KIMBERLITES OF CENTRAL SASKATCHEWAN (CANADA): COMPILATION AND SIGNIFICANCE OF INDICATOR MINERAL GEOCHEMISTRY WITH RESPECT TO DIAMOND POTENTIAL

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The central Saskatchewan Fort à la Corne (FalC) kimberlite field is located 60-km east of Prince Albert and comprises over 70 *in situ* bodies forming one of the largest diamondiferous kimberlite provinces in the world (Fig. 1) (Scott-Smith *et al*., 1994). The bulk of the bodies are located in the Fort à la Corne cluster, a north-northwest trending linear zone 50 km long and 15 km wide. Several satellite clusters, including the large Snowden cluster to the northeast, the Foxford and Weirdale kimberlites to the northwest, and the Candle Lake kimberlites to the north are also north-northwest trending.

The kimberlites are dissimilar from most kimberlites worldwide in that they are dominantly comprised of 'crater facies' volcaniclastic rocks (Lehnert-Thiel *et al.*, 1992; Scott-Smith *et al.*, 1994), which consist of pyroclastic lapilli- and olivine-dominated rocks, local debris flows and reworked volcaniclastic kimberlite (Kjarsgaard *et al.*, 1995; Leckie *et al.*, 1997; Jellicoe *et al.*, 1998; Kjarsgaard *et al.*, 2001). They are classified as group I bodies with most containing mantle derived (peridotitic and eclogitic) xenoliths and xenocrysts (e.g. garnet, chromite), along with xenoliths of Archean and Paleoproterozoic basement and Phanerozoic rocks.

