Table 1. Potassium, calcium and sodium content (mg g^{-1} F.wt) of wheat shoot measured 1 and 3 min after the application of 500 mM NaCl to the root zone (Values in the parenthesis indicate ± S.E.)

Variety	Control	500 mM NaCl	
		1 min	3 min
Calcium			
Moti	9.20 (0.80)	8.60 (0.30)	7.80 (0.01)
Kharchia	10.65 (0.85)	13.30 (0.40)	14.30 (0.70)
Potassium			
Moti	17.95 (1.45)	19.20 (2.61)	15.80 (0.70)
Kharchia	19.30 (0.79)	27.30 (0.60)	27.50 (3.60)
Sodium			
Moti	4.15 (0.35)	4.90 (0.02)	4.90 (0.70)
Kharchia	2.50 (0.10)	3.10 (0.70)	3.00 (0.02)
K/Na ratio			
Moti	4.4	3.9	3.2
Kharchia	7.7	8.8	9.1

lowest in kharchia (2.50 mg g^{-1} F.wt). Marked changes in shoot K^+, Ca^{2+} and Na^+ content were seen at 1 min and 3 min after the addition of 500 mM NaCl to the root zone (Table 1). Kharchia showed highest increase in K^+ and Ca^+ content (27.5 and 14.30 mg g^{-1} F.wt, respectively) and lesser change in shoot Na^+ content (3.0 mg g^{-1} F.wt). Hence it had a higher K/Na ratio of 8.8 and 9.1 at 1 and 3 min respectively. In moti a marginal increase in shoot K^+ and Ca^{2+} content was seen at 1 min but it decreased later, whereas the Na^+ content increased suddenly, thus it had a very low K/Na ratio of 3.9 and 3.2 at 1 min and 3 min respectively.

Figure 1 shows the change in amplitude of shoot EP on addition of different concentrations of NaCl in the root zone. The change in EP is proportional to the concentration of NaCl. At 100 mM NaCl the change in amplitude of EP and its speed was less compared to the addition of 500 and 1000 mM NaCl wherein the change in EP rises sharply and then begins to level off. This response is a typical variation potential essentially similar to that found in *Lycopersicon* with either heat or wounding[8], wheat leaves with wounding[9] and pea seedlings upon stem exicision[10].

An interesting observation recorded in this study was the change in amplitude of EP and its speed on addition of NaCl between a salinity-tolerant and salinity-sensitive variety of wheat. While addition of NaCl produced less noticeable change of EP in the salinity-tolerant variety kharchia, the amplitude of EP rose sharply and then gradually levelled off in the salinity-sensitive variety moti. Shoot ionic content measured 1 and 3 min after application of NaCl showed that the K^+ and Ca^{2+} content had suddenly increased in kharchia, while moti had higher Na^+ content. This is in conformity with earlier reports that salinity-tolerant varieties transport less sodium from roots to shoots than salt-sensitive genotypes[11]. Thus, kharchia had higher K/Na ratio compared to moti. Similar results were reported earlier in other crops[12]. Thus it is clear that the variation seen in uptake of ions between the wheat varieties under salinity had caused a change in shoot surface EP. It is a preliminary observation and needs to be seen in other crops before generalizing it as a tool for rapid screening of genotypes for salinity tolerance.

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Boron isotopic composition in early solar system solids

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Abundance and isotopic composition of boron (B) are determined in refractory silicate phases from the primitive carbonaceous chondrite Efremovka using an ion microprobe. These refractory phases represent some of the earliest solids to condense from the solar nebula. All the analysed phases (anorthite, melilite and fassaite) have very low B content ranging from 0.1 to 1.3 ppm; anorthite has relatively higher B content than melilite and fassaite. The measured values of the $^{11}B/^{10}B$ ratio in anorthite grains are similar and indistinguishable from the normal ratio of 4.04558 within experimental uncertainties. This is at variance with the reported large magnitude B isotopic anomalies within individual meteoritic chondrules[1] whose formation in the nebula postdates refractory silicates. Although B isotopes could have been homogenized during the formation of refractory phases, plausibility considerations suggest that our data are consistent with a uniform distribution of B isotopes of normal composition in the solar nebula.

