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Uranium-lead ages of Defeat granitoid rocks near the Con mine, Yellowknife, Northwest Territories[1]

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Abstract: The Yellowknife greenstone belt is located in the southern Slave Province, Northwest Territories, and hosts the Con and Giant lode-gold deposits. This paper reports the ages of two pre-D_2 granitoid rocks of the Defeat plutonic suite from near the Con gold mine, selected to provide a maximum age for D_2 deformation zones that are broadly contemporaneous with syn-D_2 mineralization in the mine area. The Pud tonalite has a U-Pb age of 2632 ± 3 Ma, defined by both zircon and titanite, and a granitic dyke has a U-Pb zircon age of 2635 ± 4 Ma. These ages are the oldest yet determined for the Defeat plutonic suite.

Résumé : La ceinture de roches vertes de Yellowknife est située dans la partie sud de la Province des Esclaves (T.N.-O.) et renferme les gîtes filoniens d'or des mines Con et Giant. La présente étude fait état des âges de deux roches granitoïdes antérieures à D_2 de la suite plutonique de Defeat. Situées à proximité de la mine d'or Con, ces roches ont été choisies afin de définir l'âge maximal des zones de déformation D_2, lesquelles sont globalement contemporaines de l'épisode de minéralisation dans la région de la mine que l'on associe à cet épisode de déformation. La tonalite de Pud a été datée à 2 632 ± 3 Ma à l'aide de la méthode U-Pb sur zircon et sur titanite, alors qu'un dyke granitique a livré un âge U-Pb sur zircon de 2 635 ± 4 Ma. Ces âges sont les plus anciens déterminés jusqu'à maintenant pour la suite plutonique de Defeat.

[1] Contribution to EXTECH III Program

INTRODUCTION

The late Archean Yellowknife greenstone belt hosts the large Con and Giant lode-gold deposits. The Geological Survey of Canada recently initiated a collaborative study (EXTECH III) to enhance the understanding of the relationship of gold mineralization to the geological evolution of the belt, to develop new exploration strategies, and to boost mineable resources. One of the more important questions that remains unanswered is the absolute timing of gold mineralization.

This study was undertaken in an attempt to provide absolute age constraints on gold mineralization in the Con and Giant gold mines. Because suitable rock types for U-Pb geochronology are rare within the gold-bearing systems themselves, it was necessary to use indirect approaches to bracket the age of mineralization. A study of the deformation history and its relationship to gold mineralization in the Con and Giant deformation zones (Siddorn and Cruden, 2000) has shown that D_2 deformation and syn-D_2 mineralization in the deposits are broadly contemporaneous with regional D_2 deformation. Thus, relationships between regional D_2 structures and granitic dykes and small plutons have been used in an attempt to provide a meaningful maximum age for D_2 and, by inference, gold mineralization.

REGIONAL GEOLOGY

The Yellowknife greenstone belt is a north-northeast-trending, steeply southeast-dipping, upright homoclinal sequence. It is locally underlain by basement of the Central Slave Basement Complex (Bleeker et al., 1999, Fig. 1) and its autochthonous cover sequence, the Central Slave Cover Group (Bleeker et al., 1999). As defined by Helmstaedt and Padgham (1986), the Kam Group forms the base of the greenstone belt and consists predominantly of pillowed basalt and gabbro dykes and sills, with minor felsic volcanic rocks toward the top (Fig. 1). The Kam Group is thought to be unconformably overlain by predominantly felsic volcanic rocks of the Banting Group, although exposed contacts in the Yellowknife belt are marked by a fault (Martel et al., 2001). The Banting Group grades up into greywacke of the Burwash Formation. Polymictic conglomerate of the Jackson Lake Formation, the youngest supracrustal sequence in the belt, sits unconformably on top of the Kam and Banting groups.

Based on relationships in the Burwash Formation, the belt has undergone two regional deformation events (D_1 and D_2), characterized by large-scale folds (e.g. Davis and Bleeker, 1999). The D_1 deformation was at low metamorphic grade and is characterized by upward-facing, doubly plunging,

