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# SUBSTORMS OVER APATITY DURING THE PERIOD OF ENHANCED GEOMAGNETIC ACTIVITY 7-17 MARCH 2012

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***Abstract***

*The period 7–17 March 2012 is one of the most geomagnetically active periods during the ascending phase of Solar Cycle 24. Therefore the solar and interplanetary phenomena during this period along with the consequent processes in the magnetosphere and ionosphere were object of study of the scientific society. The whole chain of events was discussed on several scientific conferences. The solar flares, coronal holes, coronal mass ejections, high speed solar wind streams and interplanetary shocks were identified and the resulting response of the magnetosphere and ionosphere was examined. Four strong geomagnetic storms occurred during this period. The substorms generated in this time are the final effect of all these events. Measurements of the Multiscale Aurora Imaging Network (MAIN) in Apatity (Russia) and data of IMAGE magnetometers network have been used to verify the substorms onset and subsequent development. The characteristics of these substorms were studied and they were compared to substorms originated during similar or different conditions.*

## Introduction

It is known that certain types of solar wind, mainly Interplanetary Coronal Mass Ejections (ICME) and Corotating Ineraction Regions (CIR) (e.g. 1, 2]), generate magnetic storms. During solar maxima, most common are the sporadic flows associated with CME [3]. Near the Earth, they are observed as magnetic clouds (MC) (e.g. [4]). The magnetic clouds (MC) are characterized as regions, where the magnetic field strength is higher than the average, the density is relatively low and the magnetic pressure strongly exceeds the ion thermal pressure; the magnetic field direction changes through the cloud by rotating parallel to a plane, which is highly inclined with respect to the ecliptic [4]. In front of MC, a region of interaction with undisturbed solar wind (Sheath) is known to form, which is characterized by high density, increased pressure and strong Interplanetary Magnetic Field (IMF) variability. CIR is a region of the interaction between high-speed recurrent streams and the adjacent slower streams. Recurrent streams and their CIR are more frequent during solar minima. CIR is defined as a region with magnetic field and plasma compression [5]. It should be noted that there are differences between storms generated by Sheath, MC, and CIR (in intensity, recovery phase duration, etc.) (e.g. [6, 7, 8]). However, there are more complicated storm cases, when the magnetic storms are caused by several sources in the solar wind, coming consecutively one after the other or partly overlapping. Events of strong geomagnetic activity are of special interest because magnetic storms can affect the energetic systems, the spacecrafts, or the ground based systems. That is why coordinated actions of the scientific community are needed to perform and gather observations, to create models of the whole chain of phenomena from the Sun to the Earth in order to make successful predictions of space weather and to prevent failures in the technologic infrastructure caused by strong geomagnetic storms [9]. Storms are the final effect of the enhanced solar and interplanetary activity. Substorms generated during geomagnetic storms are significant features. Therefore, it is important to have more observations of substorms during storms, especially under strongly disturbed conditions.

In this paper, a period of high geomagnetic activity (7–17 March 2012) was examined by ground based aurora observations at Apatity (Russia) and the observed substorms were studied.

## Instrumentation and data used

The *Apatity*'s location at auroral latitudes: geographic coordinates (67.58ºN, 33.31ºE) and Corrected GeoMagnetic (CGM) ones (63.86ºN, 112.9ºE) is expedient to examine the variety of substorms.

Measurements from the Multiscale Aurora Imaging Network (MAIN) in *Apatity* (Russia), during the strongly disturbed period 7–17 March 2012, have been used. The all-sky camera observation system has been built in *Apatity* since 2008. The cameras' characteristics, their mutual situation and the measurement process are described in detail by Kozelov et al. [10].

To study the substorm development data from the *Apatity*'s all-sky camera (images and keograms) and the Guppy F-044C (GC) camera, with a field of view ~67° (keograms), were used. The GC camera data were corrected regarding the exposition time, the gain, the heterogeneity of the dark field, and the objective transmittance change depending on the angle of observation. The keograms were constructed in direction magnetic North (up). The zero angle coincides with zenith.

