diffusion parameters of a typical anorthite, with an age of 500 Ma constituting 0.8% of the samples' potassium. The degassing peak of the relict phase coincides by and large with the second reservoir of SA1-302 but the degassing feature is broader (Fig. 3). The resulting calculated age pattern shows a low-temperature plateau of 65 Ma and an irregular shape in the high-temperature steps. That means that the measured age pattern can only be interpreted as a result of 65-Ma age and a relict phase if the relict phase has exactly the same gas release pattern—but if this is the case, the relict phase should have been reset by the cratering event as well as the sample unless it would have been incorporated afterward, e.g., as contamination. A further condition that must be fulfilled to fit this scenario is that the K fraction of 500-Ma old relict phases in the different samples must be nearly the same (1 ± 0.2%), or another proper combination of age and K content. We regard this as improbable.

Although the age spectra show well-defined plateaus, the plateau fractions still exhibit fine-scale structures that deviate from a theoretical calculated plateau (Fig. 2, bottom) as expected for a maximum precise measurement of an undisturbed sample. Normally the mass-dependent diffusion difference of ^{40}Ar and ^{39}Ar is considered as negligible, but if we induce it in our calculations in the case of SA1-302 we get an age spectra as shown in Fig. 2 with slightly increasing ages within each reservoir. This strengthens the assumption that these deviations are not of statistical, but of systematic nature, an artifact induced by the ^{40}Ar-^{39}Ar stepheating technique. In this sense, the spectrum of SA1-302 seems to represent the "ideal" spectrum of an undisturbed sample. For the fine-scale deviations of the other three impact melts ^{39}Ar recoil redistribution seems to play a major role, but this has to be investigated by further petrographic studies on grain size and potassium distribution.

We conclude an age of 69–71 Ma for the Kara impact structure. Hydrogen isotopic measurements by Nazarov et al. [6] show that the impact occurred on dry land and the authors concluded a maximum age of 69–70 Ma, the time of the end of the last regression within the crater's region before the end of the Cretaceous. Our data are consistent with an impact a short time after the regression.

Figure 4 shows the K/Ca and the age spectra of two impact metamorphic anorthite samples (10BD5 and 10BD3C) of the Manicouagan Crater, Canada. As visible in the K/Ca spectra (only 10BD5 is shown), the samples consists of two different phases, one degassing at low temperatures having an age plateau indistinguishable from the cratering event of 212 Ma (7), the second one showing the signature of a partially degassed phase, having ages increasing up to 950 Ma (10BD5), the age of the target rocks [8]. 10BD3C suffered a more complete degassing, having ages ranging only up to 300 Ma. The low-temperature plateaus are in agreement with the crater age of 212 Ma and do not improve the age of the impact structure. Anyway, while the crater age is quite accurate, the ages of the adjacent geologic boundaries seem not to be. The last revision [9] of the Triassic-Jurassic boundary in 1982 delivered an age of 213 Ma, while a later determination [10] gives a lower age of 208 Ma. We think so far as ages are concerned it is not possible to conclude or exclude an association of the two events until the age of the boundary is determined more precisely.

Our measurements enable us to estimate the intensity of the thermal event induced by the cratering event for the two Manicouagan samples. Our results are consistent with a time-temperature combination of 1 Ma at 337°C or 12 hr at 1100°C for 10BD5 and 1 Ma at 361°C or 50 hr at 1100°C for 10BD3C. Future investigations may allow us to infer a cooling model for the Manicouagan impact melt sheet.

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^{40}Ar-^{39}Ar DATING OF PSEUDOTACHYLITES FROM THE WITWATERSRAND BASIN, SOUTH AFRICA, WITH IMPLICATIONS FOR THE FORMATION OF THE VREDEFORT DOME.

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The formation of the Vredefort dome, a structure in excess of 100 km in diameter and located in the approximate center of the Witwatersrand basin, is still the subject of lively geological controversy. It is widely accepted that its formation seems to have taken place in a single sudden event, herein referred to as the Vredefort event, accompanied by the release of gigantic amounts of energy. It is debated, however, whether this central event was an internal one, i.e., a cryptoexplosion triggered by volcanic or tectonic processes, or the impact of an extraterrestrial body.

