



### 3-D minerals. Auxiliary material for the Physical Geology classes

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#### Abstract

The paper presents a method for enhancing the learning process of mineral species by the students of the first year in Geology, at the Physical Geology classes. However, the method can be applied in many other fields that study physical objects. To be able to help students, the photogrammetry techniques were used, together with a game engine platform, in order to create a digital atlas containing 70 3D mineral samples. The atlas provides students with essential information for those minerals, along with the opportunity to study some of the mineral’s optical properties, interact with the sample and perform measurements.

**Keywords:** 3-D minerals, physical geology, first year students, photogrammetry, Unity 3D.

#### 1. Introduction

Teaching geology is both fun and satisfying as you expect to see your students becoming experts in a field that eventually will lead them to aid the society through their activities. However, sometimes, making the students understand some parts of geology can be very difficult, especially today when technology can be a distraction. To be able to counteract these distractions, we came to the conclusion that it is necessary to use the same “weapons”. Interestingly enough, we later found out that students also

expected this to happen and they were much happier to be able to learn by using these methods.

The idea of the project was born in early 2016, after discussions with the students of the first year, regarding alternative methods for studying the mineralogical samples in the “Physical Geology” laboratory. Considering that this laboratory is also used by other students, the time assigned to those of the first year is rather short. Moreover, the collection of samples that the students of the first year can use has quite a limited number of specimens for each mineral species.

Because of these factors, the first year students always had some difficulties in learning all the minerals, in order to be able to recognize them later in their work. It became clear that an additional solution had to be found to resolve this problem, a solution that will enable the study of samples at home, without taking or damaging the samples and having, at the same time, all the information at hand.

The proposed solution was to create a digital database with all the samples needed to study, in a 3-D format and with all the complementary information. This digital database can be considered a digital atlas which allows users to interact with the samples in different and useful ways, for better learning. The methods used for achieving this goal was the 3-D modeling technique known as “Structure from Motion” Photogrammetry and the game creation platform (Unity3D Game Engine).

Previous works of Minocha (2013) and Minocha et al. (2014) have shown us how using game engines for different teaching purposes can improve the students’ knowledge and help them to overcome some other difficulties.

In regard to photogrammetry, there are many papers which contribute to the field, of which only a few refer to its contribution in teaching, e.g., Kosmatin Fras and Grigillo (2016) and Nikolić et al. (2012). Very recently, an author has begun a parallel work with us (<https://blog.sketchfab.com/photogrammetry-for-the-classroom-3d-scanning-for-geology-and-paleontology/>), and has described a method to obtain 3-D models from samples and place them online, but without any possibility to extract measurements or any other information which can be crucial in a mineralogical study.

## 2. Methods

In order to build up the “3D Mineral Atlas”, the photogrammetry techniques, with their related tools, as well as a game engine platform known as Unity 3D were used.

The entire process can be separated into six major stages, which have their own subdivisions: the testing stage, photography stage, photogrammetry stage, cleaning stage, game engine stage and the dissemination stage.



Fig. 1 Setup for testing different positions and angles for photo taking.

### 2.1 Testing stage

In the testing stage (Fig. 1), we have looked for the best way to take photos (sample position, light setup, camera position) of the mineral, so that the final model would be as close to reality as possible, with utmost errors as possible, yet keeping the time needed to create it short. We found out that a good balance between time and quality (in both taking and processing photos) is achieved with about 150 photos for each side of the sample, taken from two different angles. The processing of the 150 photos for each side of the sample by using Photoscan and other

softwares like 123DCatch, RecapPhoto, VisualSFM, resulted in two separate 3-D models, which would have been later aligned manually through a somewhat lengthy process that often may return a poor result. Trying to avoid as much as possible the human interaction in the modeling process of the samples, the best method was to position the sample support in a white environment with diffuse, white light (white led bulbs with white paper wrapped around) and take two sets of photos, i.e., at two different positions (top tilted view and front slightly tilted view) of the sample and at an interval of about  $5.6^\circ$  (Fig. 2). This way, we were able to model the whole sample in an automatic way, using Photoscan, without the need for further alignment of the two halves.



Fig. 2 Final setup with diffuse white lights, a tripod and a turning table for the sample.