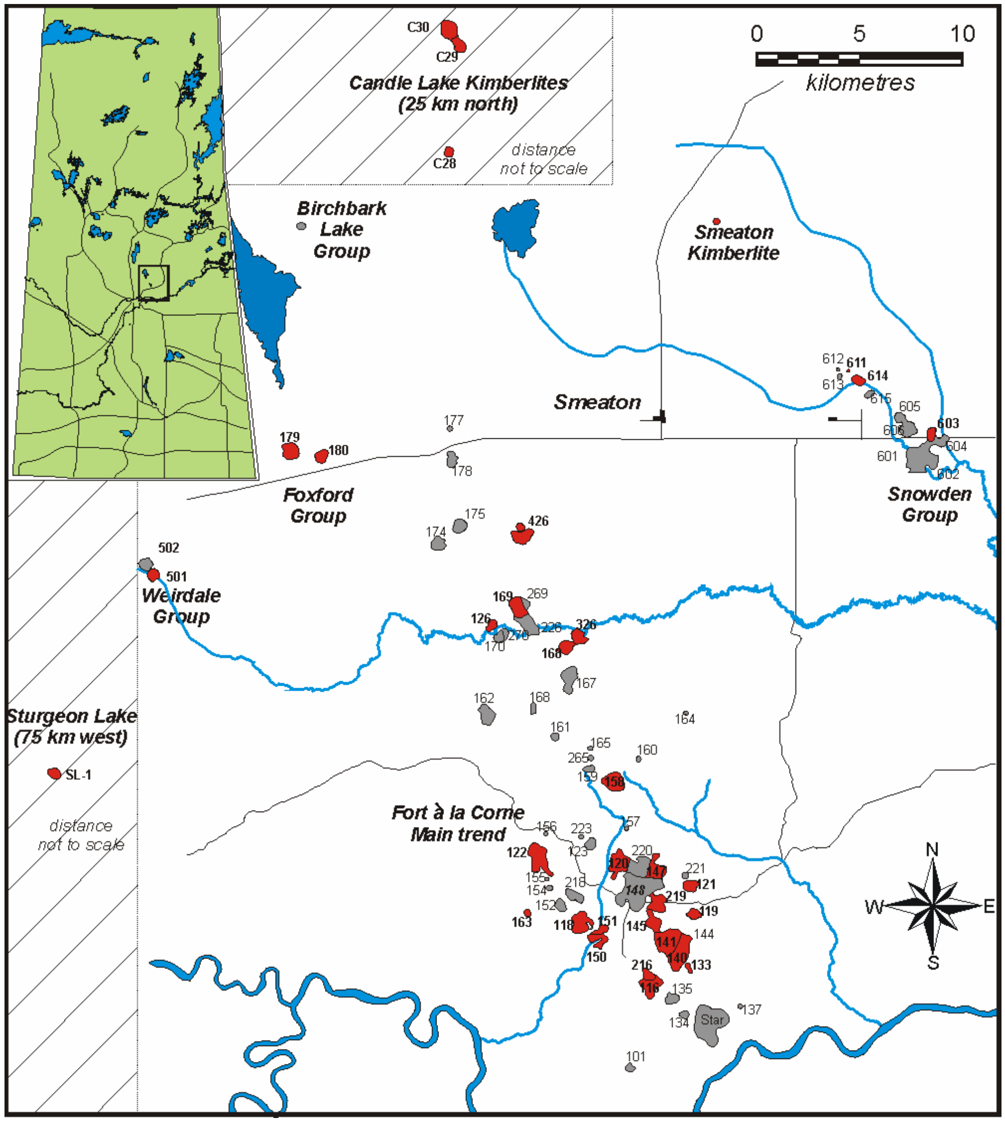

Figure 1: Map of central Saskatchewan kimberlites investigated in this study (red) (modified from Jellicoe *et al*., 1998). Note: Sturgeon Lake and Candle Lake areas are projected into the location map and distances are not to scale.

Analytical geochemical data for indicator minerals (garnet, chrome spinel and ilmenite) from 33 kimberlites have been compiled from non-confidential government assessment files and interpreted (Table 1). The bulk (22 of 33) of the mineral chemistry data are from kimberlites in the main Fort à la Corne field; the others are from the outlying clusters (Fig 1). The quality of the compiled data is highly variable and caution must be exercised when interpreting it: sampling procedure, mineral selection and analytical methodology varied between companies; sample weights and the number of drill holes utilized per kimberlite differed, resulting in a highly variable number of indicator grains analyzed per kimberlite; many of the kimberlite bodies are very large and composite, thus data from one drill hole may not be representative.

Table 1: Summary of heavy mineral sample compositions and counts from the central Saskatchewan kimberlites investigated.