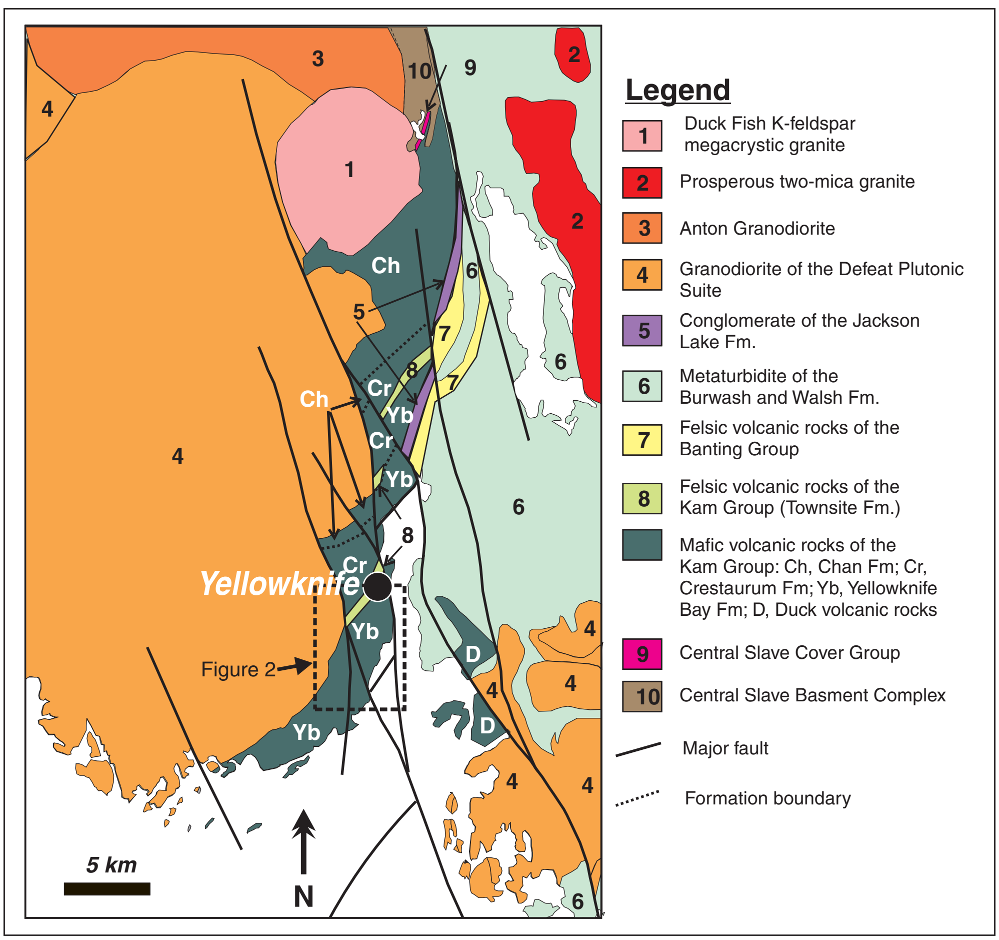

Figure 1. Simplified geology of the Yellowknife greenstone belt.

northeast-trending, tight chevron folds. The second event occurred broadly synchronously with peak metamorphism and generated north- to northwest-trending folds that are characterized by an axial-planar crenulation cleavage. Metaluminous rocks of the Defeat plutonic suite form large composite plutons west of Yellowknife and around Defeat Lake, and range in composition from tonalite to granite (Henderson, 1985). Defeat plutons generally cut D_1 folds but contain the S_2 foliation (Davis and Bleeker, 1999). Younger granitic rocks (e.g. Prosperous, Awry, and Morose granites) range from late syn- to post-D_2 (Davis and Bleeker, 1999).

The Giant and Con gold deposits are hosted in a series of brittle-ductile deformation zones that cut mafic volcanic rocks of the Yellowknife Bay Formation of the Kam Group. The two deposits are interpreted to represent different structural levels of a once-linked Archean gold system (e.g. Campbell, 1949; Boyle, 1953; Armstrong, 1997; Siddorn and Cruden, 2001). Siddorn and Cruden (2001) have documented three episodes of Archean deformation (D_1 to D_3), the first two of which are related to distinctive styles of mineralization. All the mineralization, however, postdates regional D_1 deformation and either predates or is synchronous with regional D_2 deformation (J. Siddorn, pers. comm., 2002). Regional D_2 deformation clearly outlasted gold mineralization, as the ore bodies are modified by D_2 (Siddorn and Cruden, 2000, 2001). Deformation zones belonging to D_2, similar in orientation and kinematics to the Campbell zone at the Con mine, occur in the Defeat-type 'western granodiorite' (Jolliffe, 1942) and contain free-milling gold (Siddorn and Cruden, 2000). The youngest age determined for this plutonic complex (2620 ± 8 Ma; Henderson et al., 1987) is presently the maximum age estimate of the regional D_2 deformation zones and their related gold mineralization.

SAMPLE LOCATIONS

A number of locations within the Yellowknife greenstone belt were examined in an attempt to find relationships between datable intrusive phases and regional D_2 structures. Crosscutting intrusive relationships that bracket D_2 were not observed. Granitoid bodies deformed by D_2 deformation zones are common, but only provide a maximum age bracket. In the immediate vicinity of the Con mine (Fig. 2), in addition

