh, greased…).

How could quantitative texture analysis be integrated into the standard methodology of identification of tool use? After a detailed knowledge of the context in which a Prehistoric tool was found, use wear analysis starts with the visual observation of the artifact, allowing the evaluation of the technical capacities of the tool (considering size, weight, morphology....), the potential use zones (edges, points bisels...) and the presence/absence of macroscopic use traces. The observation through binocular microscope would permit identifying the use zones and the presence and characteristics of scarring, edge rounding and use shines/polishes. Analysis through incident light microscope allows the detailed study of use wear polishes, including its distribution along the edge, invasiveness, relationship with scarring... Striantions can also be evaluated at his stage of the analysis. In case of preservation of meaniningful use wear traces, these three steps of analysis would adress to a confident identification of the active zones, the movement of the tool and the hardness and, in the better cases, the nature of the worked material. Quantitative texture analysis of use wear polish could be used at this stage of the inference, confirming the identification of the worked material and even going further the analyst's capacity of inference. Ideally, texture quantification would allow distinguishing between wood, antler and bone polishes, when the distinction is not clear, discriminating between different plant polish, providing information on the state of the hide when it was cut or scraped, giving details on the type of minerals materials which were engraved or perforated and so on. In fact, the potential and limits of the technique are still a matter of exploration. Anyway, it is evident, thus, that the proposed method cannot be applied without previous expertise in use-wear analysis as a whole.

Thus, we are not trying to substitute the traditional method of use-wear analysis by a quantitative one, but only obtaining a tool for improving the method. Then, if we only try to improve the method, why have we replicated the capacity of identification of "classical" worked materials (wood, bone, antler, hide…) when it is recognized that standard use-wear analysis is able to obtain similar results? First, we felt that if we want to use quantification to gain precision in micropolish identification and reach discriminating capacities that are not at hand for specialists using visual analogy, it is necessary to demonstrate first that texture quantification can match the specialist's skill. Second, it should be acknowledged that among many ill-informed archaeologists the capacity to identify worked materials through the study of micropolish characteristics is under suspicion, especially after the criticism of R. Grace and colleagues (Grace, 1989). In this way, this study can be considered as a covering procedure.

This study represents a relevant step forward towards using texture analysis for micropolish identification. However, important challenges have to be solved before being able to use quantitative analysis as a standard use-wear method. We have analyzed well-developed polishes, avoiding areas with lower intensity of polish. The specialist's experience allows her/him to take account of the degree of the development of the polish, in an attempt to identify exclusively the worked material that generated the well-developed polishes. However, we have not implemented a method for identifying different phases of polish development, but just a static model of micropolish identification, in which only well-developed polishes can be identified. Thus, establishing dynamic models in which the degree of development of the polish will be integrated in the process of inference of the worked material is a task for future research (see Evans et al., 2014; Giusca et al., 2012; Key et al,, 2015; Stemp et al., 2015).

Controlling quantitatively other sources of alteration of flint (technological, transport, hafting…) is another important challenge and, among them, post-depositional alterations are especially relevant (Caux et al., 2018 ; Werner, 2018).

Previous studies have shown that different lithic raw materials have particular properties and rates of wear (Lerner, et al., 2007). However, we showed that the variability in the natural texture of different varieties of fine-grained flints does not significantly affect the measurements of the use-wear polish (Ibáñez et al., 2014). This has been confirmed in the present study. Tools made from different fine-grained flints are correctly grouped according to the contact material despite tiny differences in the natural texture of these flints (Ibáñez et al., 2014). However, if tools made from materials other than fine-grained flint are being analyzed, new experimental programs and measurements have to be carried out, as data in this paper are not applicable to all kinds of rock.

CONCLUSIONS AND PERSPECTIVES

During the last four decades, use-wear analysis has largely contributed to a better understanding of Prehistoric technology. Methodology of use-wear analysis is based on the comparison of experimental and archaeological use traces. This comparison mainly depends on the analyst's experience and visual memory. Despite numerous trials to develop a quantitative use-wear analysis methodology, especially in those aspects related to the discrimination of microwear polishes, advances have been limited. However, in the last decade, texture analysis of 3D surfaces obtained through confocal microscopy has emerged as a promising technique for discriminating micropolishes originated by contact with different worked materials. However, the degree of overlapping between various microwear polishes did not allow the discrimination of experimental tools depending on the material worked. In a previous paper we succeeded in distinguishing with a reasonable degree of certainty experimental tools used for cutting four types of plant polish: domestic cereals, wild cereals in natural stands, cultivated wild cereals and reeds. We are using this discriminating capacity to shed light on the process of cereal cultivation and domestication in the Near East.

In this paper, by discriminating 30 experimental tools used for working eight contact materials we have moved forward in use-wear polish quantification considerably. We have distinguished with a good level of accuracy experimental tools used for working bone, antler, wood, hide, domestic cereals and fresh plants (wild cereals and reeds). Bone and antler working tool also seem distinguishable, though new research must be carried out in order to determine the extent to which the discriminant capacity between bone and antler experimental tools in our test is due to the nature of the materials themselves or to the degree of humidity of the materials. The capacity of distinction between wild cereal and reed-working tools has appeared limited in this study. However this should be explained by the characteristics of the parameters chosen in this study, mostly because of the limited surface area of the samples (50 microns), as in a previous study we managed to distinguish between tools used for cutting both materials successfully. Finally, our study has failed to identify tools used for working fresh and dry hide. New research is needed to address this issue, to establish the procedure to characterize the state of hides when worked.

Factors related to this study which can explain our relative success in discriminating microwear polishes are: the analysis of relatively large surfaces (2500 sq microns or more) showing an advanced degree of polish development, besides the use of a procedure of texture quantification including the filtering of the sampled surfaces, which are measured using multiple parameters, and the elimination of the outliers before looking for the discriminant algorithm. Using this algorithm, we have tested a one-step and a step-by-step discriminant strategy, observing that the first one seems more useful.

Work toward use-wear quantification should not be understood as a sign of distrust in the traditional method of use-wear analysis. On the contrary, polish quantification, like any kind of use-wear quantification, has to be understood as a procedure to improve current use-wear methodology. In the present state of use-wear methodology, micropolish quantification can be useful for advancing in our capacity of discrimination of worked materials. This is what has been achieved by distinguishing four types of plant polishes. Distinguishing between micropolishes from working various types of hard animal materials (bone, antler, ivory, horn), hides worked in different states (fresh, dry, humid, greased…), stones of various hardness and compositions, and so on, are challenges which can be now tackled. For efficient quantitative discrimination, use-wear polishes have to be well-developed and not or slightly affected by post-depositional alterations. In the middle term, new challenges need to be addressed to widen the use of quantitative analysis in use-wear polish identification. It will be necessary to characterize the less advanced phases of polish development, post-depositional alteration and the variability in polish textures depending on the type of rock used to make the tools.

Even if we are aware that the main role of microwear polish quantification is, in the current state of the methodology, to go beyond the analyst's discriminant capacity, the tests have been carried out with "classical" types of contact materials (wood, antler/bone, hide…) which are within the analyst's discriminant capacity. This has been done to build a kind of "covering procedure". First, it is difficult to explain how it is possible to reach detailed work material identification (e.g. reed working) quantitatively if the possibility of discriminating between more distinct polishes (such as hide and plants) is not previously tested. Second, we have tried to reduce the skepticism that still exists among many colleagues about the possibility of identifying worked materials based on the characteristics of use-wear polish. Finally, we think that we have moved towards the development of a quantitative use-wear analysis methodology. We are aware we are still far from that objective, but it now looks more plausible than before.

FIGURE CAPTIONS

1. PE 112, polish from scraping Wood, 60 minutes.
2. PE 179, polish from scraping wood, 30 minutes.
3. PE 107, polish from engraving wood, 60 minutes.
4. PE 180, polish from scraping wood, 30 minutes.
5. PE 105, polish from scraping wood, 60 minutes.
6. PE 115, polish from scraping wood, 60 minutes.
7. PE 116, polish from scraping wood, 60 minutes.
8. PE 238, polish from scraping bone, 35 minutes.
9. PE 233, polish from scraping bone, 35 minutes.
10. PE 215, polish from scraping bone, 60 minutes.
11. PE 221, polish from scraping bone, 45 minutes.
12. PE 309, polish from engraving antler, 60 minutes.
13. PE 319, polish from engraving antler, 7 minutes.
14. PE 345, polish from scraping antler, 25 minutes.
15. PE 347, polish from engraving antler, 25 minutes.
16. PE 352, polish from engraving antler, 20 minutes.
17. PE 502, polish from scraping fresh hide, 60 minutes.
18. PE 504, polish from scraping fresh hide, 60 minutes.
19. PE 526, polish from scraping fresh hide, 45 minutes.
20. PE 537, polish from scraping fresh hide, 50 minutes.

21. PE 568, polish from scraping fresh hide, 25 minutes.
22. PE 507, polish from scraping fresh hide, 60 minutes.
23. PE 508, polish from scraping fresh hide, 60 minutes.
24. PE 548, polish from scraping fresh hide, 120 minutes.
25. PE 749, polish from cutting domestic cereals, 420 minutes.
26. PE 750, polish from cutting domestic cereals, 420 minutes.
27. SV1, polish from cutting wild cereals, 240 minutes.
28. SV2, polish from cutting wild cereals, 240 minutes.
29. R16, polish from cutting reeds, 90 minutes.
30. R17, polish from cutting reeds, 90 minutes.

TABLE CAPTIONS

Table 1. Experimental program

Table 2. Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions. Variables are ordered by absolute size of correlation within function. * Largest absolute correlation between each variable and any discriminant function. For this calculation fresh and dry hide working tools have been grouped together, as, in this analysis, the capacity of discrimination between them is very limited (see below).

Table 3. Classification using discriminant function analysis of 3D images obtained through confocal microscopy into the eight types of microwear polish. Rate of correctly classified cases: 67.0%.

Table 4. Results of the blind classification of each tool into the eight groups of microwear polish (wood, bone, antler, fresh hide, dry hide, domestic cereals, wild cereals and reeds) using discriminant function analysis.

Table 5. Results of the blind classification of each tool into three groups of microwear polish (wood/bone/antler, hide and plants) using discriminant function analysis.

Table 6. Results of the blind classification of each tool previously classified as wood/bone/antler working tool into two groups of microwear polish (wood or bone/antler) using discriminant function analysis.

Table 7. Results of the blind classification of each tool previously classified as bone/antler working tool into two groups of microwear polish (bone or antler) using discriminant function analysis.

Table . Results of the blind classification of each tool previously classified as hide working tool into two groups of microwear polish (fresh hide or dry hide) using discriminant function analysis.

Table 9. Results of the blind classification of each tool previously classified as plant working tool into three groups of microwear polish (domestic cereals, wild cereals and reeds) using discriminant function analysis.

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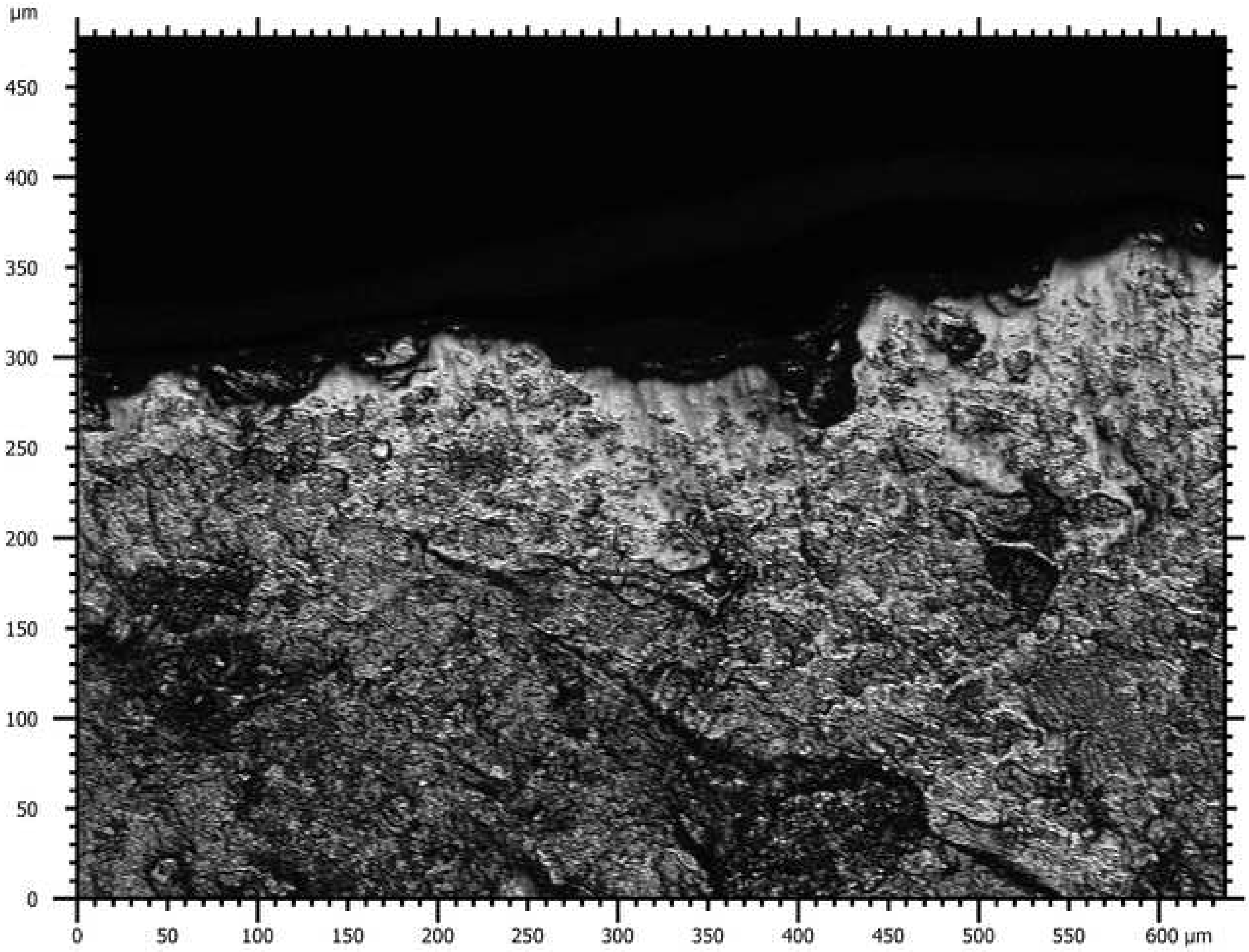
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Figure 2

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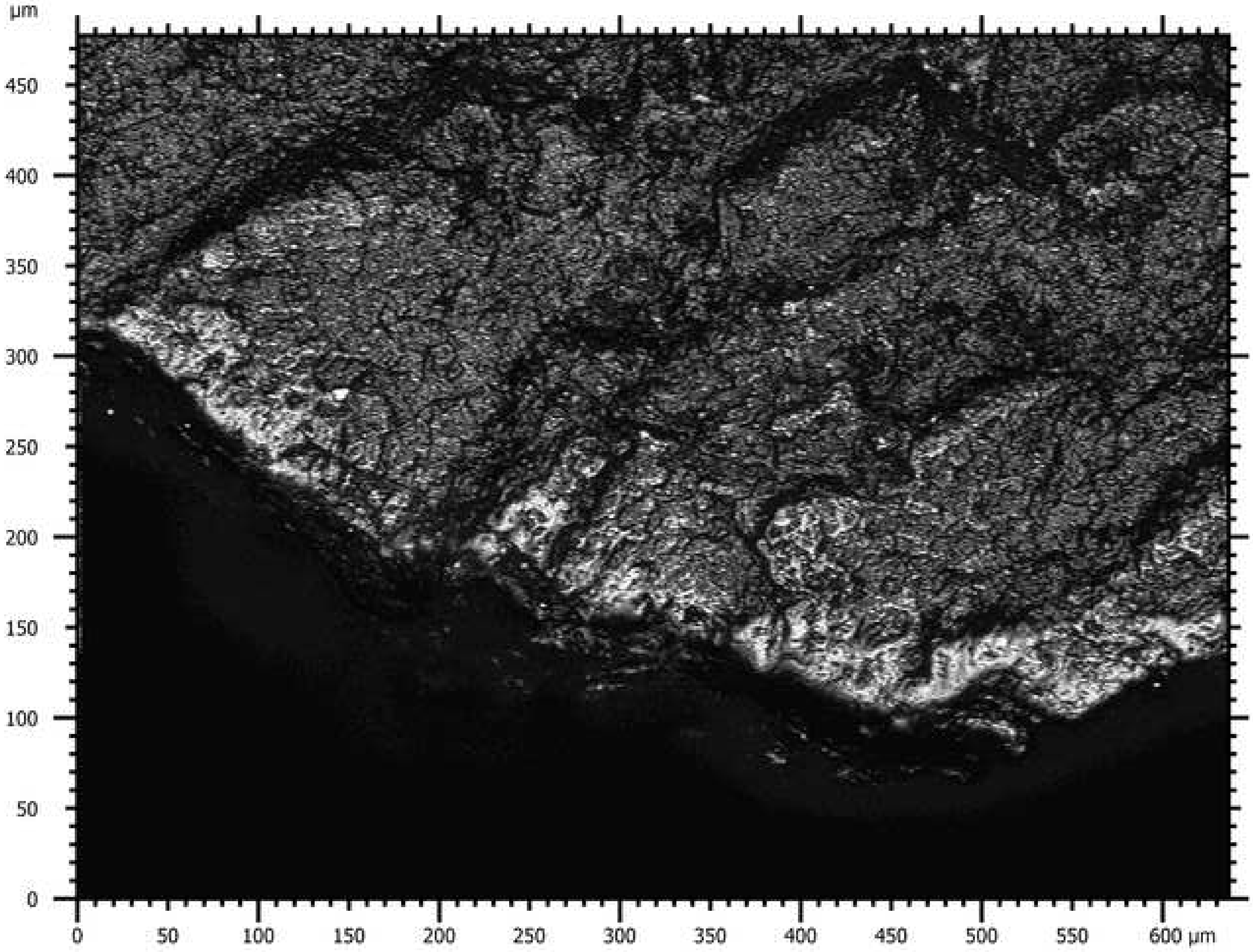