Kimberlite	n= Total Garnet	n= Cr-Garnet (>2 wt%)	% Cr-Garnet (>2 wt%)	n= "G10" Garnets	% "G10" Garnets**	n= Sub-Cr Garnet (<2 wt %	%Sub-Cr garnet (>2 wt %)	n= Total Chromite	DI	% DI	n= Ilmenite (n=)	DPP
FalC 116	34	31	91	2	5.9	3	9	105	0	Nil	23	poor
FalC 118	53	22	42	0	Nil	31	58	9	0	Nil	14	v good
FalC 119	400	338	85	0	Nil	62	16	200	1	0.5	187	good
FalC 120	392	191	49	12	3.1	201	51	46	2	4.3	118	v good
FalC 121	46	18	39	3	6.5	28	61	13	3	23.1	12	poor
FalC 122	500	433	87	11	2.2	67	13	270	1	0.4	299	good
FalC 126	399	355	89	8	2.0	44	11	200	15	7.5	198	good
FalC 133	598	547	91	12	2.0	51	9	300	2	0.7	300	good
FalC 140	700	676	97	40	5.7	24	3	395	4	1.0	399	good
FalC 141	100	89	89	5	5.0	11	11	103	3	2.9	100	good
FalC 145	100	77	77	2	2.0	23	23	105	0	Nil	99	good
FalC 147	200	157	79	3	1.5	43	22	100	3	3.0	100	good
FalC 150	247	217	88	4	1.6	30	12	215	1	0.5	212	good
FalC 151	48	17	35	0	Nil	31	65	9	0	Nil	13	good
FalC 158	42	14	33	1	2.4	28	67	14	0	Nil	15	good
FalC 163	203	186	92	8	3.9	17	8	187	0	Nil	126	good
FalC 168	99	86	87	0	Nil	13	13	91	1	1.1	103	good
FalC 169	294	134	46	25	8.5	160	54	78	0	Nil	97	good
FalC 216	99	71	72	1	1.0	28	28	66	2	3.0	27	v good
FalC 219	66	38	58	4	6.1	28	42	5	0	Nil	21	v good
FalC 326	19	13	68	0	Nil	6	32	115	0	Nil	97	poor
FalC 426	192	115	60	1	0.5	77	40	110	0	Nil	72	v good
Candle Lk 28	652	588	90	65	10.0	64	10	123	6	4.9	323	good
Candle Lk 29	176	156	89	22	12.5	20	11	59	2	3.4	10	gd
Candle Lk 30	518	438	85	27	5.2	80	15	201	9	4.5	55	good
Foxford 179	101	67	66	2	2.0	34	34	106	0	Nil	122	good
Foxford 180	180	159	88	0	Nil	21	12	30	1	3.3	15	good
Smeaton RS-1	29	19	66	0	Nil	10	34	44	0	Nil	ND	
Snowden 603	47	44	94	0	Nil	3	6	117	0	Nil	101	poor
Snowden 614	28	28	100	0	Nil	0	0	130	0	Nil	96	v good
Snowden 611	63	32	51	2	3.2	31	49	17	0	Nil	20	v good
Sturgeon SL-1	89	53	60	0	Nil	36	40	3	0	Nil	45	good
Wierdale 501	4	3	75	0	Nil	1	25	123	0	Nil	85	v good

****** % G10 = # G10/Total Garnets
DI chromites that plot in the diamond inclusion/intergrowth field
DPP Diamond Preservation Potential: based on comparison with Fipke *et al.* (1995) analyses

INDICATOR MINERAL CHEMISTRY

GARNET

Most of the kimberlite bodies studied are dominated by garnets of peridotitic composition (> 2 wt % Cr_2O_3) (Fig. 2a-c; Table 1). Megacryst garnets, which overlap with P-type, E-type and crustal garnets in the range 0 to 4 wt % Cr_2O_3 and 3.75 to 6.0 wt % CaO, are common in most bodies (e.g. FalC 140, 169 and Candle 28). Cr_2O_3 contents of the P-type garnets reach 15.2 wt % and CaO contents vary from 0.6 to 9.7 wt % with lherzolitic compositions being dominant. This lherzolitic trend is clearly defined in many of the kimberlite bodies (e.g. FalC 140 and Candle Lake 28). Some of the garnets with >12 wt % Cr_2O_3 may be derived from garnet dunites.

Twenty-two of the 33 kimberlite bodies contained G10 garnets and show a large range in abundance, degree of calcium depletion and chrome enrichment (Fig. 2a-c; Table 1). G10 populations range from 2.6 to 15.2 wt % Cr_2O_3, and 0.9 to 6.2 wt % CaO. Kimberlites with significant G10 populations include the Candle Lake kimberlites, FalC 169, 140, 141, 120, and 163. A few others possibly contain noteworthy G10 populations, however there are too few data for a meaningful assessment.

