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Magnetotelluric and teleseismic experiments as part of the Walmsley Lake project, Northwest Territories: experimental designs and preliminary results

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Abstract

The southeastern part of the Slave craton offers high potential for diamonds as well as possibly for base and precious metals; however, the geology at the surface and geophysical properties at depth are poorly known compared to other parts of the craton, notably the Lac de Gras region. The Walmsley Lake project addresses this deficiency with collocated bedrock, isotopic, and geophysical data acquisition. This paper describes the initiation of the deep geophysical component of the project, and presents the preliminary qualitative results of the data from the magnetotelluric component. The main result at this early stage is the discovery of a large conductivity anomaly, likely within the Thelon–Talston magmatic zone, comparable to the North American Central Plains conductivity anomaly.

Résumé

La partie sud-est du craton des Esclaves renferme un grand potentiel de diamants et sans doute de métaux communs et précieux. Cependant, la géologie de surface et les propriétés géophysiques en profondeur ne sont pas aussi bien connues que celles des autres parties du craton, particulièrement dans la région du lac de Gras. Le projet du lac Walmsley vise à combler cette lacune grâce à l'acquisition de données regroupées sur le substratum rocheux, sur les isotopes et sur les caractéristiques géophysiques de la région. Le présent article décrit le début des travaux géophysiques en profondeur entrepris dans le cadre du projet et présente les résultats qualitatifs préliminaires des données provenant des travaux magnétotelluriques. La découverte d'une forte anomalie de conductivité, probablement à l'intérieur de la zone magmatique de Thelon-Talston, qui serait comparable à l'anomalie de conductivité des plaines centrales de l'Amérique du Nord constitue à ce jour le principal résultat de cette étude.

INTRODUCTION

As a consequence of diamond exploration activities, the Slave craton has become the most intensely studied Archean craton in the world over the last decade. One component of these activities has been the regional geophysical imaging of the deep lithosphere using passive seismic and electromagnetic methods. Combined with geochemical data from kimberlite material, these experiments have resulted in superior lithospheric mantle information for the Slave than for any other craton.

The southeastern Slave craton is considered to be a particularly prospective area for diamond potential, and, in addition, its base and precious metals potential is poorly known. Accordingly, a new project was initiated, under the auspices of the Targeted Geoscience Initiative, to improve geoscience knowledge in the area, and in particular in the Walmsley Lake map area (NTS 75 N). The primary goals of the project are 1) to improve the framework for mineral exploration in the Walmsley Lake area, in the southeastern Slave Province (250 km northeast of Yellowknife, Northwest Territories) by generating new bedrock and surficial geological maps and geoscientific understanding in a poorly documented region; and 2) to use isotopic and geophysical methods (both teleseismic and magnetotellurics) to map lithospheric structure in the southeastern Slave Province and evaluate its significance to diamond exploration models for the Slave craton. Full details about this project can be found in MacLachlan et al. (2001).

Herein we describe the geophysical experiments and present preliminary results from one of them.

PREVIOUS EXPERIMENTS

The locations of the existing teleseismic and magnetotelluric sites are shown in **Figure 1** on Bleeker et al.'s (1999) Slave Province map showing the known and inferred extent of the Central Slave Basement Complex. The main results of these experiments are described briefly below.

Teleseismic studies

Previous research using teleseismic sources in mantle exploration has either focused on the Yellowknife area, because of the permanent seismic array located there (Bostock and Cassidy, 1997; Bostock, 1998), or covered a very large area for a reconnaissance survey of the diamond-bearing mantle underlying the entire Slave Province (Bank et al., 2000). Bostock (1998) identified a number of mantle discontinuities beneath the Yellowknife array and correlated some of them with prominent reflections observed on LITHOPROBE SNORCLE line 1 (Cook et al., 1999). Bostock (1998) interpreted these discontinuities and reflectors to represent images of a fossil subduction zone associated with orogenic structures to the west. An alternative interpretation that we hope to test in this project is that the nearly horizontal discontinuities underlie most of the Slave craton. The regional study reported by Bank et al. (2000) provides hints of such structures, but lacks sufficient resolution to make substantive interpretations. The present study redresses this lack of information.

