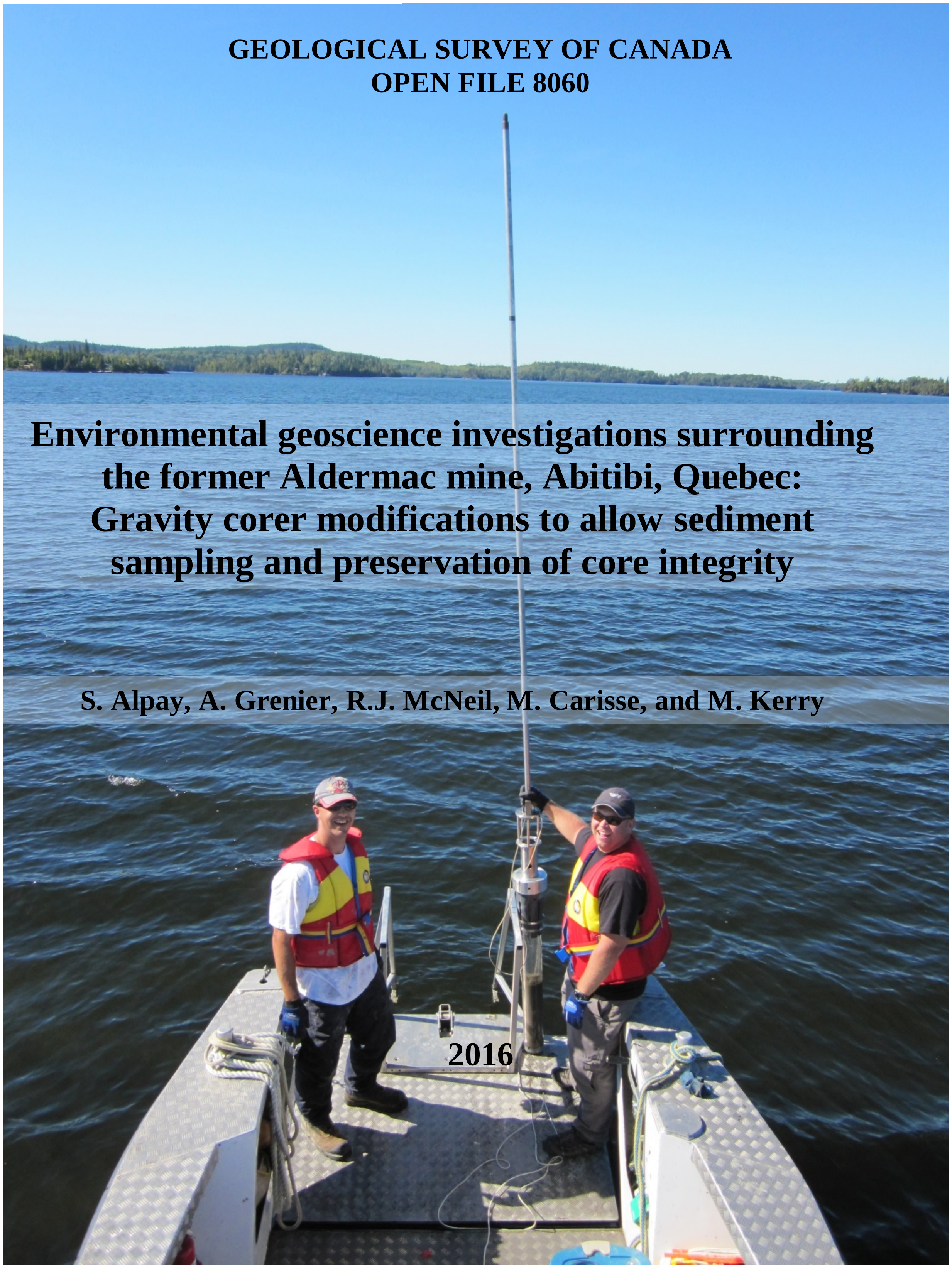
Natural Resources Canada Ressources naturelles Canada



GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8060

Environmental geoscience investigations surrounding the former Aldermac mine, Abitibi, Quebec: Gravity corer modifications to allow sediment sampling and preservation of core integrity

S. Alpay, A. Grenier, R.J. McNeil, M. Carisse, and M. Kerry

2016

Celebrating 175 yrs

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8060

Environmental geoscience investigations surrounding the former Aldermac mine, Abitibi, Quebec: Gravity corer modifications to allow sediment sampling and preservation of core integrity

S. Alpay, A. Grenier, R.J. McNeil, M. Carisse, and M. Kerry

2016

doi:10.4095/299200

This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

Recommended citation
Alpay, S., Grenier, A., McNeil, R.J., Carisse, M., and Kerry, M. 2016. Environmental geoscience investigations surrounding the former Aldermac mine, Abitibi, Quebec: Gravity corer modifications to allow sediment sampling and preservation of core integrity; Geological Survey of Canada, Open File 8060. 29 p. doi:10.4095/299200

Cover photo: Initial deployment of the partially modified gravity corer by A. Grenier and R.J. McNeil (pictured) from a stable Environment Canada field vessel during joint field work in Lac Dasserat; Photo: Environment Canada, September 2011

Publications in this series have not been edited; they are released as submitted by the author.

SUMMARY

Sediment coring is a valuable tool for environmental risk assessment to identify geochemical baselines and as a temporal archive of industrial contamination. In freshwater aquatic sediments, where classic gravity coring had inadequate depth penetration and did not yield sufficient sediment recovery, alternate coring strategies and modifications to the coring device were explored and successfully implemented. The addition of threaded drive rods and a sediment depth control ring to a classic gravity corer improved core penetration and retrieval, which resulted in more effective and efficient sediment sampling for geochemical surveys.

INTRODUCTION

CONTEXT

Sediment coring was an essential component of delineating the temporal and spatial distributions of metal contamination in natural receiving waters and aquatic sediments downstream of an abandoned mine in western Quebec (Alpay *et al.*, 2015). Widely-used sediment sampling techniques for environmental risk assessment typically include grab, dredge, or spoon sampling of the top 2-10 cm of aquatic sediments. This is the sediment depth of interest to monitor toxic effects and to generate sediment quality guidelines (e.g., Canadian Council of Ministers of the Environment, 1995). Analysis of the uppermost sediment layers is inadequate when an investigation requires a record of historical metal contamination, an assessment of accumulated effects over time, or paleolimnological studies for use in forward modeling, when an understanding of the past provides insight into the future. Furthermore, results for environmental risk assessment must be obtained rapidly (i.e., within one year; Environment Canada, 2012). More data and interpretation become available by obtaining high-quality vertical sediment cores, extruding them and subsampling at specific depth intervals (e.g., Alpay *et al.,* 2015). Although broadly used in a wide variety of paleolimnological research over several decades (e.g., Mott, 1975; Ishiwatari & Uzaki, 1987; Verta *et al.,* 1989; Prévost *et al.,* 1995; Hall & Smol, 1996; Enache & Prairie, 2002; Dixit *et al.,* 2007; Mayer *et al.*, 2007; Lennox *et al.*, 2010; Hamilton *et al.*, 2015), sediment coring has only recently started to be transferred to environmental consultants for risk assessment in Canada (e.g., Cascade Environmental Research Group Ltd., 2014). Sediment depth intervals can be dated using various techniques (e.g., Appleby & Oldfield, 1978; Glew *et al.*, 2001; Sanchez-Cabena & Ruiz-Fernández, 2012), which can produce a natural archive of metal contamination, barring significant post-depositional metal mobility, physical disturbance of the sediments, and diagenetic alterations.

