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by email; original by courier

6 July 2005

Dear Mr. Maracle,

RE: The De Beers Victor Diamond Project Comprehensive Study.

Ms Gillian McEachern, director of the Forests Program of the Canadian Parks and Wilderness Society – Wildlands League, has drawn our attention to the open pit diamond mine operation that De Beers Canada is proposing at the Victor kimberlite pipes near Attawapiskat, Ontario, and has invited our comments. She has guided us to the Comprehensive Study Environmental Assessment, Technical Reports and Comprehensive Study Report prepared by De Beers. These are very substantial documents. We received them at short notice because the Canadian Environmental Assessment Agency deadline for receipt of comment on the Comprehensive Report is July 11 this year. We therefore have limited our reading to the geological, hydrogeological and water chemical quality discussions in the reports, including the SRK-HCI report of February 2004 entitled "Dewatering of Victor Diamond Project: Predicted Engineering, Cost and Environmental factors".

The Victor area is a karsted rock terrain of low relief that is overlain by generally shallow glacial and marine detrital sediments laid down during the recession of the last (and perhaps earlier) ice. It is very wet. Nowhere in the Reports, peer reviews, and invited comments by government, etc. agencies can we find any suggestion that competent karst scientists have been involved at any stage in this work. We are karst specialists. We have worldwide experience in karst geomorphology, geology, hydrogeology and hydrochemistry, both academic and applied. We live in Ontario, however, and so have gained a large part of our experience within Canada and the USA, including all provinces and territories except PEI (which has no karst) and sixteen of the American states. Recently, much of our research has been focused on karst groundwater problems in the rocks of the Cataract, Clinton and Lockport Groups of Southern Ontario, which are the temporal and stratigraphic equivalents of the bedrock formations of concern at the Victor site and which exhibit many relevant similarities in their behaviour. One of us (Ford) is co-author of the leading international textbook in the field (D.C.Ford & P.W.Williams 1989 'Karst Geomorphology and Hydrology', London, Chapman and Hall; 601 pages. (Second Edition pending)), which makes many references to the distinctive nature and development of karst in Canada's glaciated environment. We have many other pertinent publications in leading journals, books, etc. We find no reference to any of these or to the work of any other pertinent karst scientists in the De Beers reports we have had time to peruse.

We understand that the major relevant concerns about the impact of the proposed mine are (1) that it may significantly reduce low stage flows in the Attawapiskat River to the north, in the Nayshkootayaow River to south, and in local lesser tributaries, affecting fish, etc. habitat; (2) that return of pumped groundwater enriched in suspended and dissolved solids downstream of the mine may also adversely affect fish habitat, etc; (3) a possible Bioherm Karst ANSI at the Bioherm Meadows downstream may be affected

On the basis of our technical competence and our reading of the De Beers reports to date we wish to express our serious reservations concerning the validity of the hydrogeological work, modeling and predictions that are being made. We suspect that the impacts may be more complicated and hazardous than the reports suggest, and that the integrity of the mine itself and associated buildings, roads, etc. may also be hazarded by karst effects . Our principal reasons for this are as follows:-

(1). The relevant bedrocks. The mine is to be taken to a depth of approximately 225 m. The bedrocks are regularly bedded, flatlying, potentially karstic sediments throughout this depth. At the stratigraphic base, the **Churchill River** and **Red Head Rapids Groups** are interbedded limestones, dolomites, mudstones and evaporites, probably a *sabkha* (inter-tidal to supra-tidal) depositional sequence of a kind that is common and often associated with development of large karst forms. A somewhat unusual feature here is that the sulphate strata are reported as being entirely of gypsum ($CaSO_4.2H_2O$), lacking any anhydrite ($CaSO_4$). The latter is common at such depths in strata that have been more deeply buried previously, as they have in this region; their probable rehydration to gypsum here suggests that there has been effective deep groundwater circulation at this site (despite the flatness of the surface) for a long period. The modern groundwaters display high sulphate and salt concentrations (5000 – 10,000 mg/l or more).

The so-called **Overburden Trench** (a non-geological and inappropriate term) that extends immediately NE of the mine site bottoms in this Group or a little below it

(Environmental Assessment, Figure 8-3). It is correctly defined as a 'bedrock closed depression' but where such are seen in evaporite karst regions they are usually described as 'infilled sinkholes', 'buried sinkholes' or 'paleokarst'. Many examples quite similar to the Trench are known elsewhere in Canada, the United States, etc. Here, because this particular feature is elongated and apparently without local bedrock breccia at the base of its infilling, we tentatively interpret it as an evaporite solutional collapse structure that has been modified in form by basal glacier scour. Other evidence suggests that it is older than the last (or last few) glaciations which, like the lack of anhydrite noted above, points to a long history of deep dissolution in this region.