Solar wind and interplanetary magnetic field parameters were taken from OMNI database (http://sdaweb.gsfc.nasa.gov/cdaweb/istp_public). The *Kp* indices were taken from NOAA database: (http://www.ngdc.noaa.gov/stp/GEOMAG/kp_ap.html). Substorm presence was verified by ground-based data of IMAGE magnetometers network (using the meridional chain Tartu (TAR) /CGM latitude=54.47°/ – Ny Ålesund (NAL) /CGM latitude= 75.25°/).

## Overview of the interplanetary conditions

The time interval 7–17 March 2012 (11 days) is one of the first major geomagnetically active periods of the ascending phase of SC24 [11]. It was examined and the detected features were described [11, 12]. Magnetic storms occurred on 7, 9, 12, and 15 March, and they were called the S1, S2, S3, and S4 events. These storms were caused by Sheath, MC, and HSS, the detailed scenario for all four storms were different. The storms are classified by the maximal $k_p$ index value. During the four periods of storm activity the $k_p$ index exceeded the limit of the "storm" conditions ($k_p$=5). During S2 the level of severe storm ($k_p$=8) was reached, the three other events are at the level of moderate storms ($k_p$=6). The interplanetary conditions during the examined period and the geomagnetic responses are presented in Fig.1. In all frames, from top to bottom the panels are: the magnitude of the IMF $B$, the IMF $B_z$ component, the solar wind velocity $v$, its $x$ component $v_x$, the proton density, the proton temperature, the flow pressure and two geomagnetic activity indices, AE and SYM/H. On Fig.1a is presented an overview of the interplanetary conditions from 7 to 20 March 2012. The vertical lines point out the beginning of the four events. On Fig.1 *b*, *c*, and *d* are represented the conditions during S1, S2, and S4 in more detail. The continuous vertical lines indicate the interplanetary shocks (S) and the borders of the solar wind streams (for details, see [11]).

## Results

The measurements during the time interval 7–17 March 2012 were examined together with the interplanetary conditions during the measuring periods. Ten substorms were identified over *Apatity* under clear sky conditions: 4 of them developed during S1, 3 – during S2, and 3 – during S4. The times of the substorms are marked by dashed vertical lines in Fig. 1*b*, *c*, and *d*. They occurred during different interplanetary conditions and at different stages of the geomagnetic storms development. Two typical cases of substorms were chosen presenting a substorm generated during the recovery phase in the vicinity of the maximal development and a substorm during the late recovery phase.