The study site is downstream of the former Aldermac mine, located in Abitibi, western Quebec, 25 km west of Rouyn-Noranda (**Figure 1**). During operations from 1932-1943, the mine exploited a group of massive sulphide lenses, which produced copper, zinc, gold and silver, in addition to decades of unregulated acid mine drainage contamination to the watershed downstream. Studies demonstrated metal contamination and toxic effects in Lac Arnoux and Lac Dasserat, downstream of the Aldermac site (**Figure 1**; e.g., Perceval *et al.*, 2006; Goulet & Couillard, 2009; Hamilton *et al.*, 2015; Alpay, S., 2016). Scientific evidence, combined with increasing concern raised by citizens and environmental groups (e.g., Doucet, 2005; Conseil regional de l'environnement de l'Abitibi-Témiscamingue, 2007; Bradley, 2009), led to the restoration of the Aldermac property by the government of Quebec (Cyr, 2008). Exploration and property transfers (e.g., Abcourt Mines Incorporated, 2008; 2009) indicate that the site remains active for further mineral exploration.

Sediment coring was a critical element for achieving the scientific objectives of the study to:
(1) identify the physical, chemical, biological, and toxicological effects of metal contamination in space and time, and
(2) develop scientific tools to assess spatial and temporal environmental effects, including potential recovery, from metal contamination in aquatic receiving environments.

These objectives were developed within a multi-disciplinary framework with collaborations in both academia and government (Alpay, 2016).

In this Open File report, the lake-sediment coring methods initially used at the study sites are described and the problem identified. The methods and materials used to resolve the coring challenges are presented, along with an assessment of the coring modifications and their overall performance. Finally, recommendations are offered for coring in similar aquatic sediments.

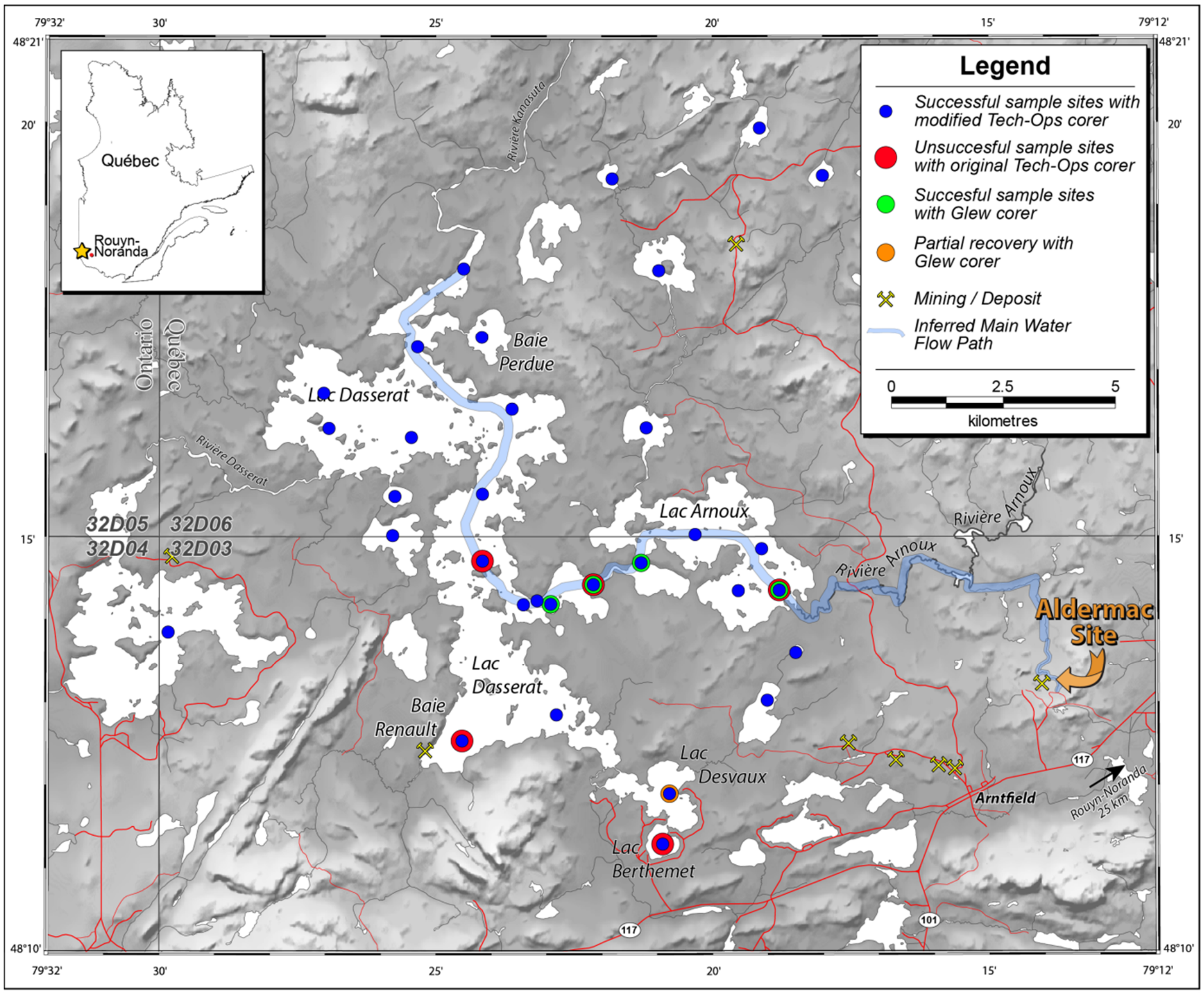


Figure 1. Digital elevation map of coring sites downstream of the Aldermac site; the yellow crossed hammers represent sites of identified mining activity (past or present). A complete documented inventory of historical mining activities in the study areas was not available.

The problem

In July 2011, a field crew of three scientists from the Geological Survey of Canada initiated reconnaissance studies in Lacs Berthemet, Desvaux, Arnoux and Dasserat (Figure 1). The preliminary investigation included sampling of surface water and lake sediments. The approach to sediment sampling was similar to techniques used successfully in other lakes in the Abitibi-Timiskaming region (Prévost *et al.*, 1995; Kliza & Telmer, 2001; Alpay, unpublished data) and in concurrent scientific studies (e.g., in Bancroft; Friske, unpublished data).

An open barrel Tech-Ops gravity corer (Machine All Incorporated, 2010) was deployed with a wide Plexiglas® core barrel (10-cm inner diameter) to obtain enough sediment material for each 1-cm depth interval to satisfy analytical requirements of concurrent multi-disciplinary scientific investigations (Alpay, 2016). Several attempts to use the Tech-Ops gravity corer were made at different lake locations (**Figure 1**). However, there was no sediment retrieval (i.e., loss of core) at the planned sampling stations in Lac Dasserat in July 2011 (**Figure 1**). The penetration of the core barrel was insufficient to establish adequate suction for sediment retrieval. One possible cause is the sediment composition of mixed glaciolacustrine silts and clays, originating from glacial Lake Barlow-Ojibway (Veillette, 1994), which were likely more stiff than dy or gyttja in organic-rich lakes (e.g., Wetzel, 2001). Additional weights (5 and 10 kg) were progressively added to the gravity corer to help induce greater penetration into the sediments, however, attempts yielded the same results.