The **Severn River** and **Ekwan River** formations that overlie the Red Head Rapids strata have a total thickness of around 90 m. They are limestones with minor dolomite. They are described as occurring in massive beds 3-6 m thick that interspersed with a few sections of thin interbed. Such 'sandwich' structures are common in carbonate rocks and favour efficient karst development with lengthy flowpaths because the water is focused preferentially through the interbeds. Total Dissolved Solids in the groundwaters are generally >2000 mg/l, high values that suggest that there is some flow upwards from the evaporites beneath them.

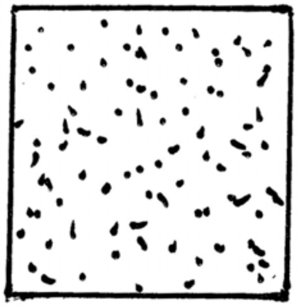
The **Attawapiskat Formation** is 100-130 m in thickness. Like its equivalent in Southern Ontario (the Guelph - Amabel formations) it consists of sequences of shallow platformal limestones laid down in regular beds, with clusters of small reefs (bioherms) and weaker inter-reef strata built on top of them from place to place, and later buried by further accumulations of them. At the Victor site the Formation displays many features are that are not common in other flatbedded, glaciated limestone terrains of lowland Canada. First, from the geotechnical reports, the uppermost bedrock (generally beneath 1.5-30 m of overburden) is 'shattered and/or weathered' to depths of 0.1 to 2.2 m, occasionally as deep as 10 m. This 'has the texture of and appearance of sands and gravels, and occasionally sandy silt to clayey silt.' This is a good description of deeply weathered, fossiliferous limestone or dolomite sometimes found in pods or other low (groundwater) energy environments in warm, non-glaciated terrains such as Hungary, Jamaica, etc. 'Grus' is the standard term for it. It is most unusual in Canada because, normally, basal ice scour will remove it and any underlying more solid (but still densely weathered) epikarst. Second, beneath this uppermost zone the limestones to depths of 30 m or so are described as 'intensely karsted', with many open vugs and other small voids, plus larger voids up to 0.3 m or more. Core recovery was often very poor. There is some infilling with clay and other sediments, especially in the upper parts. Below the intensely karsted zone, the reports suggest to us that the Attawapiskat limestones display more normal appearance, with a lower frequency of karstic voids and lower hydraulic conductivity. The 'Overburden Trench' figure, (Environmental assessment, Fig 8-3) shows one bedrock closed depression ~400 m in diameter extending down into it, however, and we suppose that there may be others not detected. This indicates that the lower Attawapiskat strata are well karstified. We have not seen photographs of core samples of the Formation or found any mention of downhole video observations in it. Total Dissolved Solids measured in water samples from it range from ~200 to 2000 mg/l. In this setting, any values above 400 - 500 mg/l TDS should be considered exceptionally high, indicative of vigorous dissolution taking place beneath the overburden today.

In our (considerable) experience of glaciated lowland limestone terrains in Canada, the karstic conditions in the upper Attawapiskat Formation are very unusual. No other limestone surface known to us exhibits such extensive spreads of grus as the reports suggest. We suspect that the explanation for this phenomenon is that the last Laurentide ice sheet to cover the region (and perhaps some of the earlier ones) was cold-based, i.e. frozen to its bed and thus unable to erode it fiercely. This kind of preservative behaviour was first explained by Ford (1983, Journal of Hydrology, pp 149-158, 177-180) for the case of the Winnipeg dolomite epikarst aquifer that is preserved under melt-out glacial tills and Glacial Lake Agassiz clays. The Attawapiskat case appears to be more remarkable and the preservation more complete. This has important practical implications – the rock is probably in geotechnically poorer condition than at any other Canadian karst site we have investigated. Acidic waters have been passing down through the overburden and rotting it for a long while. We return to this point in Comment 5 below.

