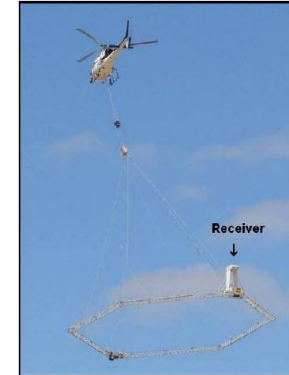
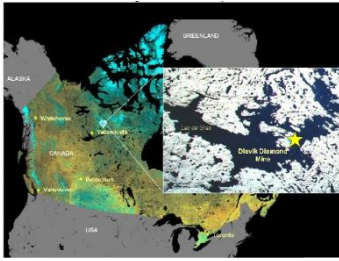


# Exploring for Diamonds with Airborne EM



Keith Jones-Geophysical Consultant  
ASEG- AEM Workshop Perth November 7 2012



# Are Diamond Mines Profitable?



## Diavik Mine NWT

Capital cost for construction C\$1.3 billion  
 Payback period-24-32 months  
 Life Expectancy-16-22 years



## Palaeo-Plunge-Pool-Angola

Mined 70X50X8m  
 52000ct from 37000 cu m  
 1.4 Ct/cu m @260 \$/Ct  
 13.5 M US\$

# Where do we find diamonds?

Two main sources

Alluvials



Typical Gravels



Typical High Quality Stones

Hardrock-Kimberlite /Lamproite



Argyle Mine

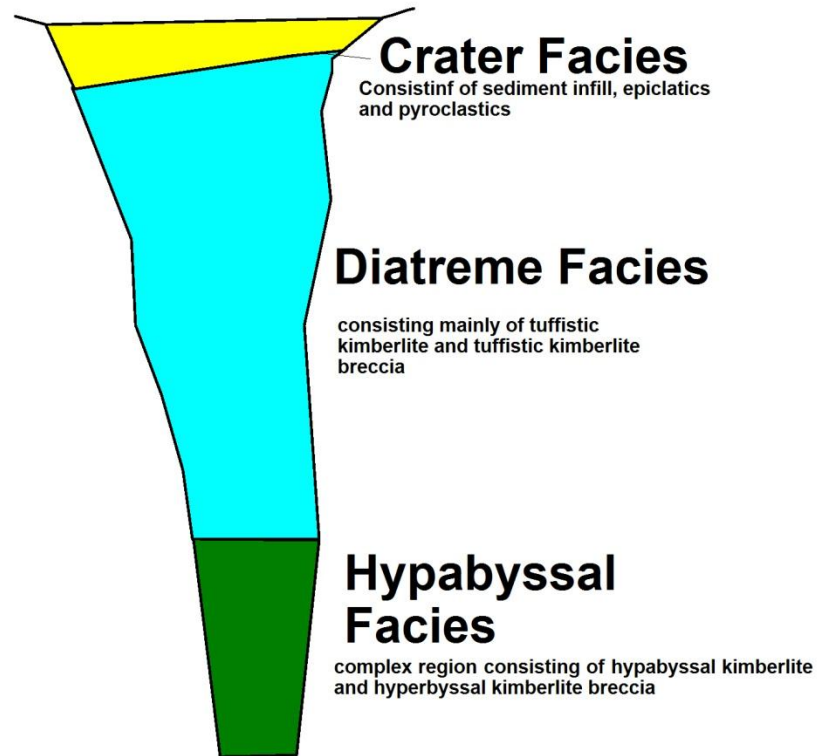


Argyle Pinks

# What is kimberlite?

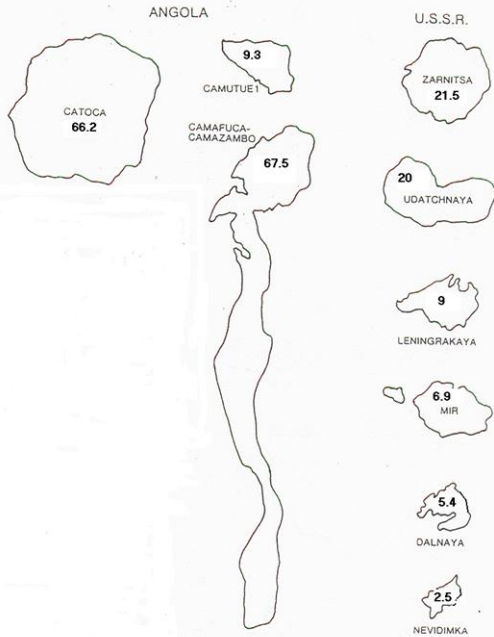
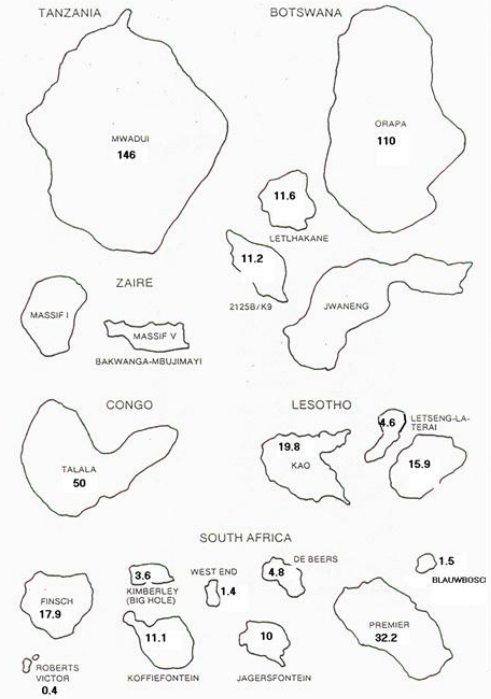
Kimberlites are a clan of volatile-rich (mainly carbon dioxide) potassic ultrabasic rocks which are formed at depths >150km below the surface. They commonly exhibit a distinctive inequigranular texture resulting from the presence of macrocrysts (and megacrysts) set in a fine grained matrix. It is composed principally of olivine with lesser amounts of phlogopite, diopside, serpentine, calcite, garnet, ilmenite, spinel and other minerals. **Diamond is only a rare constituent**

Kimberlite is the vehicle by which diamonds reach the surface



# What Does the Target Look-like

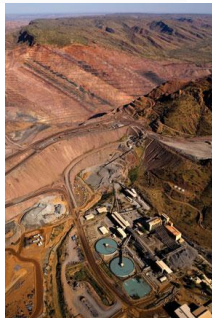
SURFACE SHAPES AND SIZES OF DIAMOND PIPES



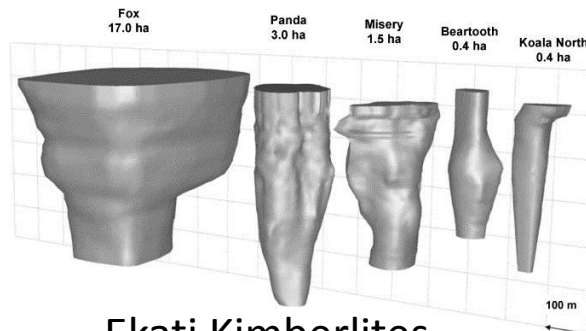
Range in size and shape  
Luikonlahti Kimberlite Cluster



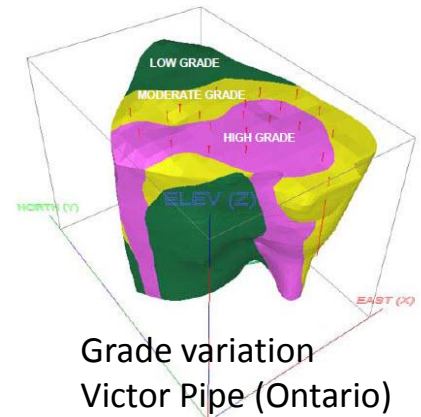
International



Argyle



Ekati Kimberlites



Grade variation  
Victor Pipe (Ontario)