A messenger-operated, albeit narrower (2-½″ (6.35 cm) inner diameter) Glew corer (Glew *et al.*, 2001) was also available during field work. Separate attempts were made to deploy it for gravity coring, although with limited success in Lac Dasserat at two sites west of Baie Arnoux (**Figure 1**). Again, at other test sites, the core barrel would not penetrate the lake floor adequately to hold suction during its ascent to the water surface. The Glew corer achieved moderate core retrieval in Lac Desvaux (connected to Lac Dasserat to the south; **Figure 1**), where the uppermost sediments were more organic-rich, but the length of the core was inadequate for studies of natural archives dating back to pre-industrial time (**Figure 2**).

A light-weight Livingstone piston corer (Livingstone, 1955) was also an option, although not on hand during field work in July 2011. However, the narrow diameter (2″; 5.08 cm) would make its use prohibitive for the study because wide-diameter cores were required to yield adequate sediment material for analyses. Likewise, the Livingstone corer would necessitate a longer core set-up time to remove the piston between samples, rendering its use less efficient, although likely effective, as demonstrated in another trial in September 2011 (**Figure 3**). Its design and subsequent modifications were originally intended to obtain longer and narrower sediment cores for paleolimnological studies (e.g., Wright *et al.*, 1965; Glew *et al.*, 2001; Tingstad *et al.*, 2011).

Although there are many other proven coring methods in aquatic sediments, they were not attempted because they did not meet the criteria of the study objectives. Percussive (e.g., Gilbert & Glew, 1985; Reasoner, 1986; 1993; Bourgeois *et al.*, 2011) or vibracorer (e.g., Glew *et al.*, 2001; Brooks, 2011; Smith, 1995) techniques inherently generate vibration and can induce disturbance of soft sediments; the sediment-water interface or internal core integrity could not be ensured at the required resolution. Freeze coring (e.g., Renberg, 1981;

Glew *et al.*, 2001; Renberg & Hansson, 2010; Gammon & Alpay, 2011) would compromise analytical requirements (e.g., for microbial enumerations). Light-weight box corers typically allow for a maximum depth of approximately 20 cm (e.g., Glew *et al.*, 2001) and, therefore, could not ensure adequate penetration to sample sediments deposited before the onset of industrialization. A longer box corer is essentially a square gravity corer (e.g., Kuehl *et al.*, 1985) and could have met the study criteria, but its additional weight would have been more cumbersome to operate and necessitate a winch to lower and raise it through the water column; a winch was not practical for the field study and not consistent with the objectives to develop rapid, cost-effective surveys for assessments of environmental risk.

An alternate strategy for retrieving high-quality short sediment cores was to use professional divers at a subsequent field sampling. Although this was a reasonable approach for 4-5 study sites targeted for detailed research (**Figure 4**), the risk, cost, and time required for diver-taken cores could not be justified for a regional sediment survey of over 30 sites (McNeil *et al.*, 2015). It was also an unrealistic approach for widespread use by consultants who prepare environmental risk assessments for mining development projects. Therefore, the goals of the study, combined with the nature of the sediments in Lac Dasserat, warranted modifications to the Tech-Ops gravity corer. The criteria for the modifications were to enable adequate yield of sediment per core slice (wide diameter), efficient and effective sediment core retrieval with adequate penetration into sediments deposited during pre-industrial time, preservation of undisturbed sediment cores, including the sediment-water interface, to simulate cores hand-collected by divers.

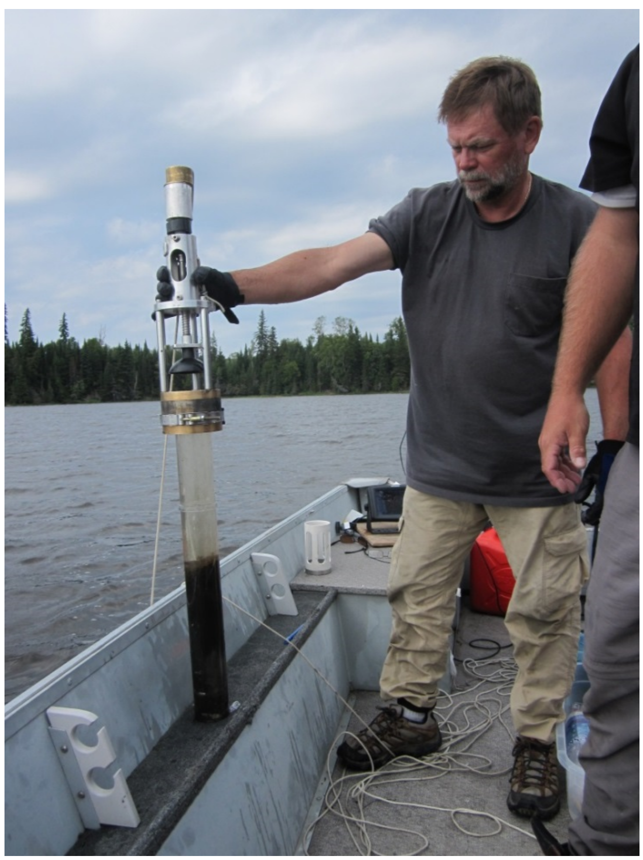


Figure 2. Deployment of the Glew corer in Lac Desvaux with insufficient core retrieval (< 30 cm); Photo: Geological Survey of Canada, July 2011

Figure 3. Test deployment of the Livingstone piston corer in Lac Desvaux; Photo: Geological Survey of Canada, Sept 2011

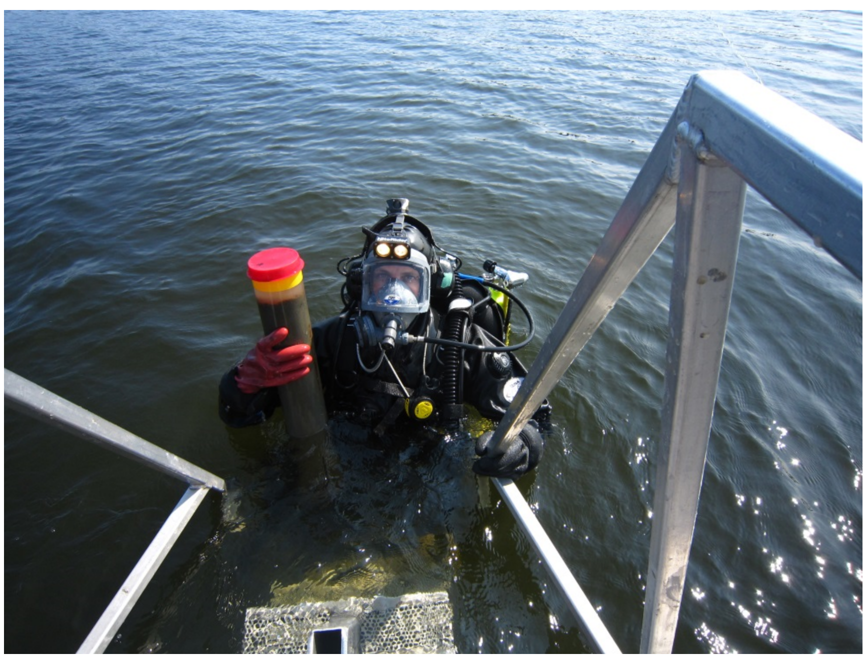


Figure 4. Hand-taken core from Lac Dasserat by a professional diver from Environment Canada during joint field work between Environment Canada and Natural Resources Canada; Photo: Environment Canada, Sept 2011