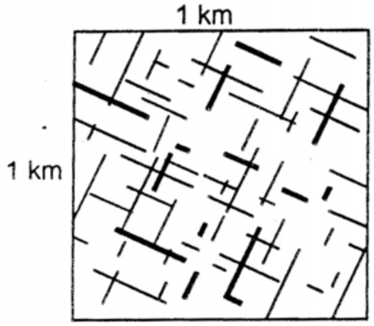
The reports emphasise that there is a wide range in the frequency of fracturing (meaning jointing and faulting) in all of the formations. As would be expected, it is intense around the kimberlite pipes. Around the Trench it will also be locally high due to the undermining processes, if our interpretation of that feature is correct. Elsewhere, the fractures appear to vary considerably in both scale and density. Some fault breccia and slickensides are mentioned, and sand, silt or clay fillings.

More important is the fact (mentioned at many points in different sections of the reports) that the most vigorous groundwater flow was usually along some near-horizontal bedding planes in all formations. This occurs despite the exceptional abundance of major vertical or inclined fracturing attributed to the pipe emplacements at the Victor site. Predominance of flow in bedding planes is the standard behaviour of groundwater in near-horizontal carbonate and sulphate karst rocks worldwide. Sadly, many hydrogeologists fail to grasp that simple point; it vitiates much of their conceptual and numerical modeling. The reasons for it are summarized in Ford &Williams, *op.cit.* pp. 35-6, and many other of our publications. Branchwork patterns of dissolutional conduits form readily in bedding planes, transforming aquifers from simple porous or fracture-dominated entities into karst aquifers that exhibit triple porosity with the conduit component being dominant. There has been intensive, sophisticated computer modelling of this process in recent years, work that is completely ignored in the Attawapiskat studies. We summarise the main points in the next section.

POROUS



FRACTURE



KARST

Table . **Principal differences between single-, double-, and triple-porosity aquifers**

Parameter	**Aquifer type**		
	Single porosity (porous medium)	**Double porosity***	**Triple porosity (karst)**
Flow components	matrix	matrix fracture	matrix fracture channel
Flow laws	Darcy	Darcy, Hagen-Poiseuille	Darcy, Hagen-Poiseuille, Darcy-Weisbach
Flow modes	laminar	laminar	laminar turbulent
Flow lines are	parallel	mostly parallel	convergent to channels
Do boreholes provide representative samples?	yes	yes	no
Are there troughs in the potentiometric surface?	no	no†	yes
Ease of numerical modelling to depict flow and transport in an aquifer	Straightforward	Complex	Never achieved yet at the aquifer scale

(2). The nature of karst aquifers; applicability to the Attawapiskat aquifer.

The figure and table we have attached to this letter illustrate the main differences between karst and other aquifers. In karst, branchwork patterns of dissolutional channels (conduits) develop in bedding planes or joint or fault systems, or at the juncture of bedding planes and joints. They may be enlarged to diameters of meters and convey groundwater at rates of many metres to hundreds of metres per hour, depending upon hydraulic gradients and recharge rates.

From the information we have read about the Victor site it seems highly probable to us that the aquifer will exhibit triple porosity, with karst flow quantitatively predominant in the bedding planes and at the regional scale, and fracture flow more important in the massive beds and perhaps in the highly shattered immediate surrounds of the kimberlite pipes. There will also be some diffuse Darcy flow in the grus and in perhaps some bioherms.

The dewatering model that has been applied at the site does not take these complexities into account, instead treating the entire aquifer as a simple Equivalent Porous Medium (EPM) case. We do not believe that it is sufficiently accurate for predictive purposes at the regional scale, or coping with flow towards the pit as dewatering proceeds. One of us (Worthington) was involved in characterizing the karstic attributes of an important limestone aquifer in Texas for input to a computer model which used the popular MODFLOW code (U.S. Geological Survey Scientific Investigations Report 2004-5277). Karst effects can be successfully incorporated into such models, which can reasonably simulate flow but not transport in karst aquifers. We address some matters of detail in the choice of model parameters in the next section.

(3) Comments on the aquifer modeling parameters and field tests.

A major concern is the potential for large groundwater inflows to the pit from the two nearby rivers. The prediction from the groundwater model is that water levels in the limestone underneath the Attawapiskat and Nayshkootayaow Rivers will be lowered by more than 40 m and more than 70 m, respectively, by the end of mining (HCI Dewatering Report, Figure 22). If there are significant karst conduits in the limestone beside or under the rivers then inflows to the pit may be very much greater than predicted. In the "intensely karstic" uppermost bedrock we are concerned that there are very few measurements of hydraulic conductivity. There are no measurements in this zone within 3 km of the Attawapiskat River. The model uses one single value of 1 m/day for all of this zone, which is a very low value for any karstified limestone. Much more testing of the uppermost bedrock is needed between the mine and the two rivers.

