AGE VARIATIONS AMONG ORDINARY CHONDRITES: U-PB CHRONOLOGY OF CHONDRULES. E. Rotenberg[1,2] and Y. Amelin[1,3], [1]Department of Geology, University of Toronto, 22 Russell St., Toronto, ON, M5S 3B1, Canada (ethanr@galena.geology.utoronto.ca), [2]Department of Earth Sciences, Royal Ontario Museum, 100 Queen's Park, Toronto, ON, M5S 2C6, Canada, [3]Geological Survey of Canada, 601 Booth St., Ottawa, ON, K1A OE8, Canada (yamelin@NRCan.gc.ca).

Introduction: Silicates from ordinary chondrites have been successfully dated using the U-Pb system. Preliminary studies focused on silicate mineral fractions and pyroxene-rich chondrule fragments and individual chondrules [1,2]. Here we report the results from U-Pb analyses of whole chondrules and chondrule fragments from a wider range of ordinary chondrites of various chemical classes and metamorphic types. Unlike chondritic phosphates, which are secondary minerals [3], chondrules are primary components of chondrites. Dating them may allow us to reach back to their formation.

It is as yet unclear whether the chondrule ages reflect primary formation ages, or resetting during an early stage of thermal metamorphism. It is also unclear whether chondrules from any ordinary chondrite can be dated using U-Pb method with necessary precision and accuracy. We discuss the potential of chondritic silicates as cosmochronometers as they relate to our knowledge of the early history of the solar system.

Procedure: Because all samples analyzed were either whole chondrules, or large chondrule fragments, sample separation was rendered comparatively easy - there was no need for either magnetic or heavy liquid separation. Chondrules were hand-picked from coarsely ground material. They were ultrasonicated in a mixture of 6N HCl and ETOH to remove matrix material adhering to the chondrules. Chondrules were further washed in 2N HCl in ultrasonic for four cycles of ten minutes each. The purpose of the repeated washing was to remove terrestrial common Pb which may have contaminated the sample. Pb blanks processed with the samples average 2.4 pg and blank corrections were small for most analyzed samples.

Results: A brief summary of the data is presented in Table 1. U concentrations in chondrules range from 1 ppb to 2.2 ppm; Pb concentrations range from 3 ppb to 3 ppm. L6 Barwell, LL5 Tuxtuac and the Unnamed Antarctic LL3 [4] have much higher Pb concentrations than the other meteorites studied here, averaging 1.2, 1.3 and 0.2 ppm respectively. This high Pb content is most likely due to terrestrial contamination, as reflected by the low ^{206}Pb/^{204}Pb of approximately 17 - far lower than for any of the other analyses reported here.

Among these meteorites, those from the H class contain the most radiogenic Pb, although L6 Holbrook also has high ^{206}Pb/^{204}Pb with a maximum of 164. However, none of the meteorites analyzed have such high ^{206}Pb/^{204}Pb ratios as those reported for H5 Richardton [1], some of which exceed 1000.

Chronology: ^{207}Pb-^{206}Pb isochron ages are shown in the Table 1. Five of these ages have precisions of 15 Ma or better. These are: H4 Ankober (4563 ± 3 Ma), L4 Saratov (4548 ± 8 Ma), L4 Bjurböle (4552 ± 11 Ma), L6 Holbrook (4561 ± 15), and H4 Kidairat (4531 ± 15 Ma).

These ages almost all overlap making comparisons between different classes of meteorites difficult. Two which can be clearly resolved are Ankober and Kidairat. These two meteorites both belong to the same chemical class and petrologic type, H4, and thus we can expect similarity in their origin and age. Both have reasonably high ^{206}Pb/^{204}Pb, which generally indicates that they have experienced a minimum of Pb redistribution or terrestrial contamination. Moreover, both meteorites are falls, further reducing the chances of terrestrial contamination while exposed to the elements on the Earth's surface. And finally, both are petrographic type 4, indicating a minimum of thermal metamorphism. All this would hint at precise and similar ages. And yet, the dates are not similar, and that of H4 Kidairat is not particularly precise. However, ^{206}Pb/^{204}Pb ratios are higher for Ankober than for Kidairat (maximum value of 424 vs. 253). It seems likely, therefore, that Kidairat has experienced a disruption to its U-Pb system while Ankober has escaped this disturbance.