METHODS

The Tech-Ops corer is a classic open-barrel gravity corer (no messenger required); it is shown in **Figure 5** and described by Machine All Incorporated (2010). The head assembly includes an auto valve (**Figure 6**); the internal plunger in the valve is held open as the corer is lowered through the water column. Once the sediment seals the open end of the core tube and the corer is pulled up to reverse direction, the valve closes and a partial vacuum is created to hold the sediment inside the core barrel during its ascent through the water column. Core tubes used were approximately 80 cm in length with an ideal core retrieval intended to be between 30 and 40 cm to ensure retrieval of sediments pre-dating industrialization, which satisfied the study objectives (assuming a sedimentation rate of approximately 1-3 mm/a; e.g., Grenier & Kliza, 2005). In most cases, the corer was operated from a 16´ (4.88 m) aluminum boat and deployed by hand (cf., Mudroch & McKnight, 1991; Glew *et al.*, 2001; Alpay *et al.*, 2011).

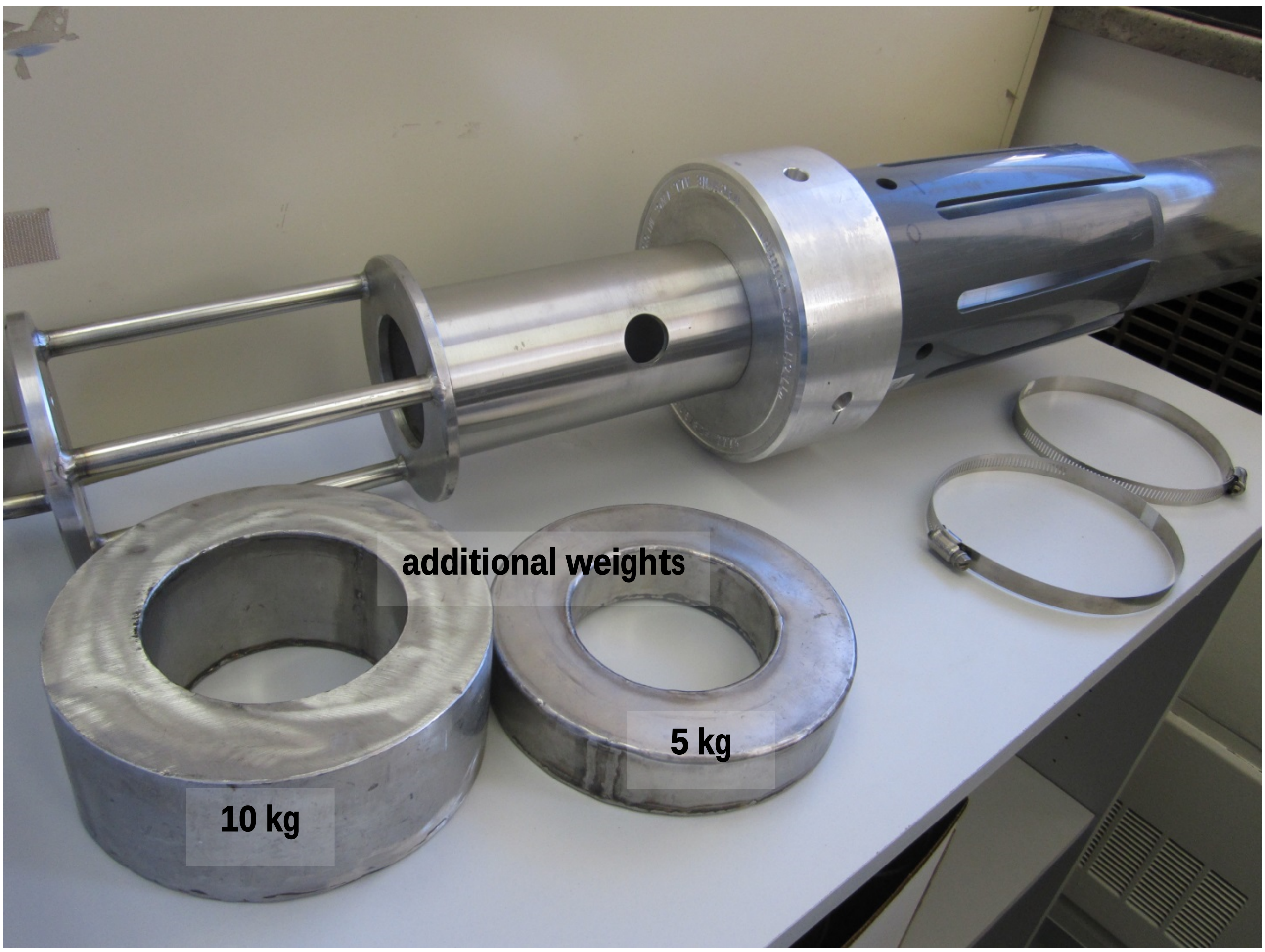


Figure 5. Unmodified Tech-Ops corer deployed in July 2011 without successful core retrieval in Lac Dasserat; Photo: Geological Survey of Canada, December 2010

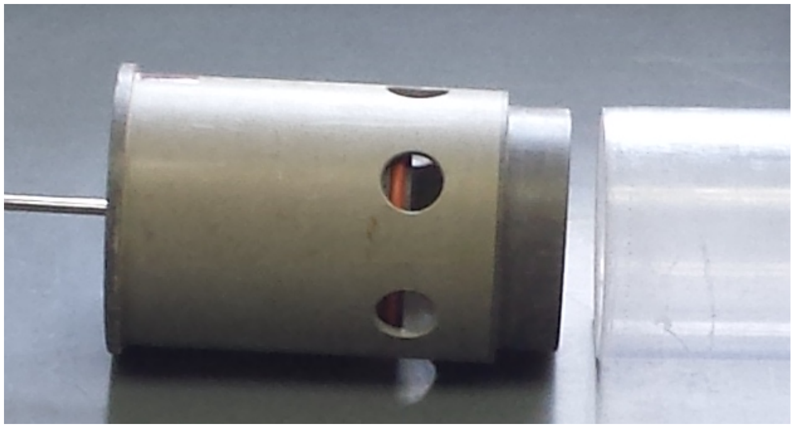


Figure 6. Auto valve on the head assembly of the Tech-Ops corer; Once the sediment seals the open end of the core tube, it creates a partial vacuum to prevent sediment from flowing out during ascent through the water column and retrieval. Photo: Geological Survey of Canada, May 2016

MODIFICATIONS

Two main modifications were made to the Tech-Ops gravity corer. It was chosen to be modified, rather than the Glew corer, to preserve the wide diameter cores warranted by the study objectives and multi-parameter analyses (Alpay, 2016). Although the Livingstone piston corer was effective, it was not practical because of its narrow diameter and the time needed to re-load the piston between sediment cores. However, one principle in the operation of the Livingstone piston corer was appropriated as a modification to the Tech-Ops gravity corer.