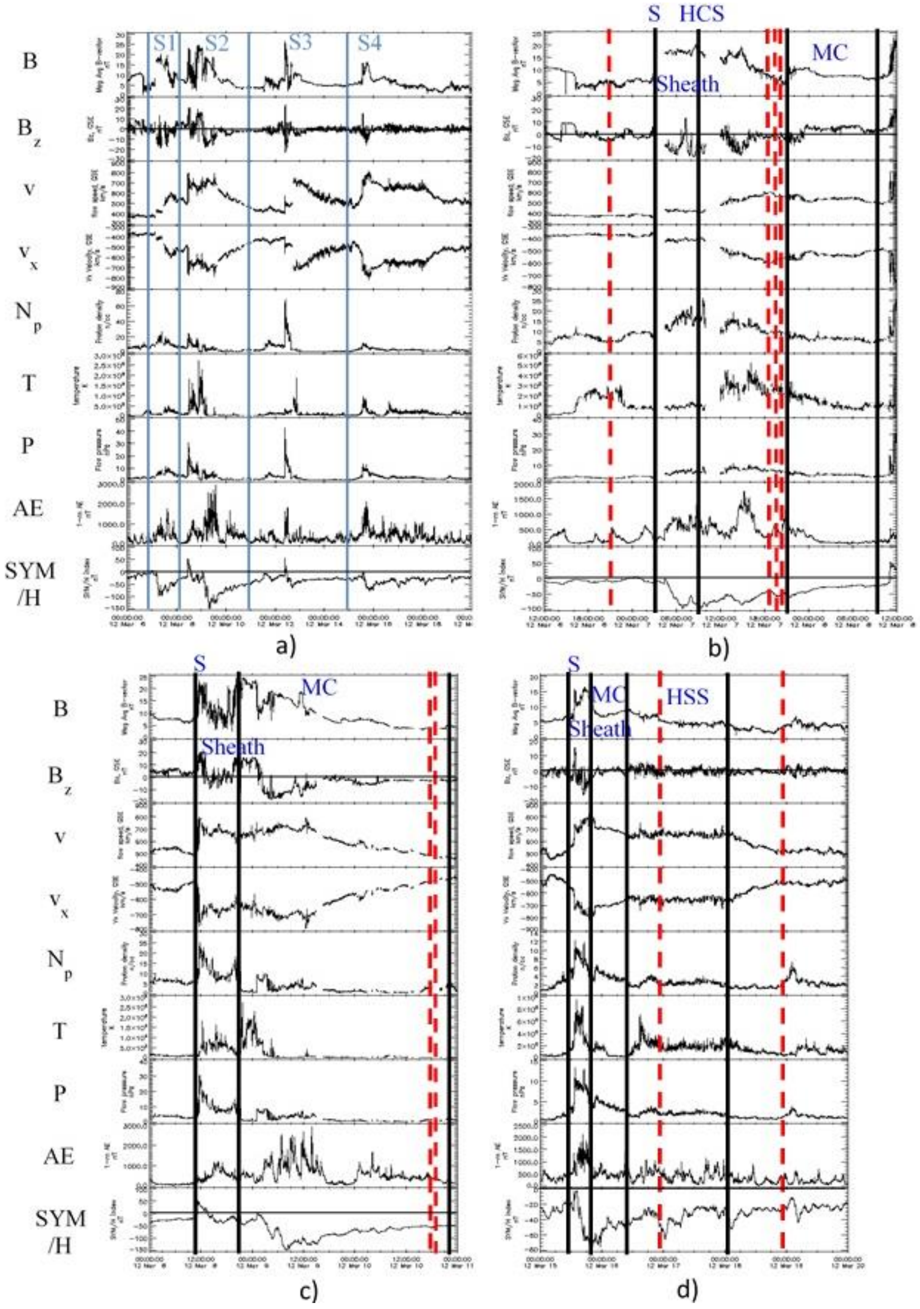


*Fig. 1. a) Overview of the interplanetary conditions during the time period 7–20 March 2012; b) Detailed view of the interplanetary conditions during S1 event (6–8 March 2012); c) The same as b) for S2 event (8–11 March 2012); d) The same as b) for S4 event (15–20 March 2012).*

**Case 1**. Substorm at 18:45 Universal Time (UT), 7 March 2012.

The substorm began during the first event (S1) of the disturbed interval 7-17 March 2012 during a storm with $Dst_{\min}$ = -98 nT caused by the southward directed sheath fields (Fig.1b). In Fig.2 are shown the variations of *x* magnetic field component from 12:00 to 24:00 UT on 7 March 2012 by the IMAGE meridional chain TAR-NAL. The substorm time is indicated by an ellipse. The magnetic disturbance began at *Oulujärvi* (OUJ) at CGM latitude=60.99°N and spread to *Sørøya* (SOR) at CGM latitude=67.34°N. The substorm development is presented in Fig. 3 by chosen images of the all-sky camera. The world directions are shown on the first image and UT is written above the images. The substorm occured during the recovery phase of the storm, near the maximal storm development and the *Dst* was -45 nT. Subtsorm auroras appeared in the South part of the field of view in 18:45 UT. The auroras moved towards North, reached zenith in about 18:53 UT and after that auroras surpassed it. The substorm development can be studied in more detail by the GC keograms (Fig. 4). In the GC keograms the substorm auroras are seen first in 18:52 UT. The substorm development is clearly expressed up to 19:20 UT.