A 10-day pumping test close to Nayshkootayaow River was conducted to estimate the potential leakage from that river into the aquifer during dewatering. The match between the groundwater model and the test data is poor. Some wells have responses that are much greater (HCI-10, HCI-11) or much less (HCI-3) than the model, indicating that it poorly captures the aquifer heterogeneity, as we have suggested must be the case in (2) above. Of more concern are the large simulated responses and the zero actual responses at the shallow wells (HCI-6 and HCI-7) on either side of the river. This shows that the model performs poorly in simulating the important effect of interaction between Nayshkootayaow River and the aquifer. The model simulates a reduction of more than 70% in baseflow in the river. In light of the poor match of the model to the pumping test data, it is a concern that baseflow in the river could be reduced to zero in the neighbourhood of the mine.

A 30-day pumping test was conducted to estimate inflows from the Attawapiskat River. However, there is only a single well (HCI-1) between the pumping well and the river, this well is more than 2 km from the river, and the modelled drawdown (1.3 m) is significantly different from the measured drawdown (2.3 m). In cross-section, the report describes the uppermost bedrock as "intensely karstic", as noted. Wells should have been installed adjacent to the river both to the north and to the south of it and one or more pumping tests conducted close to the river. Without such testing there is no assurance that there will not be major losses from the river to the pit. Such flows could be several times greater than the estimated total pumping from the pit, which is estimated at maximum of around one m^3/sec, a figure that we consider may prove to be too optimistically low. The Attawapiskat River has a base flow of ~70 m^3/s, more than enough to flood the pit catastrophically if the karst really opens up during dewatering!

We are concerned about the inadequate documentation of groundwater discharge where limestones outcrop along the rivers. In the reports, these are often described as “seeps”. Meinzer (1927 USGS Water-Supply Paper 557) defined eight magnitudes of springs. The largest (1st Magnitude) are >100 cubic feet per second (>2800 L/s), the great majority of such being karstic. The smallest are less than one pint per minute (~0.01 L/s).). We consider it highly likely that there are major springs with discharges of at least some tens of litres per second (rather than just seeps) along the Nayshkootayaow and Attawapikat Rivers. Detailed multi-season mapping of such springs should have been carried out because these springs could become the major inflow points from the rivers to the mine once dewatering commences

(4) The presumption that conditions in the aquifer will remain the same during the dewatering. A fundamental assumption of the consultants is that the conditions of e.g. hydraulic conductivity, measured in their sparse boreholes and brief pumping tests will not change significantly during the ten years or more of dewatering that will radically increase local and regional hydraulic gradients. This is not likely to be the case. On the contrary, we anticipate some quite rapid changes that (with the present levels of information) are unpredictable in space and time

Because of the karst conditions of the site we have summarized above, there is a very close analogy between the proposed dewatering at Victor and the damming of valleys that have relict karst in their walls. The (considerable) worldwide published experience where there is heterogeneous, partly filled, karst in such dam abutments is that there can be rapid but erratic flushing of clastic detritus, with ancient filled conduits and other cavities suddenly being re-opened and functioning as leaks (sometimes catastrophic in magnitude) around the dam. Every developed nation with karst has a selection of abandoned reservoirs or enormous cost overruns that it prefers to forget!

Further, the flow of fresh, low pH, river water into the karst (predicted by the consultants) will boost the solvent capacity of the groundwater in the shallow aquifer. Deeper in it, dissolution rates will be enhanced by mixing corrosion and ionic strength effects when high TDS waters are added (see Ford & Williams, 1989, p 69 *et seq*). The rates of conduit link-up and enlargement by detrital flushing, increased rates of flow and of dissolution rates, may create quite rapid changes in the local and regional conductivity of the aquifer, both in the Attawapiskat Formation and below it.

Under the present conditions, the consultants emphasise that the vertical hydraulic conductivity of much of the bedrock is low. Rapid local changes in this behaviour could occur as the dewatering proceeds, however. There may be considerable, point-located, leaks from the saturated Attawapiskat Formation strata into the lower formations. By analogy, at Crowsnest Pass (Alberta), upper, massively bedded, limestones are drained quickly through >40 m of black shales with coals into lower limestones (see Ford, 1983, Journal of Hydrology, pp 187-192); there are no potentially resistant aquitards such as this at the Victor site.