Magnetotelluric studies

Three different electromagnetic experiments have taken place on the Slave craton since 1996 under the auspices of LITHOPROBE, all using the natural-source magnetotelluric (MT) technique (Vozoff, 1991). This technique is complementary to seismic methods for both crustal and mantle imaging (Jones, 1998, 1999). The first of these was conventional land-based acquisition along the all-weather road from the eastern end of the Ingraham Trail (Tibbit Lake) through Yellowknife to Rae and off the craton to Fort Providence and beyond (Jones et al., 1997) (**Fig. 1**). Subsequently, taking advantage of Echo Bay's winter road from Tibbit Lake to the Lupin mine on Contwoyto Lake, plus additional access roads, novel MT measurements were made during March of 1998, 1999, and 2000 (Fig. 1). For these experiments, the electrodes were deployed through holes in the lake ice and the magnetometers were installed on the lake shores (McNeice and Jones, 1998). Finally, using specialized instrumentation designed and constructed for deploying on the bottoms of oceans for both oceanographic and geoscientific purposes (Petitt et al., 1994), measurements have been made at nineteen lakes regionally distributed around the Slave craton (Fig. 1).

These MT experiments identified an anomalous upper mantle conductor at depths of 80–120 km beneath the Lac de Gras region (Jones et al., 1999, 2000) and spatially collocated with a region of anomalous ultra-depleted harzburgite (Griffin et al., 1999a, b). The cause of this central Slave Province conductivity anomaly remains an open question, with the two primary candidates being carbon on grain boundaries (Duba and Shankland, 1982) and the diffusion of hydrogen (Karato, 1990) in hydrated material, likely oceanic or island-arc lithosphere.

WALMSLEY LAKE PROJECT EXPERIMENTS

Telesesimic experiment

The objectives of the teleseismic experiment are to assess whether the geochemical and conductivity anomalies that have been spatially associated with diamondiferous kimberlites in the Lac de Gras area (Jones et al., 1999; Griffin et al., 1999a, b) have an elastic signature, and to determine the elastic properties of the mantle beneath the Walmsley Lake map area and adjoining map areas. The experiment is using ORION recorders and Guralp seismometers, owned by the GSC and the University of British Columbia, deployed along a profile oriented at about 340° (north-northwest) (**Fig. 2**). The profile orientation was chosen to take advantage of distant earthquake clusters off the two ends for 2-D tomographic and scattering analysis. An internet search reveals that 97 earthquakes with a magnitude greater than 5.5 have occurred since all 6 stations listed in **Table 1** have been operating. Typically only a few of these earthquakes each month provide seismic signal appropriate for the analysis planned for this project. The sites will be serviced in the late winter (March, 2001), and the first data will be retrieved from them at that time.

Over the course of the next four years, thirty additional stations utilizing novel satellite telemetry and real-time data transmission will be installed as part of the POLARIS project. These additional stations will enhance this profile, provide more regional coverage, and thereby enable the finer resolution of the elastic properties of the Slave craton’s mantle.

Magnetotelluric experiment

The objectives of the magnetotelluric experiment are to define the eastern boundary of the central Slave conductivity anomaly and to determine the electrical properties of the mantle beneath the Walmsley Lake area. The experiment employed the GSC's long-period MT systems (LiMS) installed along two profiles (**Fig. 2**, **Table 2**). The main profile of nine sites (sites 01–10, Fig. 2. There is no site stg005) runs east from the winter road to the Talston–Thelon magmatic zone at a latitude of about 64°15′N. Within this profile are two of the lake-bottom sites referred to in the section 'Magnetotelluric studies' in Aylmer and Healey lakes. The second profile of four sites (sites 12–15, Fig. 2) extends the Kennady profile to the southeast.

Deployment of the stations occurred between July 7 and 17, 2000. Each site was installed in a magnetic north-south, east-west orientation and the instruments were programmed to record for 40 days with a 5 second sampling rate. Intense magnetic storms occurring throughout the installation interval inhibited precise orientation of the magnetometer at several sites. This was corrected during data processing.

A service check was performed on each instrument between July 31 and August 2. In general the quality of the measured data was good throughout the first recording interval with the exception of three sites. At site stg013 the west telluric wire was found to have been detached from the LiMS recorder box, so no data for this component were recorded prior to the site service. Site stg006 appeared to have been disturbed by a bear; both telluric wires as well as the magnetometer cable had been disconnected from the LiMS recorder and only 3–4 hours of usable data were recorded before the event occurred. Four days after installation the west wire at site stg010 was chewed through.