THE light elements Li, Be and B are not produced in primordial nucleosynthesis, with the sole exception of ^7Li. They are also destroyed by proton-induced reactions during stellar nucleosynthesis at temperatures of two to

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five million degrees. These elements and their isotopes are therefore considered to be products of energetic particle interactions with interstellar matter within our galaxy[2–4]. The primary mode of production of these elements is high energy galactic cosmic ray (GCR) proton and alpha particle induced reactions on heavier elements like C, N and O present in the interstellar medium. Theoretical calculations suggest that the production by high-energy GCR particles will yield a value of 2.5 for the $^{11}B/^{10}B$ ratio. However, the measured values for this ratio in solar system objects such as meteorites and lunar samples are close to 4 (see e.g., ref. 5). Additional contribution from interactions of low energy (tens of MeV) heavy ions (C, N, O) with interstellar H and He, that preferentially produce ^{11}B has been proposed to account for this mismatch[6–8]. These interactions will also lead to excitation of ^{12}C and ^{16}O atoms. The detection of gamma ray emissions from such excitations provides proof for the existence of such a population of low energy heavy ions in our galaxy[9–11]. It has also been proposed that production of isotopes by these low energy ions within the protosolar molecular cloud fragment may explain some of the observed isotopic anomalies in meteorites, including the reported B isotopic anomalies in chondrules[1,11–14].

Measurement of the abundance and isotopic composition of B in natural samples is a difficult task both due to its low abundance, typically less than a ppm (parts per million), and the problem of laboratory contamination. High quality data for bulk samples of meteorites indicate a nearly uniform $^{11}B/^{10}B$ ratio in them that lies within ± 10‰ of the normal B isotopic ratio[5]. However, Chaussidon and Robert[1] reported large magnitude B isotopic anomalies within individual silicate chondrules from three meteorites, with variations in the $^{11}B/^{10}B$ ratio of up to ± 50‰ from the normal value. Chondrules are spheroidal objects found in chondritic meteorites and considered to have formed by rapid crystallization of molten silicate droplets produced in the solar nebula during high temperature events[15]. The observed anomalies were attributed to varying amounts of B isotopes produced by low energy particles within the protosolar cloud with presolar grains as carriers of these anomalous B isotopic components. The variation seen within small spatial scales of a few tens of microns within individual chondrules was

