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The contrast scale of minerals for neutron tomography of paleontologic and geologic objects

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Abstract

Neutron tomography is considered as an alternative to X-ray tomography in the study of paleontologic and geologic objects. Based on experimental data, a contrast scale of minerals and rocks, including those present in paleontologic objects, has been constructed for neutron tomography. Examples of application of neutron tomography of geologic objects are given, and the potentialities of the above methods are compared.

Keywords: tomography; neutrons; X-rays

Introduction

Tomography examination provides information about the internal structure of an object and the relative location of its details and is used in many fields of research. Tomography is based on the measurement of 2D images of penetrating-radiation transmission by an object followed by the mathematical reconstruction of its 3D image. The most commonly used penetrating radiation are X-rays generated by laboratory or synchrotron sources. In recent time, large world research centers have created neutron tomographs based on neutron sources (Lehmann and Ridikas, 2015). The main difference between X-ray tomography and neutron tomography is different mechanisms of interaction of radiation with matter; as a result, materials that are not distinguished when using X-rays can be distinguished when using neutrons.

Paleontology is one of the science fields applying tomography. Numerous X-ray and synchrotron tomography studies of unique paleontologic objects have been performed (Ketcham and Carlson, 2001; Pakhnevich, 2010). The original biologic tissues of such objects were replaced by mineral components that can differ from each other within the object. If the object consists of components that equally attenuate X-rays, then X-ray tomography provides limited information about its structure. This problem can be solved using neutron tomography. Only few (mainly demo) neutron tomography experiments on paleontologic objects have been carried out (Schwarz et al., 2005). This method was applied to study hydrogen-containing materials (Carlson, 2006; Vlassenbroeck et al., 2007), in particular, to search for organic matter in fossilized flora and fauna remains (Cunningham et al., 2014; Dawson et al., 2014). The joint use of X-ray, synchrotron, and neutron radiation provides new information about the structure of paleontologic objects (Hess et al., 2011; Kaloyan et al., 2014; Martins et al., 2011; Winkler, 2006).

To predict the results of an X-ray tomography examination, Pakhnevich (2011, 2013) made a laboratory comparison of contrasts of minerals and rocks and constructed an X-ray contrast scale. The aim of this work was to construct a contrast scale for thermal-neutron tomography. Comparison of the X-ray and neutron contrast scales will demonstrate the specifics of neutron tomography as applied to paleontologic and geologic objects and will help to choose the optimal investigation method depending on the object composition.

Material and methods

Fourty-seven samples of different minerals and rocks (Table 1) were used to construct a neutron tomography contrast scale. Most of them are found either in fossils or in the host rocks. In addition, some objects of similar chemical composition were studied. The samples were of natural shape,

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Table 1. Minerals and rocks used for construction of the scale; the composition is given after Fleischer (1971)

No.	Mineral	Chemical formula	Deposit, region
1	Augite	$(Ca,Na)(Mg,Fe^{2+},Fe^{3+},Al,Ti)(Si,Al)_2O_6$	Vici Hora, Czechia
2	Aquamarine	$Be_3Al_2Si_6O_{18}$	Mt. Sherlovaya, Chita Region
3	Amazonite	$AlSi_3O_8$	Ilmeny Mts, Urals
4	Apatite	*	Slyudyanka, Cisbaikalia
5	Aragonite	$CaCO_3$ (rhomb.)	Shakh-Tau, Sterlitamak
6	Arfvedsonite	$Na_3(Fe^{2+}, Mg)_4\ Fe^{3+}Si_8O_{22}(OH)_2$	Tul'ok River, Khibiny, Murmansk Region
7	Barite	$BaSO_4$	Belorechenskoe, Northern Caucasus
8	Biotite	$(Mg,Fe^{2+})_3(Al,Fe^{3+})Si_3O_{10}(OH,F)_2$	Kandalaksha district, Murmansk Region
9	Vivianite	$Fe_3(PO_4)_2{\cdot}8H_2O$	Kerch' district, Crimea
10	Galena	PbS	Transbaikalia
11	Halite	NaCl (with Rb impurity)	Solikamsk, Perm' Region
12	Hematite	α-Fe_2O_3	Morocco
13	Goethite	α-$Fe^{3+}O(OH)$	Vrancice, Czechia
14	Gypsum	$CaSO_4{\cdot}2H_2O$	Ul'yanovsk
15	Clay	*	White Sea Biological Station of Moscow State University, Kandalaksha district, Murmansk Region, White Sea coast
16	Dolomite	$CaMg(CO_3)_2$	Belorechenskoe, Northern Caucasus
17	Calcite	$CaCO_3$ (hex.)	Tura, Siberia
18	Quartz	SiO_2	Cisuralia, Piramida Peak
19	Cassiterite	SnO_2	Merek, Khabarovsk Territory
20	Corundum	Al_2O_3	Karelia
21	Labrador	*	Madagascar
22	Limonite	*	Libyan Desert, Egypt
23	Magnesite	$MgCO_3$	Far East
24	Malachite	$Cu_2(CO_3)(OH)_2$	South Urals
25	Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$	Voron'i Tundry, Murmansk Region
26	Olivine	Fe_2SiO_4–Mg_2SiO_4	Gilgit, Pakistan
27	Opal	$SiO_2{\cdot}nH_2O$	Voznesenskoe, Kazakhstan
28	Orthoclase	$KAlSi_3O_8$	Kandalaksha district, Murmansk Region
29	Pyrite	FeS_2	Guizhou, China
30	Pyrolusite	MnO_2	Ushkatyn-4, Kazakhstan
31	Rodochrosite	MnO_3	Capillitas, Argentina
32	Rutile	TiO_2	Namangan, Azerbaijan
33	Native sulfur	S	Vodino, Middle Volga region
34	Siderite	$FeCO_3$	Nikolaevka, Dal'negorsk ore district
35	Smithsonite	$ZnCO_3$ (trigon.)	Chihuahua, Mexico
36	Spodumene	$LiAlSi_2O_6$	Afghanistan
37	Stilbite	$NaCa_2Al_5Si1_3O_{36}{\cdot}14H_2O$	Pune, India
38	Strontianite	$SrCO_3$	Podolia, Ukraine
39	Sphalerite	(Zn,Fe)S	Transbaikalia
40	Todorokite	$(Mn^{2+},Ca,Mg)Mn_3^{4+}O_7{\cdot}H_2O$	Kerch', Crimea
41	Phenakite	Be_2SiO_4	Malyshev ore mine, Asbest, Ural region
42	Fluorite	CaF_2	Shangrao, China
43	Phosphorite	*	Morena, Taldom region, Moscow Region
44	Chrysoberyl	$BeAl_2O_4$	Malyshev ore mine, Asbest, Ural region
45	Celestine	$SrSO_4$	Biineu-Kyr, Turkmenistan
46	Cerrusite	$PbCO_3$	Tsumeb, Namibia
47	Amber	*	Kaliningrad Region

* Formulas of rocks and minerals with a variable chemical composition are omitted.