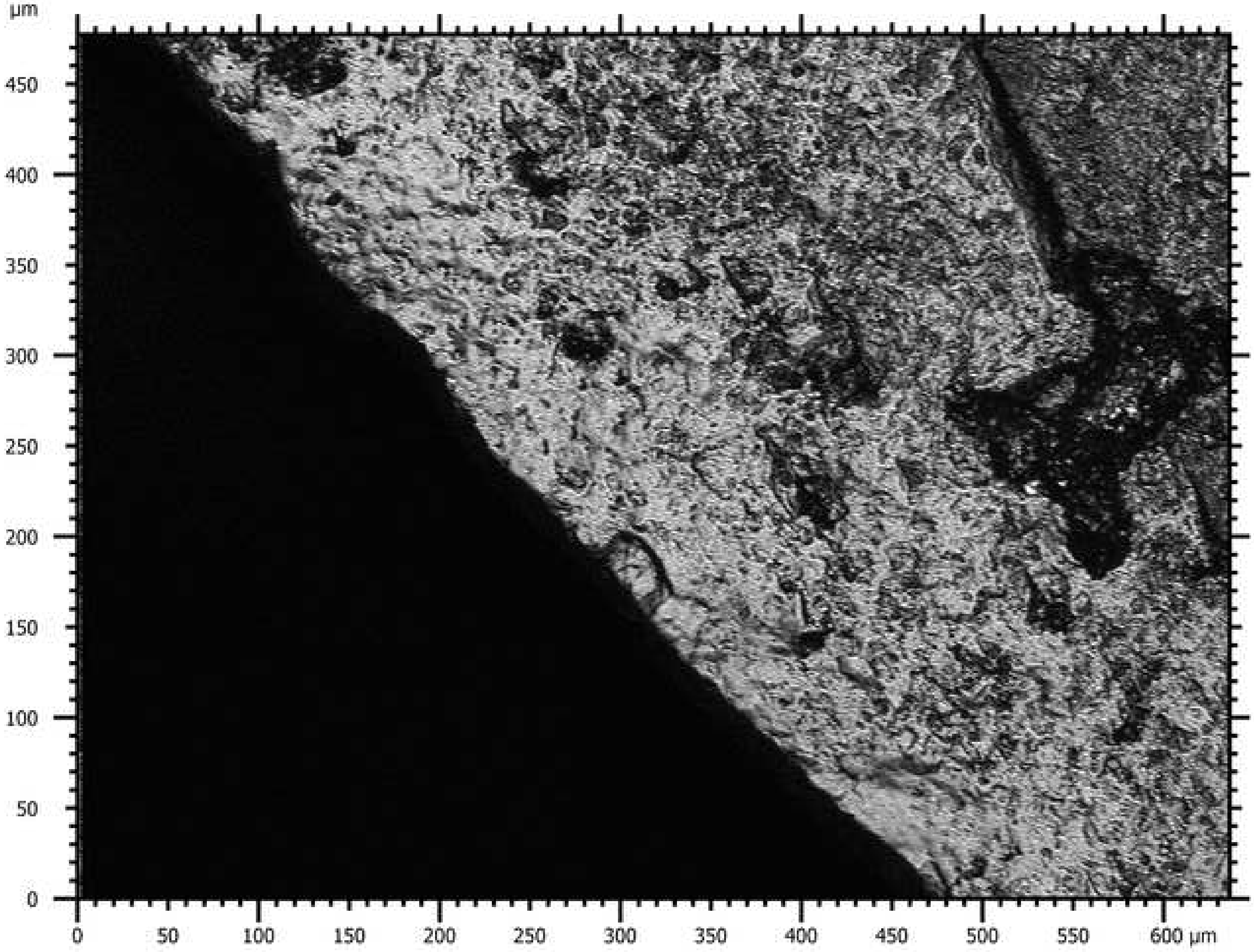
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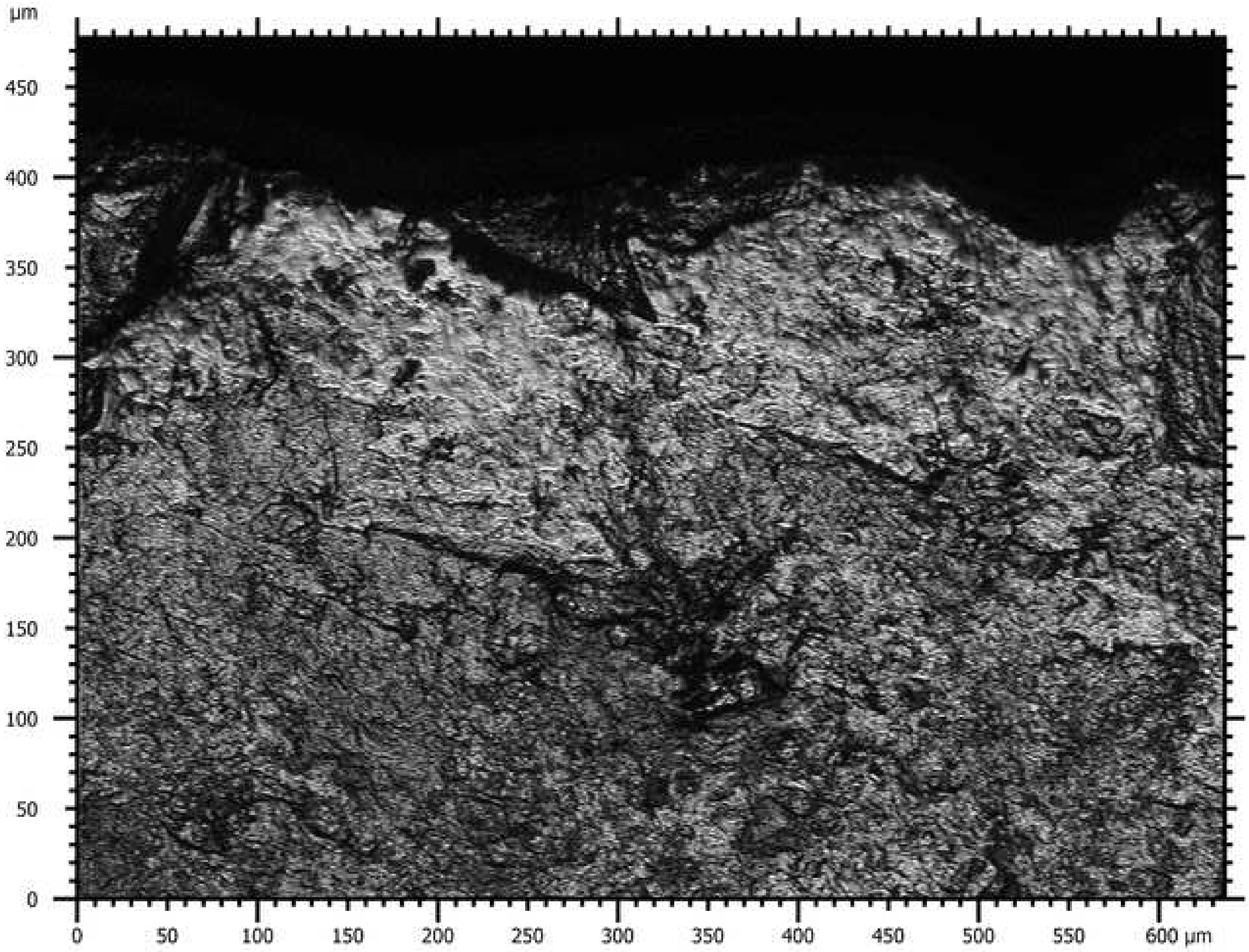
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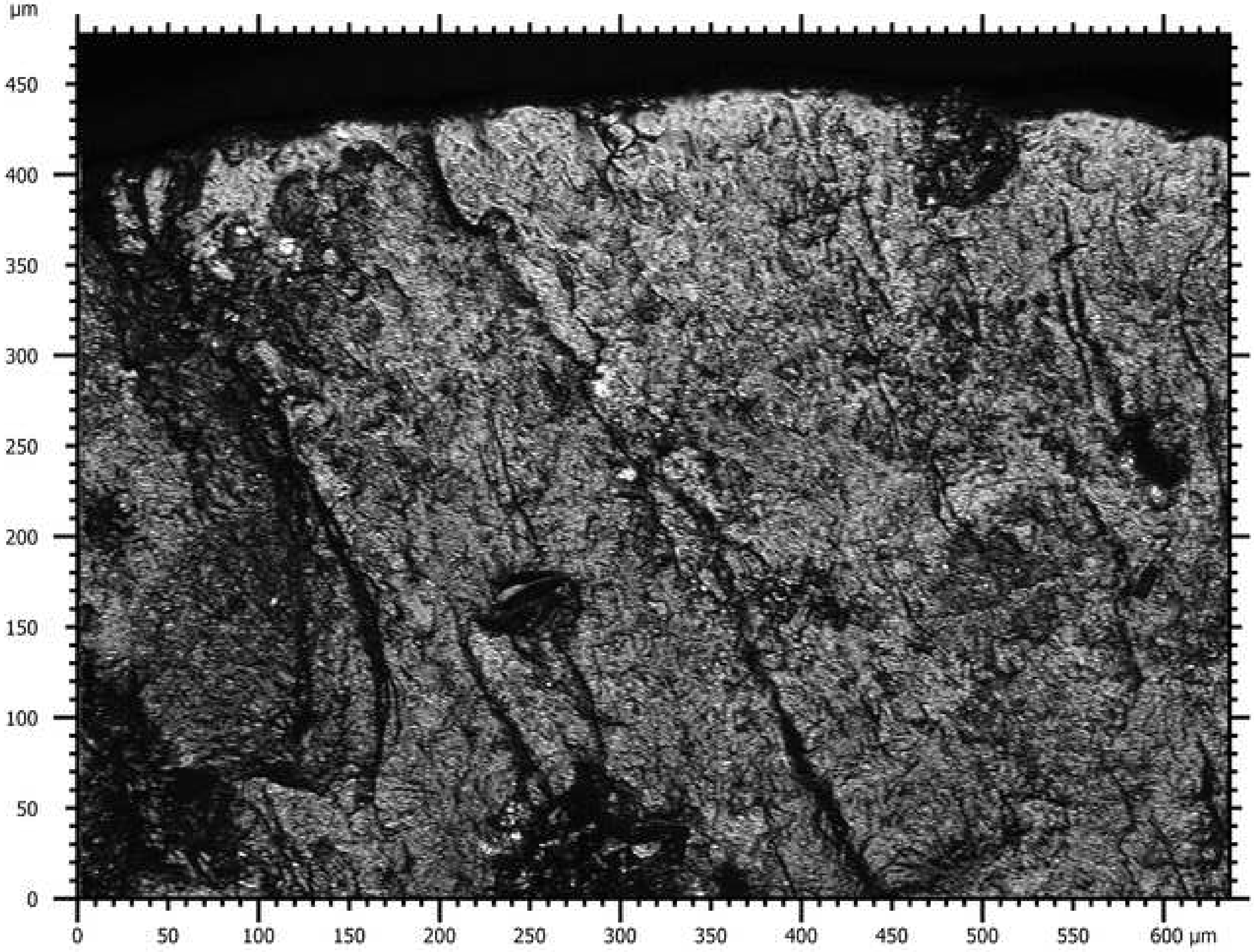
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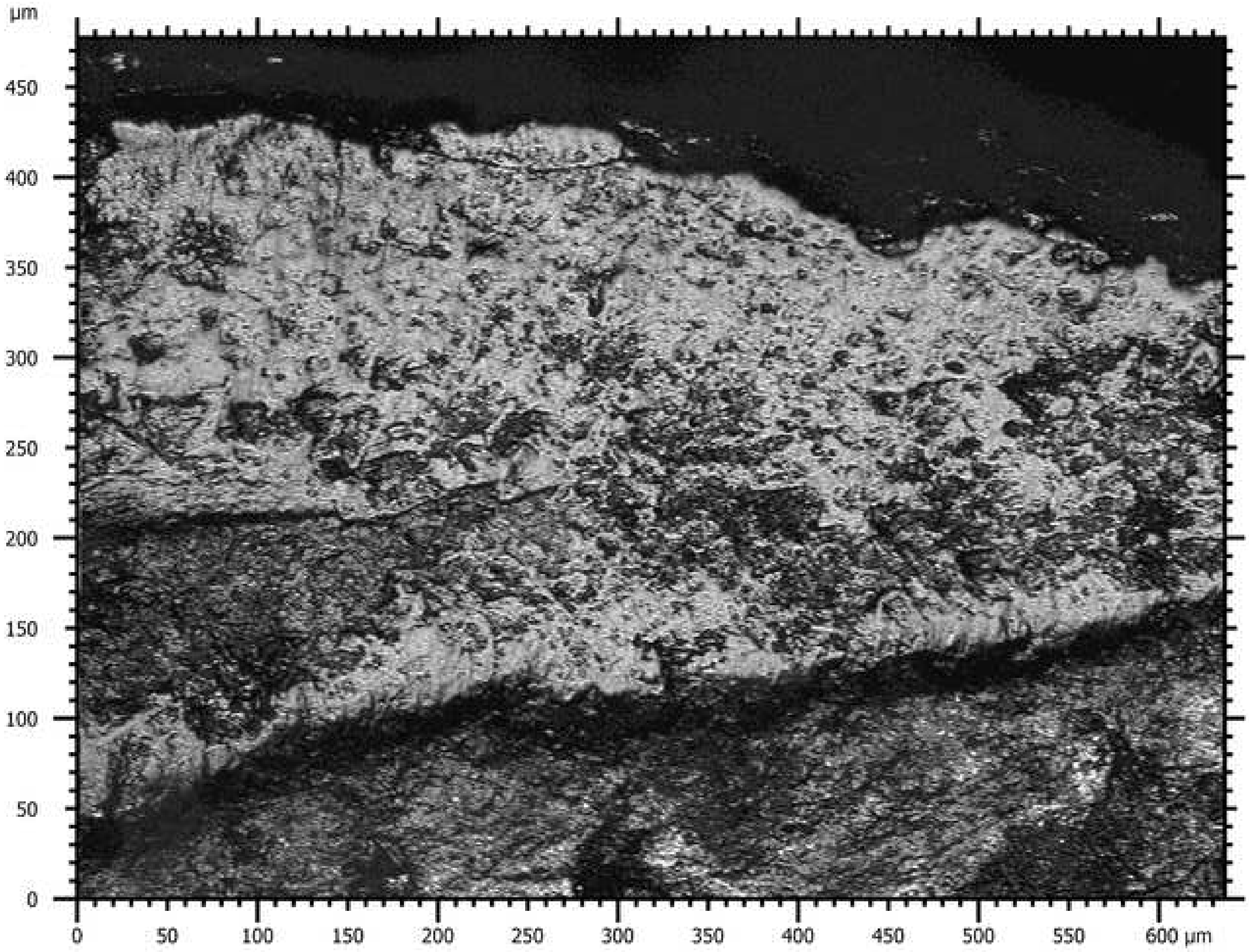
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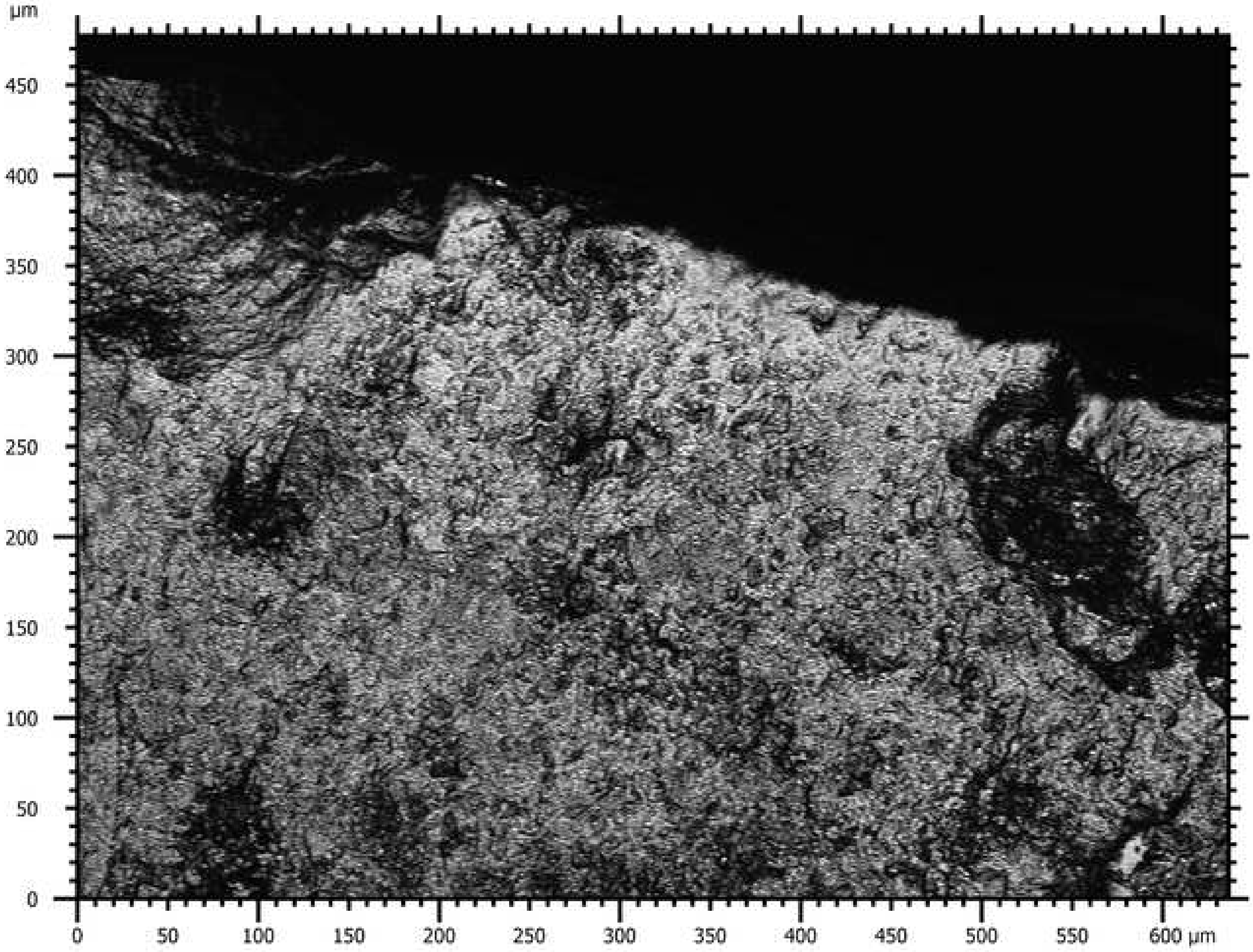
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Figure 8