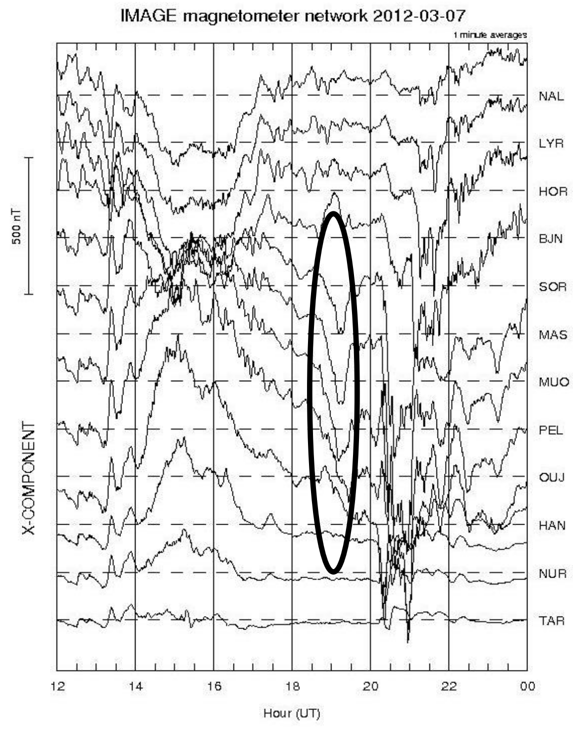


*Fig. 2. Magnetic field x-component data, 12:00–24:00 UT, 7 March 2012.*
*The substorm time is marked by an ellipse.*

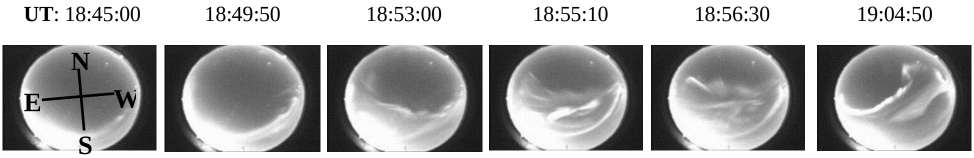


*Fig. 3. The substorm development by all-sky images at 18:45 UT, 7 March 2012.*

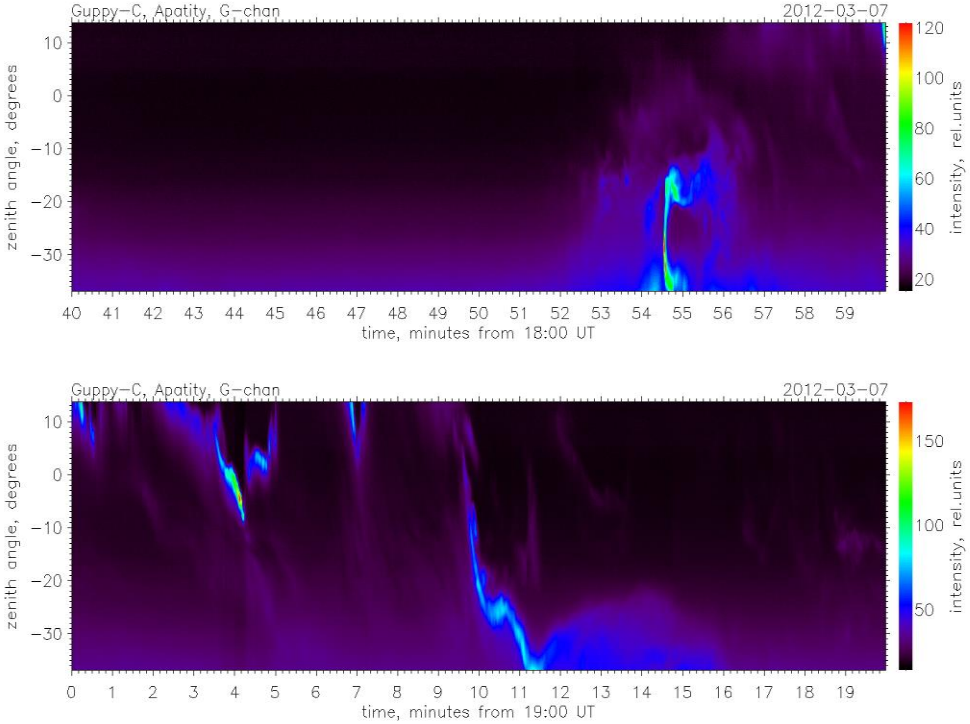


*Fig. 4. The substorm development by the GC camera keograms: 18:40–19:00 UT (up) and 19:00–19:20 UT (down).*

**Case 2**. Substorm at 18:35:50 UT, 10 March 2012.

The substorm developed during the second event (S2), when a geomagnetic storm was generated by a MC. $Dst_{\min}$ reached -148 nT. The substorm occurred in the late recovery phase, *Dst* was -50 nT (Fig. 1*c*). The magnetic field data during this time are shown in Fig. 5. The magnetic disturbance in this case was at higher geomagnetic latitudes. It extended from *Pello* (PEL) at 63.55°N