EXTENSION ROD ADAPTOR

A U-shaped steel screw adaptor was custom-built to fit and mount on the head assembly of the Tech-Ops gravity corer to allow attachment of extension rods (**Figure 7; Appendix A, Figure A1**). The measurements of the adaptor were 14 cm in length, 9 cm in width and 2.5 cm in thickness. The extension rods or drive rods were available as accessories to operate the Livingstone piston corer (e.g., Glew *et al.,* 2001); the rods were 1″ (2.54 cm) in diameter and made of stainless steel. The extension rods allow field scientists to push the core barrel through the sediments from a boat or platform at the water surface, just as a diver would take a push core *in-situ*. The principle is similar to that of Glew & Smol (2016) for sediment coring with drive rods in shallow water depths. The extension rods were in 1.5 m lengths, which could be screwed on, one after another as the gravity corer was lowered into the water (**Figure 8**). A cable remained attached to the corer to help retrieve the core. It also served as a fail-safe in case the rods or connections between them failed, so the corer could be recovered if necessary.

Figure 7. Photo of the custom-made steel U-shaped screw adaptor, which was mounted on the Tech-Ops corer head assembly to attach extension rods; Photo: Geological Survey of Canada, April 2016

Figure 8. Attaching extension rod sections to the modified Tech-Ops gravity corer during its descent through the water column in Lac Dasserat; Photo: Geological Survey of Canada, May 2012

DEPTH CONTROL RING

The second modification was to add a depth control ring on the outside of the core tube (**Figure 9**). It was a 12-⅛″ (30.80 cm) wide ring made of a $\frac{1}{16}$″-(1.59 mm-)thick stainless steel plate, perforated with ½″ (1.27 cm) diameter holes, to allow water to flow through during descent and ascent, although wide enough to control the depth of penetration into the bottom sediments (**Figure 9; Appendix B**). It was sandwiched between two PVC collars, the top collar being 2″ (5.08 cm) thick and the bottom collar ¼″ (6.35 mm) thick (**Appendix B; Figures B1, B2, B3**). The depth control ring assembly was attached to the outside of the core barrel by a hose clamp on the top ring. Saw cut slots in the body collar allowed for a snug fit (**Appendix B**). The position of the depth control disk could be modified according to the study objectives and the length of core required.

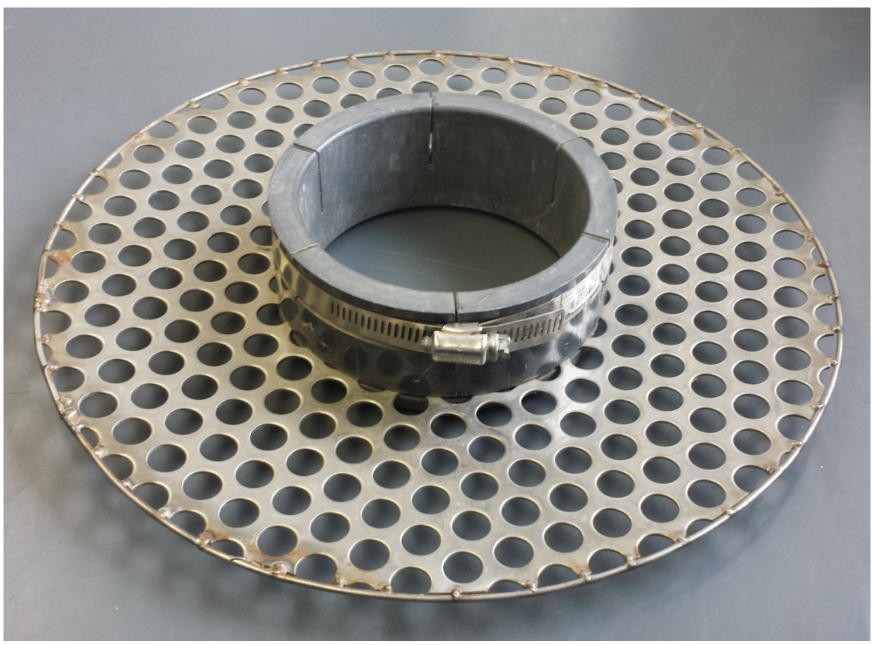


Figure 9. Photo of the custom-built stainless steel depth control ring, which attaches to the core barrel; Photo: Geological Survey of Canada, May 2016

The schematic in **Figure 10** illustrates the two main corer modifications. Detailed technical drawings are presented in **Appendices A and B**.

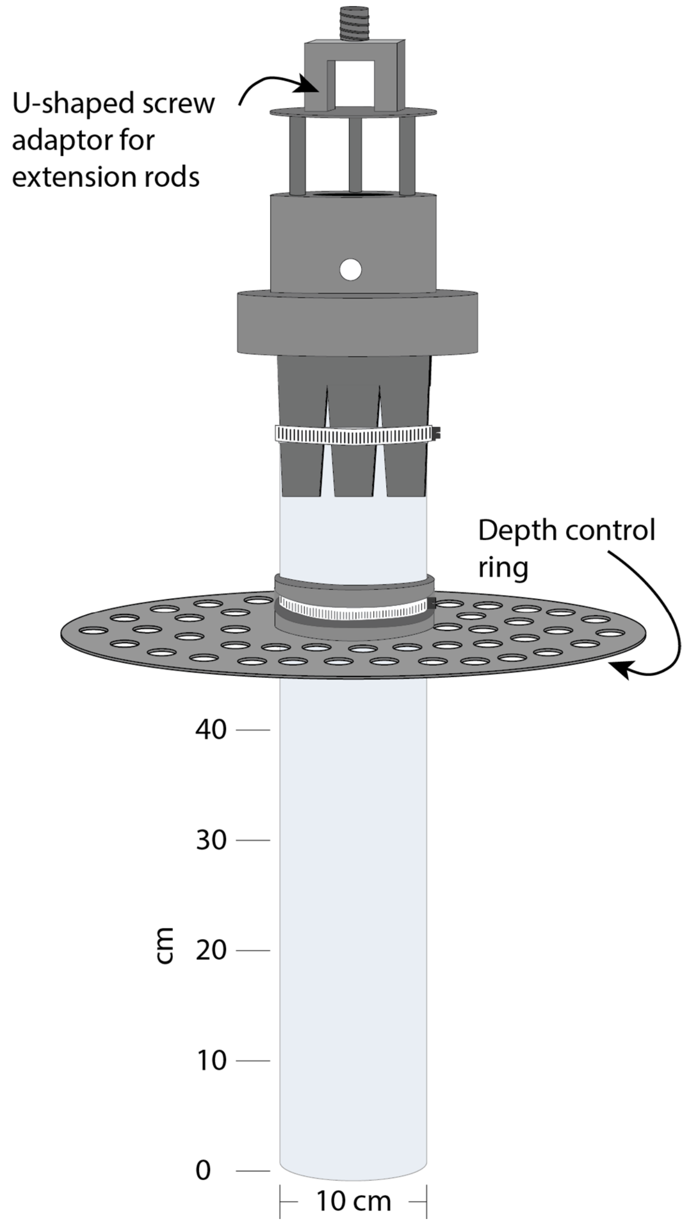


Figure 10. Tech-Ops gravity corer modifications – U-shaped adaptor for extension rods and depth control ring

RESULTS & DISCUSSION

In September 2011, the extension rods on the Tech-Ops gravity corer were first tested in Lac Dasserat. Depth penetration into the sediments was sufficient to seal the bottom of the core barrel, create enough vacuum to retain the sediment, retrieve the entire sediment core topside, and cap the bottom of the core tube. Quality of the retrieved cores was similar to that of cores hand-collected by divers with minimal vertical sediment disturbance or smearing. However, sediment depth penetration could not be controlled consistently. Sediment cores were too short (**Figure 11**), too long (**Figure 12**), or adequate by happenstance rather than by control. Cores that were too short had to be discarded because they didn't meet the study's requirement of penetrating pre-industrial sediments. Cores that were too long also had to be discarded because the sediment-water interface and shallow sediments were not preserved; the upper sediment overflowed out of the top of the core tube through the auto valve (**Figure 12**).