Each of the MT sites was removed between August 16 and 21, 2000. All of the recorded data appeared satisfactory throughout the second interval with the exception of site stg009. Both the ground electrode and the south electrode had been severed from the telluric wires by animals, affecting the last 10 days of recording.

The time-series data recorded at each site have been processed using a multiremote-reference robust method (method 6 *in* Jones et al. (1989)). In addition, time segments were chosen to minimize source field effects in the response functions (Garcia et al., 1997), avoiding in particular the extremely high activity during the first few days of recording.

Preliminary qualitative results from the MT experiment are shown in **Figure 3**, which displays the (reversed) real induction arrows at 100 s on a geological base map of the region taken from Wheeler et al. (1997). The real induction arrows, when reversed, usually point towards current concentrations in crustal and mantle conductors (Jones, 1986). The period of maximum arrow gives a qualitative indication of the depth of the conductor.

The induction arrows for the eastern sites on the main profile clearly indicate the presence of a highly conducting zone east of the easternmost site, likely at crustal levels in the Thelon–Talston magmatic zone. The arrow at site stg010 reaches a maximum length of 0.56 (at 80 s period), which means that the vertical magnetic field induced by the anomalous conductor has an amplitude of 56% of the horizontal magnetic field. This compares with maximum length arrows of about the same order (0.63) seen at approximately the same periods at sites just to the west of the North American Central Plains conductivity anomaly in northern Saskatchewan on the LITHOPROBE Trans-Hudson orogen study (Jones et al., 1993). The North American Central Plains is the most well documented conductivity anomaly associated with an orogen, and has been shown to be caused by syngenetic sulphides in sediments deposited in a hiatus in volcanism as the first of the advancing arcs (La Ronge arc) approached the Archean margin to the west (Wyoming and Rae–Hearne). The sediments were subsequently folded and the sulphides concentrated in fold hinges and connected along strike causing high electrical anisotropy (Jones et al., 1997).

The conductor that we have sensed on this project may possibly be related to the mapped iron-formation units within the Thelon–Talston magmatic zone (unit PA2 *in* Hoffman and Hall (1993)). The arrows for the Kennady profile are also consistent in indicating a major off-craton zone of anomalous conductivity to the southeast for which there is no immediate explanation on the bedrock geology map.

If this conductor is associated with the Thelon orogen, then the Slave craton is bounded by an orogen to the east with a strong expression of a conductivity enhancement, and an orogen to the west, the Wopmay orogen, with less conducting material within it (Camfield et al., 1989). Such asymmetry is observed on either side of the Trans-Hudson orogen, with a large conductor on the Rae–Hearne boundary and a small weak conductor on the Superior boundary (White et al., 1999).

These results indicate the need for additional data to be acquired extending the main profile to the east over the Thelon–Talston magmatic zone, and the Kennady profile to the south, to identify the depth, location, and extent of the large conductor associated with the Thelon–Talston magmatic zone causing the large induction arrows. The POLARIS project MT stations are not intended to extend off the craton.

Processing and quantitative modelling of the magnetotelluric data acquired as part of the Walmsley Lake project will yield electrical conductivity models of the crustal and mantle lithosphere beneath both profiles. These models will help constrain hypotheses for the tectonic history of the region.

ACKNOWLEDGMENTS

Neither Walmsley Lake geophysical experiment would have been possible without the substantial aid from many people in the north, within both government agencies and industry. In particular, we would like to recognise Hendrik Falck for his enduring support and many hours of work to put together the required logistics at very short notice, especially for the MT experiment. We thank our industry sponsors, including De Beers Canada Exploration, Inc. for providing logistical support out of their Kennady camp, including helicopter time for installation of MT sites stg012–stg015, BHP Diamonds, Inc. for providing both financial and logistical support, and Winspear Resources, Ltd. for providing transportation and field accommodation out of their Snap Lake property.