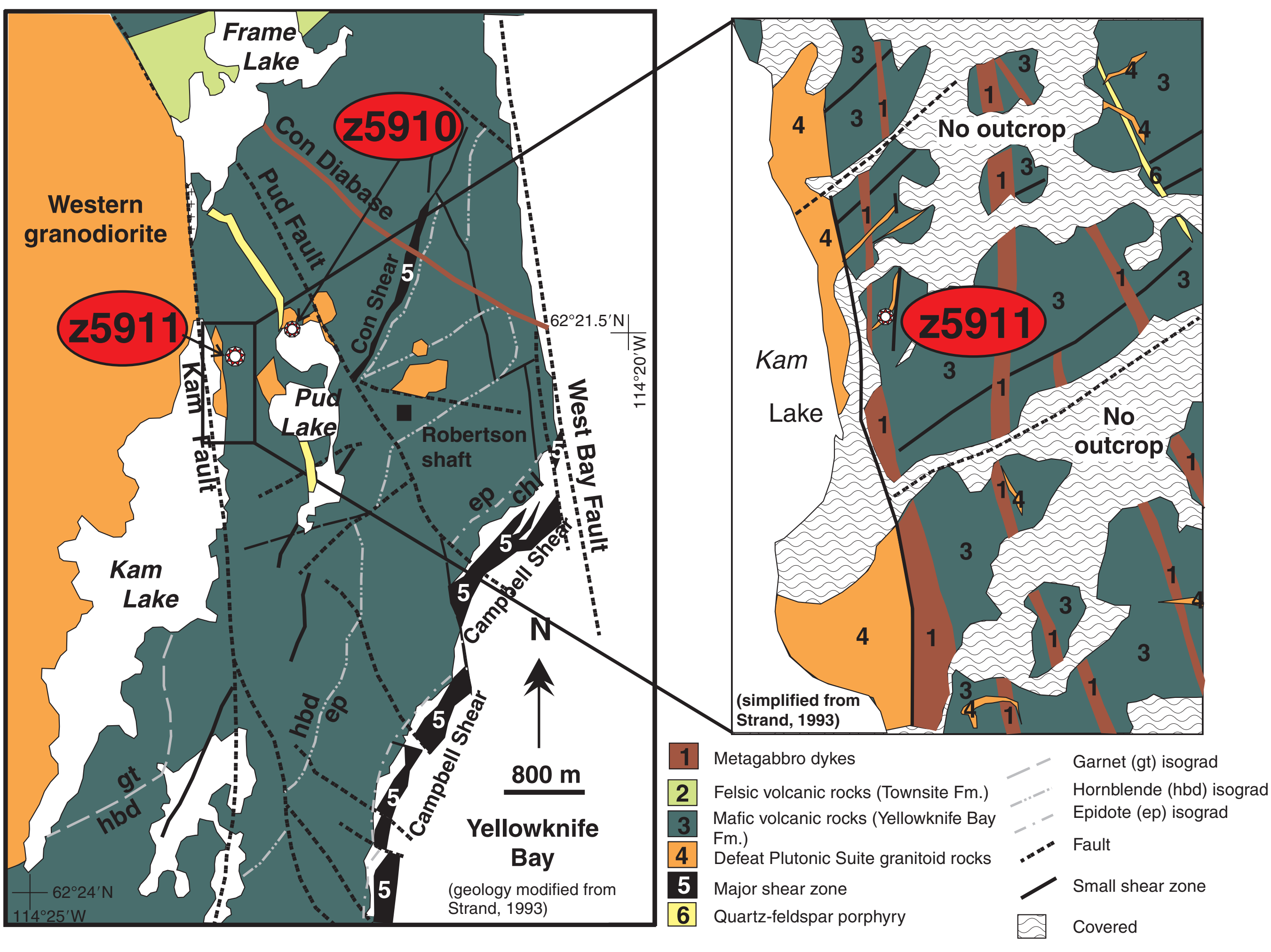

Figure 2. *Detailed geology of the Con mine area, showing sample locations.*

to the main gold-bearing structures, there are numerous other small shear zones that have orientations and sense of displacement similar to that of the Campbell zone of the Con deposit (J. Siddorn, pers. comm., 2002). There are also numerous granitic dykes and small satellite plutons related to the 'western granodiorite' that occurs immediately west of the area. The compositionally evolved nature of the granitic dykes, relative to the main part of the complex, suggests that they might be the youngest intrusive phase in the area, and provide a well-constrained maximum age for D_2.

The Pud tonalite is a small pluton that occurs beneath Pud Lake and outcrops locally around its margin (Fig. 3A). An imprecise, unpublished age of ca. 2634 Ma (Strand, 1993) has previously been reported for the Pud tonalite. The Pud tonalite occurs within the east-trending Con intrusive corridor, a domain of prolonged intrusive activity that displaces the regional hornblende isograd and is associated with numerous breccia zones (Strand, 1993). The Pud tonalite is locally affected by D_2 shearing and, in drill core, was observed to be moderately altered and weakly mineralized with sulphide minerals. A relatively unaltered sample of the tonalite was collected from the north shore of Pud Lake (sample z5910, Fig. 2) to provide a maximum age for mineralization and alteration. The Pud tonalite is a nonfoliated, hornblende±biotite tonalite with accessory titanite. Petrographic work indicates that both biotite and hornblende are variably chloritized, and plagioclase is weakly to moderately sericitized.

