Journal of Non-Crystalline Solids xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Non-Crystalline Solids

journal homepage: www.elsevier.com/locate/jnoncrysol

Nano-heterogeneity of natural impact silica-rich glasses according to atomic force microscopy and spectroscopy data

Yevgeny A. Golubev[a,*], Tatyana G. Shumilova[a,b], Sergey I. Isaenko[a], Boris A. Makeev[a], Alexandr A. Utkin[c], Elena I. Suvorova[d], Kord Ernstson[e]

[a] Institute of Geology of Komi SC of Uralian Branch of RAS, 54 Pervomayskaya st., Syktyvkar 167982, Russia
[b] Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 1680 East-West Road, Honolulu, HI 96822, USA
[c] Department of Radiophysics, Syktyvkar State University, 55, Oktyabrsky st., Syktyvkar 167000, Russia
[d] Institute of Crystallography of RAS, 59 Leninsky pr., Moscow 117333, Russia
[e] Faculty of Philosophy I, University of Würzburg, Germany

ARTICLE INFO

Keywords:
Natural silica-rich glasses
Microscopy
Spectroscopy
Surface nano-heterogeneity

ABSTRACT

In nature extreme PT-conditions result in numerous glass-like solids, the study of which allows specifying various structural and chemical features of extreme materials, which have a great application potential in various fields of technology. We studied features of nanostructure of natural impact glasses, including recently discovered ultrahigh-pressure high-temperature impact glasses, compared to low-pressure natural and synthetic standard silica glasses. In this paper we presented complex data of atomic force microscopy, X-ray diffraction, X-ray energy-dispersive spectrometry, infrared and Raman spectroscopy. We described nanostructural characteristics of impact glasses and showed influence of chemical composition on the features of their structure. We discovered that the elemental composition was the most important factor determining the glasses nano-heterogeneity. We noted an essential role of influence of Na impurity on glass nanostructure. The impact glasses with pure SiO_2 composition have the smallest sizes of nanostructural elements.

1. Introduction

Despite a wide application of glasses and a long history of their study, there is still no generally accepted understanding and definition of the state of this type of substance. Often, any solid amorphous substance is referred to as glass [1–5]. In this paper we use a classical definition [5]. We refer to the term “glass” as substance formed at a rapid solidification of the melt near the glass transition temperature, when the cooling velocity exceeds the maximum for crystallization under these PT-conditions [6–8].

In geological environment glass is formed as a result of the following processes:

(i) Meteorite impact glass, as a result of falling large asteroids, leading to melting of target rocks at ultrahigh pressures (35–90 GPa) and temperatures (up to 3000 °C and higher) [9–12], followed by rapid cooling and formation – a) *proximal impactites*, rocks with a high content of condensed impact melt, including glasses; b) distal emissions in the form of *bombs* and *tektites* deposited from a dust cloud over large areas outside craters [6,10,13–18]; c) *ultrahigh-pressure melt impactites of vein type*, forming dikes penetrating impactites of the 1st generation, which were first discovered on the territory of the Kara astrobleme [19].
(ii) Volcanic glass – *pumice*, *obsidian*, from condensation of silica-rich magmatic melts on the earth's surface.
(iii) *Tachylite*, a black volcanic glass, which is formed by the chilling of basaltic magmas.
(iv) *Pseudotachylite*, a mostly devitrified glass, which may form via frictional melting of faults, in large-scale landslides, and by impact processes.
(v) *Buchite*, from pyrometamorphism at the contact of acid rocks with intrusion magma of basic composition, leading to partial melting of the enclosing rocks.
(vi) *Fulgurites*, melting of rocks when lightning strikes the ground [20–23].

Impact glasses forming from ultrahigh-pressure high-temperature exposure to target rocks are the most interesting due to their potentially unusual properties. These glasses can be used to solve fundamental problems of the state of substance under extreme conditions and to

* Corresponding author.
E-mail addresses: yevgenygolubev74@mail.ru, golubev@geo.komisc.ru (Y.A. Golubev).

https://doi.org/10.1016/j.jnoncrysol.2018.08.031
Received 11 June 2018; Received in revised form 14 August 2018; Accepted 23 August 2018
0022-3093/