# Big vs Small-Does Size Matter?

**Table 5**  
Area, grade, value per carat and value per tonne for economic or near economic kimberlites

Pipe	Area (ha)	Grade (ct/100t)	Average US\$/ct	Average US\$/t
23 Party Congress	1.5	600	120	720.0
International	1.7	400	120	480.0
Marsfontein	0.4	300	142	426.0
A-154 south	1.0	480	63	302.4
A-418	1.0	370	56	207.5
Kimberley	3.6	100	200	200.0
Jwaneng	45.0	147	110	161.7
Dia Met Panda	1.0	109	130	141.7
Venetia 1 and 2	17.0	129	100	129.0
Aikhal	3.0	120	100	120.0
A-21	1.0	300	38*	114.0
Dia Met Misere	1.0	426	26	110.7
Udatchnaya	20.0	100	100	100.0
Yubileynaya	40.0	100	100	100.0
Dia Met Koala	1.0	76	122	92.7
A-154 north	1.0	240	35*	84.0
De Beers	4.8	90	75	67.5
Arkhangel	118.0	75	80	60.0
Mbuji-Maji	18.6	600	10	60.0
Dia Met Sable	1.0	93	64	59.5
Lethakane	11.6	33.8	150	50.7
Dia Met Fox	1.0	40	125	50.0
Argyle	46.0	549	9	49.4
Dalnaya	5.4	50	85	42.5
Orapa	110.0	68	50	34.0
Bultfontein	9.7	40	75	30.0
Finsch	18.0	75	40	30.0
Catoca	66.0	46	60	27.6
Wesselton	8.7	27	100	27.0
Camacue	9.3	12	200	24.0
Dokolwayo	2.8	40?	50?	20.0
Zarnitsa	21.5	15	120	18.0
Premier	32.2	50.6	35	17.7
Dutiotspan	10.8	20	75	15.0
Jagersfontein	10.0	7	200	14.0
Letseng	16.0	3.5	400	14.0
Koffiefontein	10.3	7.4	150	10.5
Mwadui	146.0	6	150	9.0

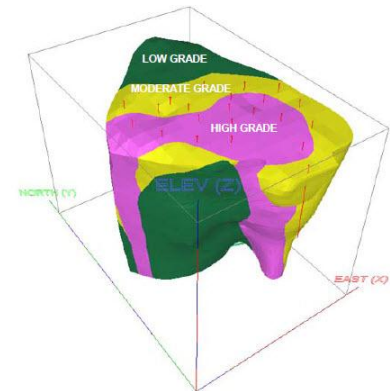
\* valuation based on small parcels.

Adopted from: Janse (1993), De Beers Annual Report 1993.

Source Jennings et al

One carat=0.2 grammes

100cts/100t=20 grammes of diamond for each 100 (metric) tonnes mined



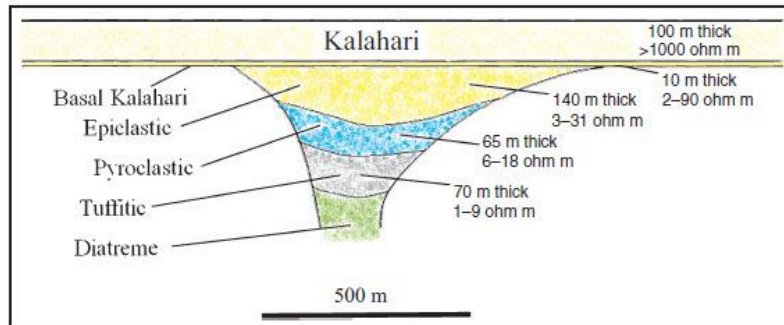
Victor Kimberlite  
Ontario, Canada

# Electrical Properties of Kimberlite

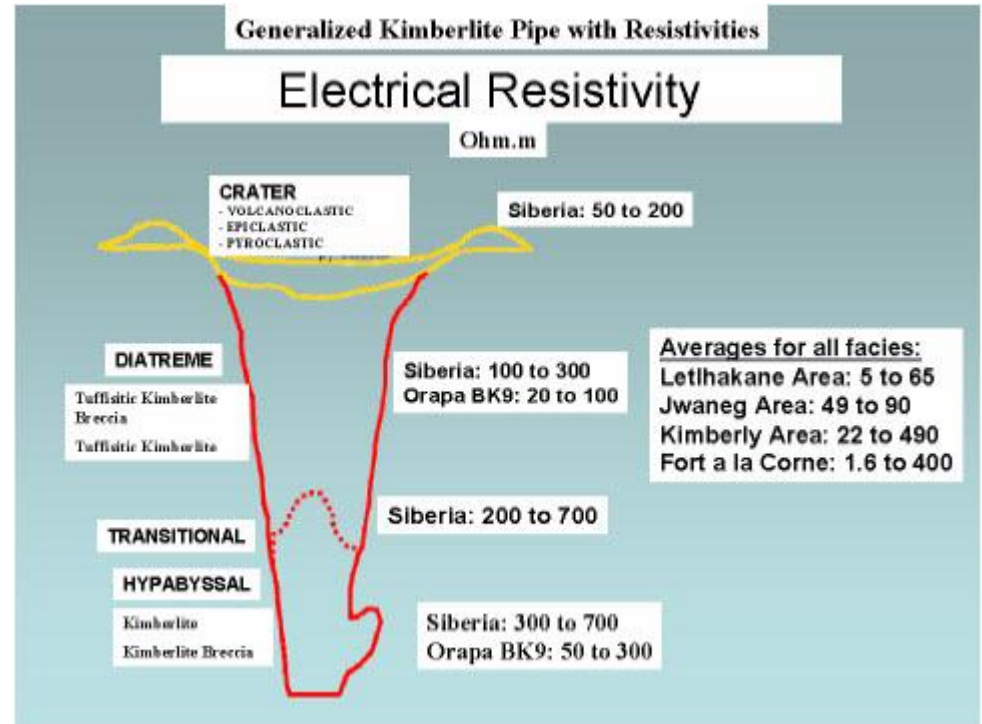
Kimberlites and lamproites, due to their ultramafic composition tend to weather more rapidly and deeply than surrounding rocks (Palacky 1986). High porosity is also developed in tuffaceous or brecciated parts of the pipe and may act as an easy conduit for groundwater flow (Macnae 1995). Crater sediments can be more conductive than weathered kimberlite.

A thin conductor will therefore develop at the top of the pipe and be a target for electromagnetic and resistivity geophysical techniques.

Where kimberlites intrude conductive sediments, particularly in glaciated areas, the kimberlite may be more resistive than the sediment and produce a resistivity “high”



Resistivities of kimberlite facies-Kokong Botswana (Cunion-Exploration Geophysics 2009, Vol 40)

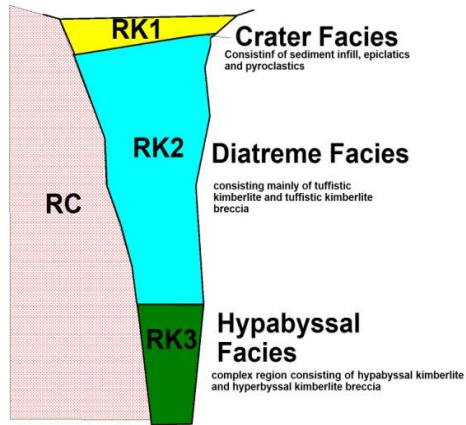


(Arnott and Kostlin 2005)

Conductivity (milliSiemen/m)							
	Shale	66.9	311.7	204.2	77.6	144.5	223.9
	Siltstone	156.6	240.2	194.0	173.8	190.5	218.8
	Sandstone	46.5	115.7	79.4	69.2	79.4	83.2
	Kimberlite	2.5	624.2	87.4	25.1	39.8	125.9

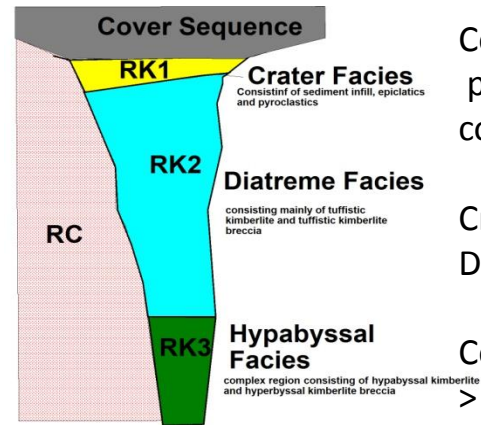
Saskatchewan -Conductivities of kimberlite and sediments (Mwenifumbo et al)