## 2.2 Photography stage

Using the method discussed previously, in the photography stage, four sets of photos (of 64 photos per set) were obtained, with a total of 256 photos for each studied sample (Fig. 3). The next step was to process the resulting photos using Photoscape software, by batch modifying each set to increase sharpness and contrast. Adding sharpness and contrast to the photos is necessary in order to help Photoscan in the photo aligning stage. To have a close to reality texture and color of the sample, the original texture used in the texturing process of the models was kept.



Fig. 3 Examples of photos taken for the sodalite sample. 12 photos from a total of 256 photos.

## 2.3 Photogrammetry stage

As shown above, in the photogrammetry stage, a 30 day trial version of the Photoscan software has been run on a Graphic Station (Intel Core i7-5820k, Nvidia Quadro K5200, 64 GB DDR4 RAM and a KINGSTON SSD). The software reconstructs the 3-D model of the

sample throughout four main steps: photo alignment (which generates a sparse point cloud), dense cloud generation, mesh generation and texture generation. Photo-scan also provides the possibility to use a fifth step (chunk aligning), which is only necessary for manual alignment of two separate parts of the model, while only one cannot treat the model as a whole. As previously discussed, the need for the fifth step was eliminated by choosing good conditions for photography, in order to eliminate the human factor from the 3-D reconstruction of the sample.

For the first step, the photo alignment, the “Accuracy” was set to “Medium”, “Pair preselection” to “Generic”, “Key point

limit” to “0” and “Tie point limit” to “0”. If the photos are taken and prepared correctly, the photo alignment step should pass without any intervention and it should generate quite a detailed sparse point cloud (Fig. 4). The process for each sample photo alignment took about 40 minutes (more or less, depending on the detail density of the sample). The number of points in the sparse cloud is different from one sample to another. For instance, a sulphur sample (named “SULPHUR 1” in the application menu) has 263,457 points, a fluorite sample (named “FLUORITE 2”) has 112,901 points and a magnetite sample (named “MAGNETITE 2”) has 243,003 points.

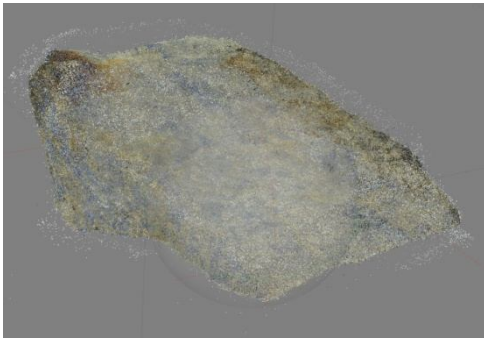


Fig. 4 Sparse point cloud generated for the sodalite sample (294,818 points).

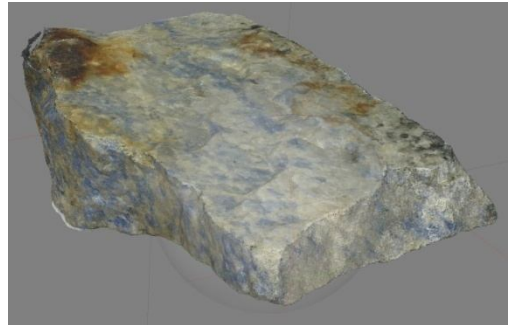


Fig. 5 Dense point cloud generated for the sodalite sample (5,357,726 points).

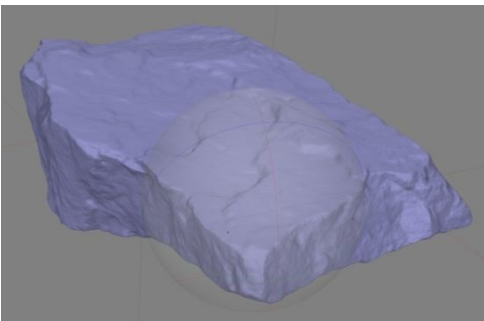


Fig. 6 Mesh generated for the sodalite sample (2,359,212 vertices and 4,589,169 faces).

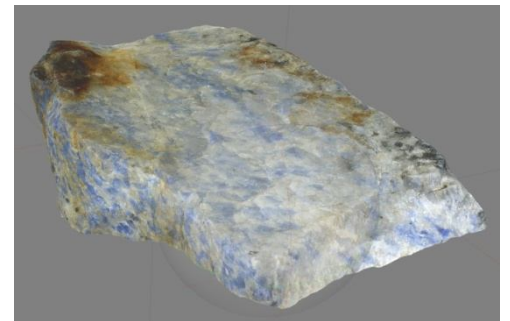


Fig. 7 Mesh with textures generated for the sodalite sample.

