provided courtesy of V. Masaitis). Data analysis is still underway, but it is evident that none of the new samples are as well-behaved in age release patterns as was the original sample, due most likely to alteration and the presence of old target-rock mineral inclusions. Predominant ages in these spectra are commonly between ~60 and 40 Ma, but portions of the gas release in the ~40–30 range are also observed. We draw no conclusions as to the age of the Popigai impact event from these data at this early stage. Planned chemical, hydrogen, and oxygen isotopic analyses may help us sort out the effect alteration has had on the Ar age systematics. It is curious to note that independent results of $^{40}Ar/^{39}Ar$ laser step-heating of other samples conducted by Bottomley, Grieve, and York (R. Grieve, personal communication, 1992) indicate well-behaved release patterns that suggest an age in the vicinity of ~34 Ma (Eocene-Oligocene boundary). At this point, our impression is that a combination of analyses of pristine melt glasses and unaltered mineral phases is recommended in order to resolve the age disparity that apparently exists with respect to the absolute age of the Popigai impact.

Using the high-resolution topography data illustrated in Fig. 1, we can attempt to reconstruct the initial crater geometry by means of standard dimensional scaling relationships, such as those summarized in Melosh (1989) and by Grieve and Pesonen (1992). Table 1 highlights some of the parameter values derived for Popigai in comparison with a small set of representative smaller terrestrial features. The maximum degree of original relief at the crater (floor to rim crest) is between 520 and 960 m (depending on the model chosen), while the present-day dynamic range of relief is 260–408 m. This suggests that between 260 and 552 m of relief has been lost due to slumping, erosion, and other processes (interior cavity sediment infill). If we adopt typical erosion models for high-latitude shield terrains (see Garvin and Schnetzler, this volume), we find that up to 0.0052 mm/yr could be eroded at Popigai, which translates into ~176 m over a 34-Ma lifetime, or 350 m over a 66-Ma lifetime. Clearly, a refined absolute age for the structure is needed to refine these erosion estimates; however, the suggestion is that Popigai has experienced up to a factor of 5 more erosional infill than the much smaller equatorial shield crater Bosumtwi. (We acknowledge the cooperation of V. Masaitis at the VSEGEI in St. Petersburg for providing us with Popigai glass samples on several occasions).

THE ZHAMANSHIN IMPACT FEATURE: A NEW CLASS OF COMPLEX CRATER? J. B. Garvin[1] and C. C. Schnetzler[2], [1]NASA/GSFC, Geodynamics Branch, Code 921, Greenbelt MD 20771, USA, [2]Department of Geography, University of Maryland, College Park MD 20742, USA.

The record of 10-km-scale impact events of Quaternary age includes only two "proven" impact structures: the Zhamanshin Impact Feature (ZIF) and the Bosumtwi Impact Crater (BIC). What makes these impact landforms interesting from the standpoint of recent Earth history is their almost total lack of morphologic similarity, in spite of similar absolute ages and dimensions. The BIC resembles pristine complex craters on the Moon to first order (i.e., "U"-shaped topographic cross section with preserved rim), while the ZIF displays virtually none of the typical morphologic elements of a 13- to 14-km-diameter complex crater. Indeed, this apparent lack of a craterlike surficial topographic expression initially led Soviet geologists [1] to conclude that the structure was only 5.5 to 6 km in diameter and at least 4.5 Ma in age [1,10]. However, more recent drilling and geophysical observations at the ZIF have indicated that its pre-erosional diameter is at least 13.5 km, and that its age is most probably 0.87 Ma [2,3,7,9,15]. Why the present topographic expression of a 13.5-km complex impact crater less than 1 m.y. old most closely resembles heavily degraded Mesozoic shield craters such as Lappajarvi is a question of considerable debate [6,7,9–11]. Hypotheses for the lack of a clearly defined craterlike form at the ZIF include a highly oblique impact, a low-strength "cometary" projectile, weak or water-saturated target materials, and anomalous erosion patterns [1,2,6,7,9]. The problem remains unresolved because typical erosion rates within the arid sedimentary platform environment [3] of central Kazakhstan in which the ZIF is located are typically low (see Table 1); it would require at least a factor of 10 greater erosion at the ZIF in order to degrade the near-rim ejecta typical of a 13.5-km complex crater by hundreds of meters in only 0.87 Ma, and to partially infill an inner cavity with 27 km^3 (an equivalent uniform thickness of infill of 166 m). Our analysis of the degree of erosion and infill at the ZIF calls for rates in the 0.19 to 0.38 mm/yr range over the lifetime of the landform, which are a factor of 10 to 20 in excess of typical rates for the Kazakhstan semidesert [3]. If we apply similar erosional models to the BIC, which is located in an equatorial crystalline shield region

TABLE 1. Observed and model parameters for the ZIF and the BIC as derived from analysis of topography and scaling relationships.