The other meteorites dated with sufficient precision to resolve the dates from one another also belong to the same chemical group, and therefore pose a similar problem. The LLs included here, LL3 Krymka, LL5 Tuxtuac, and an Unnamed Antarctic LL3 have much larger uncertainties attached to their ages, approximately ± 35 Ma, but the ages are nevertheless clearly resolved. What is interesting is that LL5 Tuxtuac and the Antarctic LL3 have nearly the same age, 4493 ± 50 Ma and 4499 ± 34 Ma respectively, while LL3 Krymka is clearly older, at 4576 ± 18 Ma. All three of these meteorites, however, have low ^{206}Pb/^{204}Pb ratios - LL3 has the highest average ratio of 39, while the other two are only 17 - and high Pb concentrations, indicating the likelihood of terrestrial contamination, and therefore casting doubt on the reliability of these ages. It is curious, however, that both LL3 Krymka and LL5 Tuxtuac are falls, and therefore should not have been exposed to abundant opportunities for terrestrial contamination.

Discussion: Following the initial success with precise ages for H5 Richardton (4563 ± 2 Ma) and L5 Elenovka (4554 ± 2 Ma) it was hoped that other chondritic silicates would yield equally precise ages. And this opened up many possibilities for the contributions that this chronometer could make to our knowledge of the early solar system. Because chondrules are primary components of meteorites, their ages reflect either actual chondrule formation, or a very early stage of thermal metamorphism. This in turn is significant for our understanding of when and how the chondrite parent bodies formed. Of special importance is the fact that when combined with phosphate ages, which reflect a later stage of thermal metamorphism, cooling rates can be determined, and these cooling rates can be fixed to an absolute time-scale.

The expansion of this study to include many other meteorites has shown that Richardton and Elenovka are perhaps the exceptions, rather than the rule, among chondritic silicates. While some meteorites have yielded precise dates, the majority do not. There are three probable reasons for this: disturbance of the U-Pb system during thermal processing on the parent bodies, redistribution of Pb during impact events, and terrestrial contamination.

Three of the meteorites studied here, L6 Barwell, LL3 Unnamed Antarctic and LL5 Tuxtuac have low ^{206}Pb/^{204}Pb ratios of about 18. In the case of the Antarctic LL3, this might be explained by weathering. Barwell, on the other hand, like Tuxtuac and Krymka, is a fall, and therefore terrestrial contamination is likely to be less extensive. The disturbed U-Pb system may be attributed to thermal processing or impact events.

Common Pb content of chondrules even within a single meteorite is highly variable. For example, ^{206}Pb/^{204}Pb in H4 Kidairat ranges from 19 - 253. Only those meteorites which are least disturbed will yield precise ages. Meteorites chosen for study must be unweathered and unshocked but this in not necessarily enough. Upon analysis, even meteorites with no external evidence to suggest disturbance of the U-Pb system turn out to have been disturbed. Our studies show the necessity of removing as much common Pb as possible, and an important future step will be to continue to experiment with methods to do this with maximum efficiency.

The most successful result from this new group of meteorites has been H4 Ankober. The age of 4563 ± 3 Ma obtained from the most radiogenic chondrules of this chondrite agrees with the age of H5 Richardton. These are the oldest reliable ages obtained for chondrules from equilibrated ordinary chondrites. The agreement between the chondrule ages of H4 Ankober and H5 Richardton, and phosphate ages of H4 meteorites Forest Vale and Ste. Marguerite [3] suggests that thermal metamorphism of H-chondrites occurred very early, around 4563-4564 Ma, and that cooling of H4 chondrites after the peak of metamorphism was fast. Thus far, a certain thermal scenario can be proposed for the H group only. It remains to be seen whether precise ages for L and LL chondrules can be determined, and whether they reflect primary or secondary processes.

Table 1

	Meteorite	[U]* (ppb)	[Pb]* (ppb)	(^{206}Pb/^{204}Pb)**	^{207}Pb-^{206}Pb isochron age
H4	Ankober		35	424	4563 ± 3
H4	Kidairat		68	253	4531 ± 15
L4	Bjurböle	25	80	81	4552 ± 11
L4	Saratov		39	82	4548 ± 8
L6	Barwell		1186	21	4526 ± 27
L6	Holbrook	19	53	164	4561 ± 15
LL3	Krymka	23	43	45	4576 ± 18
LL3	Antarctic	23	214	18	4499 ± 34
LL5	Tuxtuac		1255	22	4493 ± 50

*average vaules **maximum values

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