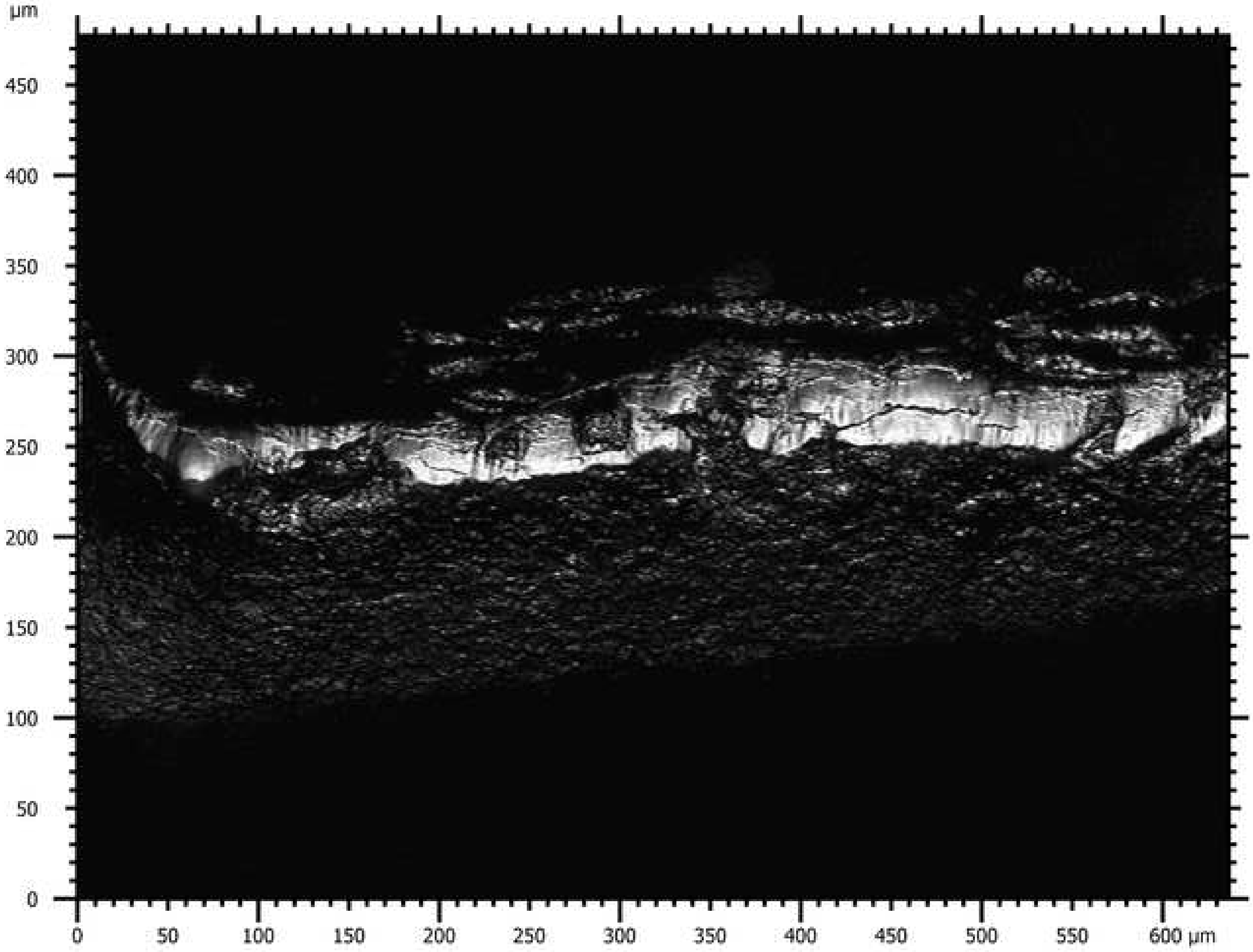
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Figure 9