Just to the west of Pud Lake, near the eastern shore of Kam Lake (Fig. 2), a swarm of small granitic dykes cuts pillowed mafic volcanic rocks of the Kam Group, and is offset and deformed by several small, north- to northeast-trending, D_2 deformation zones (Fig. 3B). These granitic dykes are the youngest intrusive phase observed in the area and therefore represent the best target to provide a younger maximum age bracket for D_2 deformation. The largest of these dykes (up to 1 m wide) was sampled for U-Pb geochronology (sample z5911, Fig. 2). It is massive, fine grained, and equigranular, with less than 1% mafic minerals. Petrography indicates that K-feldspar is relatively unaltered, whereas the mafic mineral is now completely altered to chlorite, and plagioclase is strongly sericitized.

GEOCHRONOLOGY

Analytical techniques

Heavy mineral concentrates were prepared by standard techniques, including crushing, grinding, Wilfley™ table, and heavy liquids. The concentrates were sorted by magnetic susceptibility using a Frantz™ isodynamic separator. All fractions (Table 1) were air abraded (Krogh 1982). The analytical methods for zircon have been summarized by Parrish et al. (1987), and for titanite by Davis et al. (1997). Analytical errors were determined based on the error propagation methods of Roddick (1987). A modified York (1969) regression method was used to calculate discordia upper and lower intercept ages. In the text, $^{207}Pb/^{206}Pb$ ages for concordant analyses are quoted with their respective errors, whereas discordant analyses, which on their own cannot be interpreted in terms of a meaningful age, are quoted without errors.

Pud tonalite (sample z5910)

Zircons from the 1° magnetic and nonmagnetic fractions are pale brown, clear, well-terminated, elongate to stubby prisms and needles of variable quality. Two multigrain fractions of relatively large (>150 μm), pale brown, clear, stubby, well-terminated prisms (Fig. 3E) are 2.5% discordant and have $^{207}Pb/^{206}Pb$ ages of 2621 Ma (fraction Z4, Table 1 and Fig. 4A) and 2622 Ma (Z5). Two multigrain fractions of pale brown, clear, elongate prisms with some cracks and inclusions are more significantly discordant (>5%) and have $^{207}Pb/^{206}Pb$ ages of 2610 Ma (Z1) and 2617 Ma (Z3). Two multigrain fractions of small (<100 μm), pale brown, stubby prisms with some cracks and inclusions have $^{207}Pb/^{206}Pb$ ages of 2615 Ma (Z2) and 2625 Ma (Z6). The six analyses do not fit a discordia line, indicating complex U-Pb systematics resulting from Pb loss and/or inheritance. A discordia line through all but the most discordant zircon fraction (Z3) defines an upper intercept age of 2632 ± 3 Ma (mean square of weighted deviates [MSWD] = 0.22, lower intercept of 745 ± 107 Ma; Fig. 4A). Fraction Z3 is excluded from the regression and plots below the discordia line, consistent with more significant recent Pb loss or minor inheritance in that fraction.

Two generations of titanite were observed in thin section: primary igneous titanite that occurs as euhedral to subhedral grains (Fig. 3C) and secondary titanite, related to alteration of ilmenite (Fig. 3D) and chloritization of hornblende (Fig. 3C). The titanite produced by chloritization of hornblende forms irregular patches adjacent to domains of chloritized hornblende, and is commonly nucleated on primary igneous titanite crystals (e.g. Fig. 3C). The titanite produced by breakdown of ilmenite occurs as rims around remnants of igneous ilmenite grains (e.g. Fig. 3D). Three groups of titanite were distinguished in the mineral separates: pale yellow to colourless, clear, irregular fragments (type 1, Fig. 3G); dark reddish brown, clear, irregular fragments (type 2, Fig. 3H); and pale brown, clear, irregular fragments (type 3). Although the different types were selected to test for potential age differences between the different morphologies recognized in thin section, an unequivocal correlation could not be determined. Four multigrain fractions of type 1 titanite, three multigrain fractions of type 2 titanite, and one multigrain fraction of type 3 titanite were analyzed.

Type 1 fractions have relatively low U and consequently have a high proportion of common Pb and correspondingly larger errors, but are generally the most concordant, with $^{207}Pb/^{206}Pb$ ages of 2620 ± 6 Ma (fraction T7, Table 1 and Fig. 4B), 2625 Ma (T9), 2630 ± 11 Ma (T13), and 2631 ± 10 Ma (T14,). Analyses of type 2 fractions are generally slightly more discordant, with $^{207}Pb/^{206}Pb$ ages of 2625 Ma (T8), 2626 Ma (T10), and 2627 Ma (T12). The analysis of the type 3 titanite fraction has a $^{207}Pb/^{206}Pb$ age of 2626 Ma (T11). A discordia line through all but the youngest fraction (T7) gives a lower intercept of 672 ± 563 Ma and an upper intercept age