The second step in the 3-D reconstruction was the dense cloud generation (Fig. 5). This step was the most time-consuming, as it took an average of about 3 hours to complete with “Quality” setting set to “Medium” and “Depth filtering” set to “Mild”. The resulting number of points from this process (dense point cloud) for the same samples discussed above is 3,964,489 for sulphur, 658,325 for fluorite and 6,268,345 for magnetite.

In the third step, the mesh generation process (Fig. 6), the “Surface type” was set to “Arbitrary” and “Face count” to “0”. The process lasted for an average of 2 minutes and it generated 3D models with various numbers of faces, depending on the number of points obtained in the previous step. For the sulphur sample we obtained a model with 2,273,695 vertices and 4,449,556 faces, for fluorite a model with 1,347,746 vertices and 2,621,776 faces and for magnetite a model with 2,529,779.000 vertices and 4,907,332.000 faces. It can be presumed that the higher the number of points from the point cloud and implicitly the higher the number of faces from the 3-D reconstructed mesh, the better is the quality of the 3-D model of the sample (Tab. 1).

The last step, the texture generation (Fig. 7), took on average of 15 minutes to process; it began with the replacement of the photos used for 3-D reconstruction with the original ones, which have not gone through contrast or sharpness enhancement. In this stage, the original photos for each sample was used to keep the original texture and color of the sample. Photo replacement was carried out by selecting all the photos from the “Photo” window inside Photoscan and changing their path with right mouse click “Change

Path...” command. The setting used for texture generation process were: “Generic” for “Mapping mode”, “Mosaic” for “Blending mode”, “16,384 × 16,384” for “Texture size” and “Yes”, which enabled both “Color correction” and “Enable hole filling”.

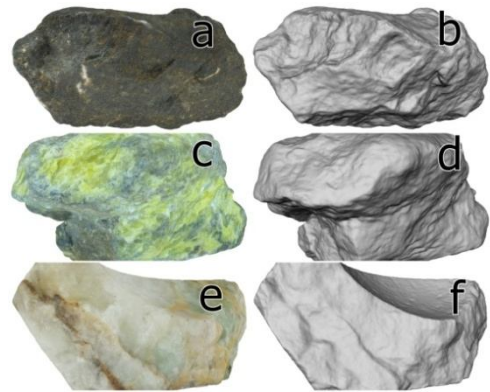


Fig. 8 Examples of 3-D models obtained for the samples. a – textured 3-D model of the magnetite 2 sample; b – only the 3-D mesh of the magnetite 2 sample; c – textured 3-D model of the sulphur 1 sample; d – only the 3-D mesh of the sulphur 1 sample; e – textured 3-D model of the fluorite 2 sample; f – only the 3-D mesh of the fluorite 2 sample.

## 2.4 Cleaning stage

From the previous stage, 3-D textured models were obtained for each sample captured earlier by camera (Fig. 8). Although the 3-D models had a high resolution, the 3-D reconstruction process was not perfect and it generated either artifacts or holes in the created models; the imperfections were generated in most part by the lack of information in some photos, due to the reflectance of the sample’s surface. The “errors” were corrected by post-processing, with help of Autodesk’s Remake software (formerly known as Memento), through manually filling of

holes or erasing the useless parts (Fig. 9). Using the same software, we corrected the orientation of the model, rotated it in the wanted direction and scaled it according to the direct measurement of the sample. Afterwards, the cleaned 3-D model meshes were resized to about 100 mb/model, in order to be properly imported into the Unity3D Engine, still keeping the original size of the texture.

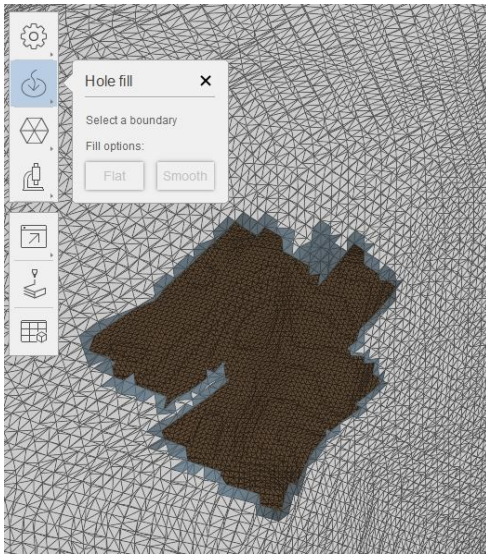


Fig. 9 Manually filling the holes of a 3-D model using Autodesk Remake functions.