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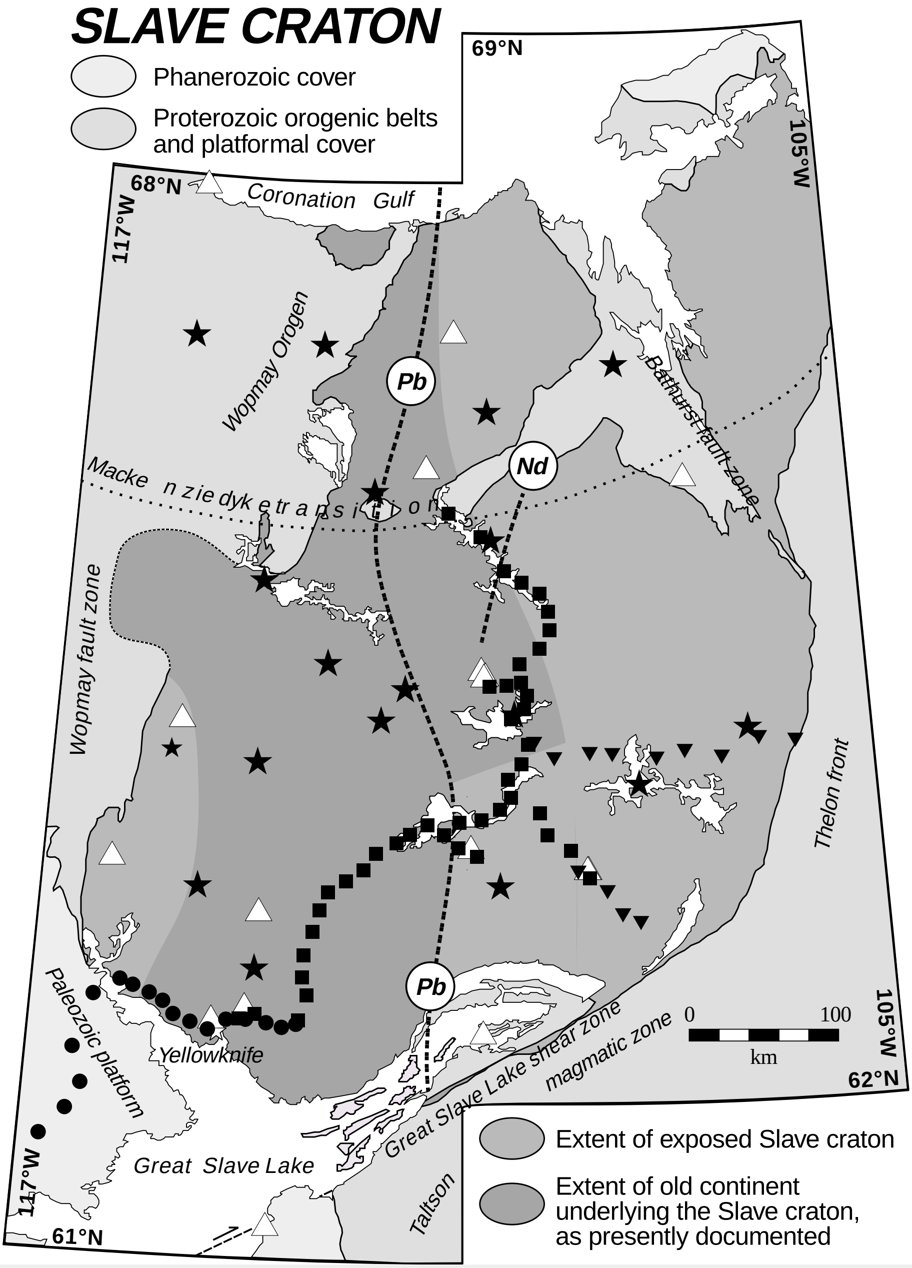

Figure 1. Map of the Slave craton from Bleeker et al. (1999) showing the locations of teleseismic and magnetotelluric sites. Filled dots, MT sites recorded during SNORCLE 1996; filled squares, MT winter road sites recorded in March 1998, 1999, and 2000; filled stars, ocean-bottom MT instrumentation deployed during 1998–1999 and 1999–2000; filled inverted triangles, MT sites for Walmsley Lake project experiment; open triangles, teleseismic sites of Bank et al. (2000); dark grey is the documented extent of the Central Slave Basement Complex (Bleeker et al. 1999), and the lighter grey region is its presumed extension beneath the Walmsley Lake area. Also shown are the isotope boundaries (Pb and Nd).