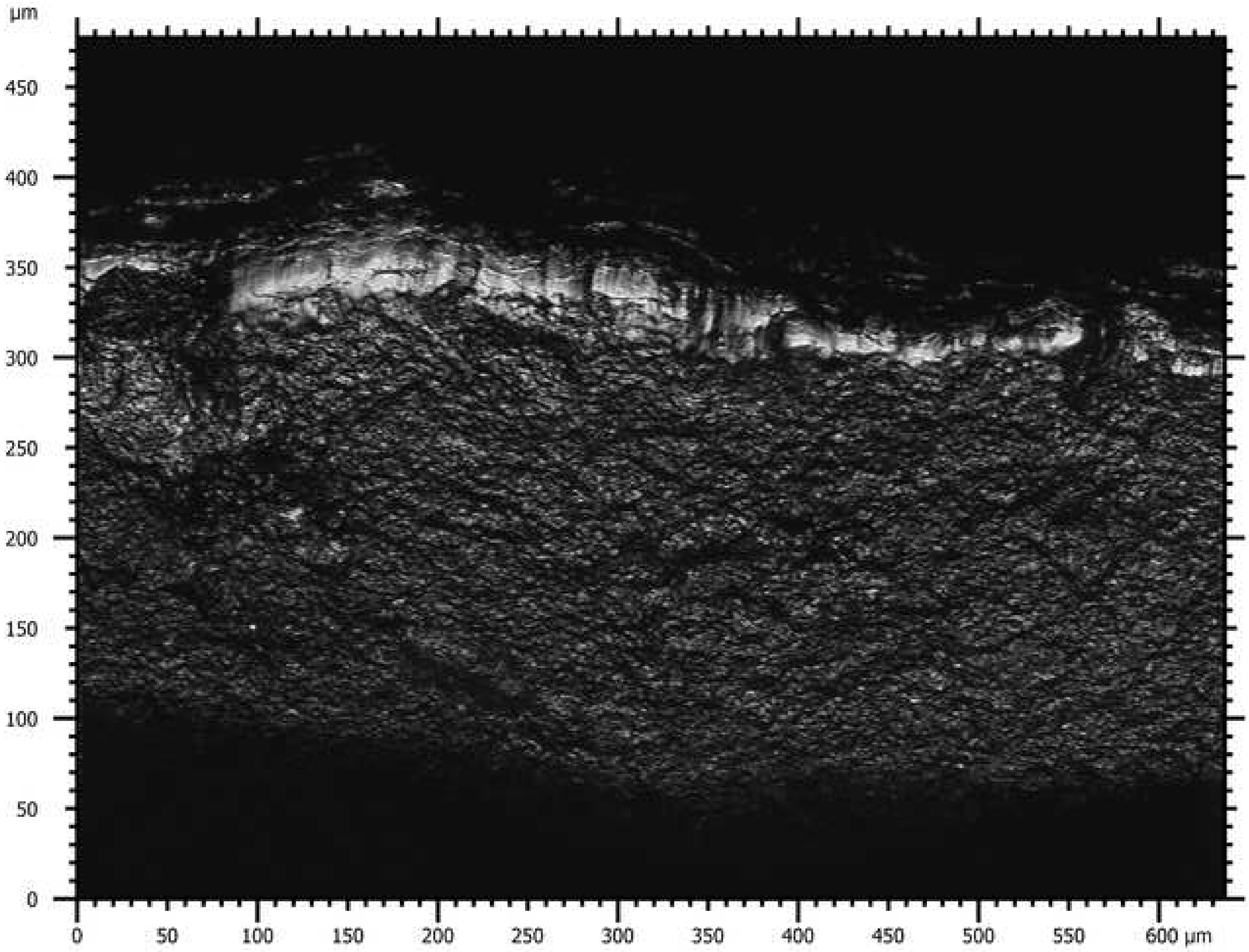
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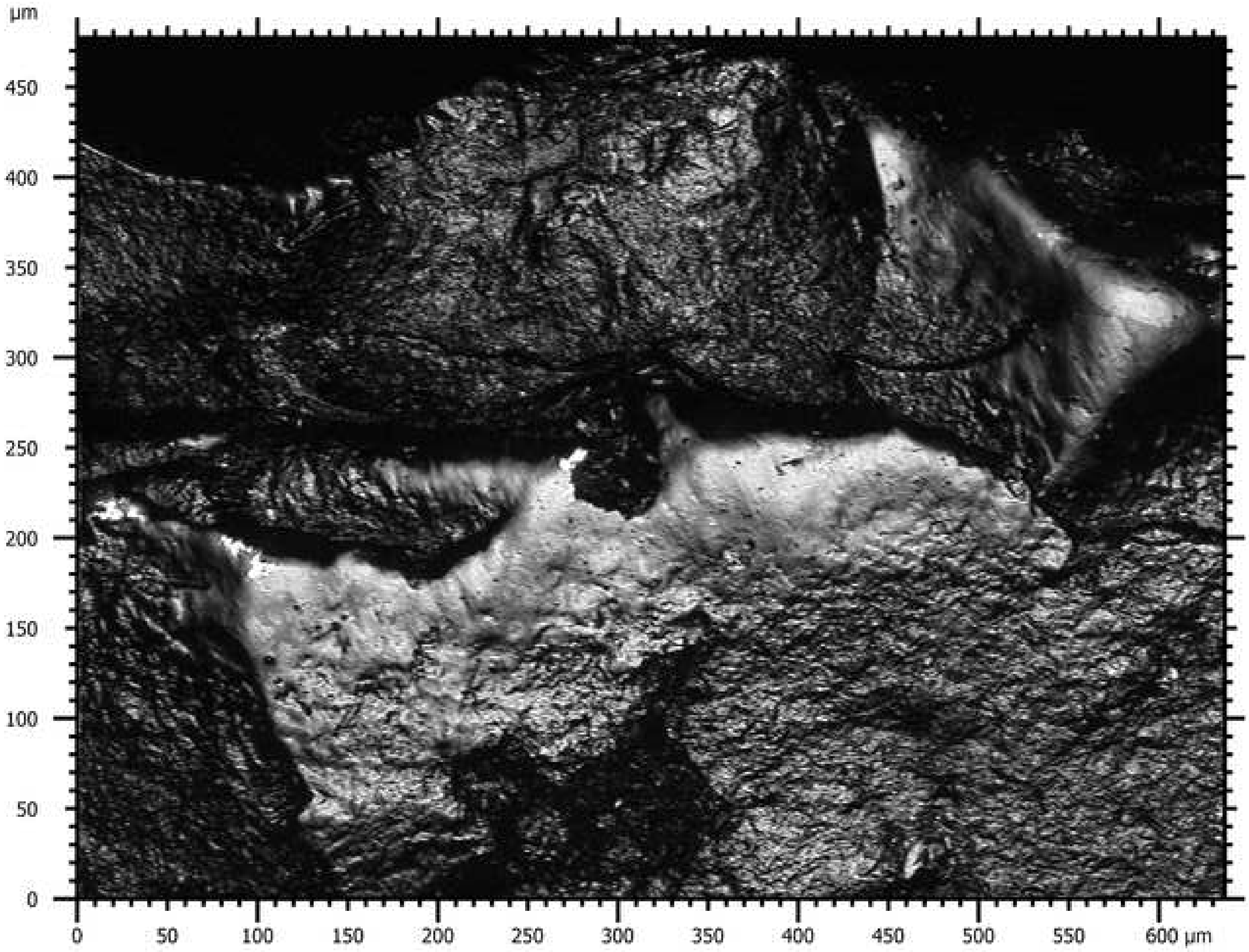
Figure 10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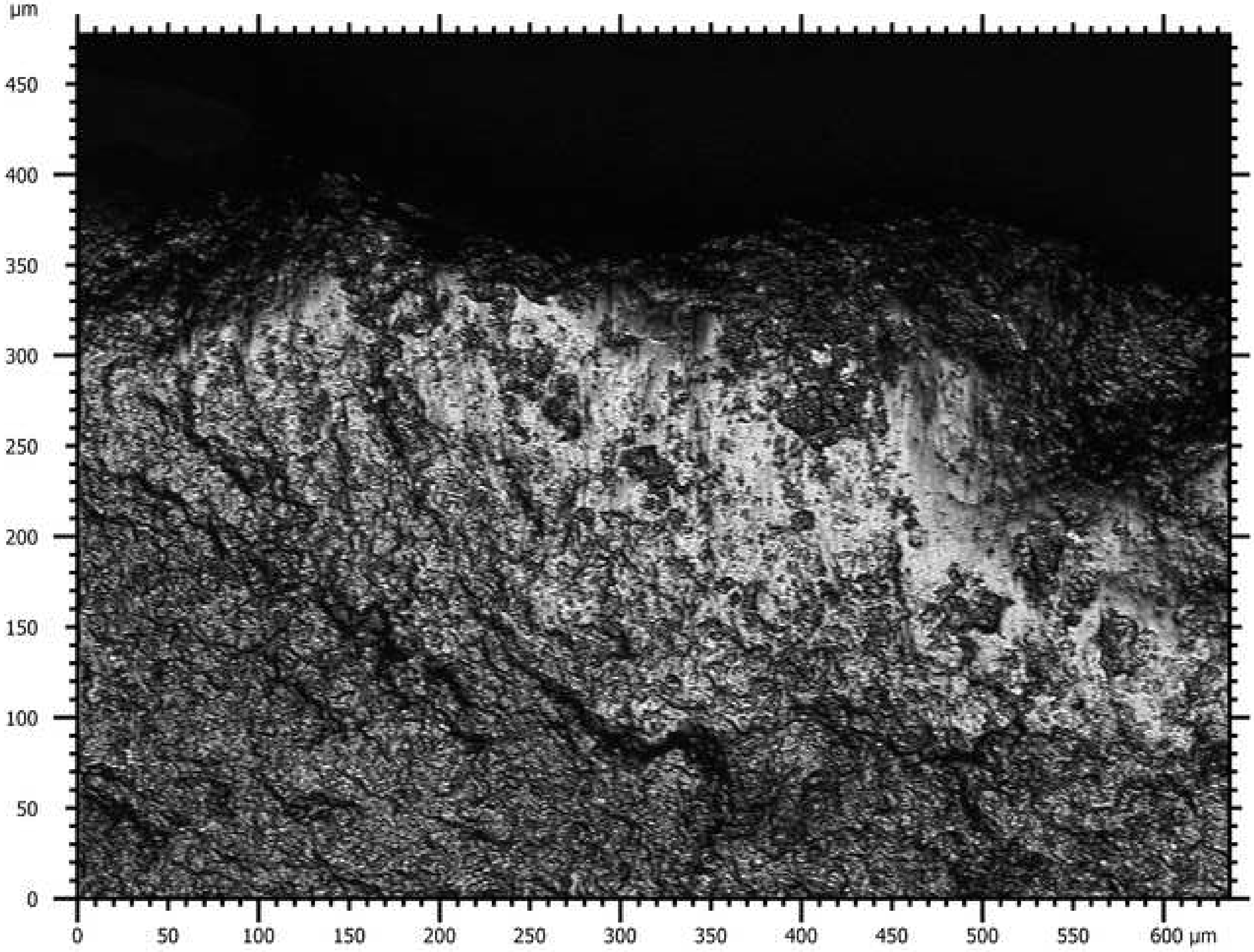
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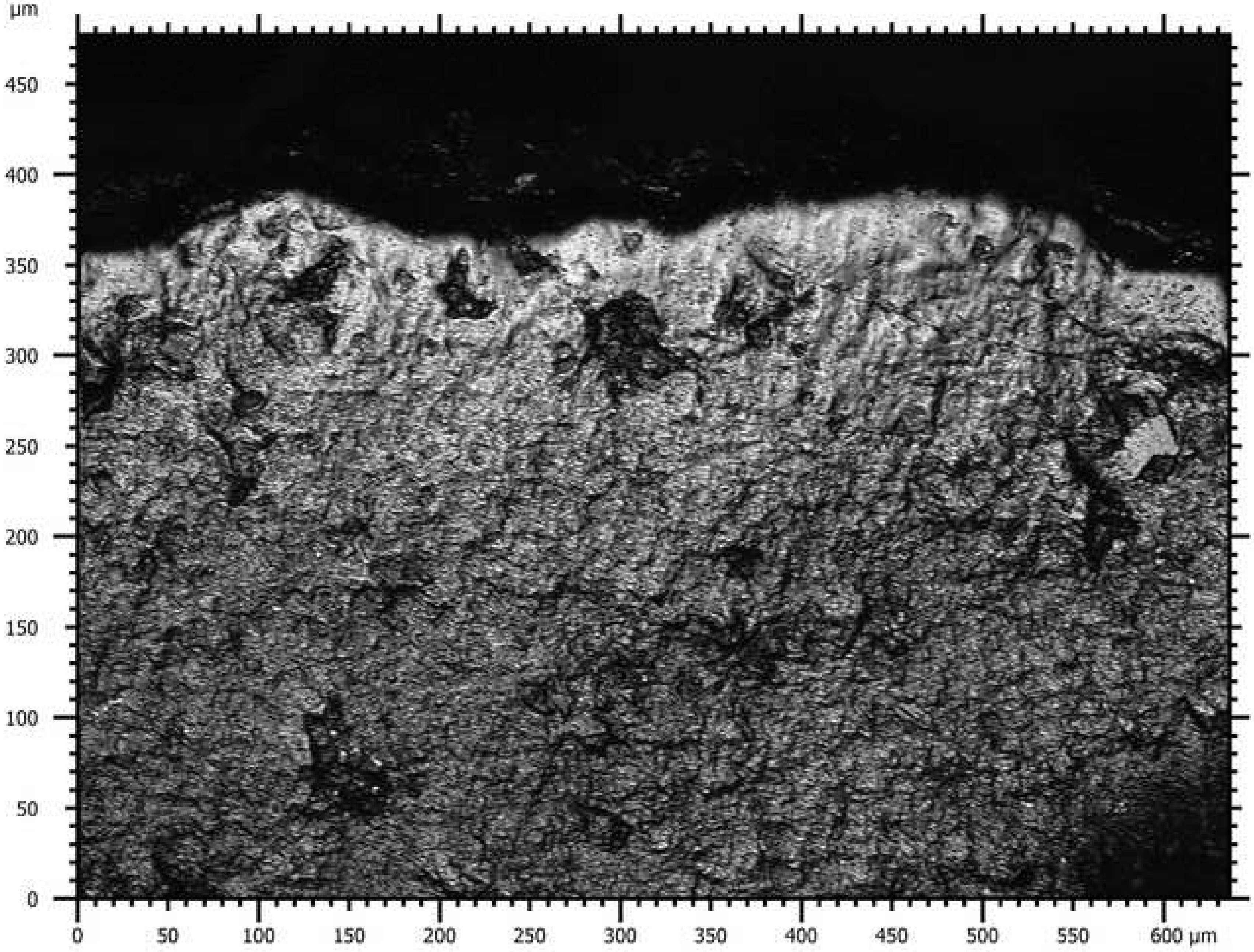
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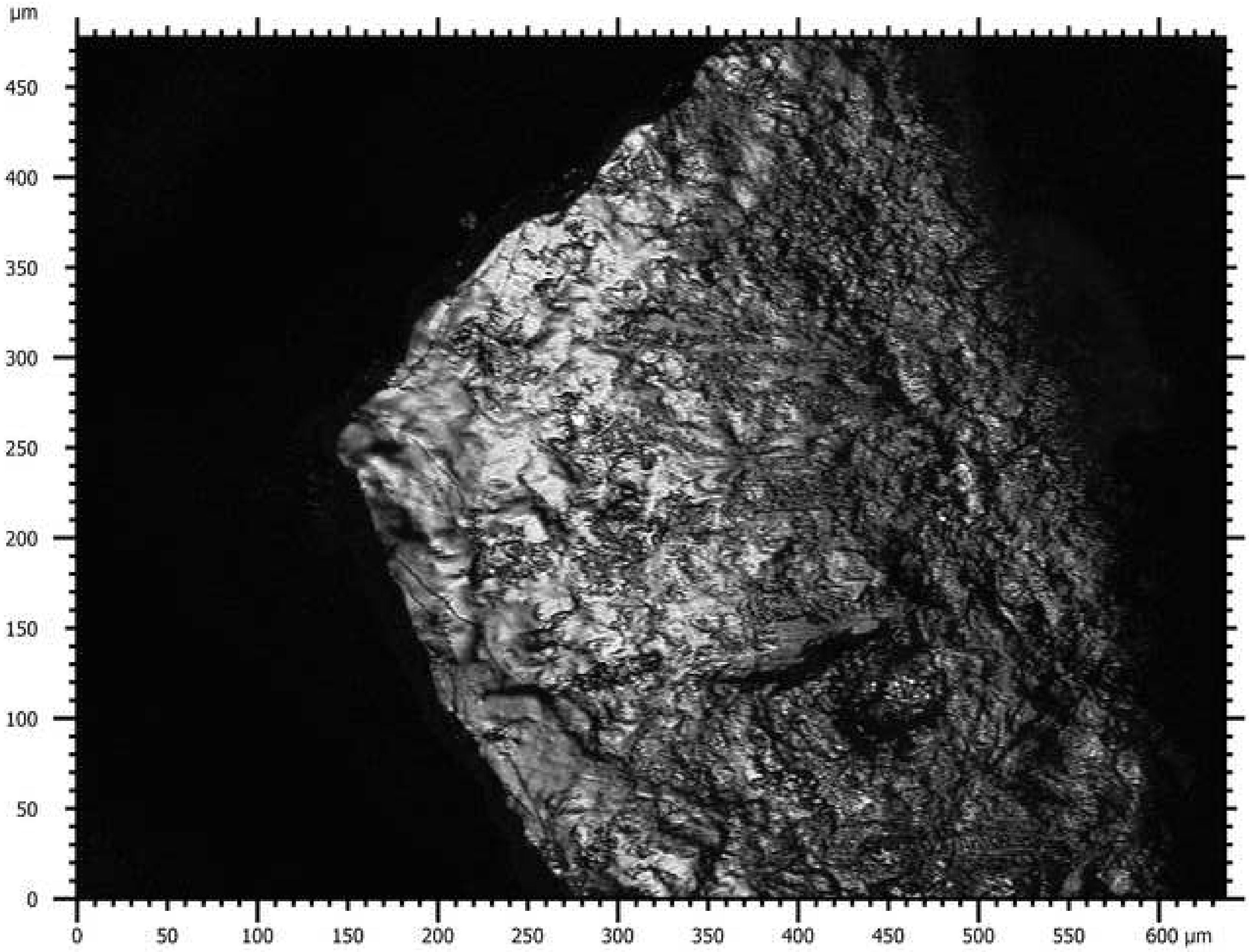
Figure 13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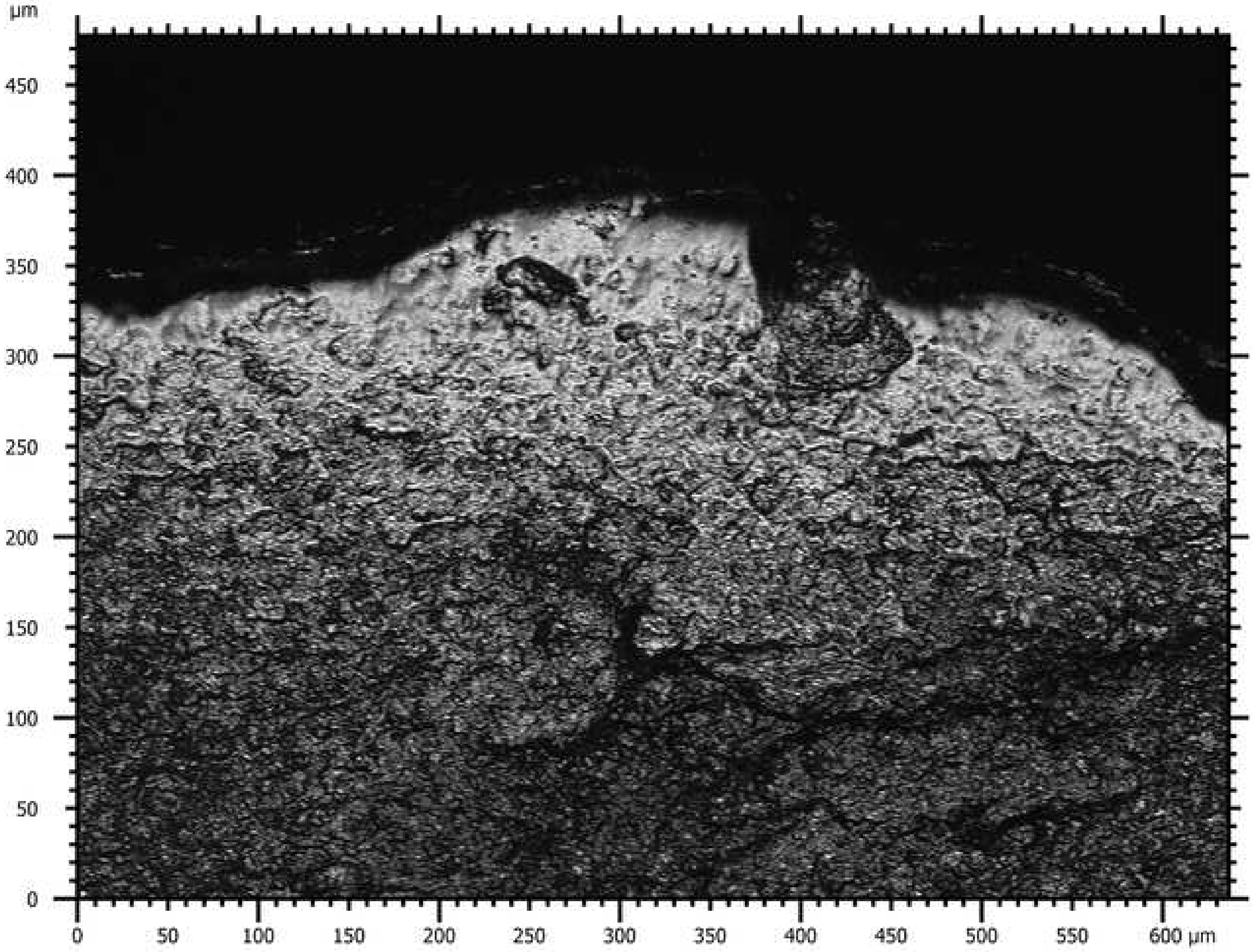
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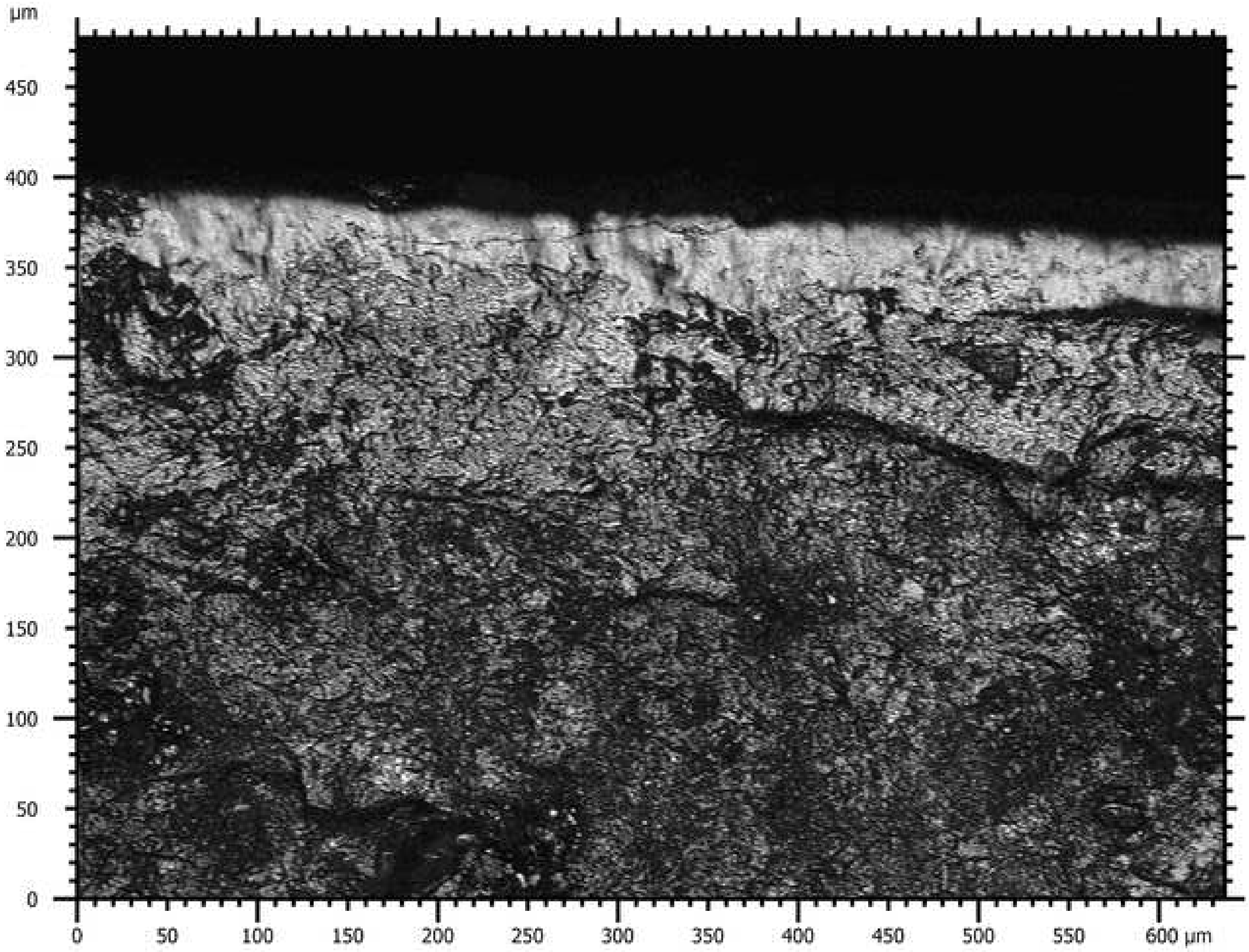
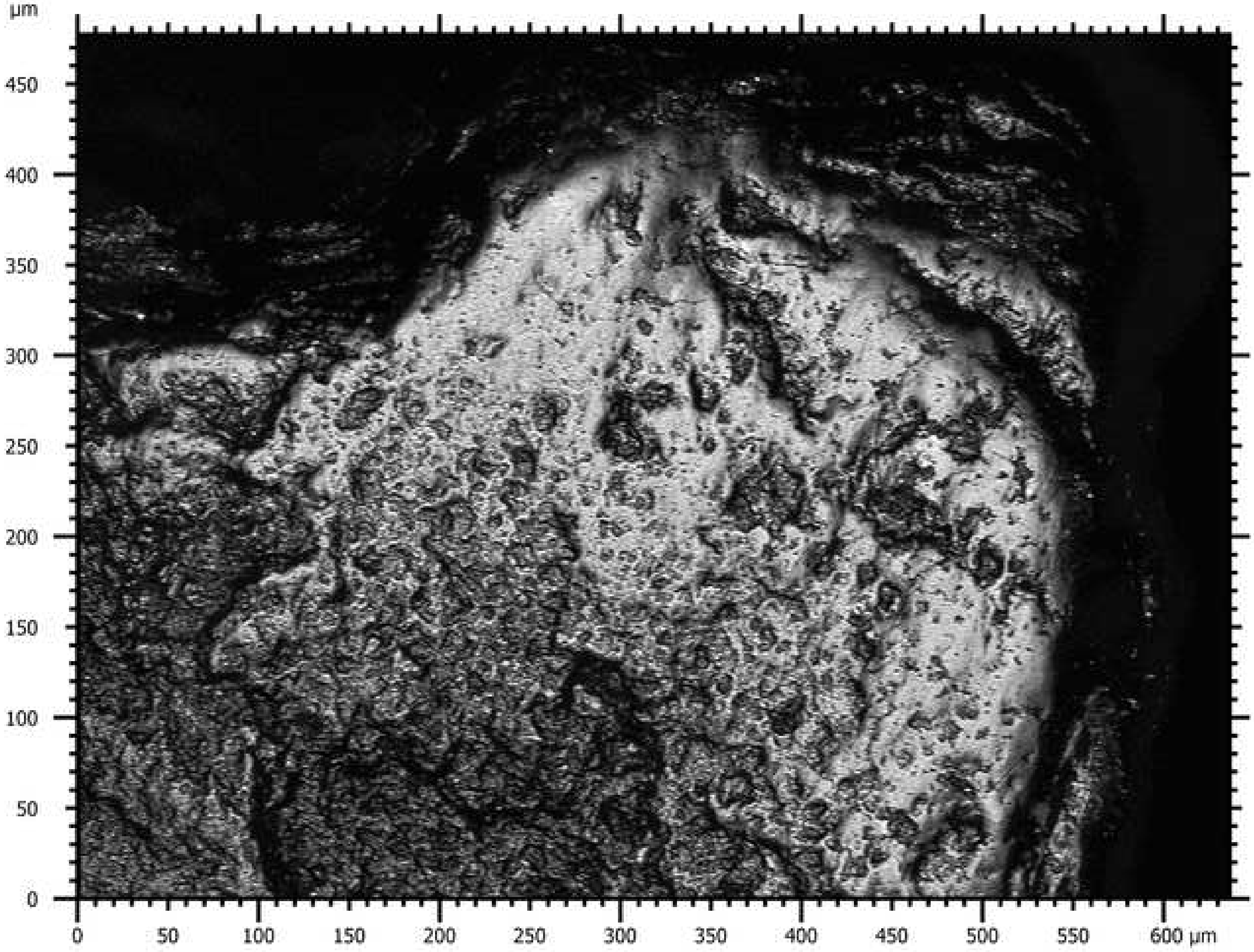
Figure 15