(5) The stability of the overburden during dewatering of the limestones. The hydrogeologic model suggests that an area as great as 300 km^2 may be dewatered around the pit. In the inner parts of it, the dewatering will extend to the full depth of the intensely karsted upper Attawapiskat Formation or below it. As noted, the overburden is of very variable thickness and composition. It is saturated and physically stable today because the natural water table is either high in it or above it, providing buoyant support. We have suggested that the widespread occurrence of limestone grus indicates that acidic water can pass down through much of this overburden to attack the rock underneath. Whether that occurs or not, the draining of grus, shattered rock or intact epikarst void systems can be expected to cause local displacement and settling that will undermine the overburden, inducing blocky fracture in it, etc. We fear that statements such as that the local creeks are "…. perched within the clay/silt overburden, and thus not connected to the deeper groundwater system, and would not therefore be meaningfully affected by well field pumping" (Environmental Assessment, page 2-8) may prove to be geo-wishful thinking. The standard experience worldwide where there is dewatering of soil-mantled karstified limestones and dolomites is that suffosional sinkholes can develop very quickly in the overburden. They take the form of steep-sided funnels that enlarge (*ravelling sinks*) in more sandy soils, or of unseen arches that can abruptly fail in more sticky clays and silt-clays (*collapse sinks*); many are a combination of these two processes. The literature on the subject is vast (see e.g. B.F.Beck and J.G.Herring (eds.) 2001. Geotechnical and Environmental Applications of Karst Geology and Hydrology. Lisse, Balkema Publishers. 438 p. for many North American case studies) but we find no significant attention paid to it in the Attawapiskat reports.

In our professional opinion, suffosion sinkhole formation is likely at the Victor site. It could hazard all buildings, roads, etc. because these tend to focus storm drainage into surrounds or ditches. At the beginning of the 1980s, overpumping for irrigation was creating an average of 18 sinkhole collapses per month in the highways of northern Florida, for example, where overburden conditions generally appear less hazardous than those at Victor. Perhaps the most notorious example of a catastrophic collapse was that at the West Driefontein Mine (Far West Rand goldfields, South Africa) in December 1962, where a three-storey crusher with 29 workers in it was lost in a few seconds; it was a consequence of dewatering upper parts of a dolomite karst with deep overburden.

Conclusions.

(1) The country rocks at the proposed Victor open pit are limestones and dolomites, plus some gypsum and mudstones at the level of the bottom of the mine. The De Beers reports suggest to us that these are probably the most highly karstified strata we have encountered in many years of study of karst in Canada. Karstification extends the full depth of the mine. The locale is flat and wet. The rocks are saturated and will function as a karst (or triple porosity) aquifer. However, for purposes of estimating the impacts of dewatering the pit and its surrounds they have been modeled only as a simple equivalent porous medium (EPM). No attention appears to have been paid to the nature of the karst phenomena or their possible effects on the mine operations. No karst specialists have contributed to the investigations at the site.

(2) The EPM predictions rest upon one single hydraulic conductivity estimated value of one metre per day for the entire karst aquifer. We consider this to be unsupported, and most inadequate.

Ten day and thirty day pumping tests carried out to estimate the potential flow of groundwater from the Nayshkootayaow and Attawapiskat Rivers respectively, and to test the EPM model, used an insufficient number of observation wells and were insufficient in number and design themselves. The correlations with the model were poor.

The nature and magnitude of karst springs along the rivers appear not to have been recorded. They may give insight into potential groundwater recharge as the aquifer is dewatered.

(3) The estimates of dewatering drawdown effects and the volumes of water requiring to be pumped are too conservative in our opinion. The volumes could be much higher at times, including mine inrushes of catastrophic magnitude. Correspondingly, the volumes of pumped groundwater enriched in dissolved solids that will have to be returned to the rivers downstream are probably underestimated.

(4) Physical parameters in the aquifer will not remain constant during the pumping. Rapid changes are to be expected, which will affect the EPM (or any other) model predictions.

(5) Sinkhole formation is likely to occur in the unconsolidated overburden as dewatering of the karst aquifer proceeds. It may hazard all physical installations, and lives if it occurs with catastrophic rapidity.

In sum, the concerns described above involve threats to both the environment and to human safety that, in our opinion, need to be fully addressed before approval to proceed with the mine is granted. The potential karst problems we describe have often been encountered elsewhere in the world, where they have been addressed with varying degrees of success. Remedial efforts to deal with these problems can be prohibitively expensive.

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