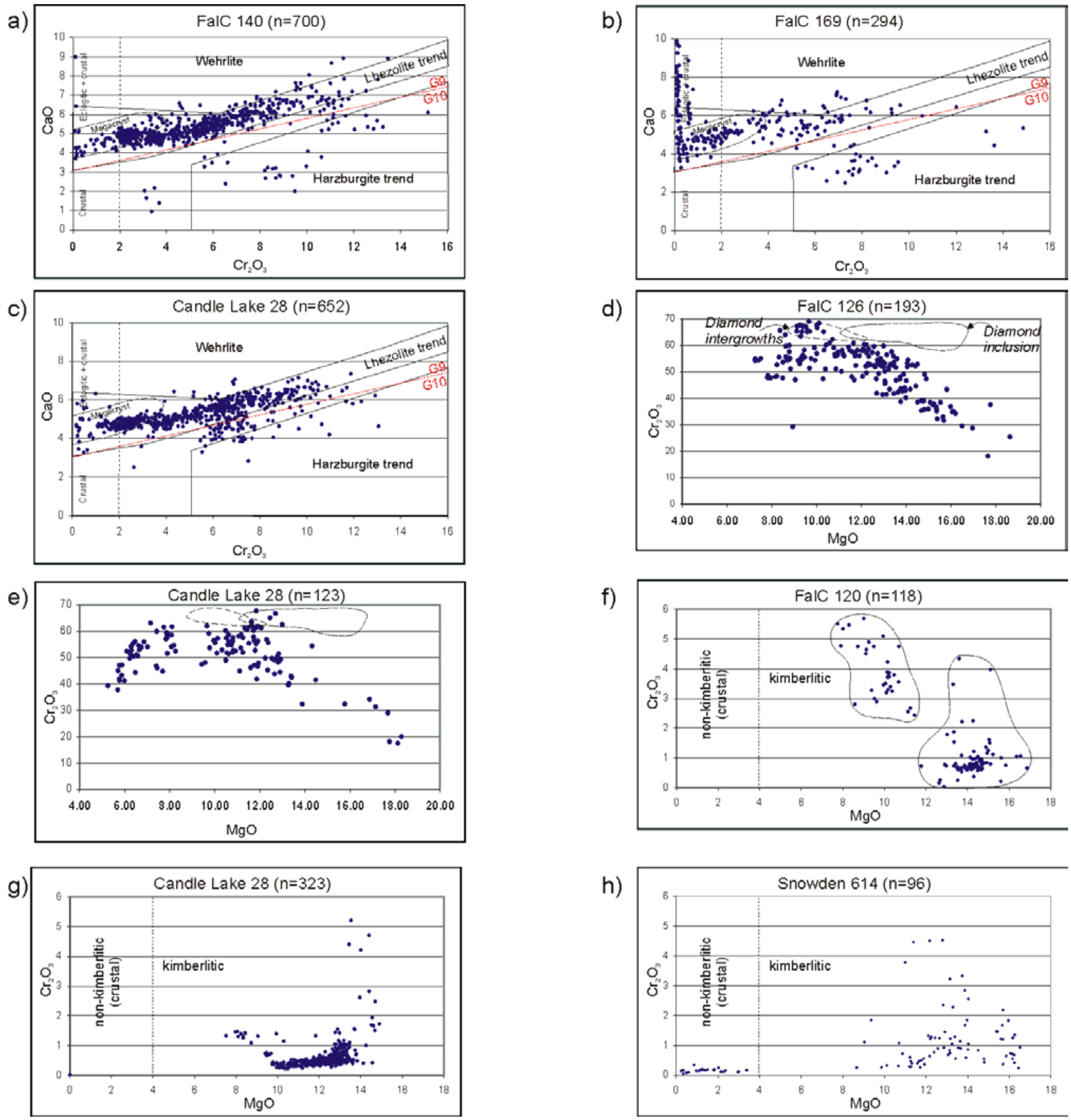

Figure 2: a-c) CaO versus Cr_2O_3 plot of garnets from some of the kimberlites examined in this study (all compositions wt %) (Peridotite fields from Sobolev *et al*., 1973; G10/G9 fields from Gurney, 1984; Megacryst field from Schulze, 1993); d-e) Cr_2O_3 versus MgO plot of chromite compositions from some of localities investigated (all compositions wt %) (Diamond intergrowth and inclusion fields after Fipke *et al.,* 1995). f-h) Cr_2O_3 versus MgO plot for ilmenite compositions from some kimberlites investigated (all compositions wt %).