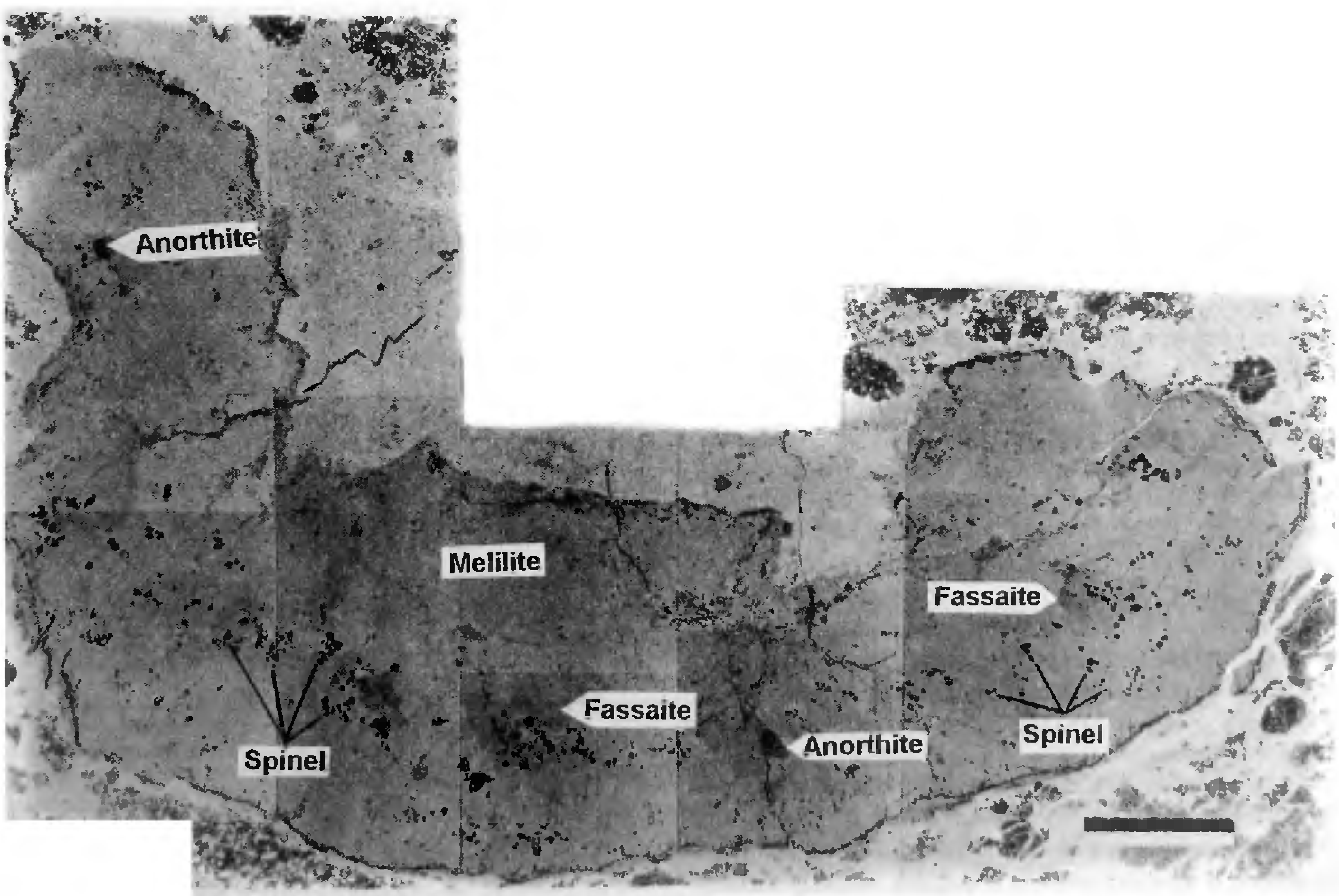

Figure 1. Backscattered electron micrograph of a polished section of a fragment of the CAI E44. The various refractory phases present in the inclusions can be easily identified. Melilite is the dominant phase, followed by fassaite. Anorthite occurs as a minor phase. Small spinel grains are distributed throughout the inclusion. Scale bar is 1 mm.

attributed to the small (~ 5 μm) size of the carrier grains whose anomalous boron isotopic signatures were not completely obliterated during the chondrule formation process.

Some of the primitive chondrites also contain refractory oxides (e.g., corundum, hibonite, perovskite, spinel) and silicates (e.g., melilite, fassaite, anorthite, diopside) that are considered to be the earliest condensates from the solar nebula[16]. The formation of these refractory phases predates that of the less refractory silicate chondrules found in these meteorites[17]. The presence of the now-extinct short-lived nuclides such as ^{41}Ca and ^{26}Al in these refractory phases confirms their extreme antiquity (see, e.g., ref. 18); chondrules are generally devoid of these short-lived nuclides. It is therefore reasonable to expect that the B isotopic anomalies seen in meteoritic chondrules are also present in the earlier formed refractory phases, with the magnitude of such anomalies being even higher than that seen in chondrules. We have, therefore, initiated a study of B isotopic composition in some very specific refractory meteoritic phases and report here the results obtained by us.

The refractory silicate phases analysed in this study were found in a Ca–Al-Inclusion (CAI) from a primitive carbonaceous chondrite Efremovka. We have analysed this CAI (E44) earlier for its Mg and K isotopic compositions and found evidence for the presence of the short-lived nuclides ^{26}Al (half-life = 7.3×10^5 years) and ^{41}Ca (half-life ~ 10^5 years) within this inclusion at the time of its formation[19,20]. These observations suggest that this CAI must have formed during the earliest stages of evolution of the solar system[19]. E44 is composed primarily of melilite and fassaite with minor amount of anorthite. Small spinel grains, distributed throughout the CAI, are poikilitically enclosed by fassaite and melilite. A scanning electron micrograph of the polished surface of an irregularly shaped fragment of this CAI is shown in Figure 1. The different mineral phases present can be easily identified in this representative section. All the measurements reported here were made on this section. We have also analysed two terrestrial samples as reference standards. One of them GB-4 (a fused glass made of Himalayan Leucogranite), prepared at CRPG–CNRS, Nancy, France (courtesy M. Chaussidon), has a known B content of 970 ppm and a ^{11}B/^{10}B ratio 12.5‰ lower than the normal value. The other sample was an anorthositic glass (from the AN–MG series) prepared at Caltech (courtesy I. D. Hutcheon), whose B content as well as B isotopic composition are unknown.