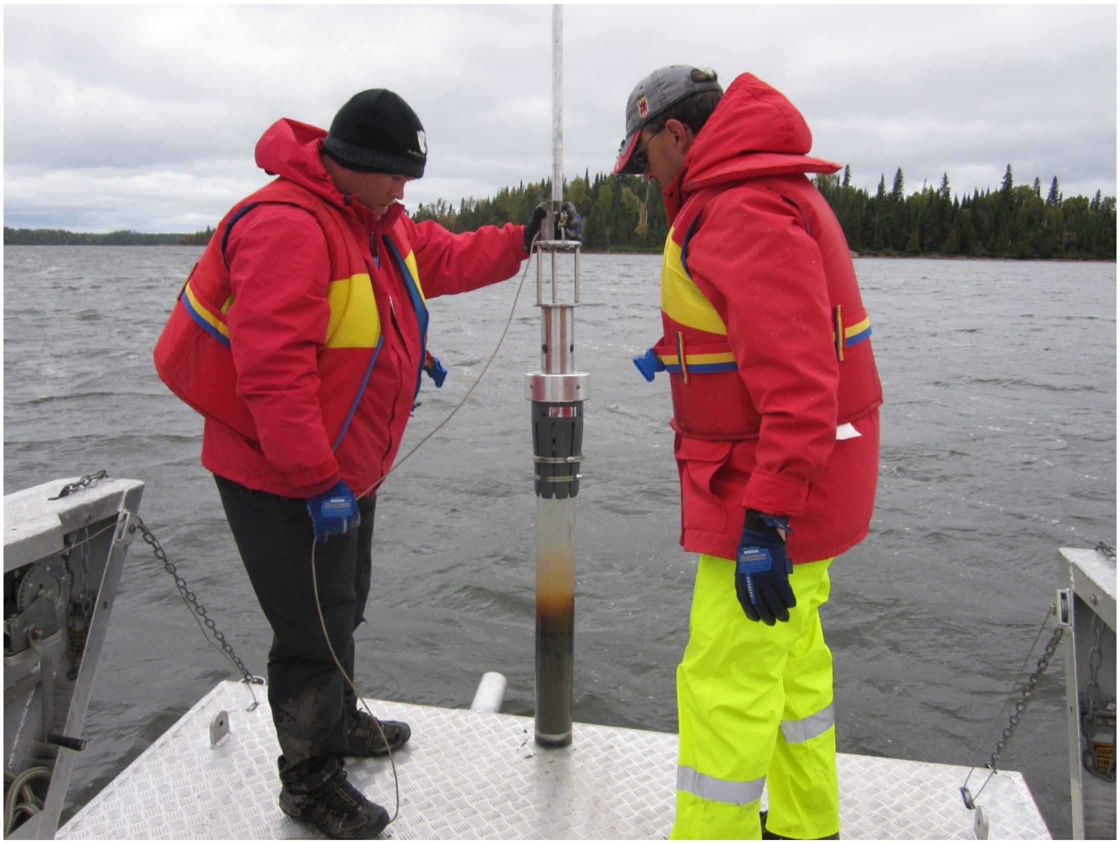


Figure 11. Successful coring with extension rods, although sediment depth was inadequate; Photo: Geological Survey of Canada, September 2011

Figure 12. Sediment depth penetration was greater than the length of the core barrel, so that the sediments overflowed the top of the core barrel; the sediment-water interface was not preserved and the core discarded; Photo: Geological Survey of Canada, May 2012

Once the sediment depth control disk was mounted on the core tube (**Figure 13**) and the fully-modified Tech-Ops gravity corer deployed, much more consistency and reproducibility of sediment core retrieval were achieved (**Figure 14**). The modified corer was quickly assembled for each deployment, which rapidly became an effective and efficient matter of routine (**Figure 15**). Insertion of the stopper or cap in the bottom of the core tube was no different than classic gravity coring once an adequate vacuum could hold the sediments inside the core barrel (**Figure 16**). The operator could easily perceive resistance to further penetration in the sediments created by the depth control ring, which allowed for greater consistency in obtaining uniform core lengths. Upon retrieval of the core, the sediment-water interface consistently lined up with the vertical position of the depth control ring.

Figure 13. (A) Adjustable position of depth control ring; (B) Assembly of the modified corer; Photo: Geological Survey of Canada, May 2012

Figure 14. Preservation of the sediment-water interface and vertical distribution of chemical and mineralogical constituents from Lac Arnoux; Photo: Geological Survey of Canada, May 2012

Figure 15. Routine operation of the modified Tech-Ops gravity corer; Photo: Geological Survey of Canada, May 2012

Figure 16. Insertion of the stopper into the bottom of the core tube upon retrieval with full modifications to the Tech-Ops corer; Photo: Geological Survey of Canada, May 2012

CONCLUSIONS & RECOMMENDATIONS

Two modifications were made to a Tech-Ops open-barrel gravity corer to facilitate sediment core collection from lake bottoms where classic gravity corers could not penetrate or retain sediments adequately. The first was to add a threaded U-shaped adapter to the top of the head assembly of the corer so that extension rods or drive rods could be screwed on sequentially. They were originally designed for use with the Livingstone piston corer as extensions which allow the operator to manually push the core barrel through the sediments. Experience with a Livingstone piston corer (Grenier, 2011) enhanced the expertise of field scientists, who suggested this modification. The rods were used comfortably for up to approximately 15 m of water depth, deployed by at least two operators from a 16′ (4.88 m) aluminum boat. Calmer waters with little or no current eased the operation of the modified corer. Although the weight of the extension rods and the corer combined could be cumbersome, two operators handled it with little difficulty. The quality of the core retrieved was comparable to cores hand-taken by divers, with less risk, cost, and time invested.

A depth control ring was designed, custom-built, and mounted on the outside of the core tube in an adjustable position, to achieve consistent sediment penetration required for the study. This modification allowed for greater reproducibility of core retrieval, resulting in improved effectiveness and efficiency of vertical sediment sampling with pre-determined core lengths.

The main goals were successfully achieved, while conserving the integrity of the sediment core, namely by: obtaining undisturbed vertical samples of bottom sediments, preservation of the sediment-water interface, retention of the original water content, conservation of the original vertical distributions of chemical, mineralogical, and biological sediment constituents, and reproducibility of retrieving consistent core lengths. In fact, unlike diver-collected cores, the extension rods and the depth control ring allowed full control of the speed of penetration into the sediments, consistent sediment penetration, and evenly-applied pressure on the core barrel while penetrating the sediments.