# What are the variables affecting the EM response of a kimberlite?



RC (Country Rock) Resistivity  
> or < kimberlite

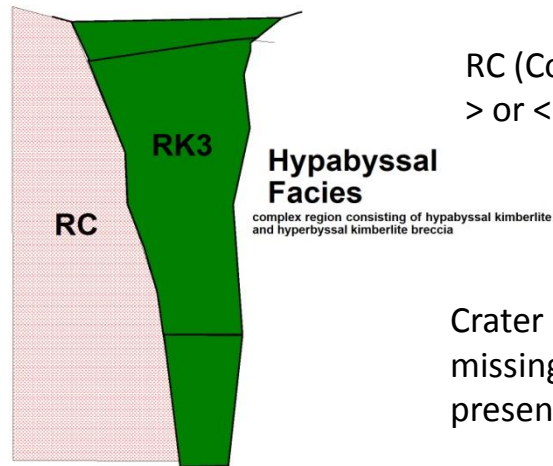
Crater facies + diatreme facies present possibly eroded to some degree



Cover Sequence present-  
conductive or resistive?

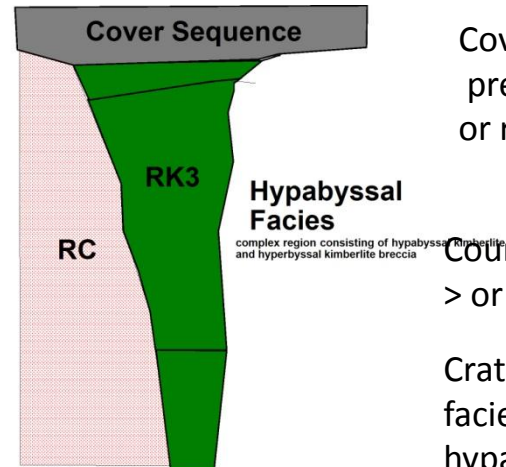
Crater facies and /or Diatreme facies present

Country rock resistivity  
> or < than kimberlite



RC (Country Rock) Resistivity  
> or < kimberlite

Crater and diatreme facies missing-only hypabyssal present



Cover Sequence present-conductive or resistive?

Country rock resistivity  
> or < than kimberlite

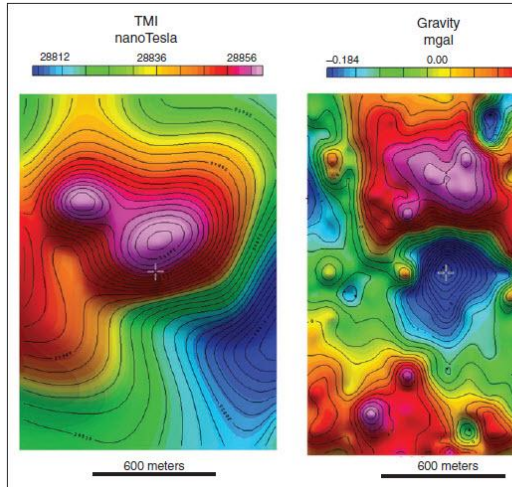
Crater and diatreme facies missing-only hypabyssal present

# Examples of kimberlites exhibiting some of the above variables

1. Kokong Kimberlite Field Botswana-Kimberlites overlain by resistive overburden Majority of kimberlites produce conductivity high with the exception of one pipe where conductive crater and diatreme facies are absent.
2. Comparison of EM responses of kimberlites in the Archaean Slave Craton and Alberta Mesozoic Sedimentary Basin-Resistive vs Conductive Host
3. EM responses of Saskatchewan Kimberlites intruding conductive mudstones and overlain by up to 100m of glacial sediments
4. Drybones Bay Kimberlite covered by thick layer of lake sediments
5. Comparison of FDEM and TDEM responses of Tli Kwi Cho kimberlites located in resistive Archaean crystalline basement
6. Comparison of variable EM responses of Merlin and Abner kimberlites –Northern Territory, Australia

# Kokong Kimberlites-Example of different EM responses in same kimberlite cluster

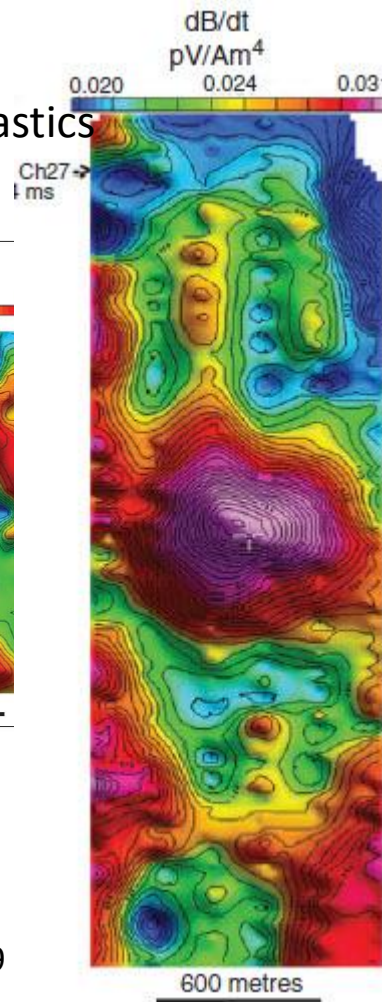
Typical Geophysical Response in kimberlite cluster  
 Conductive kimberlites due to conductive epiclastics



TMI Response

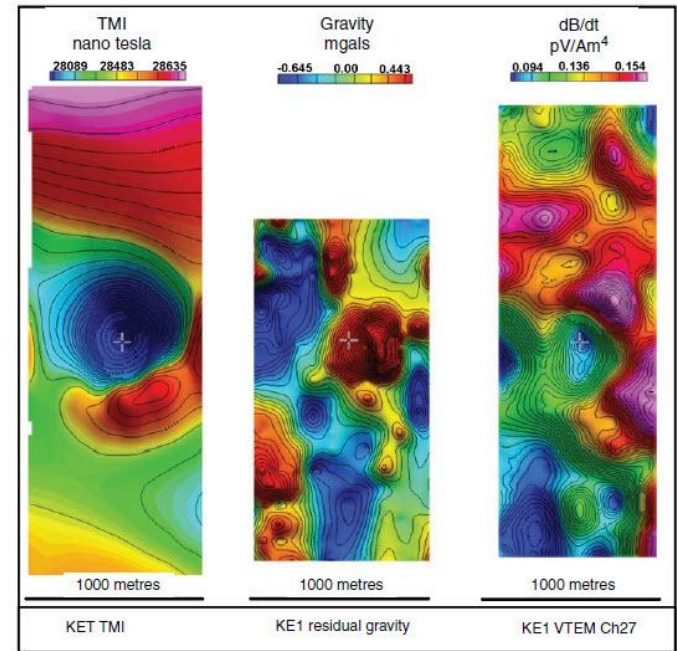
Gravity Response

Exploration Geophysics 2009  
 Vol 40



EM Response

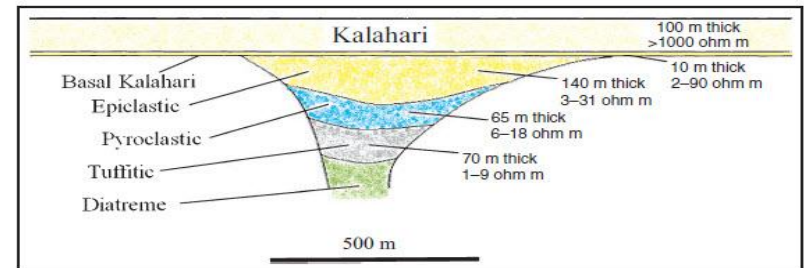
Unusual Response due to absence of conductive epiclastics