We have used a Cameca ims-4f ion microprobe to measure B content in different refractory silicate phases (anorthite, melilite and fassaite) in the CAI E44, followed by precise B isotopic ratios in anorthites. A finely focused $^{16}O^-$ primary beam of ions (17 keV energy, 8 nA) was used to sputter an area of about 20 μm of the sample surface. The secondary ions were extracted at 4.5 kV and energy filtered in an electrostatic analyser. An energy window of 25 eV was used to select secondary ions for mass analysis at a resolving power (M/ΔM) of ~ 1,500 that is sufficient to resolve the hydride [^{10}BH]$^+$ interference at mass 11 (^{11}B). A pre-burn of the selected spot for about 20 min was done to ensure removal of possible surface contaminants and steady $^{11}B^+$ count rate. The B content of each of the analysed phases was inferred by comparing its count rate of $^{11}B^+$ with that of the terrestrial standard GB-4 under identical instrument operating conditions. The B isotopic composition was measured only in the anorthite grains that have relatively higher B content (~ 1 ppm) than melilite and fassaite. The measured isotopic ratio in a grain represents the mean of 20 blocks of data, with each block constituting 5 cycles through the masses 10 and 11 counted for 30 s and 15 s, respectively in automatic peak-jumping mode. Magnetic field recalibration was done after every 2 blocks during each run. The total counts at mass 11 ($^{11}B^+$) in a complete analysis were typically ≥ 10^4.

Our results show that the refractory silicate phases contain very little boron. The B content in melilite and fassaite varies from 0.1 to 0.4 ppm, while it is somewhat higher in the anorthite (0.2–1.3 ppm). We can rule out laboratory contamination as a cause for higher B content in anorthite, as all measurements were carried out on a single section of E44 under identical instrument operating conditions. The higher B content in anorthite is consistent with inferences drawn from a recent study on behaviour of Be and B in the solar nebula under equilibrium conditions[21]. According to this study, B is less refractory than Be and will condense into solid solution with feldspar and most of it will condense as danburite ($CaB_2Si_2O_8$) in solid solution with anorthite during formation of CAIs. In contrast, the more refractory Be will be concentrated in melilite.