Given the ubiquity of sediment coring in paleolimnological research, the modified coring method could also yield longer cores, with a wider 10-cm diameter. The wide core diameter would be of advantage to those research projects which require a higher sample volume and high-resolution sample depth intervals. Retrieval of the core and rods could also be made easier using a winch or block and tackle, if practical for the field operations, facilities, and type of boat or sampling platform used. A winch would also help retrieve longer cores with the added weight of more sediment material, numerous drive rods, depth control ring, and a wider diameter core barrel.

Sampling in deeper water is also a possibility using the two corer modifications. However, water depth was limited to 18 m in this study, based on the number of extension rods available and the bathymetry of the study lakes. Using the modified gravity corer was more challenging in deeper water where there was more movement of the boat around the anchor point. Additionally, vertical penetration of the core barrel into the sediment-water interface could not be confirmed when the total length of rods and the core barrel was greater than 15 m because of the increased weight and the flexibility of the rods at greater water depths.

Although strong currents were not experienced during the trials in Abitibi, they could also have prohibited efforts to keep the core barrel vertical upon penetration of the sediments. Wind and waves are concerns during descent of the corer towards the lake bottom because the depth variation of the boat from wave action can cause the corer to penetrate the sediments on an angle, rather than in the desired vertical position. Wind and waves also can make the coring platform less stable, as experienced from the 16′ (4.88 m) aluminum boat. A larger field vessel can be a more stable platform, however, caution should be taken as the freeboard may be too high to cap the bottom of the core under water and retain the vacuum.

For other types of geochemical surveys in lacustrine sediments, the modifications to the Tech-Ops corer can be recommended where classic Livingstone piston coring or gravity coring from a platform or boat cannot retrieve sediments or cannot achieve the required sediment penetration. As demonstrated in this study, the addition of drive rods and the depth control ring allowed for consistency and predictability of coring which optimized both time and effort of field personnel.

ACKNOWLEDGMENTS

R.C. Paulen and M.J. Hinton are gratefully acknowledged for their helpful reviews of this Open File report. The technical team at Engineering Technology Services of Natural Resources Canada designed and executed the design modifications for the Tech-Ops corer. Special thanks are extended to C. Gareau for technical drawings. We are grateful to P.W.B. Friske for participation in field work in July 2011, and to I. Hicks and M. Douma in May 2012. Initial testing of the drive rods was done during joint field work in September 2011 with the support of B. Gray, L. Grapentine, and colleagues from Environment Canada and Technical Operations Services (Burlington). The research study was supported by the Environmental Geoscience Program and the Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada.

REFERENCES

Abcourt Mines Incorporated. 2008. Abcourt Mines Inc. announces good drilling results on Aldermac and Abcourt-Barvue properties. News Release, 8 December 2008. http://www.abcourt.com/autogere_doc/2008-12-08_Press_Release.pdf; last accessed, 28 Oct 2015.

Abcourt Mines Incorporated. 2009. Abcourt has renegotiated the Aldermac option. Press Release,
13 January 2009. http://www.abcourt.com/autogere_doc/2009-01-23_Press_Release.pdf; last accessed, 28 Oct 2015.

Alpay, S. (ed.) 2016. Multidisciplinary environmental science investigations surrounding the former Aldermac Mine, Abitibi, Quebec: the Lac Dasserat study workshop summarized; Geological Survey of Canada, Open File 7993, 119p. doi:10.4095/299747

Alpay, S., Day, S., McNeil, R., McCurdy, M., and Gammon, P. 2011. Variations on a theme of gravity coring: K-B, Glew and TechOps corers with core extrusion and high-resolution vertical sectioning of shallow aquatic sediments. *IN:* Summary of a workshop on light-weight coring techniques and equipment used by Northern Canada Division, Geological Survey of Canada. *ED:* G.R. Brooks. Geological Survey, Open File 6746, 18p. report + appendices. doi:10.4095/288036

Alpay, S., McNeil, R.J., Grenier, A. and Gould, W.D. 2015. Lake sediment grab sampling versus coring for environmental risk assessment of metal mining. Geological Survey of Canada, Scientific Presentation 26, 1 poster. doi:10.4095/295559.

Appleby, P.G., and Oldfield, F. 1978. The calculation of lead-210 dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. Catena 5(1):1-8.

Bourgeois, J.C., Gajewski, K., and Demuth, M.N. 2011. A universal percussion corer for sampling lake sediments. *IN:* Summary of a workshop on light-weight coring techniques and equipment used by Northern Canada Division, Geological Survey of Canada. *ED:* G.R. Brooks. Geological Survey, Open File 6746, 18p. report + appendices. doi:10.4095/288036

Bradley, L. 2009. Quebec artist inspires change through work. The Sudbury Star, 13 April 2009. http://www.thesudburystar.com/2009/04/13/quebec-artist-inspires-change-through-work-comment-on-this-story; last accessed, 28 Oct 2015.

Brooks, G.R. 2011. Vibracoring in lakes and on landslides. *IN:* Summary of a workshop on light-weight coring techniques and equipment used by Northern Canada Division, Geological Survey of Canada. *ED:* G.R. Brooks. Geological Survey, Open File 6746, 18p. report + appendices. doi:10.4095/288036

Canadian Council of Ministers of the Environment. 1995. Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life. Canadian Environmental Quality Guidelines. CCME EPC-98E. http://ceqg-rcqe.ccme.ca/download/en/226; last accessed 9 March 2016.

Cascade Environmental Research Group Limited. 2014. Now offering paleolimnology services for risk assessment. http://cerg.ca/now-offering-paleolimnology-services-environmental-assessment/; last accessed 4 March 2016.

Conseil régional de l'environnement de l'Abitibi-Témiscamingue (CREAT). 2007. Les projets du CREAT : Campagne pour la restauration du parc à résidus miniers abandonnés Aldermac. http://www.creat08.ca/even_aldermac.php; last accessed, 28 Oct 2015.

Cyr, J. 2008. Aldermac mine site restoration: a $16.5 million project. http://www.mrn.gouv.qc.ca/english/mines/quebec-mines/2008-11/restoration.asp; last accessed, 28 Oct 2015.

Dixit, A.S., Alpay, S., Dixit, S.S., Smol, J.P. 2007. Paleolimnological reconstructions of Rouyn-Noranda lakes within the zone of influence of the Horne Smelter, Québec, Canada. Journal of Paleolimnology 38: 209-226.

Doucet, V. 2005. Aldermac-Plantation Minière. http://www.veroniquedoucet.com/fr/aldermac; last accessed, 28 Oct 2015.

Enache, M. and Prairie, Y.T. 2002. WA-PLS diatom-based pH, TP and DOC inference models from 42 lakes in the Abitibi clay belt area (Quebec, Canada). Journal of Paleolimnology 27: 151-171.

Environment Canada. 2012. Environmental Effects Monitoring, Investigation of Cause Workshop for Metal Mining, Proceedings, 101 p. https://ec.gc.ca/Publications/552A238A-A0F2-4719-8D32-A3358FA867B8/EEMInvestigationOfCauseWorkshopForMetalMining.pdf; last accessed, 2 Nov 2015.