Gurney (1984) pointed to calcium depletion in the G10 population as another significant indication of prospectivity. Those kimberlites with significant G10 populations, described above, along with substantial calcium depletion (< 3 wt % CaO) include FalC 120, 140, 141, and 169. FalC bodies 140 and 169 are particularly interesting in that they both have significant G10 populations, with very low calcium and high chromium contents (Fig. 2). Those kimberlites with garnet compositions that spread across and well into the sub-calcic G10 field may have the strongest potential for higher diamond contents.

Several of the kimberlites contain a significant population of sub-chromium (< 2 wt % Cr_2O_3) eclogite-, megacryst- or crust-derived garnet xenocrysts. Figure 2 shows that some of the sub-chromium garnets examined have intermediate-Ca compositions and consequently plot in the megacryst composition field, as seen in FalC 169. In terms of eclogitic differentiation, sodium concentrations in garnets are generally less than 1 wt %, however the accuracy and precision of the Na_2O analyses are not sufficient to confidently discriminate between group I and group II garnets.

CHROMITE

Chromite macrocrysts have highly variable compositions, with MgO values ranging from 1.84 to 19 wt % and Cr_2O_3 values from 16 to 69 wt %. Chromite compositions plotted on a MgO-Cr_2O_3 graph often display an inverted "U" shape (e.g. Candle 28), as previously noted by Jellicoe *et al.* (1998). Between approximately 5 and 9 wt % MgO there is a positive correlation between Cr_2O_3 and MgO. Between 9 and 11 wt % MgO, Cr_2O_3 remains constant, and at MgO contents greater than about 11 wt %, there is a negative correlation with Cr_2O_3 (Fig. 2d-e). Of the studied kimberlites, seven had too few chromite analyses to permit confident interpretation. Of those with larger data sets, 15 contained chromites with compositions similar to chromites from diamond inclusions and intergrowths (i.e. plot in the diamond inclusion and intergrowth (DI) field) (Fig. 2d-e; Table 1). Six of those had less than one percent of their sample set plot in the DI field, while the remaining nine had greater than 2.5 percent of their sampled chromite compositions plot in the diamond inclusion field. The highest proportion of chromites with DI-compositions occurs in FalC 126, 120, Candle Lake 28 and 30, while FalC 141, 147, Candle Lake 29 and Foxford 180 contain appreciable quantities of chromites with DI compositions. FalC 121 also contained 23 percent DI-composition chromites within a very small data set.

ILMENITE

Ilmenite analyses were available for 32 of the kimberlites, although 6 of those had sample populations of less than 20 (Table 1). Most of the remaining analyses indicate moderate to high MgO contents (average 12.02 wt % MgO), with highly variable Cr_2O_3 contents (Fig. 2f-h). Magnesium in some exceeds 16 wt % MgO, and only one body, Snowden 603, has a relatively low MgO content (average 9.85 wt % MgO). Chromium contents are highly variable with some being very low (average < 0.5 wt % Cr_2O_3) and others very high (average > 2.5 wt % Cr_2O_3). Crustal ilmenites (< 4 wt % MgO) are observed in a few bodies, with some having anomalously high concentrations (e.g. Snowden 614).

In terms of diamond preservation, ilmenites with a low Fe_2O_3 (Fe^{+3}) component are deemed to have formed in a relatively reducing kimberlite, increasing the diamond preservation potential (DPP) (Haggerty, 1986). Ilmenite with relatively high MgO and low Fe_2O_3 is considered to be indicative of reducing conditions in the parent magma. As reducing conditions prevent the oxidation of diamonds, kimberlites containing ilmenite with relatively high MgO content are considered to have high diamond preservation potential. A very important aspect to note is that the diamond preservation potential is only useful if diamonds were sampled in the first place.