TMI

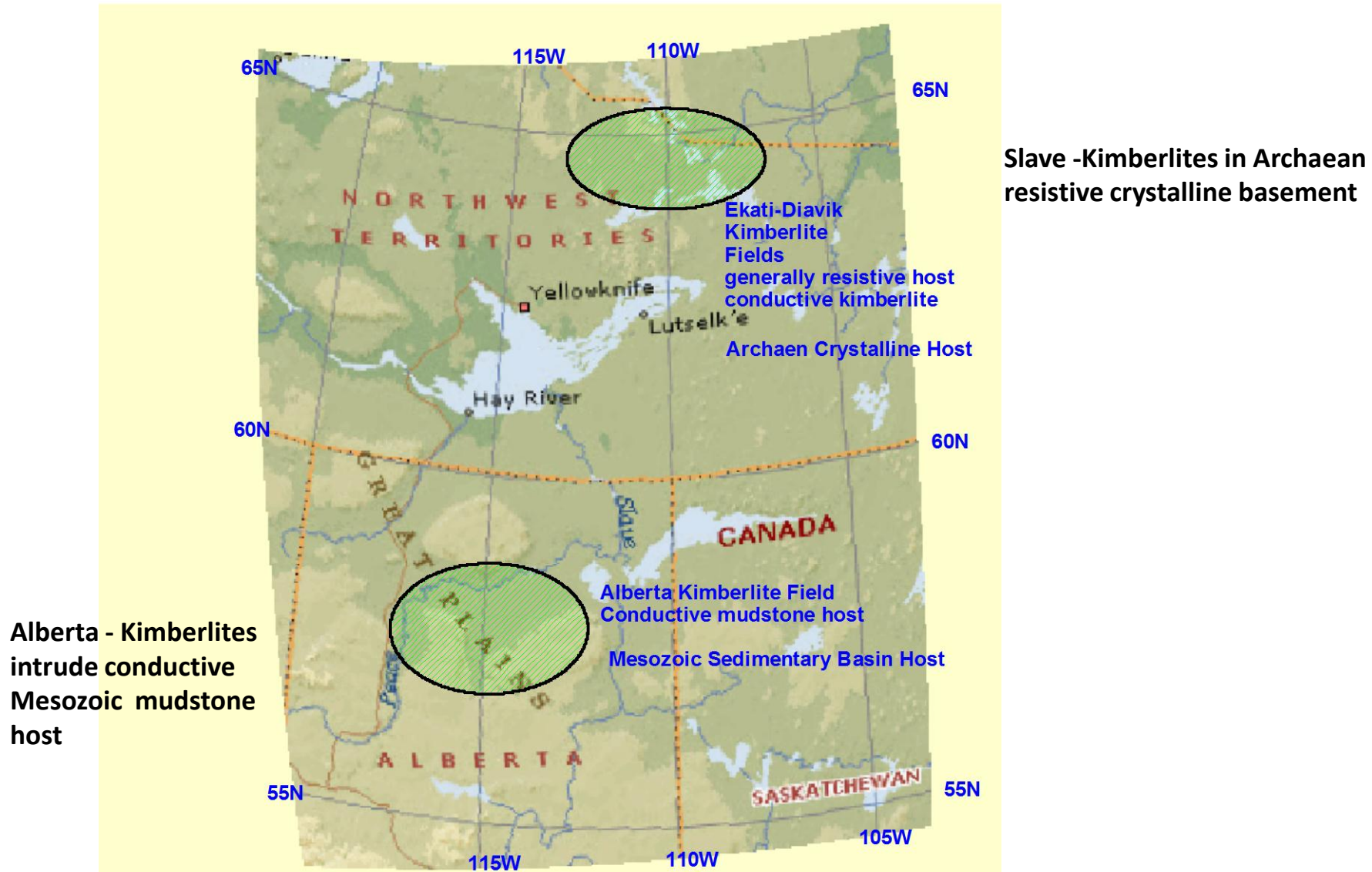
Gravity

HEM

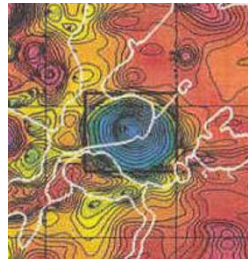


Range of resistivities in various facies

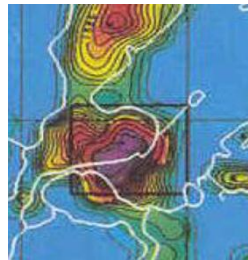
# Comparison Slave and Buffalo Head Hills Kimberlites



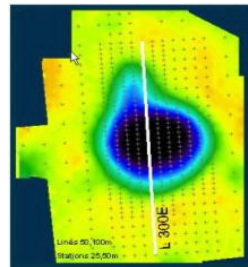
# Comparison Slave and Buffalo Head Hills Kimberlites



Magnetic Response



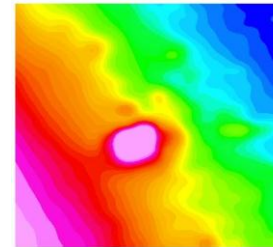
EM Response



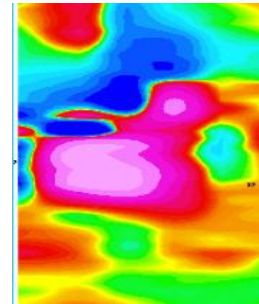
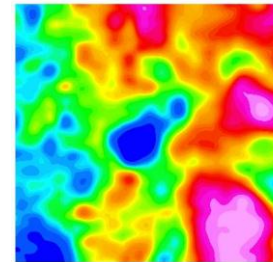
Gravity Response



Slave Craton-Resistive Host  
Conductive kimberlite

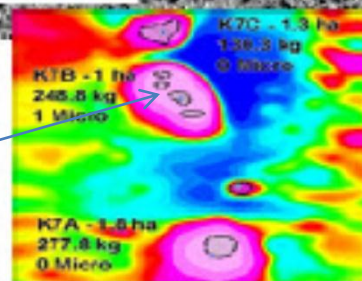
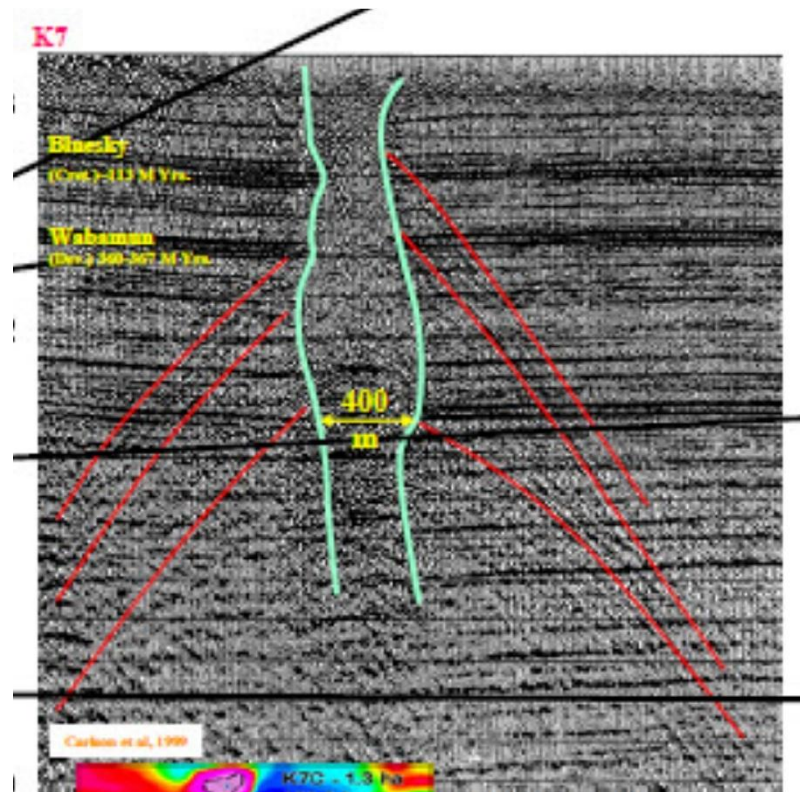