Click here to access/download;Figure;Fig 15.tif

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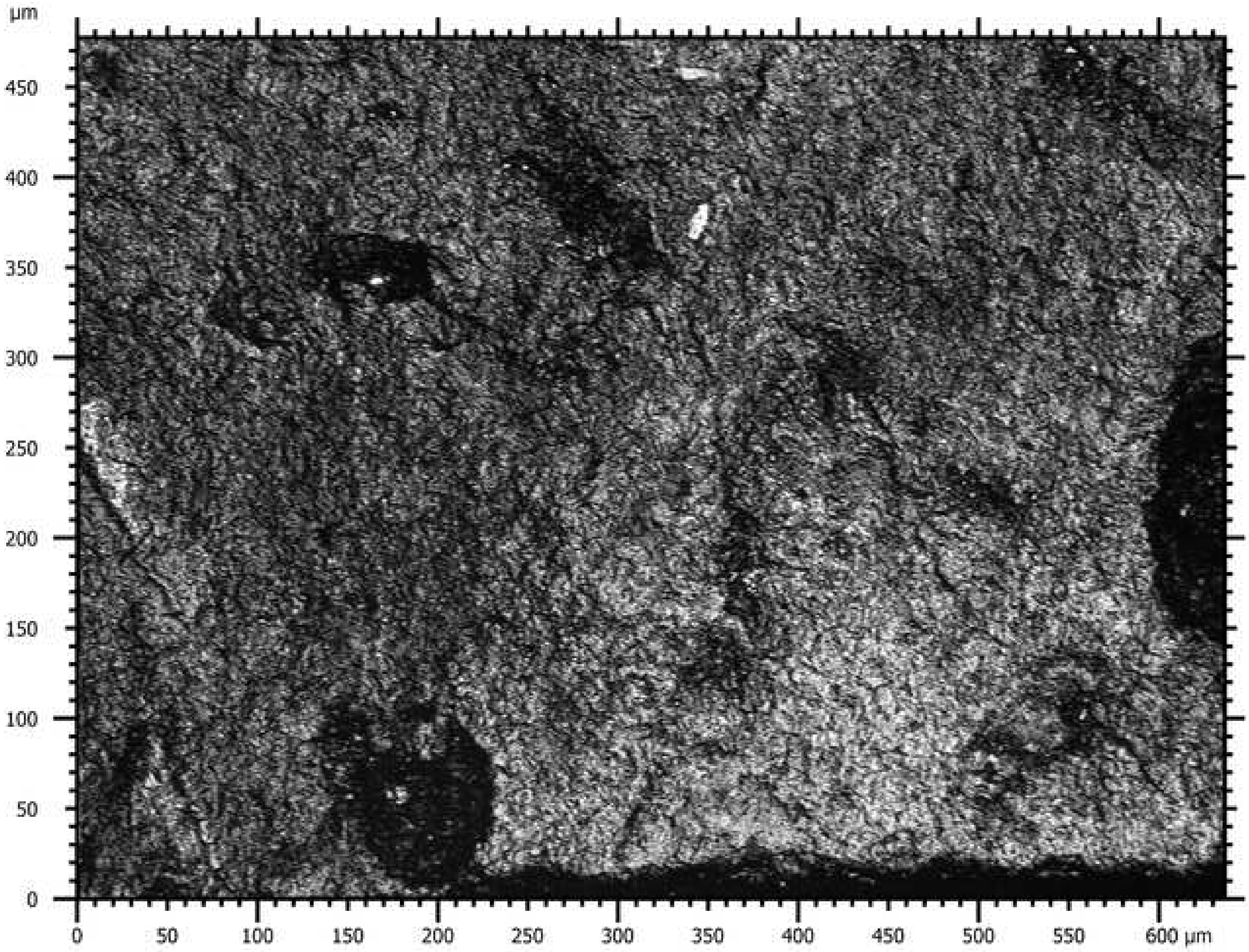
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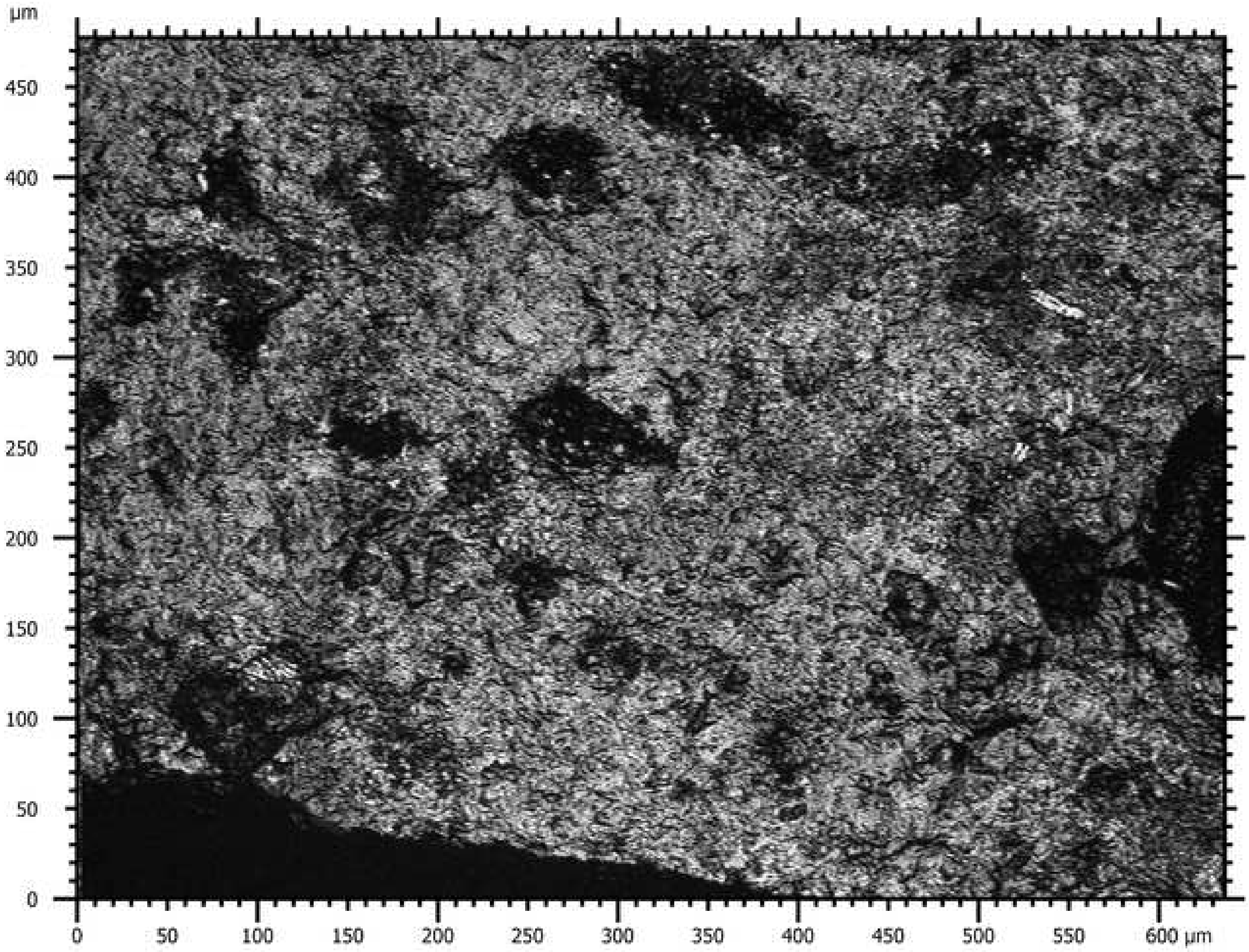
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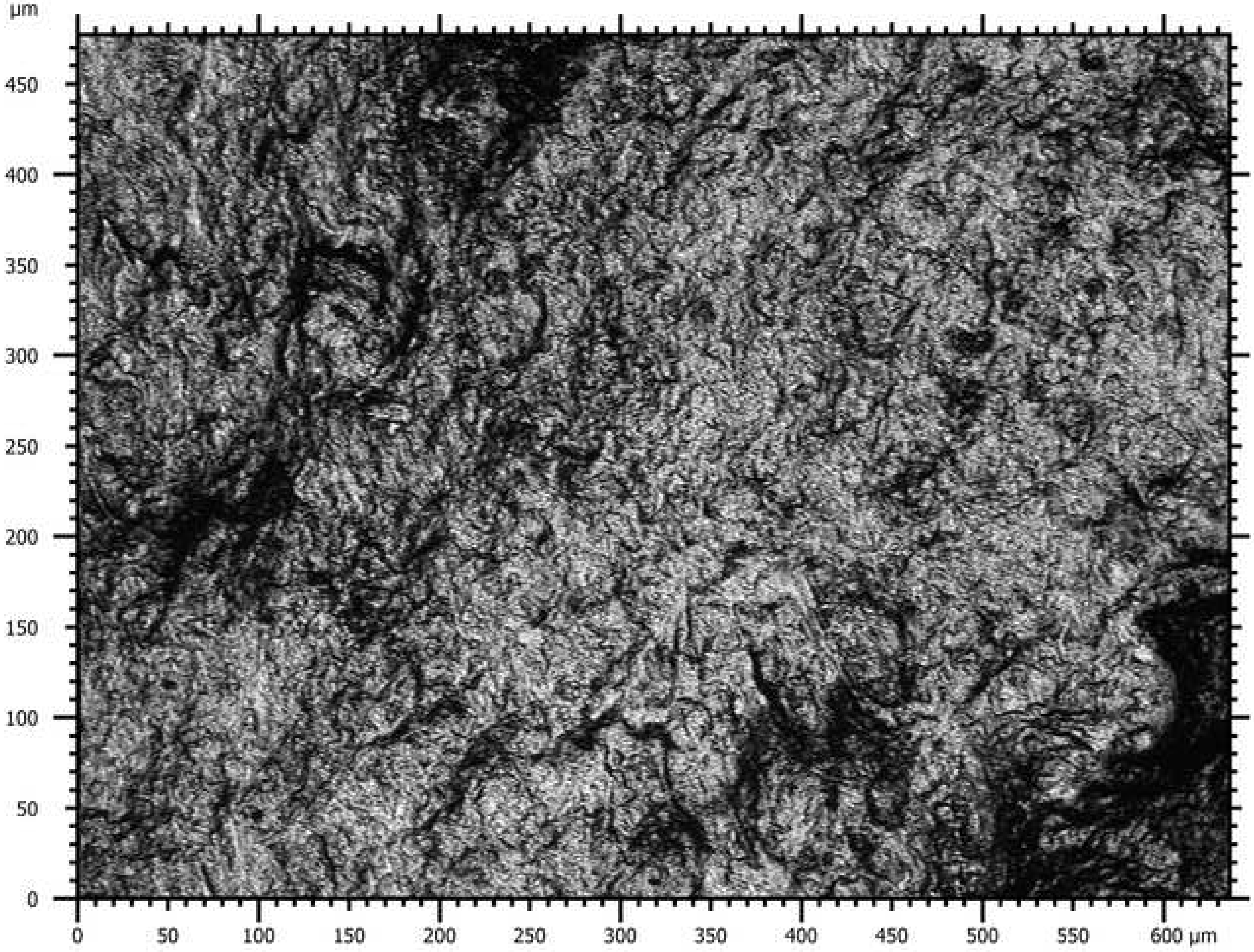
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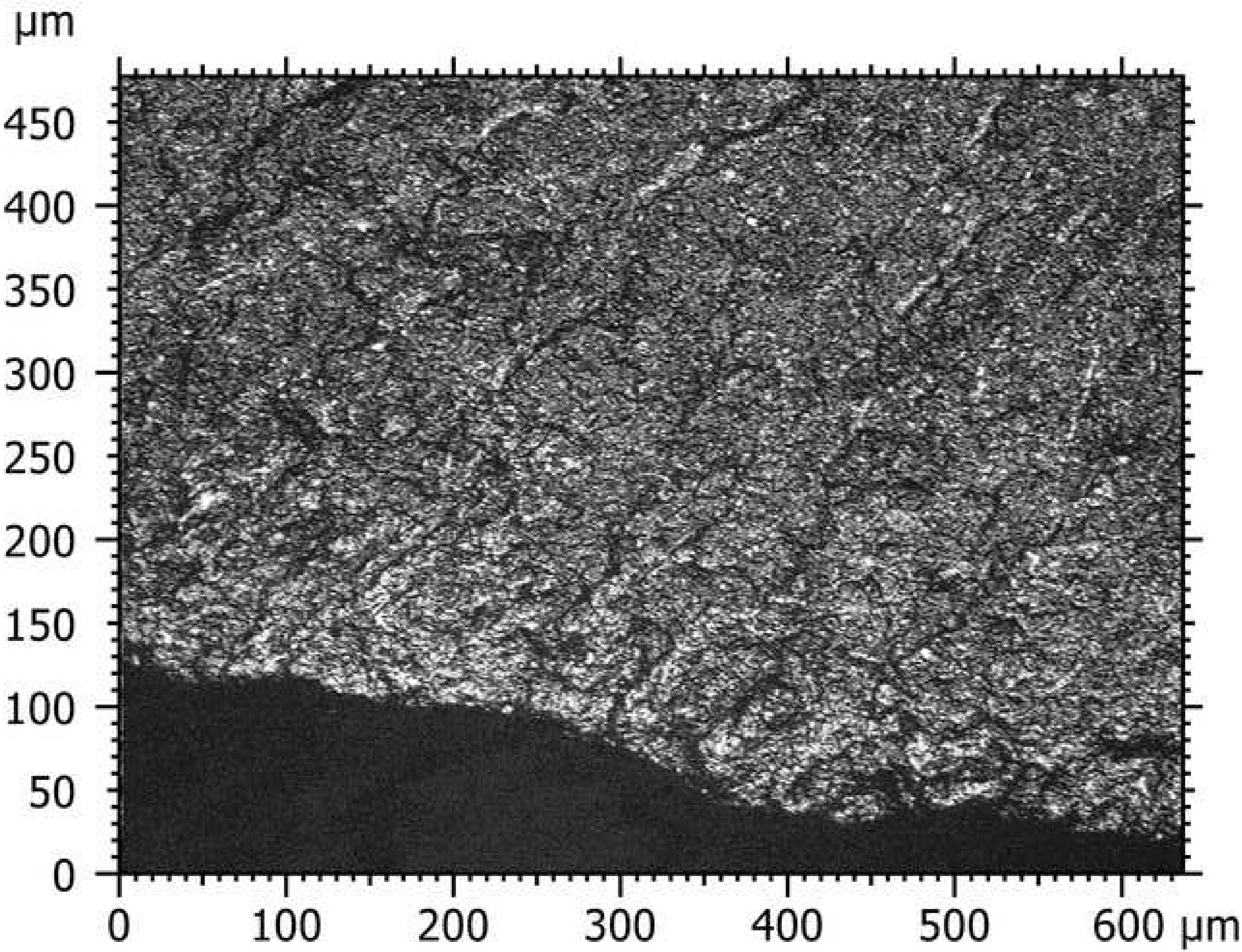
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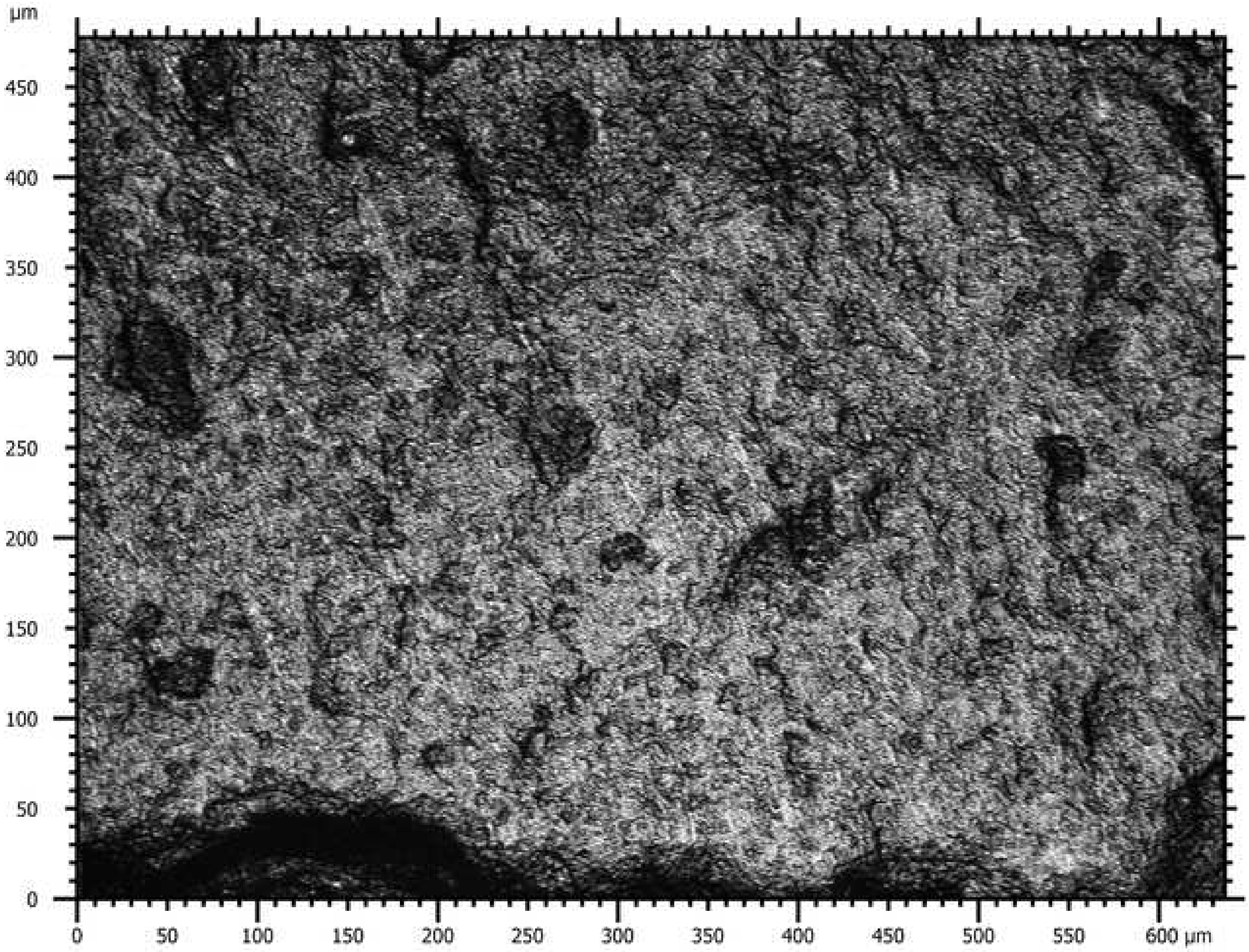
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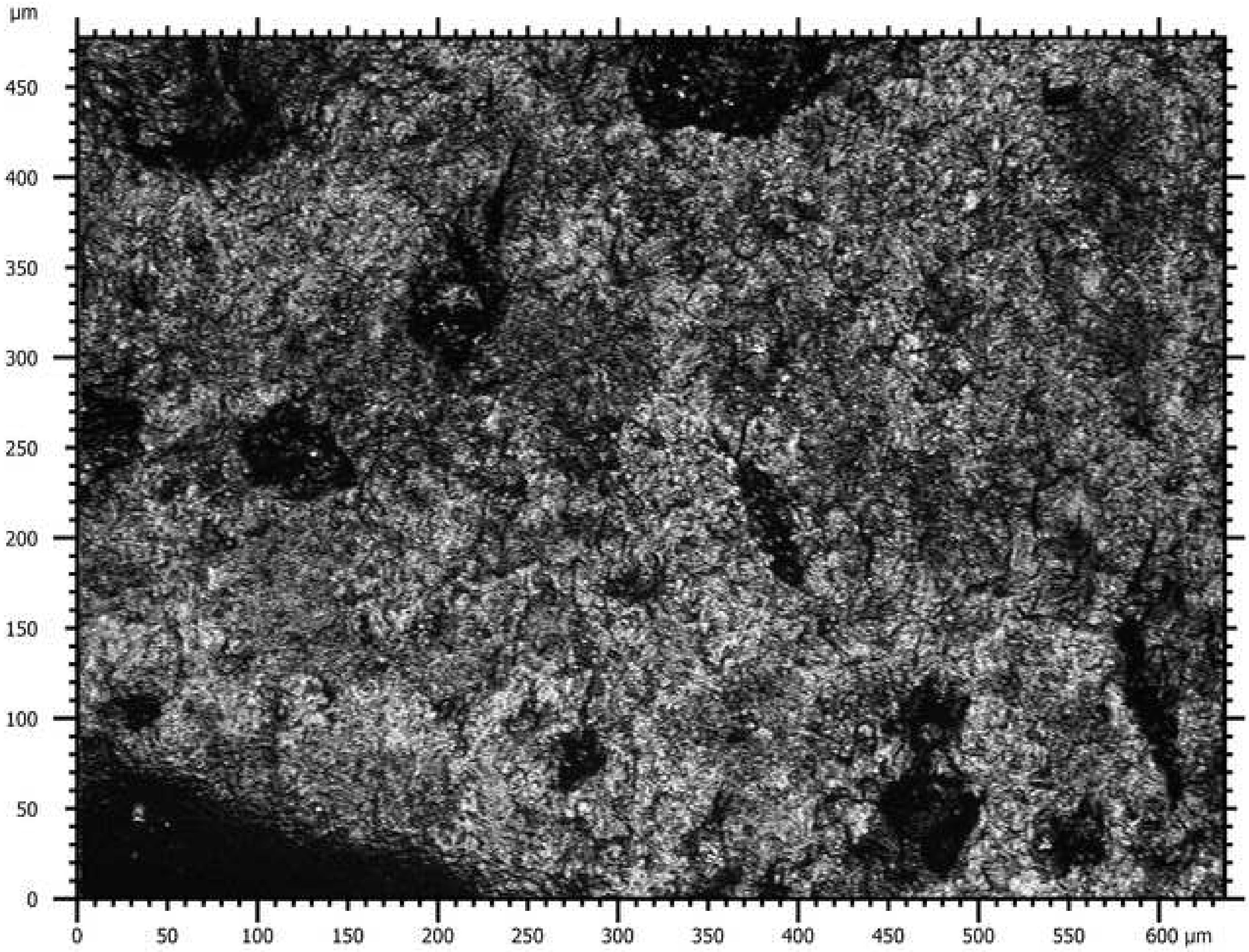
Figure 22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600 µm