## 2.5 Game engine stage

The now cleaned, scaled and resized 3-D models were imported into the Unity3D Engine, where the application that will be disseminated among students was developed. We choose to create the application with five windows, having different menus and buttons, which help choosing what to visualize. From the beginning, we wanted to create the menus in both English and Romanian language (Fig. 10) so that the students can learn the

information in their native language and understand the terms in an international language as well. The next window shows a menu with every modeled sample arranged in groups (Fig. 11) that follow the classification proposed by Gaines et al. (1997). From this menu, a mineral from one group can be chosen, so that a different window is opened, allowing the student to decide either to interact with the 3-D model, or read more information and see different pictures of that mineral (Fig. 12). In the 3-D model window, the student can use the mouse to Rotate, Pan or Zoom, in order to settle the sample on any side; he also can use a keyboard key and mouse to measure the distance between any two points on the surface of the sample (Fig. 13). The final menu was the information menu, where students can read synthesized information about that mineral and visualize photos from other mineralogical collections (Fig. 14). Information for completing this menu was processed using Gaines et al. (1997) and Ianovici et al. (1979) publications, along with <https://www.mindat.org> website. Regarding the photos from other collections they were taken from <https://www.mindat.org> and used in compliance with the license terms. Also, every mineral information menu and photo has its own link to the website information and photo pages, respectively.

## 2.6 Dissemination stage

Because the application developed through the present study uses high resolution 3-D models and a consistent volume of information and pictures, its final size is about 7 Gb. Therefore, we could not develop a version that could be placed and opened directly on a website. Since

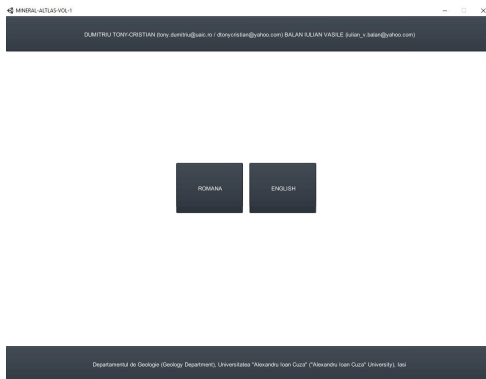


Fig. 10 Choosing the language from the start menu in the Unity3D application.

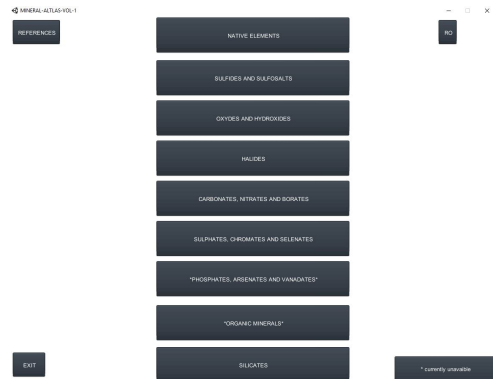


Fig. 11 The mineral group menu.

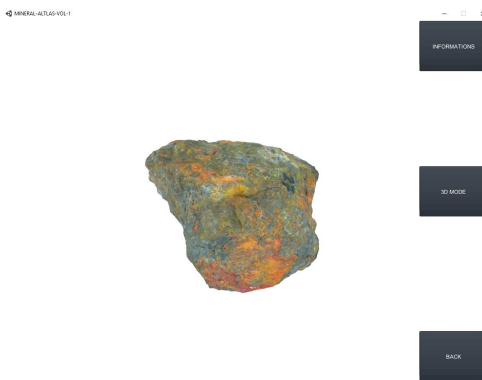


Fig. 12 An example of a mineral sample's menu. Realgar-Orpiment sample menu.

we did not want to reduce its quality, we built it up as to be used only directly on a personal computer, by downloading the archived application from a cloud, unzipping and running it up on the user's computer.