Red colours  
Indicate "highs"



Alberta sedimentary basin -  
Conductive mudstone host

# Seismic response over resistive kimberlite-Alberta

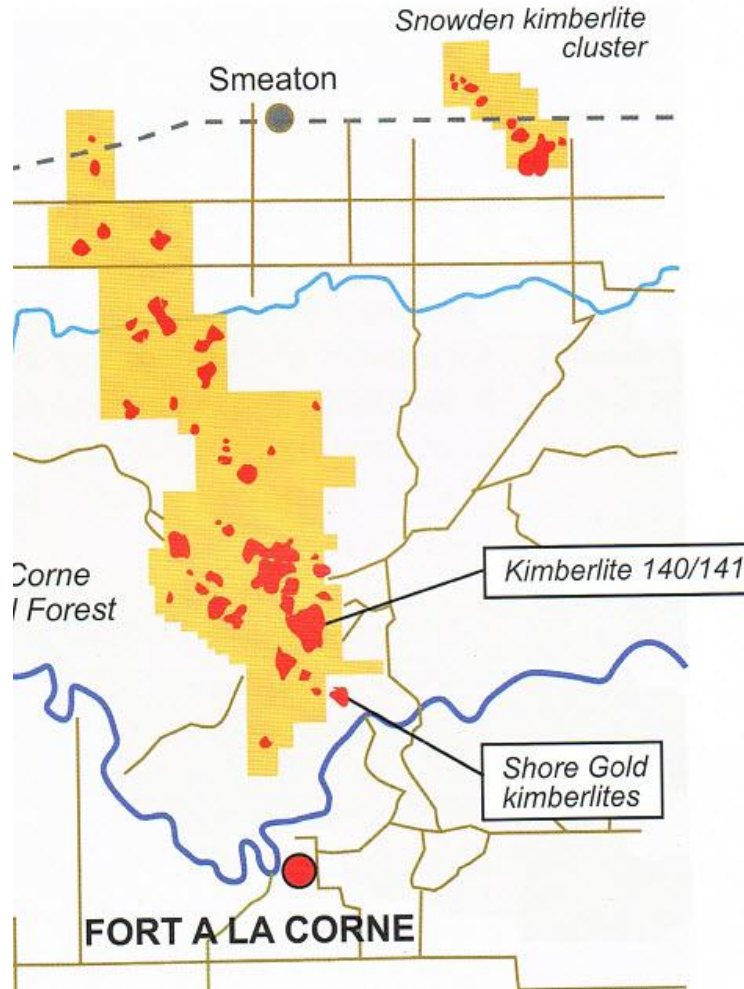


Resistive response in  
Conductive host

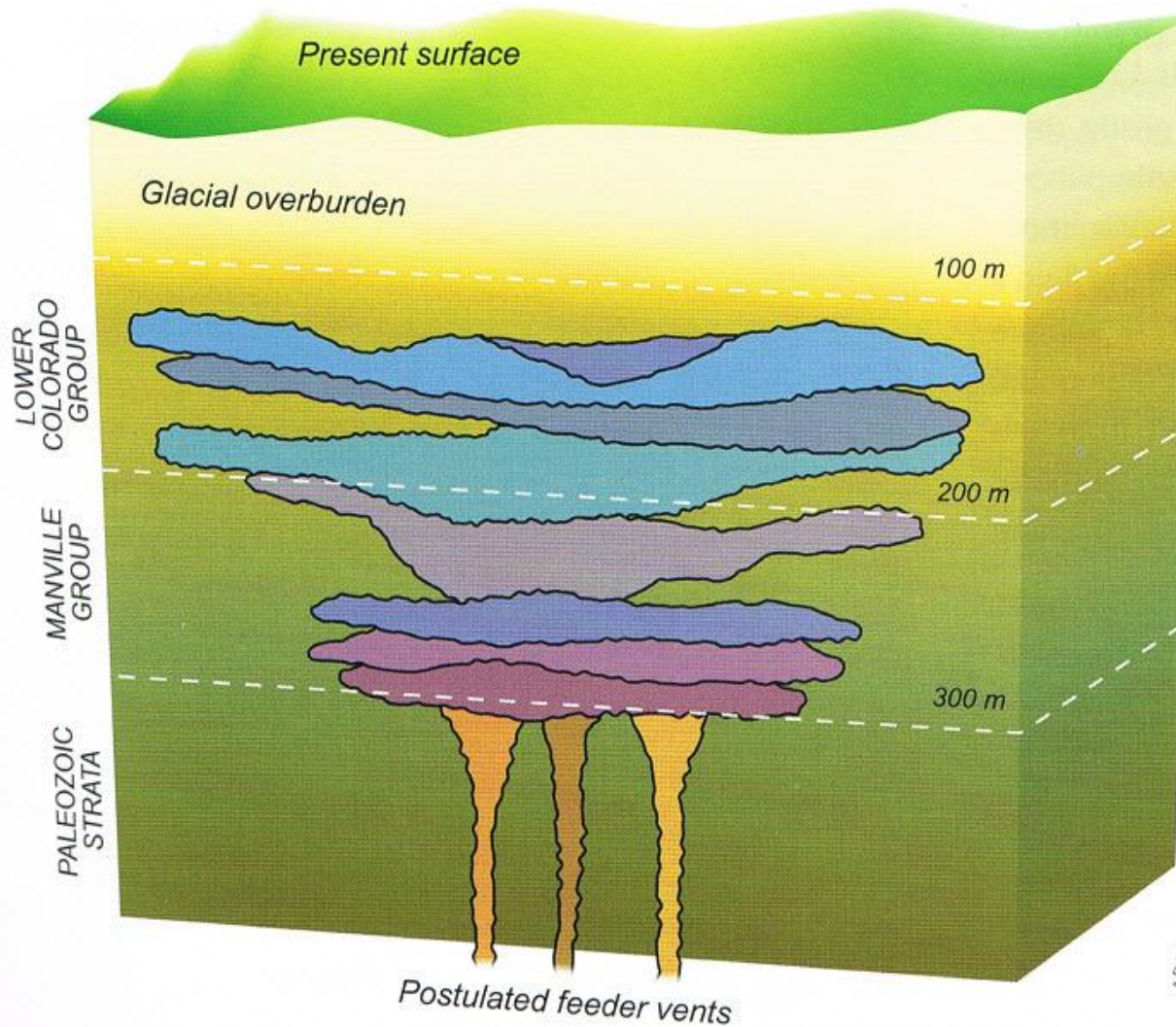
Resistive kimberlite  
in conductive mudstone

# Forte a la Corne Kimberlites

Resistive kimberlite intruding conductive mudstones  
overlain by up to 100m glacial sediments