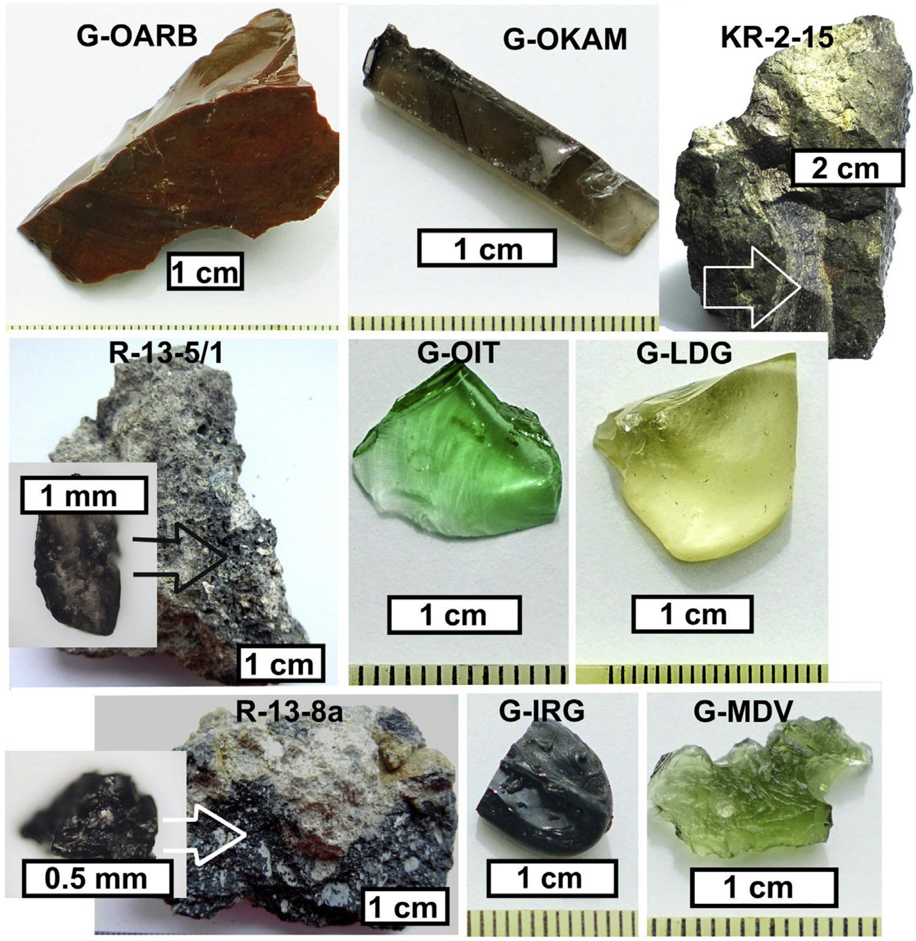

Fig. 1. Photos of studied glasses.

Table 1
Short description of the glass samples.

Sample code	Name	Origin, locality	Initial origin features	Color	Optical transparence
KR-2-15	UHPHT impact glass	Vein body within suevite, Kara astrobleme, Pay-Khoy (river Kara, left bank), sampled by T.G.Shumilova in 2015 year	UHPHT	Gray	Translucent
R-13-5/1	Impact glass	Glass drops from suevites, Ries crater, Altenburg quarry, Germany, sampled by T.G.Shumilova and K.Ernstson in 2013 year	HPHT	Gray	Translucent
R-13-8a	Impact glass	Glass drops from suevites, crater Ries, Polsingen quarry, Germany, sampled by T.G.Shumilova and K.Ernstson in 2013 year	HPHT	Gray	Translucent
G-MDV	Moldavite	Tektite, Bohemia (impact origin, probable Ries (Germany) impact distal ejecta), from N.P.Yushkin's collection	HPHT	Green	Translucent
G-IRG	Irgizite	Tektite from Zhamanshin outer crater deposits, Kazakhstan, from N.P.Yushkin's collection	HPHT	Black	Opaque
G-LDG	Libyan desert glass	Probable meteoritic origin, Egypt, from N.P.Yushkin's collection	HPHT	Yellow	Translucent
G-OKAM	Obsidian	Volcanic glass, Paratunskoye deposit, Kamchatka, from N.P.Yushkin'scollection	LPHT	Dark brown	Opaque
G-OARB	Obsidian	Volcanic glass, volcanic cone Arteny, Armenia, from N.P.Yushkin's collection	LPHT	Dark brown	Opaque
G-OIT	Obsidian	Volcanic glass, Sardinia island, Italy, from N.P.Yushkin's collection	LPHT	Green	Translucent
Suprasil	Standard quartz glass	Manufactured glass, Bruker, Germany	LPHT	Colorless	Translucent

Subscription: UHPHT – ultrahigh pressure high temperature; HPHT – high pressure high temperature; LPHT – low pressure (ambient pressure) high temperature.

create fundamentally new materials [24–28].

Differences in concentration and composition of impurities and PT-condensation conditions for different formation processes contribute to nanoscale chemical heterogeneity in these types of glasses. This heterogeneity was mainly observed by transmission electron microscopy (TEM) [29–31]. In the last two decades, atomic force microscopy (AFM) methods are actively used to study topographic nanoscale heterogeneity of glasses. Although most AFM studies were carried out for artificial glasses [e.g. 33–39], including for the evaluation of phase separation [40], natural glasses were also investigated by these methods [41–44]. The finding of new specific types of natural impact glasses, in particular ultra-high pressure glasses from the Kara astrobleme [19], stimulated interest for further studies of impact glasses, including methodological interpretations, in particular for AFM results. Here, we report on AFM quantitative estimates of nanoscale heterogeneity of the glasses surface considering the sizes of hillocks as