To be able to keep a track of how many users download and potentially use this material, we also developed a simple Google Form that after registration generates a password, which must be used in unzipping the application.

The final process is that of accessing the link to the Google Form, completing the form and receiving a password and a link to the application folder from where it can be downloaded, unzipped and started.

### 3. Results and conclusions

In the end, we managed to develop an application similar to a digital atlas with 70 3-D samples of minerals and varieties, having information, pictures and website links for each one. The students may download and use the application by completing a Google Form (<https://docs.google.com/a/geology.uaic.ro/forms/d/e/1FAIpQLSdaz3DPgWoeJadrTNTDjxQbq6xSLOX-dWETaEmYoZC02RIFNA/viewform>), which will provide them with both a download link and a password to unzip it.

After distributing the application to students, we almost instantly noticed an improvement in their understanding of the optical properties of the minerals, as they were able to study the samples for a longer time and in more detail, during individual learning. Having constant and continuous access to the collection, the students were

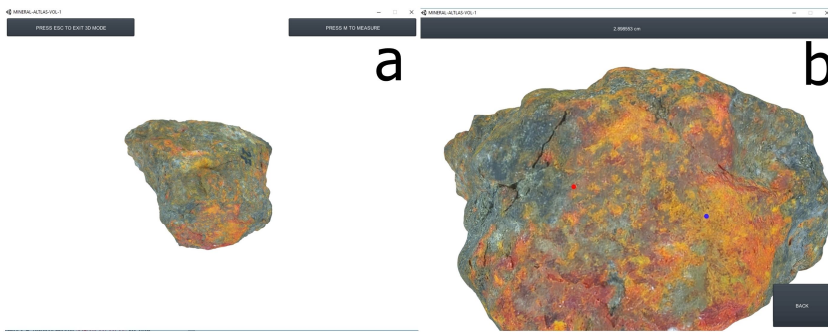


Fig. 13 Application menus. a – 3-D menu of realgar-orpiment sample; b – measurement menu of realgar-orpiment sample.

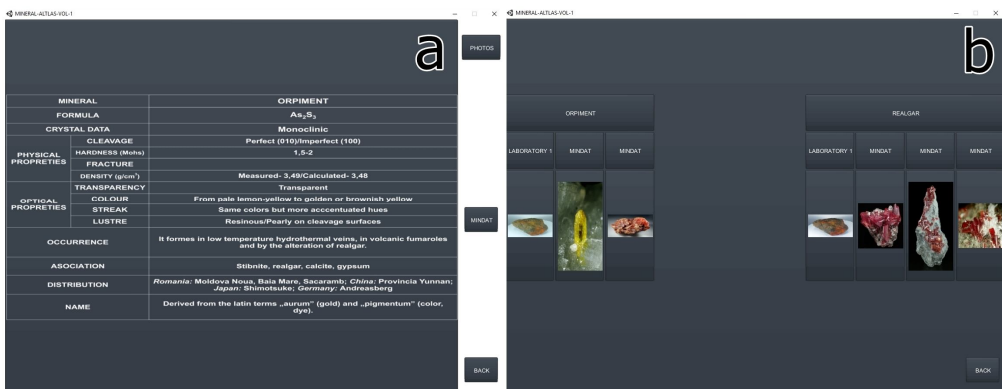


Fig. 14 Application menus. a – information menu for orpiment mineral with corresponding mindat.org links; b – photos menu for orpiment mineral with corresponding mindat.org links.

able to choose the perfect time for them to study the samples, fact that would not have been possible in the laboratory, due to the limited amount of time allocated for each class and limited number of samples that can be studied at once. Moreover, the application constantly provides the information side by side with the 3-D model, making it easier for the students to concentrate on the important parts of the class.

At the end of the semester, after the practical exam, we also noticed a considerable increase in their knowledge and interest, which in turn led to better grades.

Further work on the application will enable us to increase the quality of the existing 3-D samples, add more samples from our own collection and even integrate it on our department's website.