CGM lat. to *Longyearbyen* (LYR) at 75.12°N CGM lat. The substorm development is presented in Fig. 6 by selected AS images. The format is the same as in Fig. 3. The substorm onset over *Apatity,* towards the North of the station, was at 18:35:50 UT on 10.03.2012. The auroras traveled to South, reached zenith at 18:39 UT and moved further to South. A more detailed picture is given by the GC keograms (Fig. 7). In the keograms, the substorm auroras are seen from 18:38:30 UT at about 15° to North from zenith (the upper panel). The fast movement to South and the occupation of the field of view by substorm aurora are seen (the bottom panel).

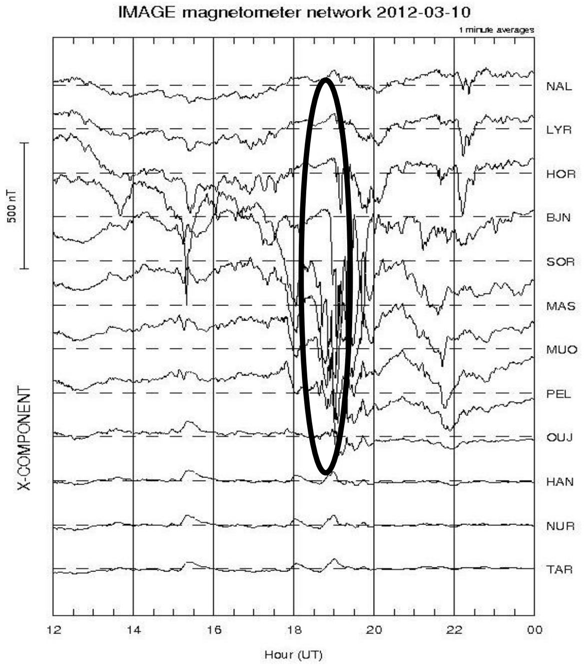


*Fig. 5. Magnetic field x-component, 12:00–24:00 UT, 10 March 2012. The ellipse indicates the substorm time.*

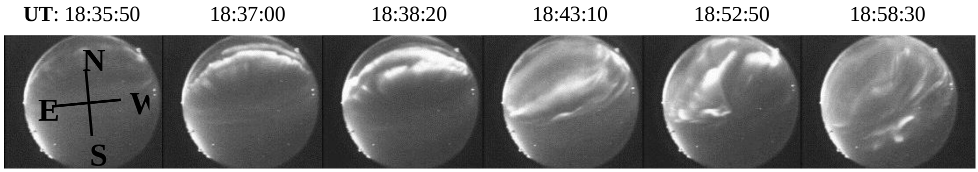


*Fig. 6. Development of the substorm on 10 March 2012 at 18:35:50 UT by chosen all-sky images.*