Ages obtained on rocks from the Vredefort structure cluster largely around 2.0 Ga (e.g., review by [1]). Granophyre, an unusual melt rock forming dykes in the Vredefort Dome and thought to be related to the Vredefort event, yielded a Pb-Pb zircon age of 2002 ± 52 Ma [2]. Pseudotachylite, a melt breccia first discovered and

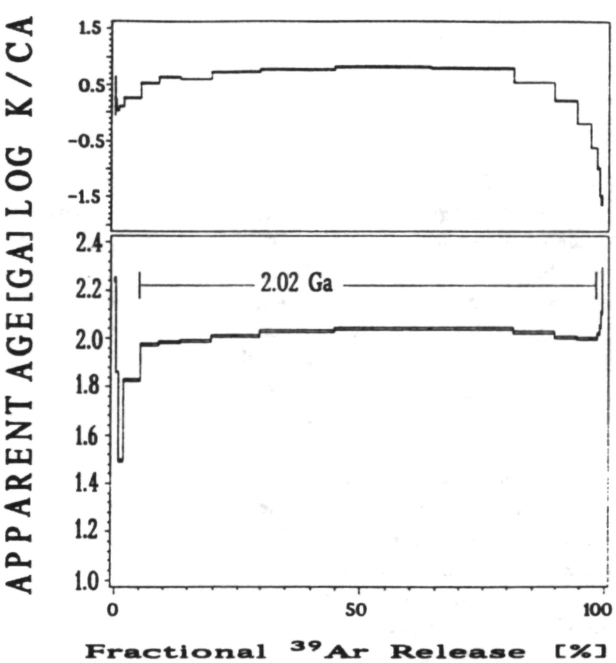

Fig. 1. Age spectrum for EL-28B.

extremely abundant in the Vredefort structure, is, like the granophyre, widely regarded to be the direct result of the dome-forming process.

We dated eight pseudotachylite samples from a bedding-parallel fault zone across the north-central Witwatersrand basin with the ^{40}Ar-^{39}Ar step heating technique. All age results (Table 1) are indistinguishable from 2.00 Ga within 1 σ errors, except for those obtained for two samples: 10D05 (2.10 Ga) seems to be severely disturbed in the low-temperature fractions; the other one, EL-30 has an extremely low K content of 20 ppm—compared to K contents of several percent in the other pseudotachylite samples. The relative fraction of excess argon is significant, which results in an unrealistic K-Ar age of 4.7 Ga.

Figure 1 shows the exemplary spectrum of pseudotachylite sample EL28B with a plateau over 92% of the ^{39}Ar release. In light of the appearance of the age spectra and the large number of samples analyzed to identical results, we do not believe that the 2-Ga ages are reset ages caused by thermal overprint. Our ages are consistent with the ^{40}Ar-^{39}Ar age of a Vredefort pseudotachylite (USA29, 2.00 Ga [3]). This indicates that the Vredefort event and the Witwatersrand pseudotachylite are related. Taking all our results into account, the resulting age for the Vredefort event is calculated to 1997 ± 5 Ma; a larger error of 19 Ma would be realistic if the additional error induced by our NL-25 hornblende standard is considered.

A circumstance in favor of an origin by internal processes is the apparent coincidence of the Vredefort dome formation and other regional magmatotectonic processes. These are the emplacements of several alkaline granites and ayenites, namely the Schurwedraal complex (Rb-Sr errorchron of 2016 ± 61 Ma [4]), the Lindequesdrift intrusion (2163 ± 31 Ma ^{40}Ar-^{39}Ar plateau age of hornblende [5]), the Rietfontein complex (2004 ± 16 Ma ^{40}Ar-^{39}Ar plateau ages of biotite and hornblende [6]), and—in an even wider regional context—the Bushveld complex, especially because Bushveld synchronous intrusives, such as the Losberg complex, occur close to the Vredefort structure. The age of the Losberg complex (Rb-Sr isochron of 2041 ± 41 Ma [7]), is in agreement with ages thought to represent the main Bushveld activity (2050–2060 Ma [1]), but, in general, ages have been determined ranging from 1900 to 2100 Ma, e.g., an ^{40}Ar-^{39}Ar age of Bushveld magnetite gabbro of 2096 ± 12 Ma [8] and an ^{40}Ar-^{39}Ar laser probe age of Merensky reef biotite of 2010 Ma [9].

In agreement with an extended rather than short period of Bushveld activity are our own ^{40}Ar-^{39}Ar step heating results obtained for a Bushveld gabbro (whole rock, anorthite, and pyroxene), where two partial plateau can be identified in the age spectra: one corresponding to a mean age of 2.00 Ga and the other to a mean age of 2.10 Ga. This could indicate a complex cooling or reheating history of the sample. Investigations are currently in progress to determine whether excess Ar could be the cause of this age dichotomy or whether the spectra are the result of a true two-stage geological history. No matter what the result will be, an event close to 2.00 Ga will remain indicated.