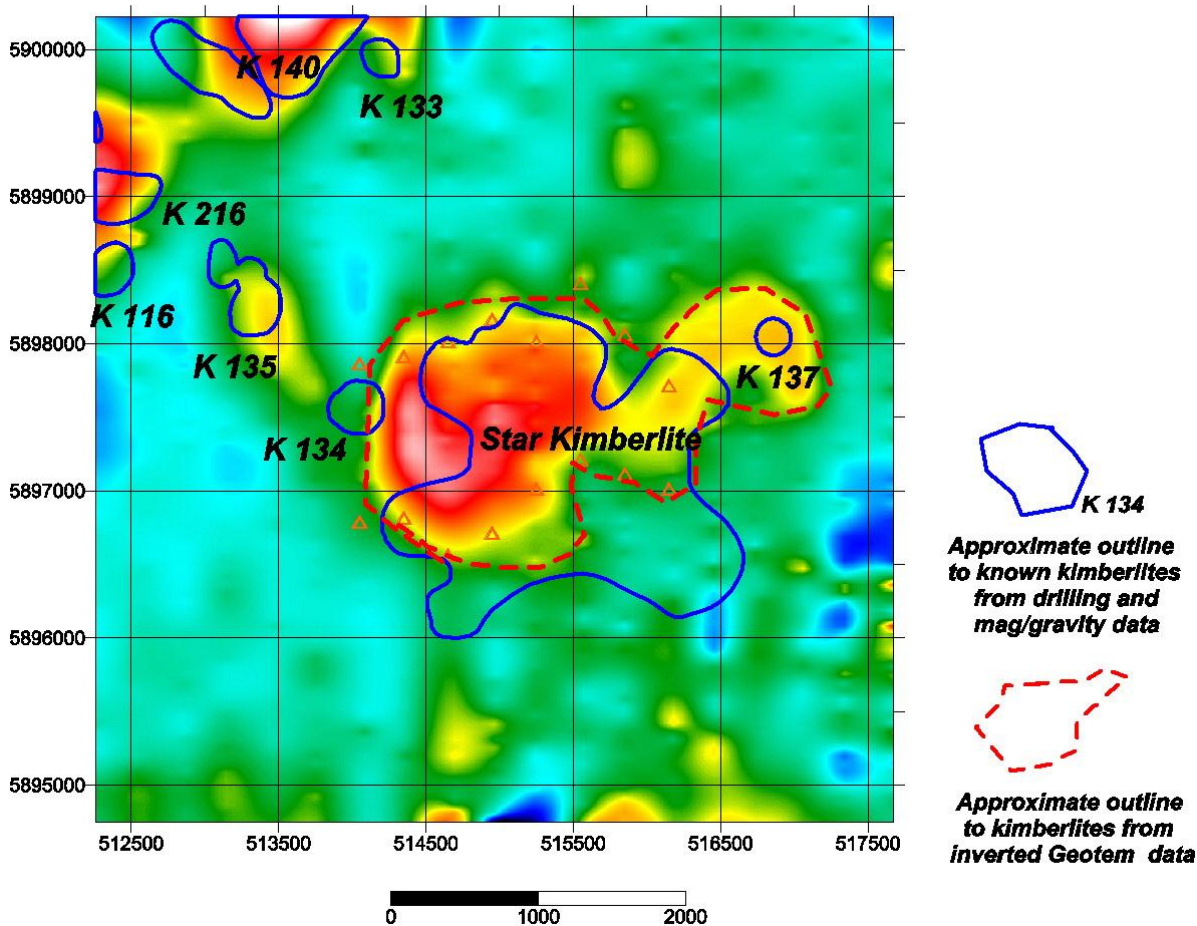


# Multiple flat lying kimberlite sheets Forte a la Corne Saskatchewan



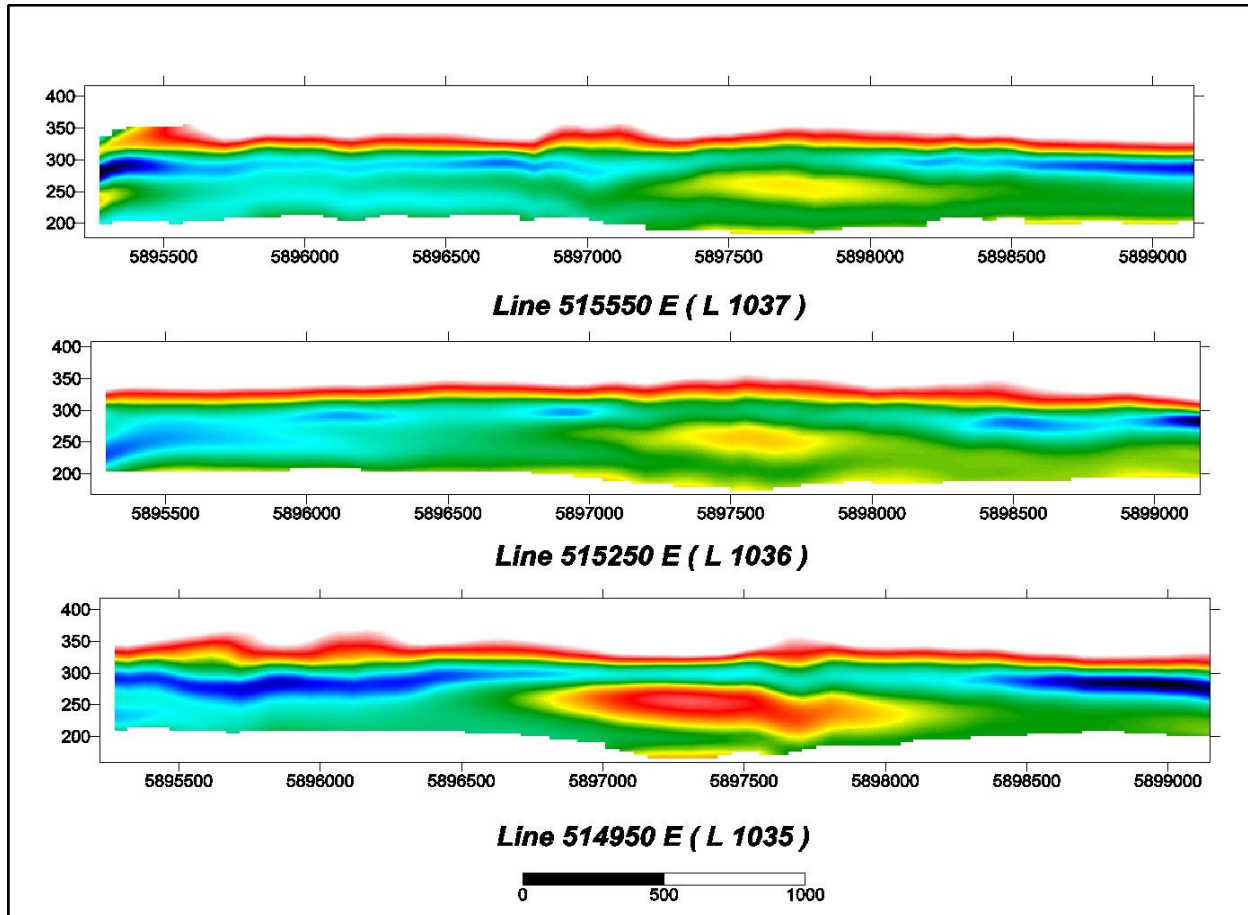
# Extent of Star Kimberlite as defined by Airborne EM

**Star Kimberlite : Log Resistivity at 270 masl**



(Source- Shore Gold Inc.)

# Star Mine –Inverted GEOTEM

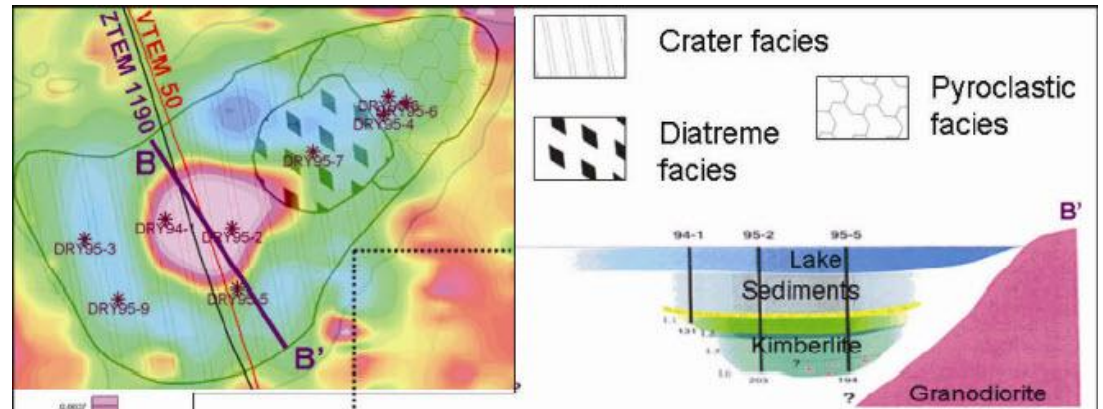


Conductive mudstone host  
kimberlites form resistive lenses

(Source -Shore Gold Inc)