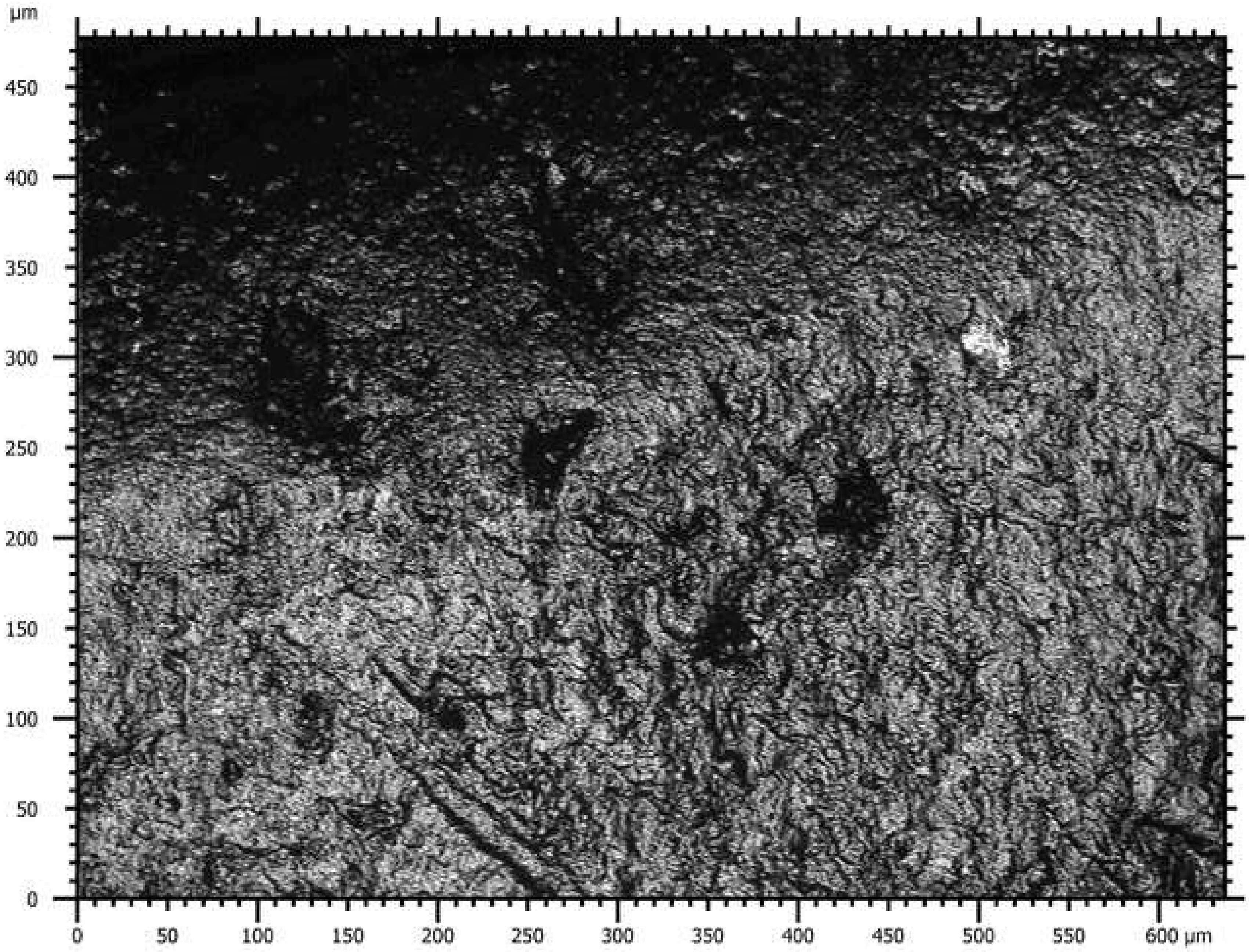
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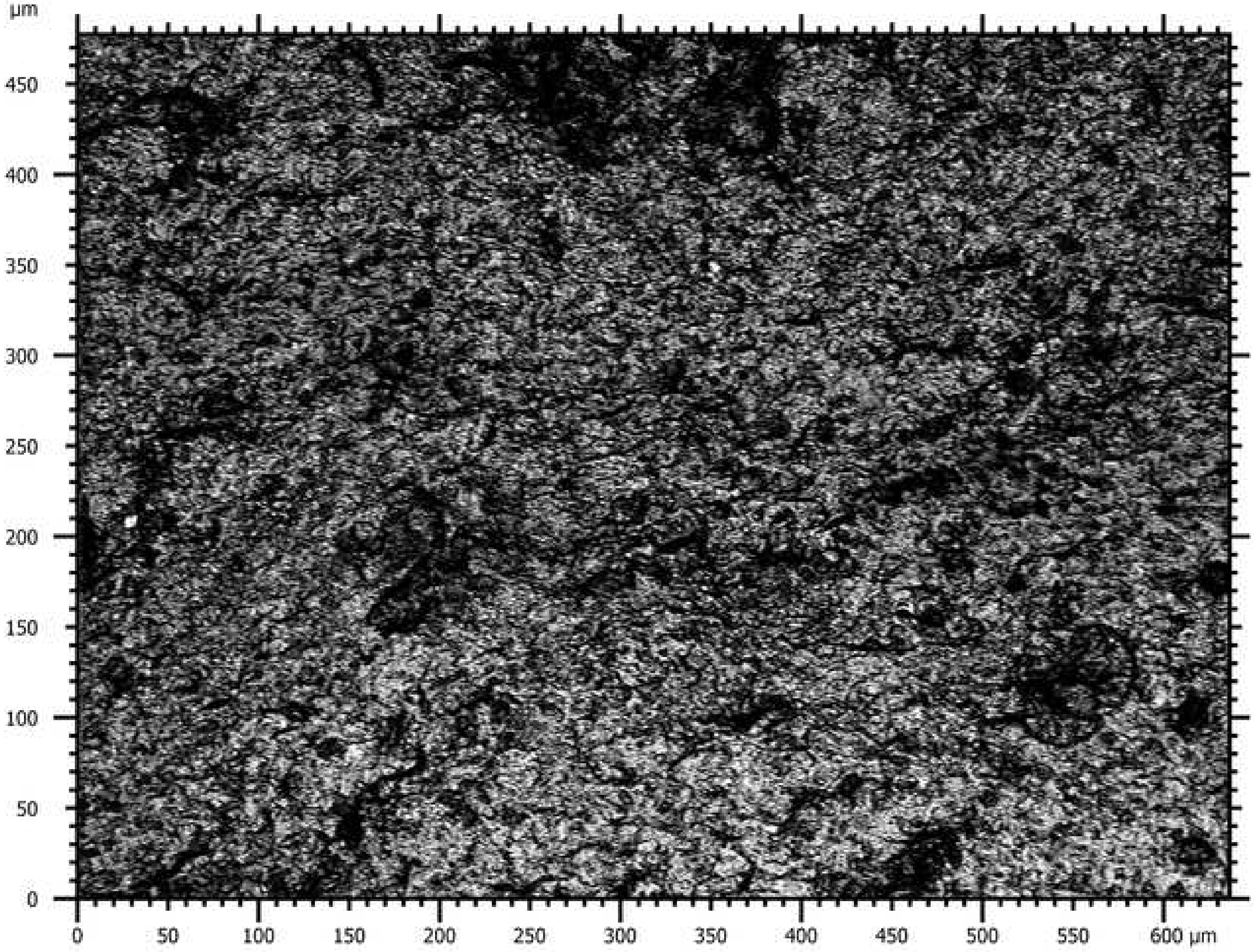
Figure 24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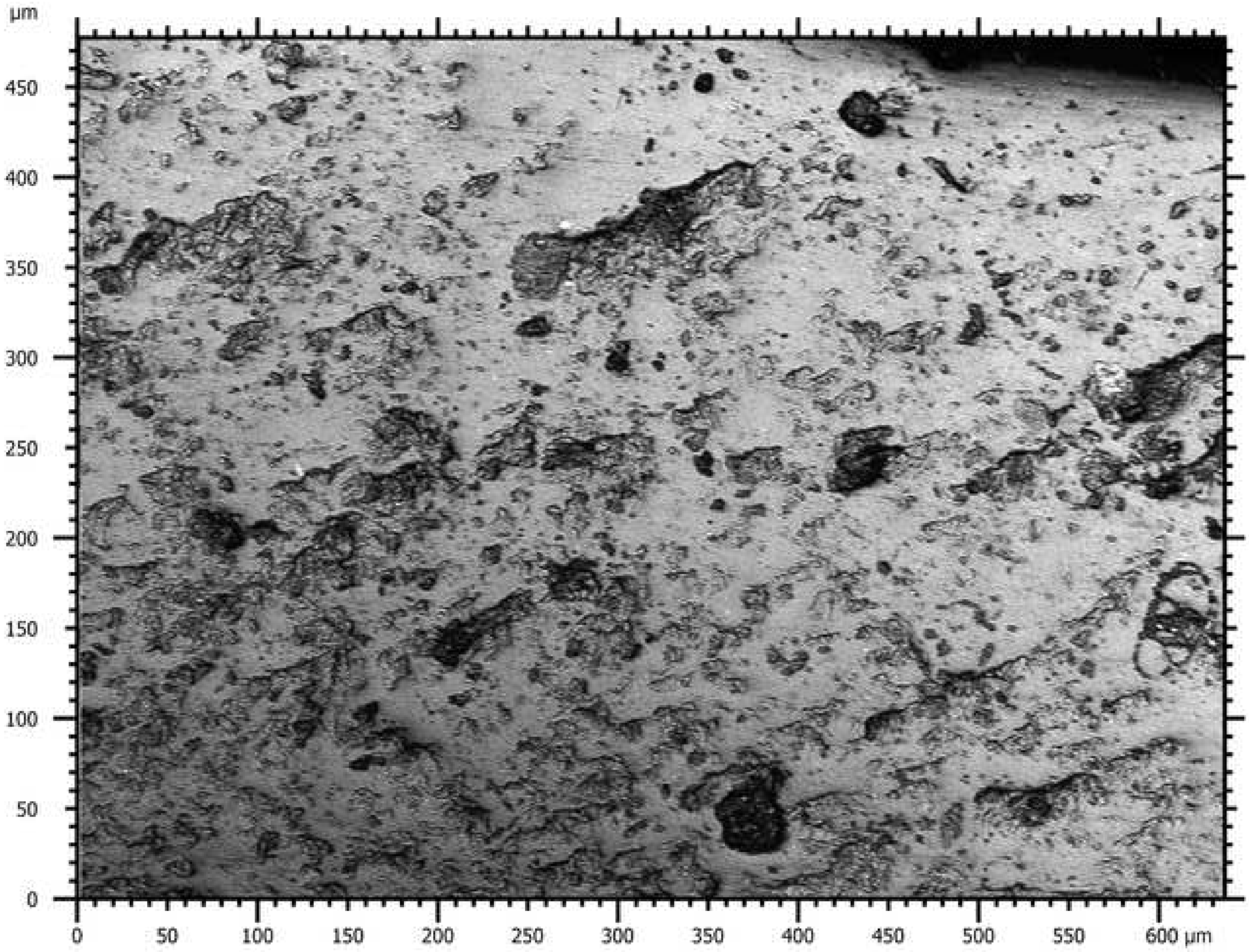
600 µm