Three compositional groups of ilmenite are distinguished (Fig. 2f-h). The first group defines backwards "L" shaped plots with most grains in the lower part of the graph (e.g. Candle 28). For ilmenites containing 10-15 wt % MgO, Cr_2O_3 is constant at about 0.75 wt %. In contrast, ilmenites with more than 15 wt % MgO exhibit a sharp increase in Cr_2O_3 (up to 5 wt %). This group represents 60 percent of the kimberlite bodies and probably corresponds to the MgO-rich limb of the "Haggerty parabola" (Haggerty, 1975). Most of these bodies have high MgO and Cr_2O_3 contents conducive to diamond preservation. However, four have low MgO or Cr_2O_3 contents that might indicate diamond resorption. FalC 116, 121, and 326 all have very low Cr_2O_3 contents (<0.5 wt %), while Snowden 603 has both low MgO (avg. 9.85 wt %) and low Cr_2O_3 (avg. 0.49 wt %).

FalC 120 (Fig. 2f), 145, 147 and 426 yielded two distinct sub-populations of ilmenite which define the second compositional group. The main sub-population contains high MgO and low to moderate Cr_2O_3 versus the other that is composed of high (2.5 to 6 wt %) Cr_2O_3 and variable MgO (7.5 to 12 wt %). The first three of the four (FalC 120, 145, and 147) have a second sub-population that plots within a very consistent range, and may indicate a relationship between them. The three kimberlites are found in a cluster surrounding kimberlite 148 (Fig. 1), for which no geochemical data was available. This group has good diamond preservation potential based on the high magnesium contents (avg. 11.87 wt % MgO) and high Cr_2O_3 contents (avg. 2.35 wt %).

The third grouping of ilmenites is defined by Cr_2O_3 contents that are independent of MgO, resulting in a large degree of scatter (Fig. 2h). For example, Snowden 614 ilmenite compositions show that the main kimberlitic population (separate from the crustal population) has a wide range in MgO contents (8 to 16 wt %) and Cr_2O_3 contents (0.25 to 4.6 wt %). These bodies have a good preservation potential as they have high average MgO content (11.95 wt %) and moderate to high Cr_2O_3 (avg. 1.26 wt %).

In order to gauge the relative diamond preservation potential based on ilmenite compositions the MgO-Cr_2O_3 plots were compared with those of Fipke *et al.* (1995), who distinguished categories of diamond preservation potential. Overall the DPP of central Saskatchewan kimberlites appears encouraging with many showing good to very good preservation potential

(Table 1). Four kimberlites, FalC 116, 121, 326 and Snowden 603, apparently have a poor preservation rating based on their very low MgO and/or Cr_2O_3 contents.

SUMMARY

The compiled indicator mineral data are interpreted to suggest great variation in potential of individual Saskatchewan kimberlites to contain diamonds. The interpretations on diamond potential are based on relationships between indicator mineral geochemistry and diamond potential recognized by various workers including Gurney (1984), Gurney and Moore (1991), and Fipke *et al.* (1995) predominantly on South African kimberlites and Sobolev *et al.* (1973) on Russian kimberlites. The applicability of such relationships in assessing the potential of Saskatchewan kimberlites will only be known in time.

Some of the more prospective kimberlites have significant garnet composition populations plotting within the sub-calcic G10 field and include FalC 169, 120, 141, 121 and the Candle Lake kimberlites. In addition, strong calcium depletion in FalC 120, 141, 169 and Candle Lake 29 suggest stronger potential. Chromite compositions plotting in the diamond inclusion and intergrowth fields are well represented in FalC 120, 121, 141, and the Candle Lake kimberlites. Taken together, the garnet and chromite compositions indicate that the potential for peridotitic diamonds in many of the central Saskatchewan kimberlites is high. The potential for eclogitic diamonds remains unresolved as sodium contents of garnet have not been determined with sufficient accuracy, however many kimberlites have significant sub-chromian garnet populations (e.g. FalC 120 and 169) suggesting potential for such diamonds.

Overall, a few kimberlites appear to have potential to be significantly diamondiferous based on indicator mineral geochemistry. Caution must be exercised, however, as the data set may not be completely representative as one or even a few drill holes can be concentrated in zones that are atypical of a particular kimberlite. Additionally, many of the bodies are very large and may be comprised of several eruptive phases emplaced over millions of years. Thus one drill hole may only represent a small fraction of these complexly diverse bodies.

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