# DRY BONES BAY KIMBERLITE

Kimberlite with thick conductive lake sediment cover



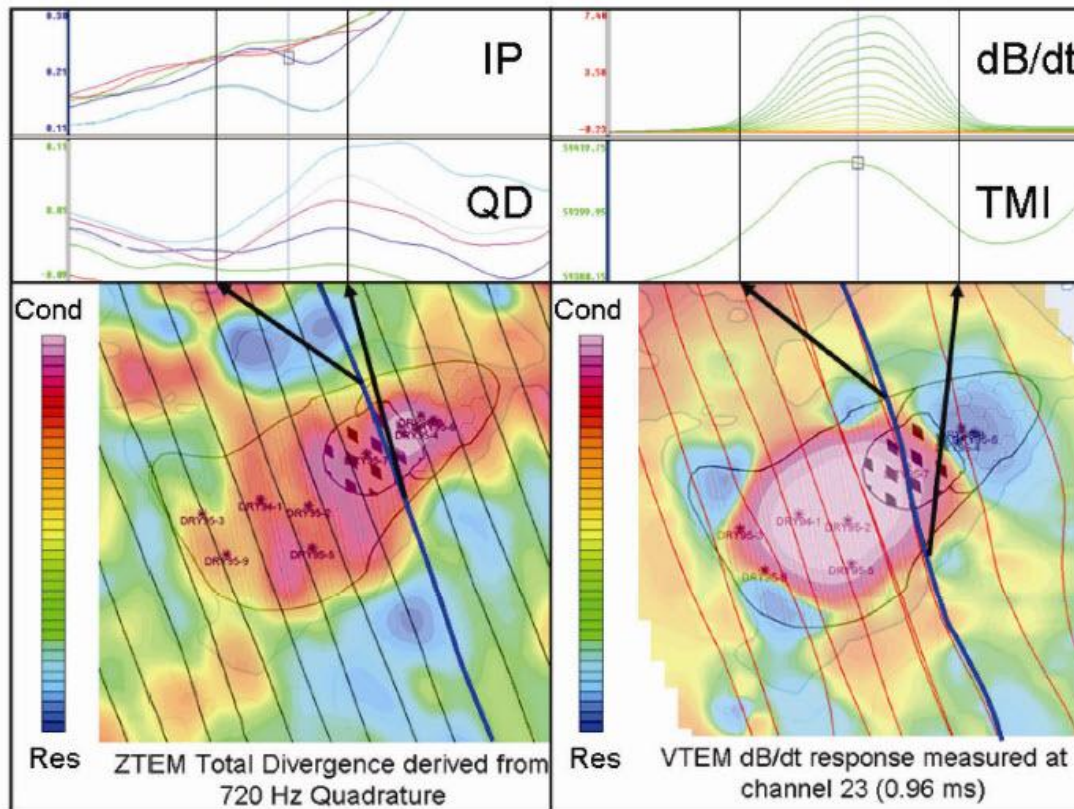
The pipe was discovered and staked in 1993 by David Smith. Mr. Smith, who is familiar with the shoreline of Great Slave Lake, had always been struck by the depth and the steepness of the shoreline of this bay when compared to others in the region. After staking the property, Mr. Smith conducted a ground-based geophysical survey over the property and located a positive magnetic anomaly. He subsequently contracted to have the property tested by diamond drill, and in early 1994 drilling recovered 24 meters of kimberlite under 77 meters of clay.

The Drybones Bay kimberlite pipe, with a surface area of approximately 31 hectares (75 acres) is the largest kimberlite discovered in the Northwest Territories to date. Widely spaced drill holes have confirmed that the pipe is diamondiferous throughout.



# Comparison VTEM and ZTEM

## Dry Bones Bay

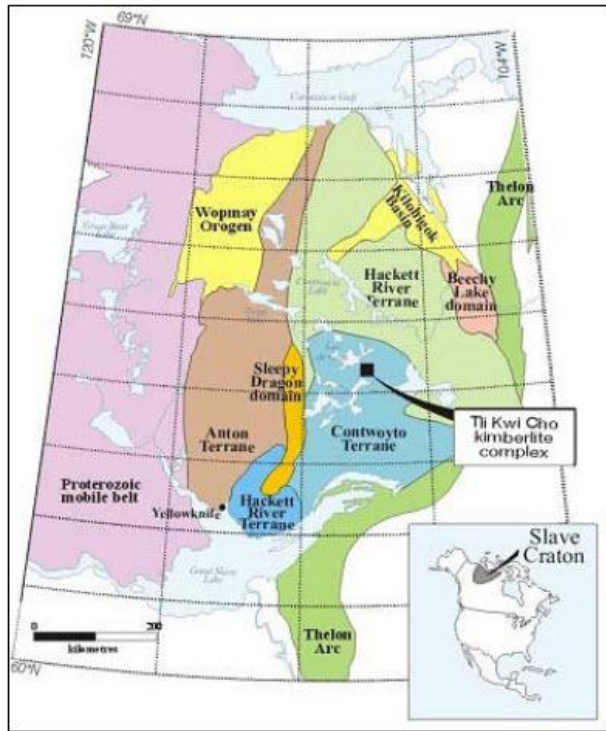


### CONCLUSIONS

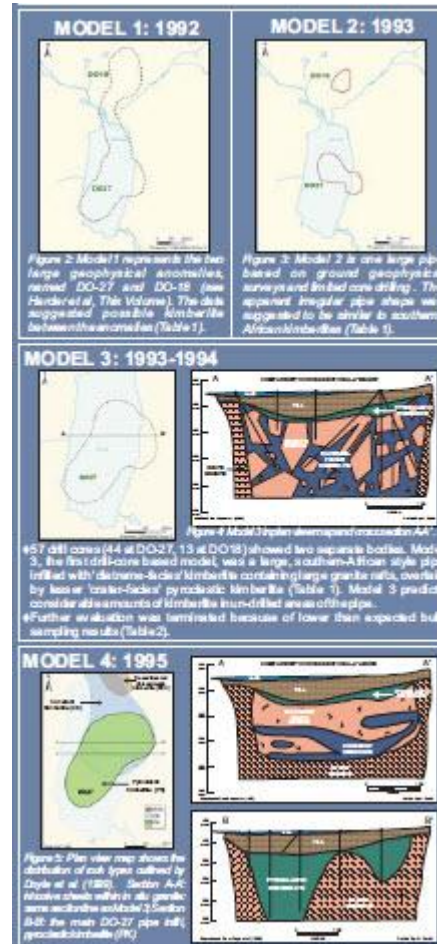
Both the VTEM and ZTEM EM technologies proved to be effective in detecting an anomalous EM response over the Drybones Kimberlite. Inversion modeling and imaging of the VTEM suggests that it mainly defines the thick overburden, overlaying the kimberlite (top 100 m) and poorly resolves the deeper crater facies. In contrast, examination of the ZTEM inversion and imaging results suggest that it defines the lateral resistivity contrasts between the deeper Archean bedrock and target kimberlite.