Parameter	Zhamanshin	Bosumtwi	Ref.
Age (Ma = 10^6 yr)	0.87	1.3	[2,14]
Apparent diam. Da (km)	14.4	10.5	Meas.
Apparent depth da (km)	0.182	0.300	"
Observed aspect da/Da	0.013	0.030	"
Obs. Ht. Rim Ejecta hej (m)	30.3	83.0	"
Obs. Vol. Cavity Vcav (km^3)	20.1 (max)	16.05	"
Obs. Vcav/SAcav (km)	0.018	0.201	"
Obs. Vol. Ejecta Vej (km^3)	16.7	11.6	"
Obs. Tej = Vej/SAej (km)	0.041	0.049	"
ΔV lost = Vcav–Vej (km^3)	3.4	4.45	"
Tejlost = ΔV lost/SAej (m)	8.3	18.6	"
EJER = Tejlost/Age (mm/yr)	0.0095	0.014	"
Model Vol. Init. Vi (km^3)	47.1	22.8	Comp.
Model Vol. Excav. Vex (km^3)	107.9	48.2	"
Model init. depth di (km)	0.436	0.384	"
Model Aspect di/Da	0.030	0.037	"
Model Vi/SAi (km)	0.289	0.263	"
Model hej* (m)	360.0	263.0	"
her = hej*–hej (m)	329.7	180.0	"
ERIM = her/Age (mm/yr)	0.38	0.14	"
ΔZ = di–da (km)	0.254	0.084	"
Δ Vol. = |Vi–Vcav| (km^3)	27.0	6.75	"
Ter = Δ Vol./SA (km)	0.166	0.078	"
CER = ΔV/SA/Age (mm/yr)	0.19	0.060	"
ΔZ/Age (mm/yr)	0.29	0.065	"
Erosion Model for Target	$\kappa\ \Delta Z^{0.94}$	$\kappa\ \Delta Z^{1.34}$	[3]
κ in Erosion Model	1.05E-4	4.25E-7	[3]
Erosion (mm/yr) @ ΔZ in m	0.019	0.00016	Comp.
Erosion (m) for Crater Age	16.5	0.21	"
Max. Vol. Eroded (km^3)	2.7	0.018	"

and subject to tropical weathering processes [14], we find that the amount of erosion and infill needed to explain its current topographic expression is between 0.06 mm/yr (infill) to 0.13 mm/year (erosion of rim and near-rim ejecta). Of course, the degree of observed erosion at both the ZIF and the BIC assumes that the pre-erosional morphology of these impact structures can be reconstructed using established dimensional scaling relationships, such as those summarized by Ivanov [4] and Melosh 15]. Table 1 summarizes the available observational data on the dimensions of the two structures and all our estimates of parameters that can be derived on the basis of high-resolution topographic data. Model values are listed for comparison on the basis of simple scaling laws [4,5]. A model for terrestrial erosion as a function of geologic environment, rock type, and local to regional relief (ΔZ) is used to compute the expected erosion/infill rates for the regions associated with the ZIF and the BIC [3]. These model erosion rates are integrated throughout geologic time, and as such are upper bounds on the rates that would be operational over a time period as short as ~1 Ma. Thus, the 0.019 mm/yr that would be predicted for the ZIF does not take into account that this region of the central Kazakhstan semidesert has apparently experienced much lower erosion during the Quaternary [2]. Indeed, the geomorphic record of erosion in the ZIF general region has been dominated by eolian redistribution and deposition of loess, with probable maximum accumulation levels in the range of 20–70 m within the interior cavity of the ZIF, based upon unpublished drilling results described by Masaitis and Boiko 12]. Thus, our impression is that it is impossible to reconcile typical erosion rates at the ZIF (in the range of 0.019 to 0.080 mm/yr) with what would be predicted (0.19 to 0.38 mm/yr) given erosion of a typical 10- to 15-km-diameter complex impact crater. While the observed erosion at the BIC appears to be within a factor of 2 of what would be predicted using terrestrial erosion models and pre-erosional crater dimension scaling laws, that for the ZIF disagrees by up to a factor of 20. We believe that the pre-erosional morphology of the initial ZIF cannot be approximated using traditional complex crater scaling relationships, and that the ZIF represents a new class of complex crater form on the Earth that may help to explain the current deficiency of observed craters in the 8- to 16-km-diameter range. Furthermore, we believe that it is possible that there are perhaps tens of ZIF-style complex craters preserved, albeit poorly, within the sedimentary platforms of the continents [13]. Thus, it is important to develop methods for reconstructing ZIF-style cratering events, and for understanding why such events produce crater forms with anomalously mundane topographic expressions [11,12].