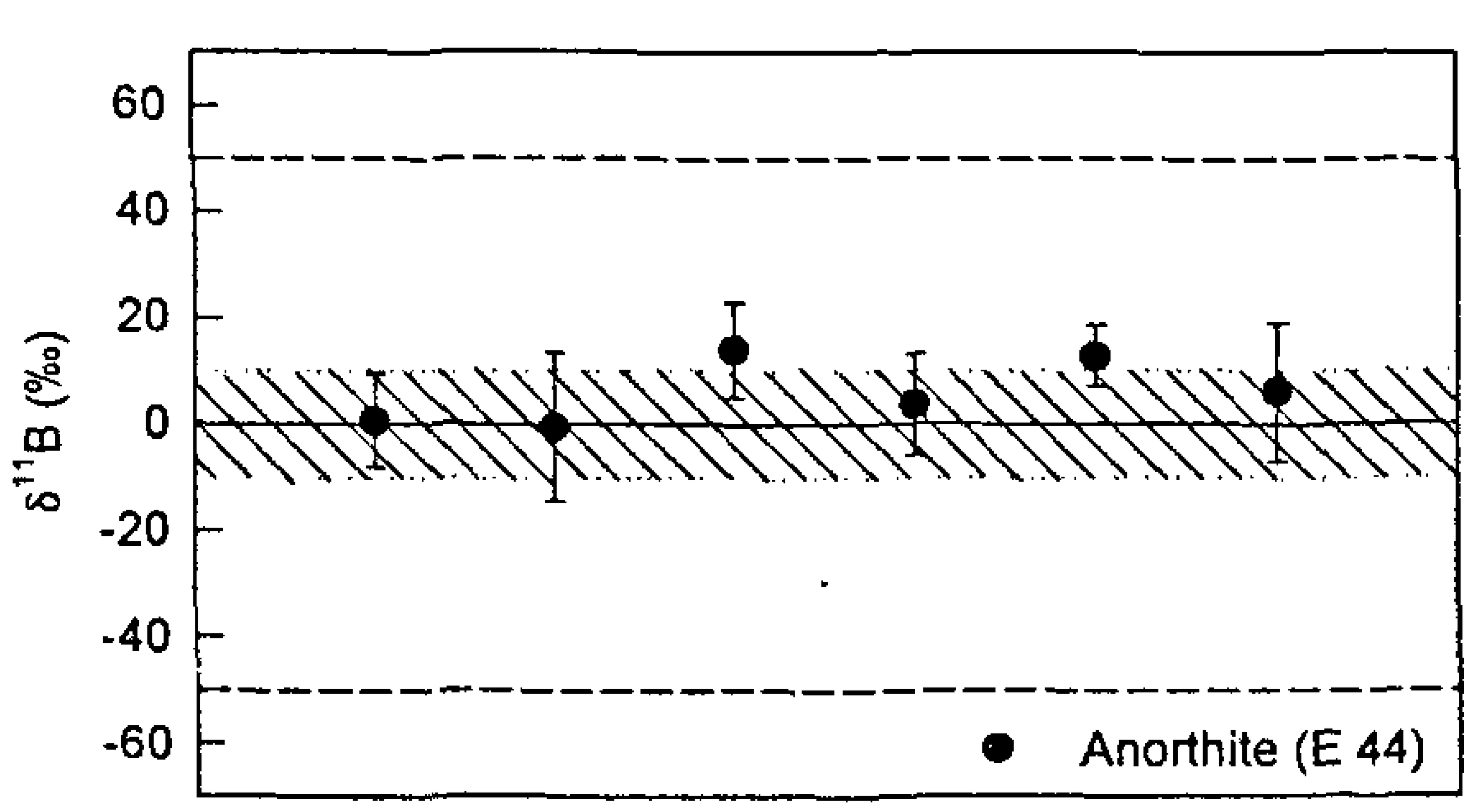

Figure 2. δ^{11}B values, defined as $[\{(^{11}B/^{10}B)_{measured} - (^{11}B/^{10}B)_{standard}\}/(^{11}B/^{10}B)_{standard}] \times 1000$, for the six analyses in four anorthite grains in the CAI E44 from the Efremovka meteorite. All the values are consistent with normal ^{11}B/^{10}B isotopic ratio defined by $\delta^{11}B = 0$ (the solid horizontal line). The dashed region encompasses the range of δ^{11}B values seen in meteorites and lunar samples[5]; the dashed lines encompass the spread in the range of the δ^{11}B values in chondrules reported by Chaussidon and Robert[1].

The measured $^{11}B/^{10}B$ ratios from all our six analyses on four anorthite grains from the CAI E44 are very similar. If the measured $^{11}B/^{10}B$ ratio in the terrestrial standard GB-4 is used to correct for instrumental fractionation, the $^{11}B/^{10}B$ ratios in the anorthite grains are indistinguishable within experimental error from terrestrial composition, as can be seen from Figure 2. As the Al/Mg ratios of GB-4 glass and E44 anorthite differ by less than a factor of 2 (~ 100 vs ~ 200), the instrumental mass fractionation on B isotopes should be similar in these two sets of samples. The typical 1σ error on the measured B isotopic ratios is ~ 8‰ and primarily reflects statistical uncertainty resulting from the low count rates due to the low B content in the anorthite grains. The measured B isotopic compositions of the E44 anorthites are also indistinguishable from that in the AN–MG anorthositic glass, within our measurement uncertainties. The boron content of this glass was determined to be ~ 6 ppm.

Our results are at variance with the reported large magnitude B isotopic anomalies over small spatial scales within individual chondrules of the three meteorites, Semarkona, Allende, and Hedjaz[1]. The range of values reported in that work is also shown in Figure 2 for comparison along with the range of values reported for bulk samples of different meteorites[5]. One might argue that the uniform B isotopic composition in anorthites from the CAI E44 is due to the complete homogenization of B isotopes during formation of this refractory phase. The mineralogy and petrology of the CAI E44 suggest its formation by crystallization of a refractory melt in the solar nebula[19]. This could have erased any heterogeneity present in the material parental to this CAI. But, meteoritic chondrules were also formed in the nebula by crystallization of silicate melt droplets[15]. So, if the B isotopic anomalies, carried into the solar nebula by small micron-sized presolar grains[1], can survive the chondrule formation process, they should also survive the CAI forming process, though the temperature is somewhat higher in the latter case. Many CAIs formed by crystallization of refractory melt in the solar nebula do show abundance anomalies in the n-rich isotopes (particularly for ^{48}Ca and ^{50}Ti)[22–25]. The carriers of these isotopic anomalies are also believed to be presolar grains. Since our data reveal only normal and uniform B isotopic compositions in some of the earliest formed solar system solids, the origin of the large B isotopic anomalies reported from chondrules remains an engima.

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