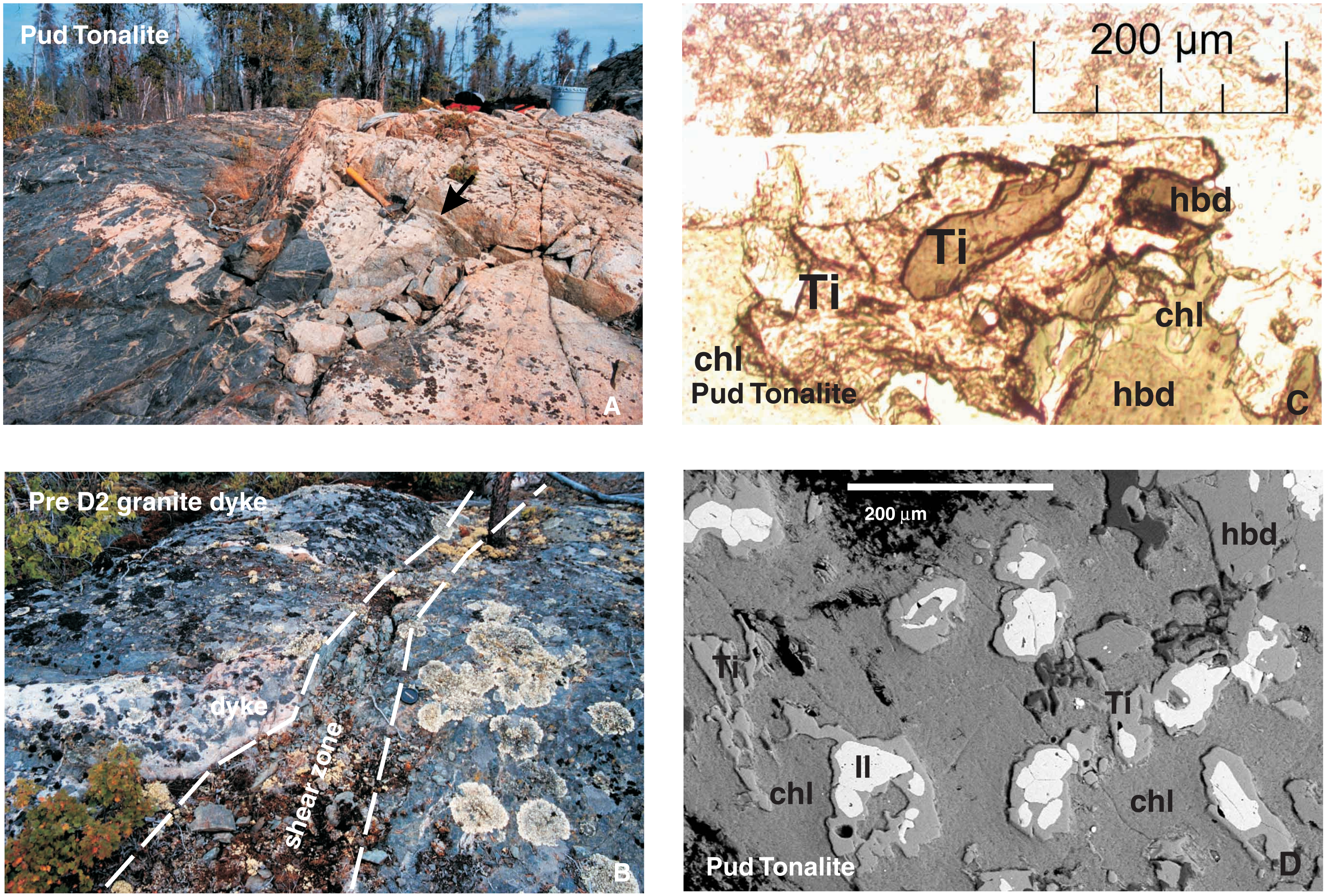

Figure 3. ***A)*** *Sample site for the Pud tonalite, near the contact with pillowed mafic volcanic rocks.* ***B)*** *Granitic dyke cut by a D_2 shear zone.* ***C)*** *Photomicrograph showing relationships between primary igneous and secondary titanite (Ti) produced by the chloritization (chl) of hornblende (hbd) in the Pud tonalite.* ***D)*** *Secondary electron microprobe (SEM) backscatter image of two different types of secondary titanite in the Pud tonalite, produced by chloritization of hornblende and alteration of ilmenite (Il).*