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ASTEROIDS AND ARCHAEAN CRUSTAL EVOLUTION: TESTS OF POSSIBLE GENETIC LINKS BETWEEN MAJOR MANTLE/CRUST MELTING EVENTS AND CLUSTERED EXTRATERRESTRIAL BOMBARDMENTS. A. Y. Glikson, BMR, P.O. Box 378, Canberra, A.C.T., Australia.

Since the oldest intact terrestrial rocks of ca. 4.0 Ga and oldest zircon xenocrysts of ca. 4.3 Ga measured to date overlap with the lunar late heavy bombardment, the early Precambrian record requires close reexamination vis a vis the effects of megaimpacts. This includes modeling of early megaimpact events [1], examination of the nature and origin of early volcanic activity [2–4], examination of Precambrian structures [5,6], and close examination of the isotopic age evidence [7]. The identification of microtektite-bearing horizons containing spinels of chondritic chemistry and Ir anomalies in 3.5–3.4-Ga greenstone belts [8,9] provides the first direct evidence for large-scale Archaean impacts. The Archaean crustal record contains evidence for several major greenstone-granite-forming episodes where deep upwelling and adiabatic fusion of the mantle was accompanied by contemporaneous crustal anatexis. Isotopic age studies suggest evidence for principal age clusters about 3.5, 3.0, and 2.7 (±0.8) Ga, relics of a ca. 3.8-Ga event, and several less well defined episodes. These peak events were accompanied and followed by protracted thermal fluctuations in intracrustal high-grade metamorphic zones. Interpretations of these events in terms of internal dynamics of the Earth are difficult to reconcile with the thermal behaviour of silicate rheologies in a continuously convecting mantle regime. A triggering of these episodes by mantle rebound response to intermittent extraterrestrial asteroid impacts is supported by (1) identification of major Archaean impacts from microtektite and distal ejecta horizons marked by Ir anomalies; (2) geochemical and experimental evidence for mantle upwelling—possibly from levels as deep as the transition zone; and (3) catastrophic adiabatic melting required to generate peridotitic komatiites. Episodic differentiation/accretion growth of sial conse-

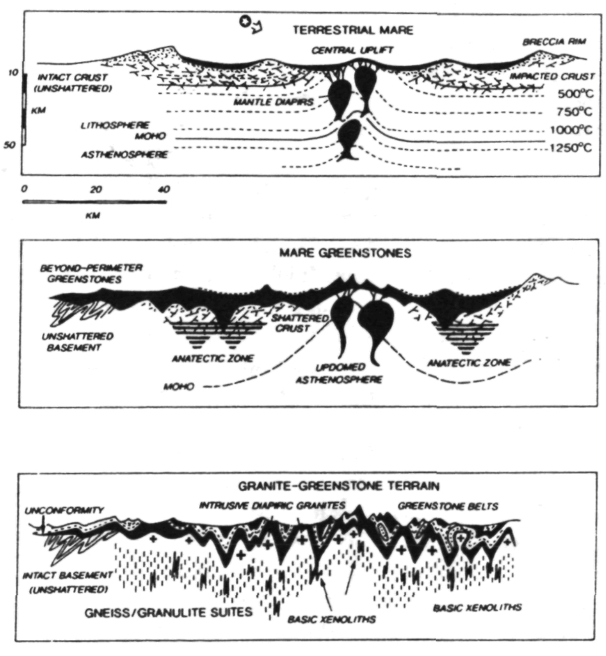

Fig. 1. Schematic model portraying the concept of evolution from terrestrial impact basins to greenstone/granite terranes.