# TLI KWI CHO-SLAVE CRATON

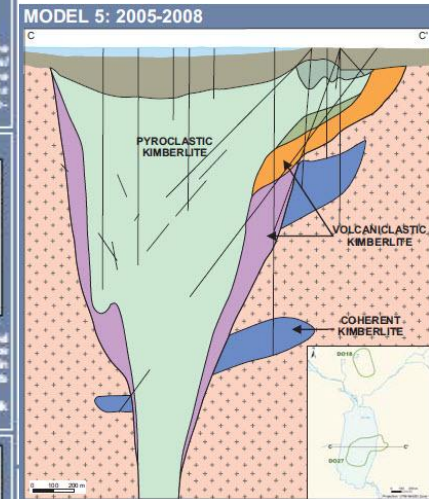
## Conductive Kimberlite in Resistive Host



Location of Tli Kwi Cho



Various Historical interpretations



Current interpretation

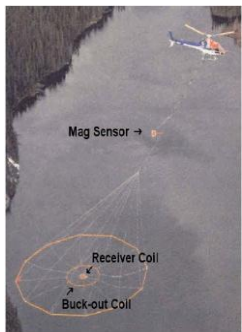
(Source Harder et al 2008)

# TDEM v FDEM

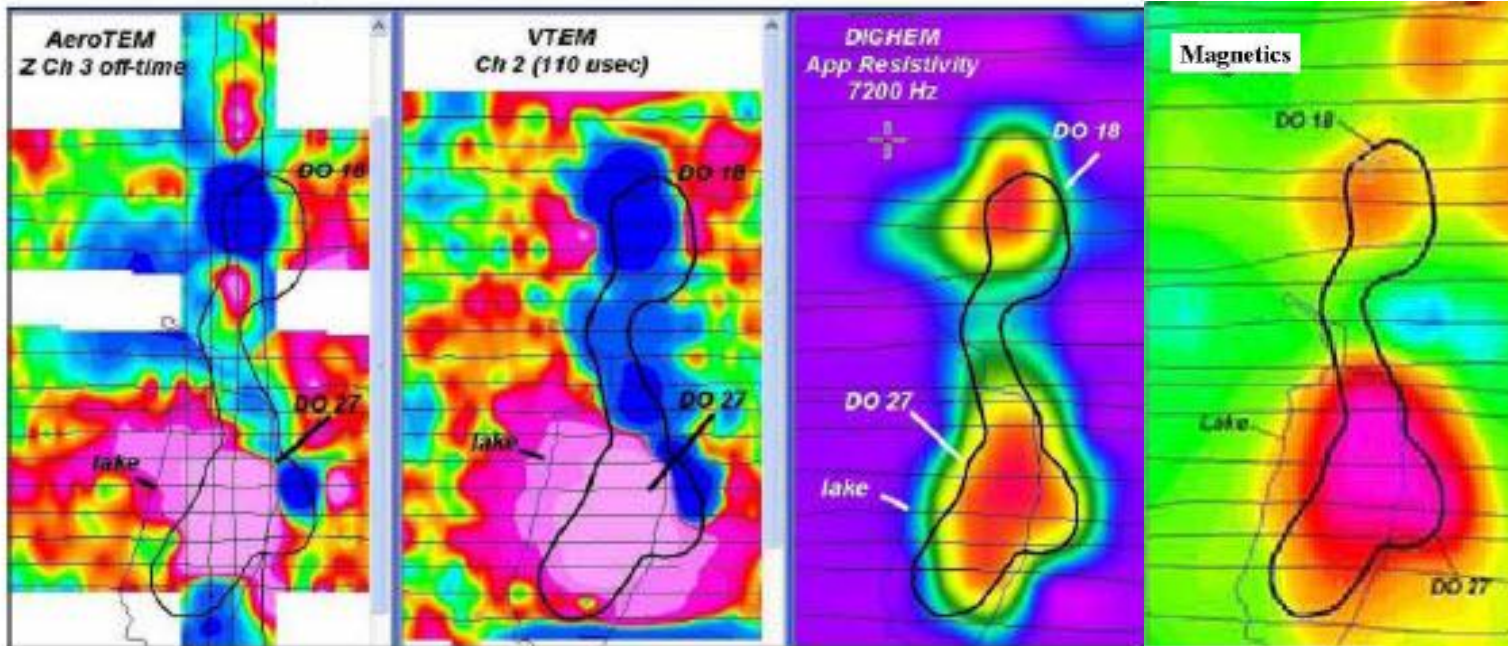
Conductive kimberlites in resistive host

Consistent FDEM Response but Variable TDEM Response

Possible IP effect in kimberlite?



Helicopter EM, NWT, Tli Kwi Cho, 1990's & 2000's



TDEM Responses

FDEM Response

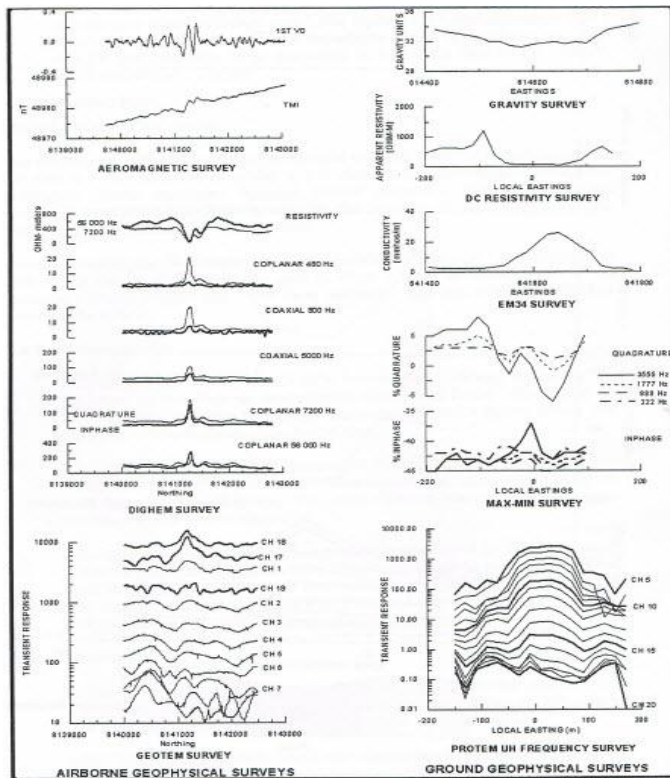
Magnetic Data

(Source-Ore Deposits and Exploration and Technology, Reed and Witherly 2007)

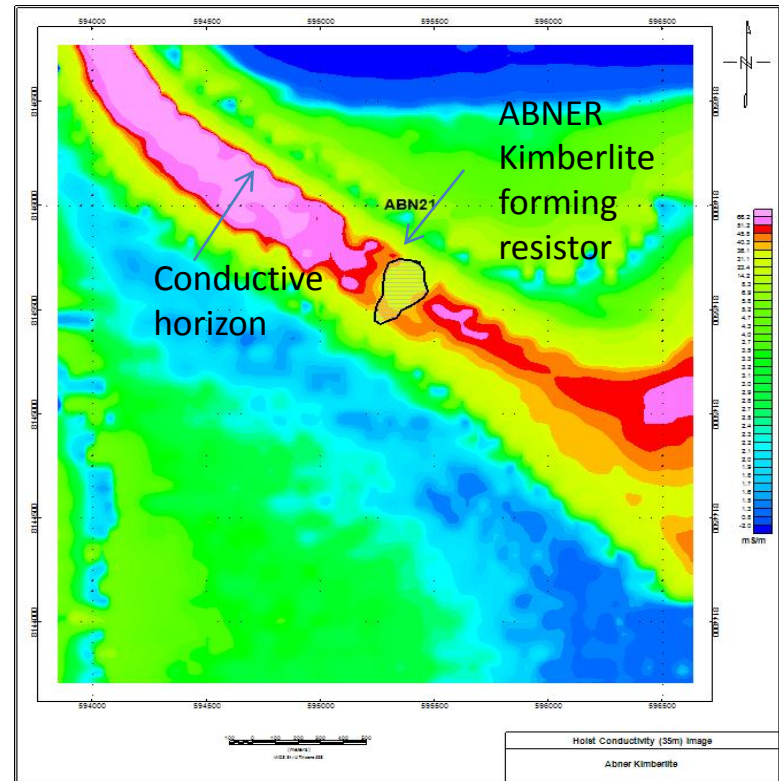
# Merlin - Abner Kimberlites –Variable EM responses

Typical Merlin Kimberlite  
Resistive sandstone host  
Conductive kimberlite-

Abner kimberlite  
Conductive host  
Less conductive  
kimberlite



(Source –Reddiciffe-Diamond Exploration Techniques Conference July 1999)



(Source Legend International Holdings Inc.)

# Important factors in exploring for kimberlites with EM

Successful exploration requires the use of complementary geophysical methods. EM alone is not adequate.

To assess the effectiveness of EM as a method it is important to understand the likely physical properties of the host rocks and the likely level of erosion of the kimberlite pipe.

Target size and geometry can vary significantly within a single cluster as can the level of facies erosion of the kimberlite.

Give considerable thought to the most appropriate airborne EM system