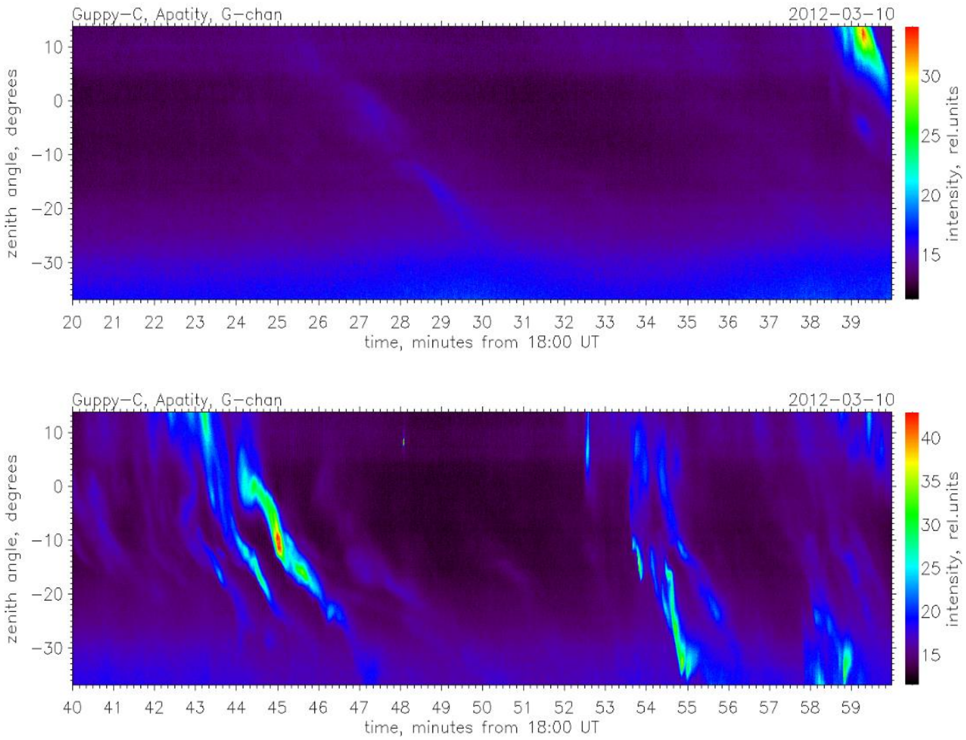


*Fig. 7. The substorm on 10 March 2012 by the GC keograms: 18:20–18:40 (up) and 18:40–19:00 UT (down).*

## Discussion

We studied substorms occurring during the highly disturbed period 7–17 March 2012 when different sources in the solar wind provoked four consecutive geomagnetic storms by data of the *Apatity*'s MAIN system. The substorm onset location is connected to the auroral oval position. It is known that under normal condition, i.e. moderate disturbance, the auroral oval is located at ~65-67° CGM latitudes ("normal oval"), under quiet conditions the auroral oval shrinks and moves to higher latitudes (>70° CGM latitudes, "contracted oval"), and in disturbed conditions the oval expands up to 50° CGM latitude ("expanded oval") [13]. Thus, in quiet conditions *Apatity* (63.86° CGM latitude) is expected to turn out equatorward the auroral oval, and in disturbed conditions – poleward the auroral oval. This was confirmed by the observations of auroras in *Apatity* during 2012/2013 winter season [14].

Therefore, for substorms generated during a geomagnetic storm the onset location depends on the stage of storm development. During the main phase of the storm or in the recovery phase, but near the *Dst* minimum, the auroral oval lies to the South of *Apatity*, the substorm onset is to the South as well, and the flash of auroras from South to North is observed from the station (Case 1). During the recovery phase the auroral oval moves to higher latitudes and in the late recovery phase it is located to the North from *Apatity*. Then the substorm onset is to the North, and auroras propagate from North to South (Case 2). Besides, it appears that the *Dst* limit between the cases of onset to the South and the ones of onset to the North is not constant and depend on the rank of the geomagnetic storm. More observations are needed to find out how to estimate this limit.

**Conclusions**

It was shown that substorms, originated during strong geomagnetic storms near the *Dst* minimum, occurred to the South of *Apatity*, and substorm auroras expanded in North direction. For substorms during the late recovery phase, auroras were observed to the North of the *Apatity* station, and their motion from North to South was registered.

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# СУББУРИ НАД АПАТИТИ ПРЕЗ ПЕРИОДА НА ПОВИШЕНА ГЕОМАГНИТНА АКТИВНОСТ 7-17 МАРТ 2012

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**Резюме**

Периодът 7-17 март 2012 г. е един от периодите с най-висока геомагнитна активност през възходящата фаза на 24 Слънчев цикъл. Поради това слънчевите и междупланетни явления през този период заедно с последващите процеси в магнитосферата и йоносферата са обект на изследване на научната общност. Цялата последователност от събития е дискутирана на няколко научни конференции. Слънчевите потоци, короналните дупки, короналните изхвърляния на маса, високоскоростните потоци в слънчевия вятър и междупланетните ударни вълни са идентифицирани и е изследвана реакцията на магнитосферата и йоносферата. През този период са настъпили 4 силни геомагнитни бури. Суббурите, възникнали през това време, са крайният ефект от всички тези събития. За да се установи началото на суббурите и да се проследи развитието им са използвани измервания от Multiscale Aurora Imaging Network (MAIN) в Апатити и данни от мрежата магнитометри IMAGE. Бяха изследвани характеристиките на тези суббури и бяха сравнени със суббури, възникнали при подобни или различни условия.