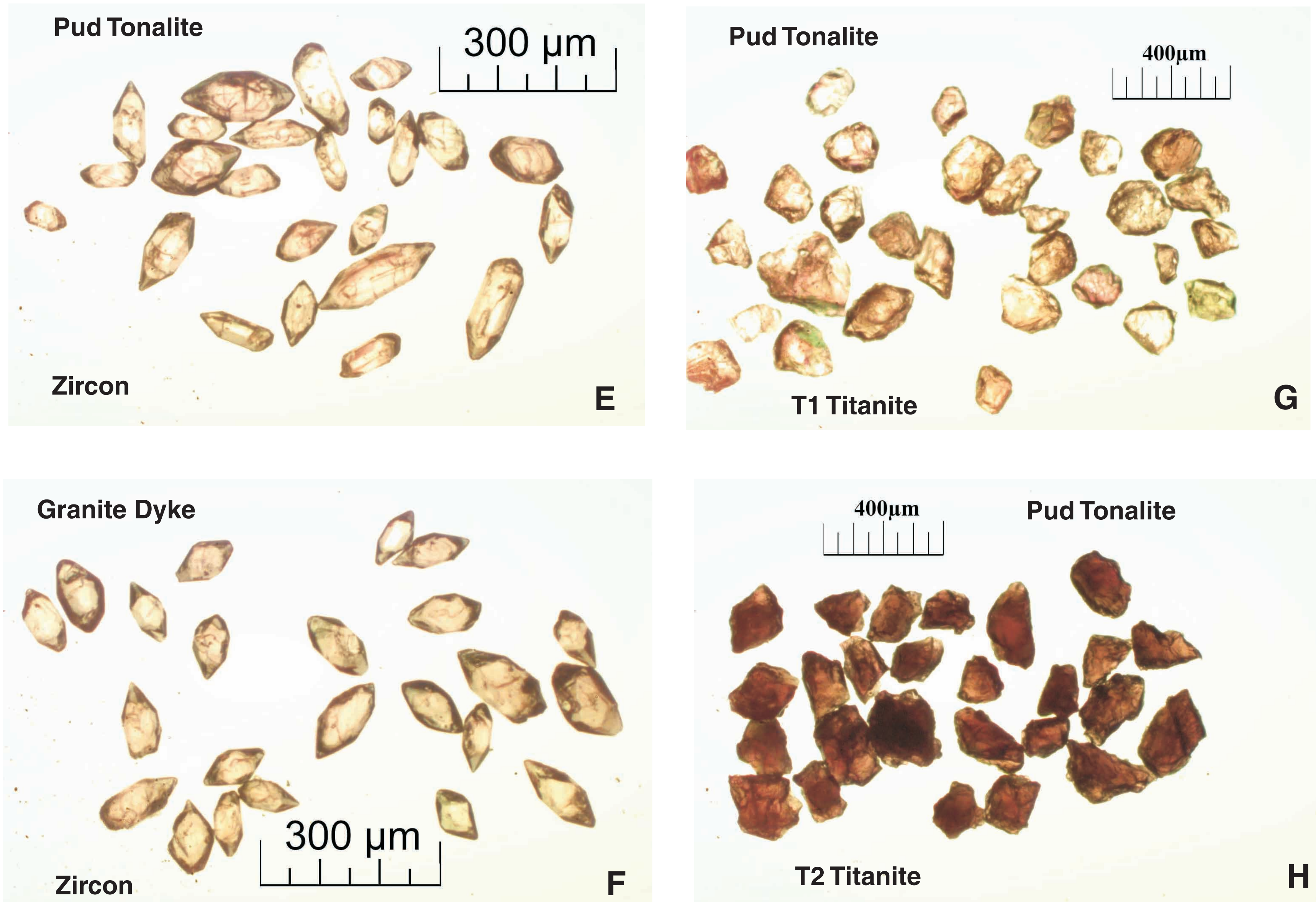

Figure 3. ***E)*** *Photomicrograph of igneous zircons from the granitic dyke.* ***F)*** *Photomicrograph of igneous zircons from the Pud tonalite.* ***G)*** *Photomicrograph of pale yellow to colourless titanite from the Pud tonalite.* ***H)*** *Photomicrograph of dark brown titanite from the Pud tonalite.*

Table 1. U-Pb data for Pud tonalite (sample z5910) and granitic dyke (sample z5911), Defeat plutonic suite, Yellowknife greenstone belt.