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<https://www.mindat.org>

Tab. 1 Information about the number of vertices and faces, surface areas and volume measurements for each 3-D reconstructed sample

Name	Vertices	Faces	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
Graphite	1,193,841	2,305,183	15,245	112,258.315
Sulphur 1	2,273,695	4,449,556	390	459.800
Sulphur 2	2,387,714	4,656,170	640	813.790
Orpiment-realgar	3,434,426	6,676,778	738	1,232.522
Sphalerite 1	2,014,410	3,925,996	262	205.749
Sphalerite 2	2,955,228	5,756,720	428	586.503
Galena 1	941,521	1,801,816	154	93.877
Galena 2	2,145,103	4,199,240	133	105.626
Molybdenite 1	2,456,976	4,798,532	302	341.834
Molybdenite 2	1,125,835	2,188,904	271	298.003
Pyrite 1	2,247,560	4,409,847	18,947	200,712
Pyrite 2	797,709	1,538,304	80	46.811
Pyrite 3	644,536	1,181,620	77	23.840
Chalcopyrite	1,324,649	2,573,902	215	212.058
Realgar	3,434,426	6,676,778	738	1,232.522
Stibinite 1	2,644,876	5,033,968	20	2.070
Stibinite 2	1,779,902	3,462,388	208	132.741
Hematite 1	1,720,759	3,356,706	495	641.458
Hematite 2	2,059,736	3,995,467	312	345.381
Magnetite 1	1,981,759	3,867,554	290	235.368
Magnetite 2	2,529,779	4,907,332	258	284.418
Fluorite 1	1,531,464	2,967,954	152	122.885
Fluorite 2	1,347,746	2,621,776	187	166.573
Halite 1	2,191,493	4,268,448	381	451.665
Halite 2	2,548,004	4,991,868	692	1,387.598
Sylvite	566,787	1,097,120	36	14.171
Aragonite 1	1,744,868	3,395,052	206	177.868
Aragonite 2	2,093,751	4,050,732	411	447.928
Aragonite 3	2,120,848	4,135,783	242	259.247
Azurite	773,697	1,500,822	72	39.474
Calcite 1	1,619,668	3,157,998	195	185.744
Calcite 2	2,658,688	5,182,405	302	319.472
Malachite	2,024,263	3,941,708	198	181.994
Rhodochrosite	1,700,855	3,324,624	297	329.260
Siderite	1,129,800	2,177,599	64	21.764

Name	Vertices	Faces	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
Witherite	2,186,170	4,263,004	248	262.761
Baryte 1	219,395	421,340	26	9.341
Baryte 2	2,403,067	4,664,912	346	426.306
Gypsum 1	3,502,321	6,813,206	306	319.936
Gypsum 2	1,816,616	3,508,660	366	308.931
Gypsum 3	1,280,104	2,482,660	167	129.140
Actinolite 1	1,725,665	3,359,141	213	172.408
Actinolite 2	624,737	1,204,774	40	13.658
Albite	2,554,791	4,980,940	168	131.688
Asbestos	2,121,175	4,126,350	327	260.443
Biotite	405,179	786,028	44	16.711
Kaolinite	1,405,930	2,740,486	187	176.523
Chlorite	902,003	1,722,714	133	66.490
Quartz (chalcedony)	2,369,836	4,613,108	429	661.897
Quartz 1	1,885,613	3,665,916	163	118.353
Quartz 2	1,497,958	2,904,574	185	142.735
Quartz 3	803,184	1,559,872	43	18.377
Quartz 4	212,268	407,417	24	10.205
Quartz 5	76,844	141,918	4	0.297
Epidote 1	2,198,583	4,278,150	230	203.346
Epidote 2	2,556,496	4,991,080	280	335.750
Garnet 1	2,505,449	4,886,042	560	691.100
Garnet 2	1,642,789	3,209,444	204	199.582
Hornblende	2,171,637	4,222,030	517	497.610
Muscovite 1	1,885,500	3,642,018	255	189.446
Muscovite 2	1,601,670	3,116,334	210	170.752
Nepheline	1,936,276	3,780,066	322	364.300
Olivine	1,787,696	3,483,996	443	654.023
Opal 1	2,266,104	4,374,066	156	106.207
Opal 2	415,051	803,944	27	8.050
Orthoclase	1,592,716	3,084,287	61	29.456
Titanite-tourmaline	1,046,244	2,024,983	114	68.102
Sodalite	2,359,212	4,589,169	411	435.093
Talc	738,805	1,427,511	66	24.367
Tremolite 1	3,061,502	5,940,878	339	350.270
Tremolite 2	1,283,817	2,465,992	233	163.212