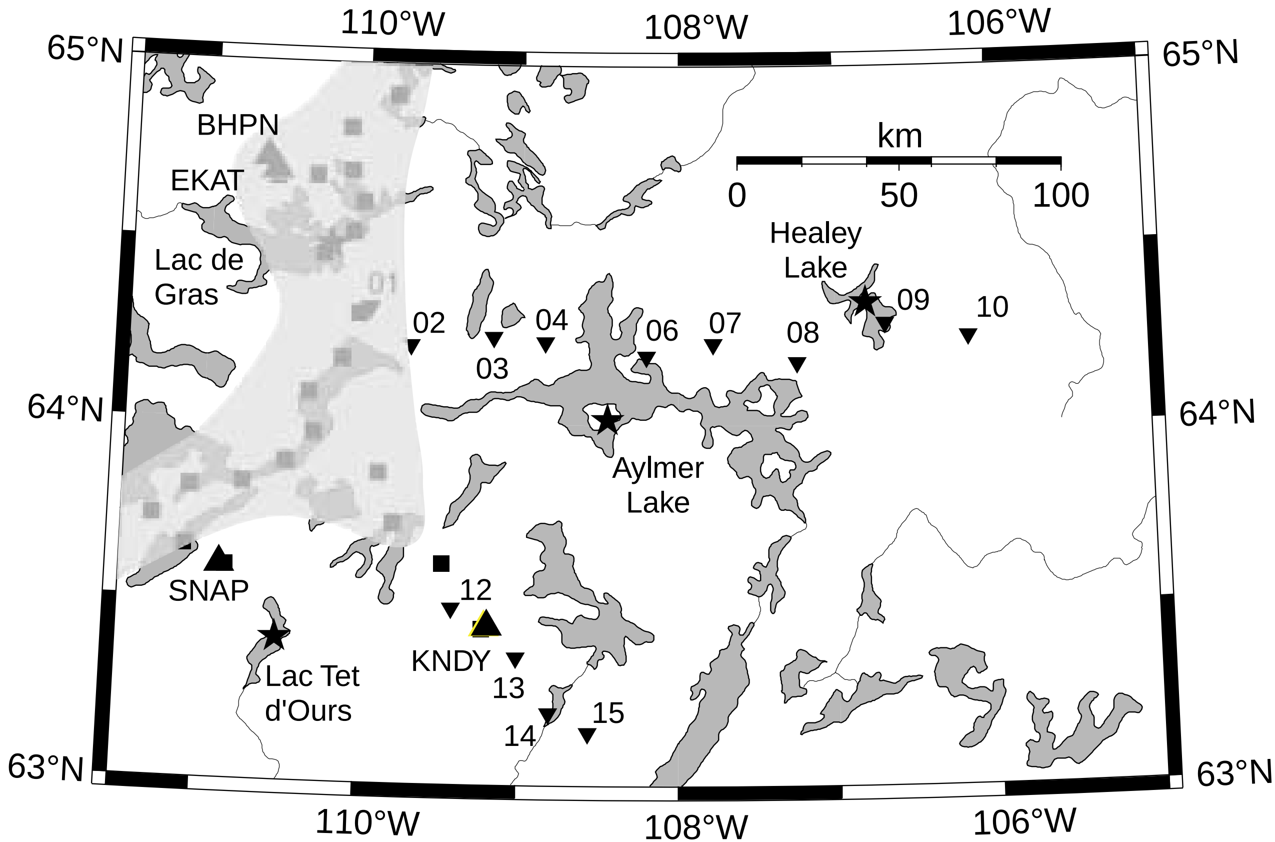

Figure 2. Map of the Walmsley Lake area showing the locations of the teleseismic and magnetotelluric sites. Filled stars, ocean-bottom MT instrumentation deployed during 1998–1999 and 1999–2000; filled inverted triangles, MT sites for Walmsley Lake project experiment; large filled named triangles: teleseismic sites, BHPN = BHP North, EKAT = Ekati, SNAP = Snap Lake, KNDY = Kennady; stipped region is the known location of the Central Slave Mantle Conductor prior to this survey.