If high-resolution geochronology could prove that the ages of the rocks related to the dynamic Vredefort event (granophyre, pseudotachylite) and the ages of the rocks formed in magmatotectonic processes are different, this would be an argument favoring Vredefort as an impact site, but considering the ages of the geologic activity around the Vredefort structure, we do not think that this is possible because of the extended duration of the tectonic processes.

Previous ^{40}Ar-^{39}Ar investigations of pseudotachylites from other localities in and around the dome resulted in a number of ages significantly lower than 2 Ga for four out of six dated specimens [3]. Such recent formation ages would even question the single-stage formation of the Vredefort dome and its associated pseudotachylites [3]. Ages lower than 2 Ga are not restricted to pseudotachylite either: a plagioclase separate of the lamprophyre from the Lindequesdrift intrusion dated at 2163 Ma yielded a 1248 ± 22 Ma age [5]. Several mineral separates from Rietfontein complex rocks gave partial plateaus at about 2004 Ma, but also showed low ages in the low-temperature release steps comprising 20 to 50% of the ^{39}Ar release, suggestive of disturbances at 1170 ± 14 and 725 Ma [6]. A pseudotachylite from the Riefontein complex (USA35) showed an irregular age pattern suggesting disturbances at 1400 Ma and 800 Ma [3]. In the outer (OGG) core of the Vredefort structure, pseudotachylite USA30A yielded an age of 1.39 Ga [3], whereas a Rb-Sr mineral isochron for the host granite resulted in an age of 2002 ± 8 Ma and Ar-dated mineral separates yielded ages ranging from 1.39 to 1.76 Ga, all significantly lower than 2 Ga [10]. Biotite separates from a granophyre sample (VVG) from a site less than 3 km from the USA30 locality yielded a possible formation age of 2006 ± 9 Ma, but with evidence in the age spectrum for significant overprinting at 700 and/or 1200 Ma [6]. Biotite from OGG sample KK55 from the northwestern sector of the core yielded a 1935 ± 8 Ma plateau age, still lower than 2 Ga [6]. Finally, pseudotachylite USA31 provided an age pattern suggestive of partial degassing at 1.4 Ga [3], whereas its host rock, NW28, gave ages of 2070 Ma (biotite) and 3030 Ma (hornblende). It should also be mentioned that four of our Witwatersrand pseudotachylite samples show low-temperature fractions consistent with disturbances at 1400 Ma. Post-2-Ga events could thus have taken place at 1400, 1200, 1000, and 700 Ma ago. There are two possible scenarios that could explain this record of low ages for Vredefort samples. Firstly, the low pseudotachylite ages are seen as formation ages that date the result of post-2-Ga tectonic events. This would explain the different resetting degrees observed for samples from different localities, as well as observations of multiple geological hints for the existence of several pseudotachylite generations in the Vredefort structure

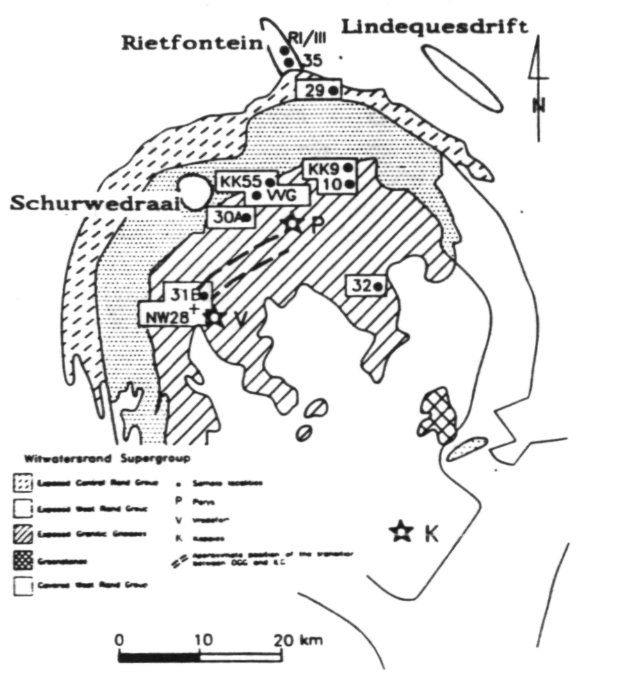

Fig. 2. Sample locality overview at the Vredefort structure (after [10]).

[10]. Then it should be clear why there are not pseudotachylites older than 2 Ga. Secondly, the low ages could be due to post-2-Ga thermal overprint. Host rocks were then more or less intensely affected in accordance with the different Ar retentivities of different minerals, or different closure temperatures in the case of Rb-Sr isotope systematics. A major problem is seen in the different intensities of the resetting events at different localities within the dome. This may be explained partly by additional hydrothermal activity.