Figure 25

Click here to access/download;Figure;Fig 25.tif



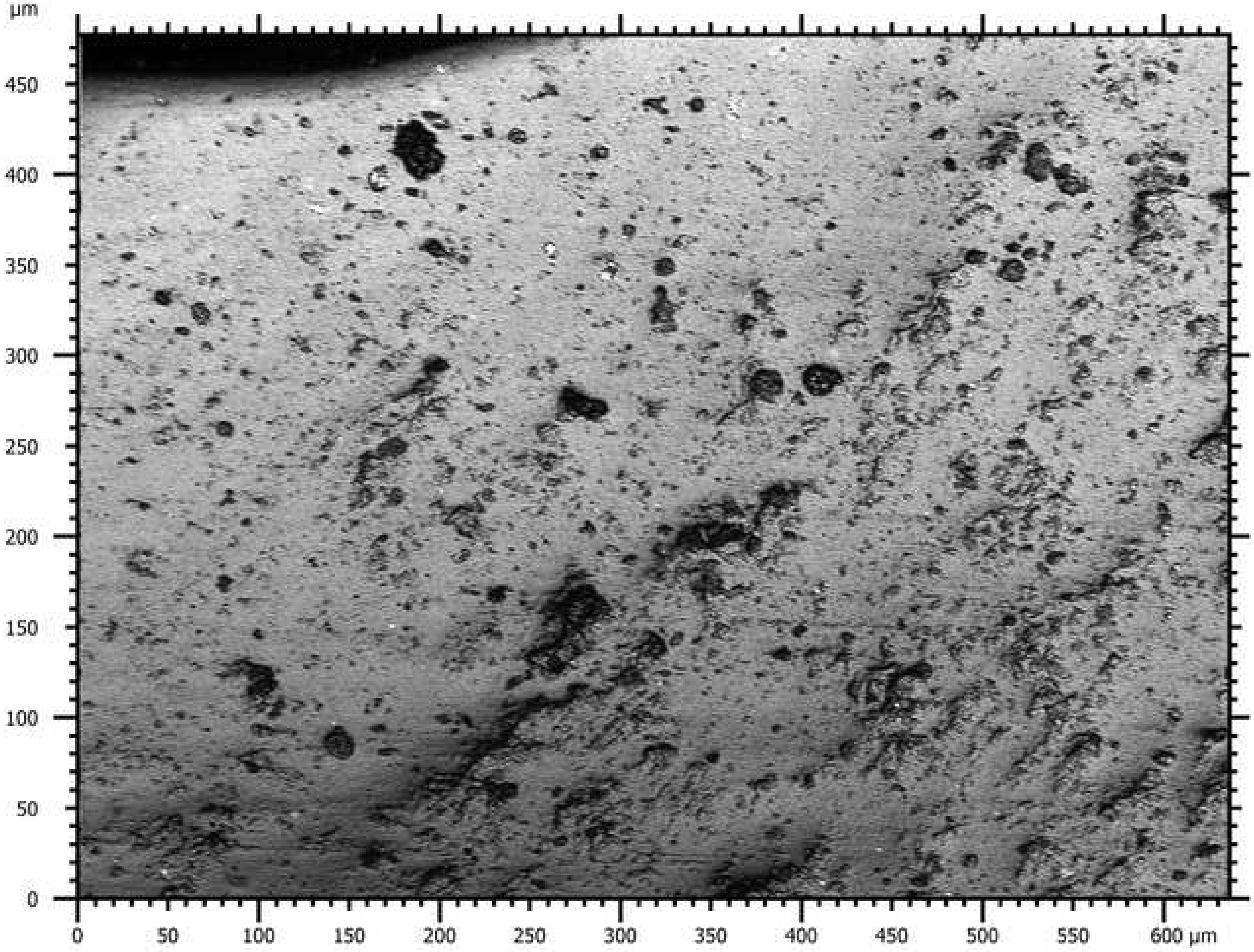

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Figure 27

Click here to access/download;Figure;Fig 27.tif

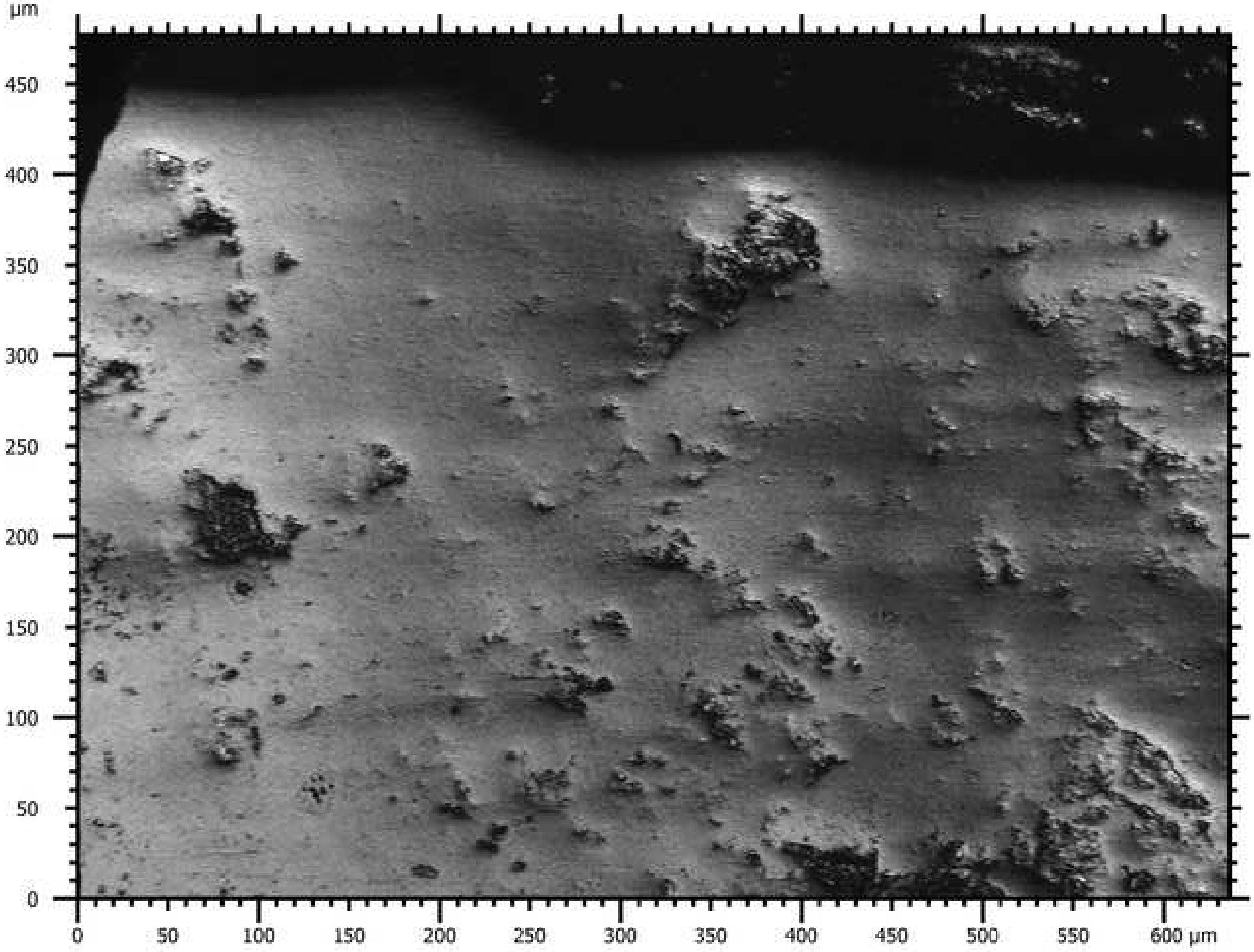


Figure 28

Click here to access/download;Figure;Fig 28.tif

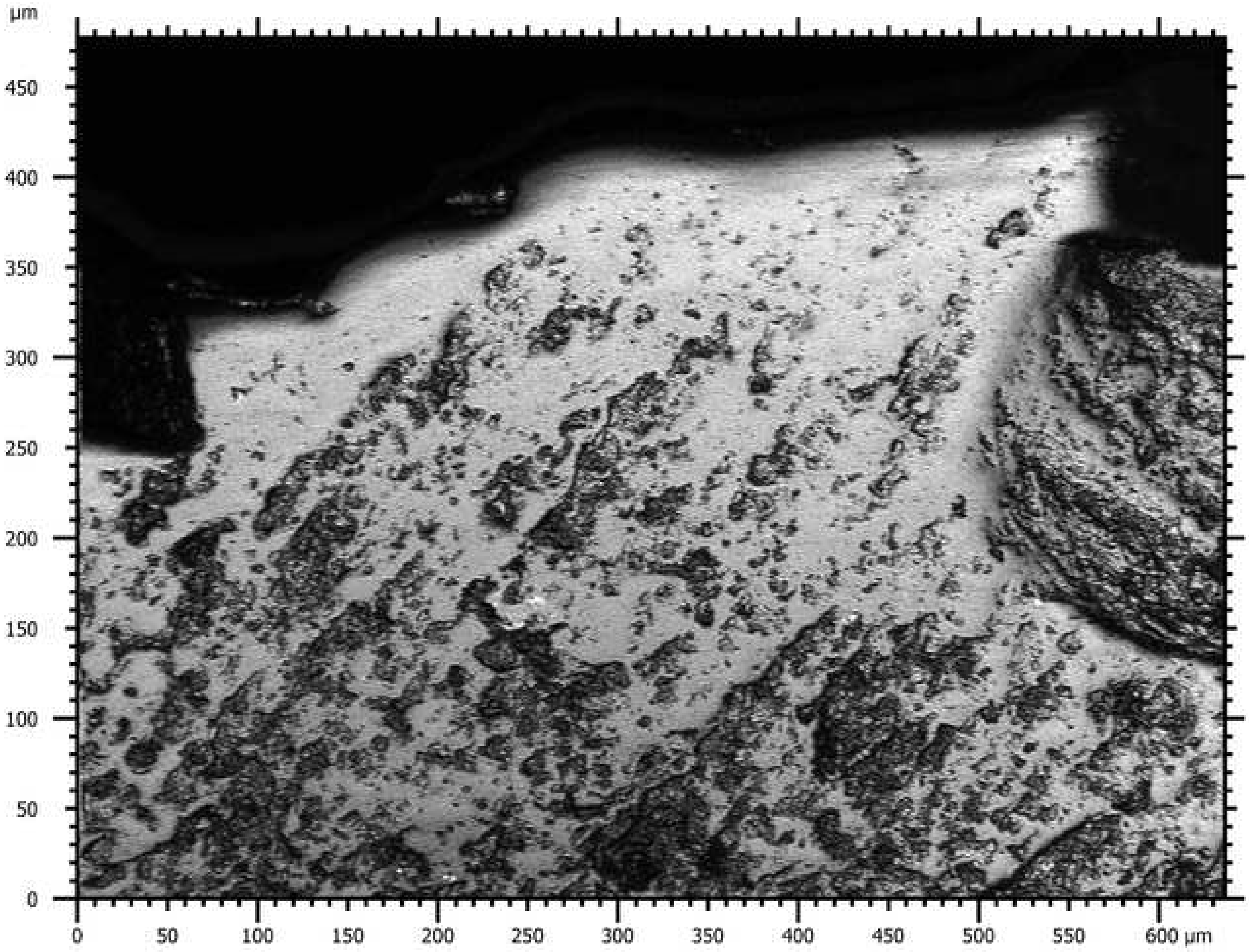
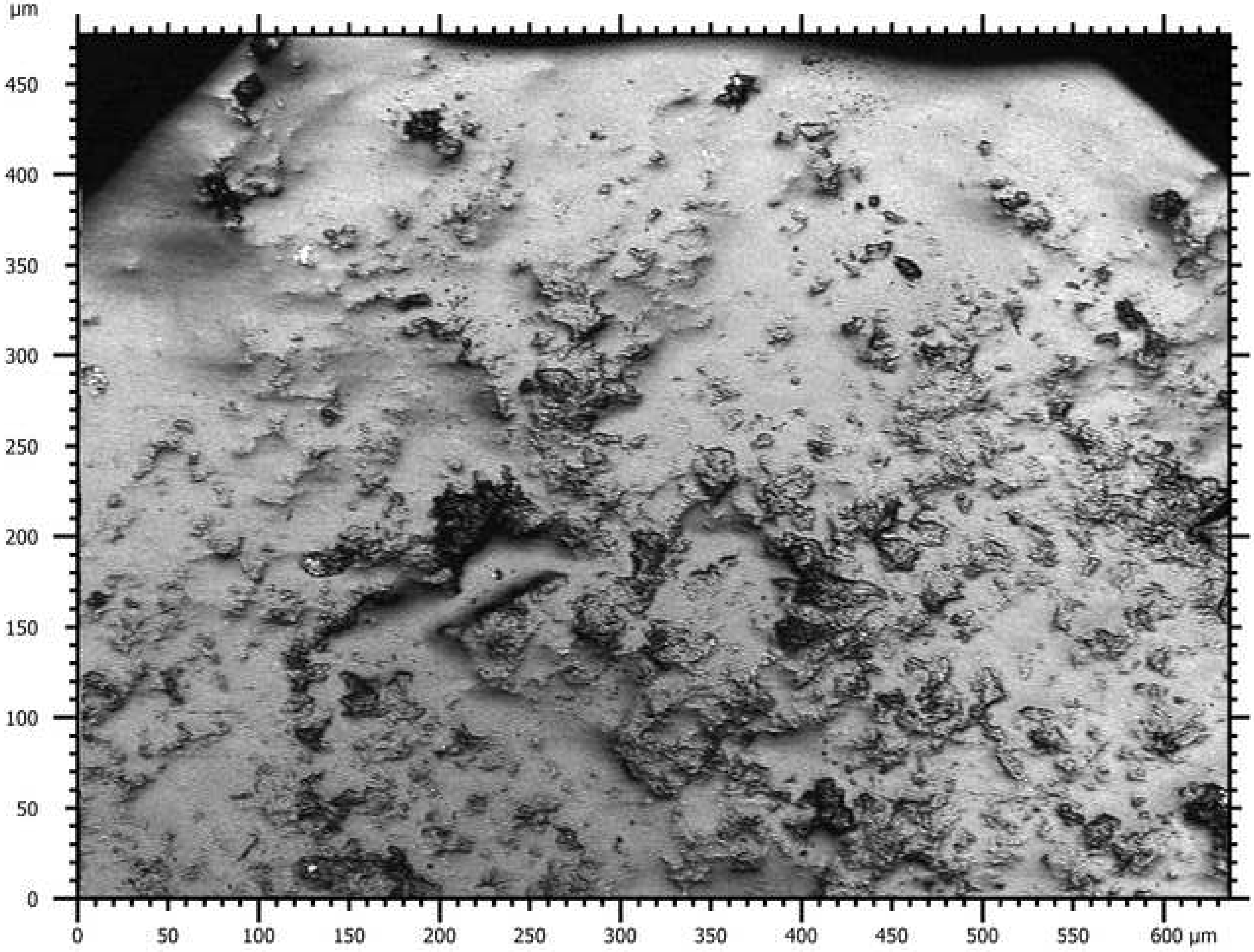
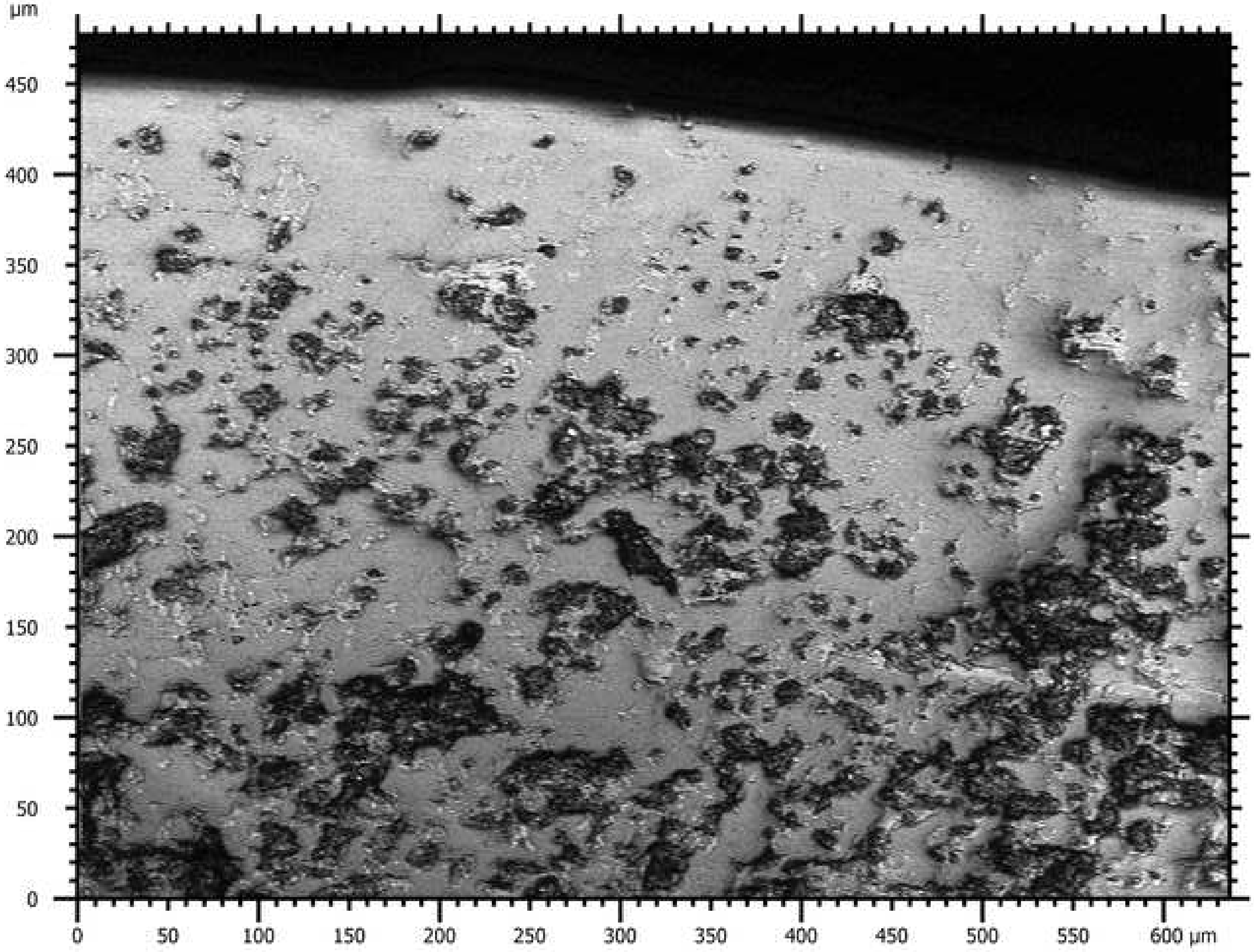