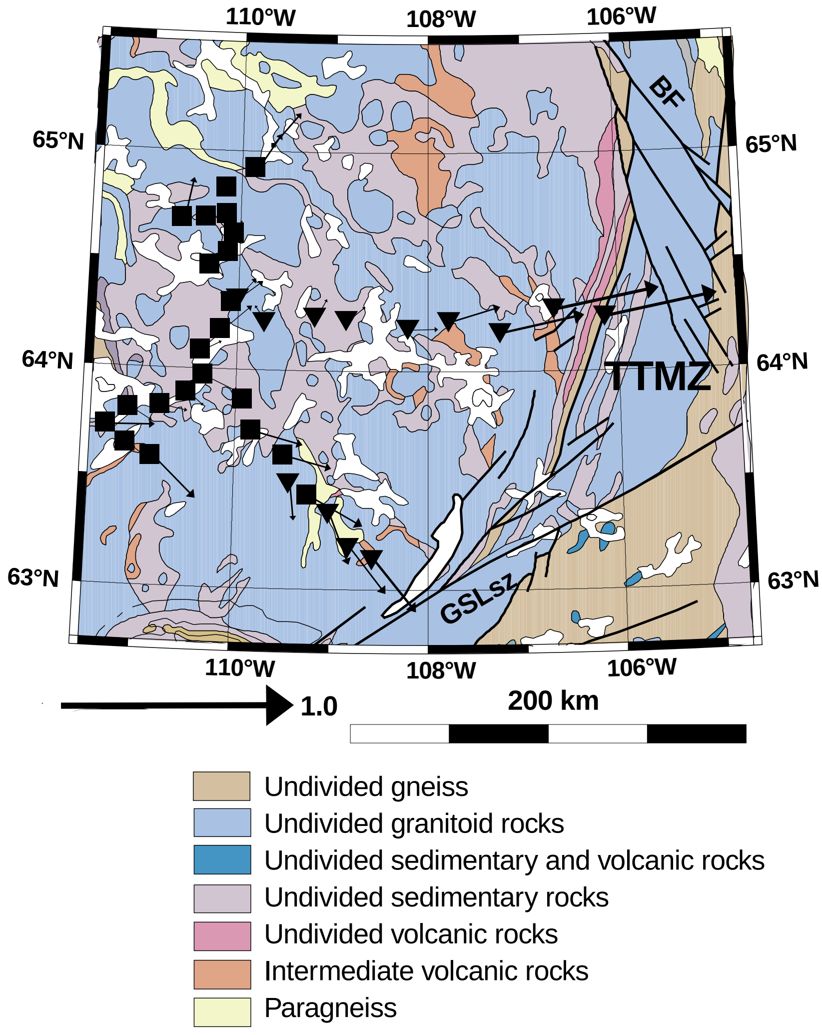

Figure 3. Real (reversed) induction arrows at 100 s on a bedrock map of the area. Unit vector shown. TTMZ, Thelon–Talston magmatic zone; GSLsz, Great Slave Lake shear zone; filled inverted triangles, MT sites for Walmsley Lake project experiment; filled squares, MT winter road sites recorded in March 1998, 1999, and 2000

Table 1. Teleseismic station locations and start dates.

Station name	Latitude (°N)	Longitude (°W)	Start time	Location
SNAP	63.5951	110.8683	23 August 2000	Snap Lake camp
KNDY	63.438	109.1916	15 August 2000	Kennady Lake camp
NORM	64.7795	110.79	20 August 2000	Exeter Lake camp
BHPN	64.7325	110.6701	20 August 2000	Ekati mine
EKAT	64.6985	110.6097	10 March 1999	Ekati mine airstrip
PRLD	62.5771	114.0475	20 September 1999	Prelude Lake

Table 2. Magnetotelluric station locations and usable data intervals.

Station name	Latitude (°N)	Longitude (°W)	Usable data interval (UT)
stg001	64:19:14	109:59:13	2000-07-14 18:00 to 2000-08-17 18:07
stg002	64:13:00	109:42:10	2000-07-17 18:00 to 2000-08-17 19:16
stg003	64:14:29	109:10:30	2000-07-16 04:00 to 2000-08-17 20:30
stg004	64:13:44	108:50:42	2000-07-16 03:30 to 2000-08-18 15:50
stg006	64:11:26	108:12:03	2000-08-02 21:15 to 2000-08-18 17:50
stg007	64:13:32	107:46:33	2000-07-16 01:00 to 2000-08-18 18:50
stg008	64:10:27	107:14:24	2000-07-15 22:00 to 2000-08-18 20:05
stg009	64:16:54	106:40:44	2000-07-17 03:00 to 2000-08-08 00:00
stg010	64:14:42	106:08:56	2000-07-16 23:00 to 2000-08-21 21:00
stg012	63:29:12	109:24:57	2000-07-11 18:30 to 2000-08-17 22:35
stg013	63:21:11	109:00:32	2000-08-01 03:15 to 2000-08-15 19:55
stg014	63:11:57	108:48:10	2000-07-10 18:45 to 2000-08-14 16:50
stg015	63:08:44	108:33:36	2000-07-09 19:45 to 2000-08-14 20:00