Future investigations are still needed to completely clarify the nature and the duration of post-2-Ga processes that took place in the Vredefort structure.

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AL UMCHAIMIN DEPRESSION, WESTERN IRAQ: AN IMPACT STRUCTURE? James R. Underwood Jr., Department of Geology, Kansas State University, Manhattan KS 66506-3201, USA.

Al Umchaimin, in Arabic "hiding place" or "place of ambush" [1], is located at latitude 32° 35.5'N and longitude 39° 25'E. It lies some 43 km S36° of the H-3 pump station on the abandoned Kirkuk-Haifa oil pipeline [2] and 60 km S49°W of the western desert town of Rutba. The nearly circular depression averages 2.75 km in diameter and is 33–42 m deep. It is floored with fine-grained, clay-rich deposits, estimated to be 36 m thick [3], the surface of which shows well-developed desiccation fissures or mudcracks when dry. Because of its nearly circular planimetric shape and its apparent isolation from other surface and subsurface features, it has been considered by some to be a possible meteorite impact structure [4] and by others [5] to be a surface collapse feature that originated following removal of magma from the subsurface as the magma extruded elsewhere. Al Umchaimin was listed in the U.S. Geological Survey tabulation of 110 structures worldwide for which a meteorite impact origin had been suggested [6]. It was placed in Category VI Structures for which more data are required for classification.

K. M. Al Naqib, Iraq Petroleum Company, reported [7] that the petroleum geology community considered that Al Umchaimin had originated by fracture-controlled dissolution in the subsurface and eventual collapse into the resulting solution cavity. Al-Din and others [3] made geological and geophysical surveys of the depression in 1969 and 1970 and found no evidence for an impact origin. They concluded, as did Al Naqib, that a solution-collapse origin was likely.

Abbas and others [8] conducted additional geophysical studies and arrived at similar conclusions: (1) Al Umchaimin was not formed by meteorite impact and (2) probably it represents a solution-collapse feature. Greeley and others [9], in preparation for the Magellan mission to Venus, studied shuttle radar images of nine maar volcanos, one volcanic caldera dome, one impact structure, and one possible impact structure (Al Umchaimin). Concerning Al Umchaimin, they wrote: "Although no definitive impact features have been reported, the circularity and slightly uplifted rims suggest an impact origin."

In 1965, the author and the late Randolph Chapman, both visiting professors at the College of Science, University of Baghdad, spent half a day at Al Umchaimin during which a section was measured up the east wall, samples were collected for later thin sectioning, and a search made for meteoritic debris, shatter cones, impact glass, melt breccia, and so on. No evidence was found for an impact origin of the depression, nor did study of the thin sections from the east wall of the depression reveal any microscopic evidence of impact.

It is concluded that, on the basis of the studies that have been made of Al Umchaimin and on the basis of the brief site visit made, Al Umchaimin probably is not an impact structure but most likely resulted from the enlargement and coalescence of sink holes and eventual collapse of the roof material into the resulting cavity.

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A LATE DEVONIAN IMPACT EVENT AND ITS ASSOCIATION WITH A POSSIBLE EXTINCTION EVENT ON EASTERN GONDWANA. K. Wang[1] and H. H. J. Geldsetzer[2], [1]Department of Geology, University of Alberta, Edmonton, Alberta T6G 2E3, Canada, [2]Geological Survey of Canada, 3303-33rd Street, N.W., Calgary, Alberta T2L 2A7, Canada.

Evidence from South China and Western Australia for a 365-Ma impact event in the Lower *crepida* conodont zone of the Famennian stage of the Late Devonian (about 1.5 Ma after the Frasnian/Famennian extinction event) includes microtektitelike glassy microspherules [1], geochemical anomalies (including a weak Ir), a probable impact crater (>70 km) at Taihu in South China [2], and an Ir anomaly in Western Australia [3]. A brachiopod faunal turnover in South China, and the "strangelove ocean"-like $\delta^{13}C$ excursions in both Chinese and Australian sections indicate that at least a regional-scale extinction might have occurred at the time of the impact. A paleoreconstruction shows that South China was very close to and facing Western Australia in the Late Devonian [4].

South China: An Upper Devonian carbonate section exposed at Qidong, Hunan, was studied for biostratigraphy, geochemistry, and sedimentology. A brachiopod faunal changeover from the traditional *Yunnanellina* to *Yunnanella* faunas [5] was recognized in the section. Abundant microspherules were found in a single stratigraphic horizon immediately below a 3-cm clay with a geochemical anomaly. The microspherule horizon occurs in the Lower