Figure 29

Click here to access/download;Figure;Fig 29.tif




µm
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600 µm

EXPERIMENT	WORKED MATERIAL	STATE	ACTIVITY	TIME OF USE	TYPE OF FLINT	FIGURE
PE 112	Wood	Fresh	Scrape	60’	Barrika (Spain)	1
PE 179	Wood	Dry	Scrape	30’	Barrika (Spain)	2
PE 107	Wood	Fresh	Engrave	60’	Barrika (Spain	3
PE 180	Wood	Fresh	Scrape	30’	Barrika (Spain)	4
PE 105	Wood	Dry	Scrape	60’	Barrika (Spain)	5
PE 115	Wood	Dry	Scrape	60’	Barrika (Spain)	6
PE 116	Wood	Dry	Scrape	60’	Barrika (Spain	7
PE 238	Bone	Natural	Scrape	35’	Charente (France)	8
PE 233	Bone	Natural	Scrape	35’	Treviño (Spain)	9
PE 215	Bone	Humid	Scrape	60’	Barrika (Spain)	10
PE 221	Bone	Natural	Scrape	45’	Treviño (Spain)	11
PE 309	Antler	Natural	Engrave	60’	Barrika (Spain)	12
PE 319	Antler	Humid	Engrave	7’	Barrika (Spain)	13
PE 345	Antler	Humid	Scrape	25’	Treviño (Spain)	14
PE 347	Antler	Humid	Engrave	25’	Palmyra (Syria)	15
PE 352	Antler	Humid	Engrave	20’	Treviño (Spain)	16
PE 502	Hide	Fresh	Scrape	60’	Barrika (Spain)	17
PE 504	Hide	Fresh	Scrape	60’	Barrika (Spain)	18
PE 526	Hide	Fresh	Scrape	45’	Barrika (Spain)	19
PE 537	Hide	Fresh	Scrape	50’	Treviño (Spain)	20
PE 568	Hide	Fresh	Scrape	25’	Barrika (Spain)	21
PE 507	Hide	Dry	Scrape	60’	Barrika (Spain)	22
PE 508	Hide	Dry	Scrape	60’	Barrika (Spain)	23
PE 548	Hide	Dry	Scrape	120’	Palmyra (Syria)	24
PE 749	Domestic cereal	Ripe	Cut	420’	Palmyra (Syria)	25
PE 750	Domestic cereal	Ripe	Cut	420’	Palmyra (Syria)	26
SV 1	Wild cereal	Green	Cut	240’	Charente (France)	27
SV 3	Wild cereal	Green	Cut	240’	Charente (France)	28
R16	Reeds	Green	Cut	90’	Palmyra (Syria)	29
R17	Reeds	Green	Cut	75’	Palmyra (Syria)	30

Table 2

Structure Matrix

	Function					
	1	2	3	4	5	6
Spd	,646*	-,298	-,190	,246	,323	-,125
Str	,411*	-,048	,032	-,021	-,103	-,176
Sv	,030	,720*	-,096	-,030	,010	,047
Sq	,236	,656*	-,049	-,304	,226	,265
Sdc	,327	,532*	-,090	-,378	,118	,314
Sdq	,292	,525*	-,044	-,183	,328	,333
Sp	,095	,516*	-,054	-,228	,173	,218
Sz	,201	,511*	-,155	-,175	,353	,363
Spc	,151	,508*	,049	-,048	,310	,424
ProfMedSurc	,251	,496*	-,305	-,337	,326	,406
Sal	-,033	,328*	,149	-,019	-,241	-,014
DensMedSurc	,102	-,196*	-,059	,062	-,034	,010
Sbi	,146	,167*	,081	-,014	-,130	,104
Sds	,383	-,175	-,167	,774*	,039	,038
Sci	,202	-,262	,002	-,502*	,011	,473
Svi	-,356	,335	,096	,460*	,414	-,076
S5p	,205	,400	-,189	-,246	,494*	,273

Worked material	Predicted group membership								
COUNT	Wood	Bone	Antler	Fresh hide	Dry hide	Domestic cereal	Wild cereal	Reeds	Total
Wood	212	18	14	10	12	17	7	5	295
Bone	6	52	4	1		1	2	0	66
Antler	18	11	108	8	8	7	5	4	169
Fresh hide	7	3	4	94	48	1			157
Dry hide	1	2	7	27	77				114
Domestic cereal	5		3			59	10	4	81
Wild cereal	1					9	39	16	65
Reeds	3	4	7			9	12	50	85
%									
Wood	71.9	6.1	4.7	3.4	4.1	5.8	2.4	1.7	100.0
Bone	9.1	78.8	6.1	1.5	.0	1.5	3.0		100.0
Antler	10.7	6.5	63.9	4.7	4.7	4.1	3.0	2.4	100.0
Fresh hide	4.5	1.9	2.5	59.9	30.6	0.6			100.0
Dry hide	0.9	1.8	6.1	23.7	67.5				100.0
Domestic cereal	6.2		3.7			72.8	12.3	4.9	100.0
Wild cereal	1.5					13.8	60.0	24.6	100.0
Reeds	3.5	4.7	8.2			10.6	14.1	58.8	100.0

67.0% of cases correctly classified

COUNT		Wood	Bone	Antler	Fresh hide	Dry hide	Wild cereal	Domestic cereal	Reeds	Total
Wood	PE 112	53	11	4			1	2	5	76
	PE 179	14	8	3	1	2	1			29
	PE 107	26	1	3	2	1	5		1	39
	PE 180	20	1		1	3	1			26
	PE 105	31	1	6		2	2	2	2	46
	PE 115	24	1	1	1	3	1	1	1	33
	PE 116	20	2	4	7	1	9	1	1	45
Bone	PE 238	4	13	4	1				1	23
	PE 233	1	10					1		12
	PE 215	0	18							18
	PE 221	2	7	2			1	1		13
Antler	PE 309	5	4	6				1		16
	PE 319	4		9	2		2			17
	PE 345	6	1	36	7	3	2		3	58
	PE 347	6	3	26	4	4	2		1	46
	PE 352	1	7	12	1		4	5	2	32
Fresh hide	PE 502	5		1	12	15	1			34
	PE 504			2	15	17				34
	PE 526	3		3	11	16	1			34
	PE 537		2	1	14	1				18
	PE 568	1	1	1	15	19				37
Dry hide	PE 507		1	2	8	21				32
	PE 508	3	2	7	24	29				65
	PE 548			1	8	8				17
Domestic cereal	PE 749	3		5	1		20	9	3	41
	PE 750	6					19	11	3	39
Wild cereal	SV 1		1				10	11	13	35
	SV 3	4		1			9	7	9	30
Reeds	R16	8		3			4	24	11	50
	R17		9	8			6	2	10	35
%		Wood	Bone	Antler	Fresh hide	Dry hide	Wild cereal	Domestic cereal	Reeds	Total
Wood	PE 112	69.7	14.5	5.3	0	0	1.3	2.6	6.6	100
	PE 179	48.3	27.6	10.3	3.4	6.9	3.4	0	0	100
	PE 107	66.7	2.6	7.7	5.1	2.6	12.8	0	2.6	100
	PE 180	76.9	3.8	0	3.8	11.5	3.8	0	0	100
	PE 105	67.4	2.2	13	0	4.3	4.3	4.3	4.3	100
	PE 115	72.7	3	3	3	9.1	3	3	3	100
	PE 116	44.4	4.4	8.9	15.6	2.2	20	2.2	2.2	100
Bone	PE 238	17.4	56.5	17.4	4.3	0	0	0	4.3	100
	PE 233	8.3	83.3	0	0	0	0	8.3	0	100
	PE 215	0	100	0	0	0	0	0	0	100
	PE 221	15.4	53.8	15.4	0	0	7.7	7.7	0	100
A	PE 309	31.3	25	37.5	0	0	0	6.3	0	100
	PE 319	23.5	0	52.9	11.8	0	11.8	0	0	100

	PE 345	10.3	1.7	62.1	12.1	5.2	3.4	0	5.2	100
	PE 347	13	6.5	56.5	8.7	8.7	4.3	0	2.2	100
	PE 352	3.1	21.9	37.5	3.1	0	12.5	15.6	6.3	100
Fresh hide	PE 502	14.7	0	2.9	35.3	44.1	2.9	0	0	100
	PE 504	0	0	5.9	44.1	50	0	0	0	100
	PE 526	8.8	0	8.8	32.4	47.1	2.9	0	0	100
	PE 537	0	11.1	5.6	77.8	5.6	0	0	0	100
	PE 568	2.7	2.7	2.7	40.5	51.4	0	0	0	100
Dry hide	PE 507	0	3.1	6.3	25	65.6	0	0	0	100
	PE 508	4.6	3.1	10.8	36.9	44.6	0	0	0	100
	PE 548	0	0	5.9	47.1	47.1	0	0	0	100
Domestic cereal	PE 749	7.3	0	12.2	2.4	0	48.8	22	7.3	100
	PE 750	15.4	0	0	0	0	48.7	28.2	7.7	100
Wild cereal	SV 1	0	2.9	0	0	0	28.6	31.4	37.1	100
	SV 3	13.3	0	3.3	0	0	30	23.3	30	100
Reeds	R16	16	0	6	0	0	8	48	22	100
	R17	0	25.7	22.9	0	0	17.1	5.7	28.6	100

Table 5

COUNT		Wood/Bone/Antler	Hide	Plants	Total
Wood	PE 105	41	0	5	46
	PE 107	35	2	2	39
	PE 112	67	5	4	76
	PE 115	27	4	2	33
	PE 116	29	9	8	46
	PE 179	24	4	1	29
	PE 180	16	9	1	26
Bone	PE 215	18	0	0	18
	PE 221	10	0	3	13
	PE 233	9	2	1	12
	PE 238	15	5	4	24
Antler	PE 3.1.	15	0	1	16
	PE 319	14	3	0	17
	PE 345	42	10	6	58
	PE 347	35	8	3	46
	PE 352	13	5	14	32
Hide	PE 504	3	31	0	34
	PE 507	5	27	0	32
	PE 526	6	28	0	34
	PE 537	0	18	0	18
	PE 548	1	16	0	17
	PE 502	6	28	0	34
	PE 508	10	55	0	65
	PE 568	0	37	0	37
Plants	PE 749	17	0	24	41
	PE 750	6	0	34	40
	SV 1	0	0	35	35
	SV 3	5	0	25	30
	Carrizo 16	9	0	41	50
	Carrizo 17	8	0	27	35
%		Wood/Bone/Antler	Hide	Plants	Total
Wood	PE 105	89.1	0	10.9	100
	PE 107	89.7	5.1	5.1	100
	PE 112	88.2	6.6	5.3	100
	PE 115	81.8	12.1	6.1	100
	PE 116	63	19.6	17.4	100
	PE 179	82.8	13.8	3.4	100
	PE 180	61.5	34.6	3.8	100
Bone	PE 215	100	0	0	100
	PE 221	76.9	0	23.1	100
	PE 233	75	16.7	8.3	100
	PE 238	62.5	20.8	16.7	100
Antler	PE 3.1.	93.8	0	6.3	100
	PE 319	82.4	17.6	0	100
	PE 345	72.4	17.2	10.3	100
	PE 347	76.1	17.4	6.5	100
	PE 352	40.6	15.6	43.8	100
Hide	PE 504	8.8	91.2	0	100
	PE 507	15.6	84.4	0	100
	PE 526	17.6	82.4	0	100
	PE 537	0	100	0	100
	PE 548	5.9	94.1	0	100
	PE 502	17.6	82.4	0	100
	PE 508	15.4	84.6	0	100
	PE 568	0	100	0	100
	PE 749	41.5	0	58.5	100
	PE 750	15	0	85	100

Plants	SV 1	0	0	100	100
	SV 3	16.7	0	83.3	100
	R 16	18	0	82	100
	R 17	22.9	0	77.1	100

	Count	Wood	Bone/Antler	Total
Wood	PE 112	59	17	76
	PE 107	33	6	39
	PE 180	26	0	26
	PE 105	36	10	46
	PE 115	31	2	33
	PE 116	36	10	46
	PE 179	21	8	29
Bone/antler	PE 221	8	5	13
	PE 238	8	15	23
	PE 233	3	9	12
	PE 215	0	18	18
	PE 309	7	9	16
	PE 319	5	12	17
	PE 345	18	40	58
	PE 347	12	34	46
	PE 352	3	29	32
%		Wood	Bone/Antler	Total
Wood	PE 112	77.6	22.4	76
	PE 107	84.6	15.4	39
	PE 180	100	0	26
	PE 105	78.3	21.7	46
	PE 115	93.9	6.1	33
	PE 116	78.3	21.7	46
	PE 179	72.4	27.6	29
Bone/antler	PE 221	61.5	38.5	13
	PE 238	34.8	65.2	23
	PE 233	25	75	12
	PE 215	0	100	18
	PE 3.1.009	43.8	56.3	16
	PE 319	29.4	70.6	17
	PE 345	31	69	58
	PE 347	26.1	73.9	46
	PE 352	9.4	90.6	32

	Count	Bone	Antler	Total
Bone	PE 221	10	3	13
	PE 238	15	8	23
	PE 233	11	1	12
	PE 215	4	14	18
Antler	PE 3.1.009	4	12	16
	PE 319	1	16	17
	PE 345	2	56	58
	PE 347	2	44	46
	PE 352	13	19	32
	%	Bone	Antler	Total
Bone	PE 221	76.9	23.1	100
	PE 238	65.2	34.8	100
	PE 233	91.7	8.3	100
	PE 215	22.2	77.8	100
Antler	PE 3.09	25	75	100
	PE 319	5.9	94.1	100
	PE 345	3.4	96.6	100
	PE 347	4.3	95.7	100
	PE 352	40.6	59.4	100

Table 8

Count	Experiment	Fresh hide	Dry hide	Total
Fresh hide	PE 504	23	11	34
	PE 568	12	25	37
	PE 526	24	10	34
	PE 537	11	7	18
	PE 502	12	24	17
Dry hide	PE 507	12	20	32
	PE 508	33	32	65
	PE 548	11	6	34
Count	Experiment	Fresh hide	Dry hide	Total
Fresh hide	PE 504	67.6	32.4	100
	PE 568	32.4	67.6	100
	PE 526	70.6	29.4	100
	PE 537	61.1	38.9	100
	PE 502	35.3	64.7	100
Dry hide	PE 507	37.5	62.5	100
	PE 508	50.8	49.2	100
	PE 548	64.7	35.3	100

Table 9

Count	Experiment	Domestic cereal	Wild cereal	Reeds	Total
Domestic cereal	PE 749	30	7	4	100
	PE 750	22	15	3	100
Wild cereal	SV 1	5	15	15	100
	SV 3	12	7	11	100
Reeds	R 16	6	30	14	100
	R 17	5	14	16	100
%	Experiment	Domestic cereal	Wild cereal	Reeds	Total
Domestic cereal	PE 749	73.2	17.1	9.7	100
	PE 750	55	37.5	7.5	100
Wild cereal	SV 1	14.3	42.8	42.8	100
	SV 3	40	23.3	36.7	100
Reeds	R 16	12	60	28	100
	R 17	14.3	40	45.7	100