Fraction[1]	Description[2]	Wt.[3] (μg)	U[4] (ppm)	Pb[4,5] (ppm)	$^{206}Pb/^{204}Pb$[4]	Pb[6] (pg)	$^{208}Pb/^{206}Pb$[6]	$^{206}Pb/^{238}U$[7]	$^{207}Pb/^{235}U$[7]	$^{207}Pb/^{206}Pb$[7]	Apparent age (Ma) $^{206}Pb/^{238}U$	Apparent age (Ma) $^{207}Pb/^{206}Pb$	+/-[8]
Pud tonalite (z5910, lat. 62°21.5'N, long. 114°22.8'W):													
Z1	2, clr, p br, elg pr, w cr + incls, abr	2	591	324	3105	11	0.1684	0.4742 (7)	11.471 (18)	0.17545 (9)	2502	2610	2
Z2	8, sm, clr, p br stb pr, abr	2	207	111	2667	5	0.1265	0.4792 (12)	11.627 (30)	0.17596 (12)	2524	2615	2
Z3	12, clr, p br, elg pr, w cr + incls, abr	2	536	276	4349	7	0.1650	0.4457 (8)	10.826 (18)	0.17616 (14)	2376	2617	3
Z4	~20, lg, clr, p br, stb pr, abr	10	294	164	11378	8	0.1499	0.4889 (6)	11.903 (15)	0.17659 (9)	2566	2621	2
Z5	12, lg, clr, p br, stb pr, abr	2	903	508	5502	9	0.1588	0.4896 (5)	11.928 (16)	0.17671 (9)	2569	2622	2
Z6	~20, sm, clr, p br stb pr, abr	2	454	253	4624	6	0.1353	0.4937 (54)	12.050 (133)	0.17702 (9)	2587	2625	2
T7	33, clr, cls to p ylw, frg, abr	105	32	19	469	201	0.1983	0.5023 (7)	12.219 (32)	0.17645 (32)	2624	2620	6
T8	24, clr, d br, frg, abr	128	231	136	1710	475	0.2037	0.4960 (4)	12.102 (16)	0.17697 (11)	2597	2625	2
T9	14, clr, cls to p ylw, frg, abr	63	75	45	878	150	0.2209	0.4972 (4)	12.134 (19)	0.17700 (18)	2602	2625	3
T10	34, clr, d br, frg, abr	160	264	157	1958	589	0.2137	0.4977 (5)	12.153 (16)	0.17710 (11)	2604	2626	2
T11	~50, clr, p br, frg abr	110	53	31	1123	145	0.2029	0.5002 (5)	12.215 (17)	0.17713 (14)	2615	2626	3
T12	15, clr, d br, frg, abr	128	196	118	1853	371	0.2241	0.4990 (6)	12.195 (18)	0.17724 (11)	2610	2627	2
T13	23, clr, cls to p ylw, frg, abr	48	11	6	222	71	0.1815	0.5024 (8)	12.299 (50)	0.17757 (98)	2624	2630	11
T14	37, clr, cls to p ylw, frg, abr	98	11	7	268	119	0.2346	0.5024 (7)	12.301 (44)	0.17759 (50)	2624	2631	10
Granitic dyke (z5911, lat. 62°21.4'N, long. 114°23.3'W):													
Z15	5, clr, p br, stb pr, w cr, inc + conc zn	2	902	459	2800	17	0.1177	0.4571 (8)	11.036 (21)	0.17509 (9)	2427	2607	2
Z16	5, clr, p br, stb pr, w cr, inc + conc zn	2	500	261	1820	15	0.1274	0.4652 (9)	11.274 (24)	0.17578 (12)	2462	2613	2
Z17	3, clr, p br, stb pr, w cr, inc + conc zn	2	269	144	910	16	0.1301	0.4746 (11)	11.518 (29)	0.17602 (21)	2504	2616	4
Z18	~ 30, clr, p br, stb pr, w cr, inc + conc zn	2	2904	1484	3453	47	0.1209	0.4580 (5)	11.121 (16)	0.17609 (9)	2431	2616	2
Z19	13, clr, p br, stb pr, w cr, inc + conc zn	2	1044	562	3391	17	0.1189	0.4833 (9)	11.781 (24)	0.17680 (9)	2542	2623	2

[1] fractions are numbered sequentially through both samples: Z, zircon; T, titanite
[2] first figure is number of grains; fraction description abbreviations: clr, clear; cls, colourless; p, pale; d, dark; br, brown; ylw, yellow; pr, prismatic; sm, small (<100 μm), lg, large (> 150 μm); st, stubby; elg, elongate; frg, fragments; w, with; inc, inclusions; conc zn, concentric zoning; frc, fractures; cr, cracks; abr, abraded.
[3] weights were measured for titanite fractions, but were estimated for zircon fractions
[4] includes sample weight error of 0.001 mg in concentration uncertainty
[5] radiogenic Pb
[6] total common Pb in analysis
[7] values in brackets are 1 standard error of mean in the last decimal places
[8] error on $^{207}Pb/^{206}Pb$ age is 2 standard error in Ma

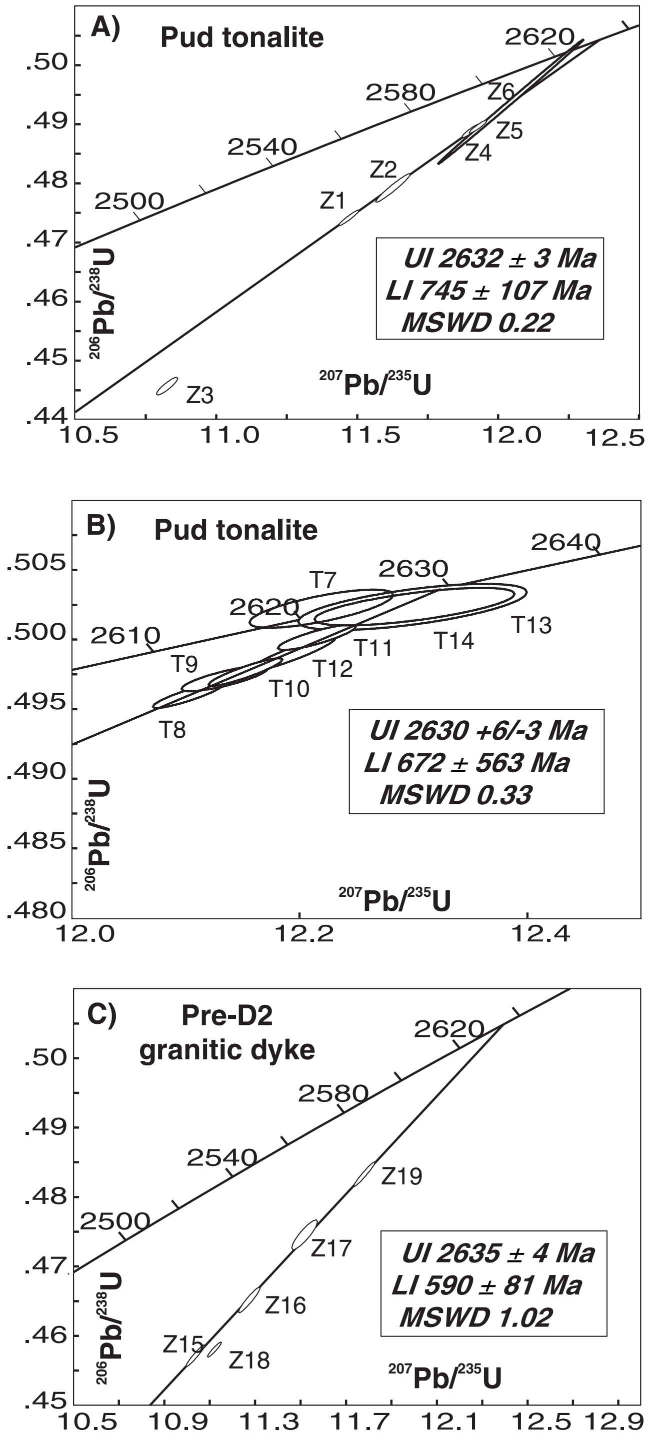

Figure 4. *U-Pb concordia plots of* ***A)*** *zircon fractions for the Pud tonalite (discordia line fitted through all but fraction Z3);* ***B)*** *titanite fractions for the Pud tonalite (discordia line defined by all but fraction T7, which may contain a component of secondary titanite); and* ***C)*** *zircon fractions for the granitic dyke (discordia line defined by all but fraction Z18). UI, upper intercept; LI, lower intercept; MSWD, mean standard weighted deviate.*

of 2629 +6/–3 Ma (MSWD = 0.33, Fig. 4B), which overlaps with the age defined by zircon (2632 ± 3 Ma). Except for the two oldest and most concordant fractions, which have low U content (approx. 11 ppm), there is not a good correlation between age and composition. The youngest fraction of type 1 titanite (T7), at 2620 ± 6 Ma, may include a component of significantly younger titanite that could correspond to the secondary titanite growth observed in thin section. This would place a maximum age of 2620 ± 6 Ma on the development of secondary titanite. However, the bulk of the titanite seems to have crystallized at the same time as the zircon, and the range in composition (but not age) could be interpreted as igneous zoning.

Granitic dyke (sample z5911)

Zircon from the 3º nonmagnetic fraction consists of small, well-terminated, stubby, pale brown prisms (Fig. 3F). Analyses of five multigrain, abraded fractions of pale brown, stubby zircon prisms with some cracks, inclusions, and visible concentric zoning are variably discordant (3.8–8.5%) and have ^{207}Pb/^{206}Pb ages ranging from 2607 to 2623 Ma (Table 1, Fig. 4C). The minimum age is given by the oldest ^{207}Pb/^{206}Pb age of 2623 ± 2 Ma. A discordia line with a lower intercept of 745 ± 107 Ma and an upper intercept of 2635 ± 4 Ma (MSWD = 1.2; Fig. 4C), is defined by four of the five analyses. Fraction Z18, one of the more discordant analyses, falls below the discordia line defined by the other four fractions and is interpreted to have experienced more significant recent Pb loss, consistent with its somewhat higher U content (2904 ppm). The 2635 ± 4 Ma upper intercept age is the best estimate for the crystallization age of this sample.

CONCLUSIONS

It was known from previous work that D_2 deformation zones and related mineralization occur within the 'western granodiorite'. Based on correlation with a 2620 ± 8 Ma age on one phase of the complex (Henderson et al., 1987), 2620 Ma is presently the best minimum bracket on the age of regional D_2 deformation zones and their related gold mineralization. The samples analyzed in this study were selected in an attempt to find younger ages for Defeat magmatism, and to refine a previously unpublished age for the Pud tonalite. The more evolved geochemical composition of the granitic dyke suggested that it might be a late magmatic phase of the 'western granodiorite'. On the contrary, the age of both the Pud tonalite (2632 ± 3Ma) and the granitic dyke (2635 ± 4 Ma) are slightly older than previously reported ages for this plutonic suite. It has been suggested that Defeat magmatism entirely postdates regional D_1 deformation (Davis and Bleeker, 1999). If that holds true in this case, then these ages provide a slightly older minimum age bracket for the timing of regional D_1 deformation.

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