Gammon, P. and Alpay, S. 2011. Aquatic soft sediment sampling methods: Freeze coring and grab/hand coring. *IN:* Summary of a workshop on light-weight coring techniques and equipment used by Northern Canada Division, Geological Survey of Canada. *ED:* G.R. Brooks. Geological Survey, Open File 6746, 18p. report + appendices. doi:10.4095/288036

Gilbert, R. and Glew, J. 1985. A portable percussion coring device for lacustrine and marine sediments. Journal of Sedimentary Petrology 55:607-608.

Glew, J.R., Smol, J.P. and Last, W.M. 2001. Sediment core collection and extrusion. *IN:* Tracking Environmental Change Using Lake Sediments. *ED:* W.M. Last and J.P. Smol. Vol 1: Basin Analysis, Coring, and Chronological Techniques. Kluwer Academic Publishers, Dordrecht. 73-105.

Glew, J.R., and Smol, J.P. 2016. A push corer developed for retrieving high-resolution sediment cores from shallow waters. Journal of Paleolimnology, doi:10.1007/s10933-015-9873-z. Published online 04 January 2016.

Goulet, R. and Couillard, Y. 2009. Weight-of-evidence assessment of impacts from an abandoned mine site to the Lake Dasserat watershed, Quebec, Canada. *IN:* Lake

Pollution Research Progress. *ED:* F.R. Miranda and L.M. Bernard. Nova Science Publishers Inc., Hauppauge NY.

Grenier, A. 2011. Livingstone coring. *IN:* Summary of a workshop on light-weight coring techniques and equipment used by Northern Canada Division, Geological Survey of Canada. *ED:* G.R. Brooks. Geological Survey, Open File 6746, 18p. report + appendices. doi:10.4095/288036

Grenier, A. and Kliza, D.A. 2005. Pollen analysis of sediment cores from lakes in the Rouyn-Noranda region, Quebec. *IN:* Metals in the Environment Around Smelters at Rouyn-Noranda, Quebec & Belledune, New Brunswick: Results and Conclusions of the GSC MITE Point Sources Project. *ED:* Bonham-Carter, G.F. Geological Survey of Canada Bulletin 584. 12 p.

Hall, R.I., and Smol, J.P. 1996. Paleolimnological assessment of long-term water-quality changes in south-central Ontario lakes affected by cottage development and acidification. Canadian Journal of Fisheries and Aquatic Sciences 53: 1-17.

Hamilton, P.B., Lavoie, I., Alpay, S., and Ponader, K. 2015. Using diatom assemblages and sulfur in lake sediments to uncover the effects of historical mining on Lake Arnoux (Quebec, Canada): A retrospective of economic benefits vs. environmental debt. Frontiers in Ecology and Evolution 3:(99) doi:10.3389/fevo.2015.00099.

Ishiwatari, R., and Uzaki, M. 1987. Diagenetic changes of lignin compounds in a more than 0.6 million-year-old lacustrine sediment (Lake Biwa, Japan). Geochimica et Cosmochimica Acta 51(2): 321-328.

Kliza, D. and Telmer, K. 2001. GSC-MITE Phase I: Lake sediment studies in the vicinity of the Horne smelter in Rouyn-Noranda, Quebec. Geological Survey of Canada, Open File 2952. 1 CD-ROM; doi:10.4095/212711

Kuehl, S.A., Nittrouer, C.A., DeMaster, D.J., and Curtin, T.B. 1985. A long, square-barrel gravity corer for sedimentological and geochemical investigation of fine-grained sediments. Marine Geology 62: 365-370.

Lennox, B., Spooner, I., Jull, T., and Patterson, W.P. 2010. Post-glacial climate change and its effect on a shallow dimictic lake in Nova Scotia, Canada. Journal of Palelimnology 43: 15-27.

Livingstone, D.A. 1955. A lightweight piston sampler for lake deposits. Ecology 36(1): 137-139.

Machine All Incorporated. 2010. Corer Instruction Sheet, Tech-Ops corer. 1 p.

Mayer, B., Alpay, S., Gould, W.D., Lortie, L., and Rosa, F. 2007. The onset of anthropogenic activity recorded in lake sediments in the vicinity of the Horne smelter in Quebec, Canada: Sulfur isotope evidence. Applied Geochemistry 22(2): 397-414.

McNeil, R.J., Alpay, S. and Grenier, A., 2015. Environmental geoscience investigations surrounding the former Aldermac mine, Abitibi, Quebec: Regional surveys of surface water and sediment geochemistry. Geological Survey of Canada, Open File 7595, 1 .zip file; doi:10.4095/296832

Mott, R.J. 1975. Palynological studies of lake sediment profiles from southwestern New Brunswick. Canadian Journal of Earth Sciences 12(2): 273-288.

Mudroch, A. and McKnight, S.D. 1991. CRC handbook of techniques for aquatic sediments sampling. CRC Press, Boca Raton. pp. 210.

Prévost, C.L., Veillette, J.J., and Hamilton, P.B. 1995. Preliminary diatom analysis of selected samples from Lake Abitibi and Glacial Lake Ojibway, Ontario and Quebec. Geological Survey of Canada, Current Research 95-C, pp. 235-242.

Perceval, O., Couillard, Y., Pinel-Alloul, B., and Campbell, P.G.C. 2006. Linking changes in subcellular cadmium distribution to growth and mortality rates in transplanted freshwater bivalves *(Pyganodon grandis)*. Aquatic Toxicology 79(1): 87-98.

Reasoner, M.A., 1986. An inexpensive, lightweight percussion core sampling system. Géographie physique et Quaternaire 40(2): 217-219.

Reasoner, M.A., 1993. Equipment and procedure improvements for a lightweight inexpensive percussion core sampling system. Journal of Paleolimnology 8: 273-281.

Renberg, I. 1981. Improved methods for sampling, photographing and varve-counting of varved lake sediments. Boreas 10: 255-258.

Renberg, I. and Hansson, H. 2010. Freeze corer No. 3 for lake sediments. Journal of Paleolimnology 44(2): 731-736.

Sanchez-Cabeza, J.A., and Ruiz-Fernández. 2012. ^{210}Pb sediment radiochronology : An integrated formulation and classification of dating models. Geochimica et Cosmochimica Acta 82: 183-200.

Smith, D.G. 1995. Vibracoring: A new method for coring deep lakes. Palaeogeography, Paleoclimatology, Paleoecology 140: 433-440.

Tingstad, A.H., Moser, K.A., MacDonald, G.M., and Munroe, J.S. 2011. A ~13,000-year paleolimnological record from the Uinta Mountains, Utah, inferred from diatoms and loss-on-ignition analysis. Quaternary International 235(1–2): 48–56.

Veillette, J.J. 1994. Evolution and paleohydrology of glacial lakes Barlow and Ojibway. Quaternary Science Reviews, 13: 945-971.

Verta, M., Tolonen, K., and Simola, H. 1989. History of heavy metal pollution in Finland as recorded by lake sediments. Science of the Total Environment 87-88: 1-18.

Wetzel, R.G. 2001. Limnology, Lake and River Ecosystems, 3rd Ed. Elsevier Academic Press.

San Diego. 1006 pp.

Wright, H.E., Cushing, E.J. and Livingstone, D.A., 1965. Coring devices for lake sediments. Handbook of paleontological techniques. Freeman, San Francisco. pp.494-520.

APPENDICES

APPENDIX A. U-SHAPED STEEL SCREW ADAPTOR SPECIFICATIONS

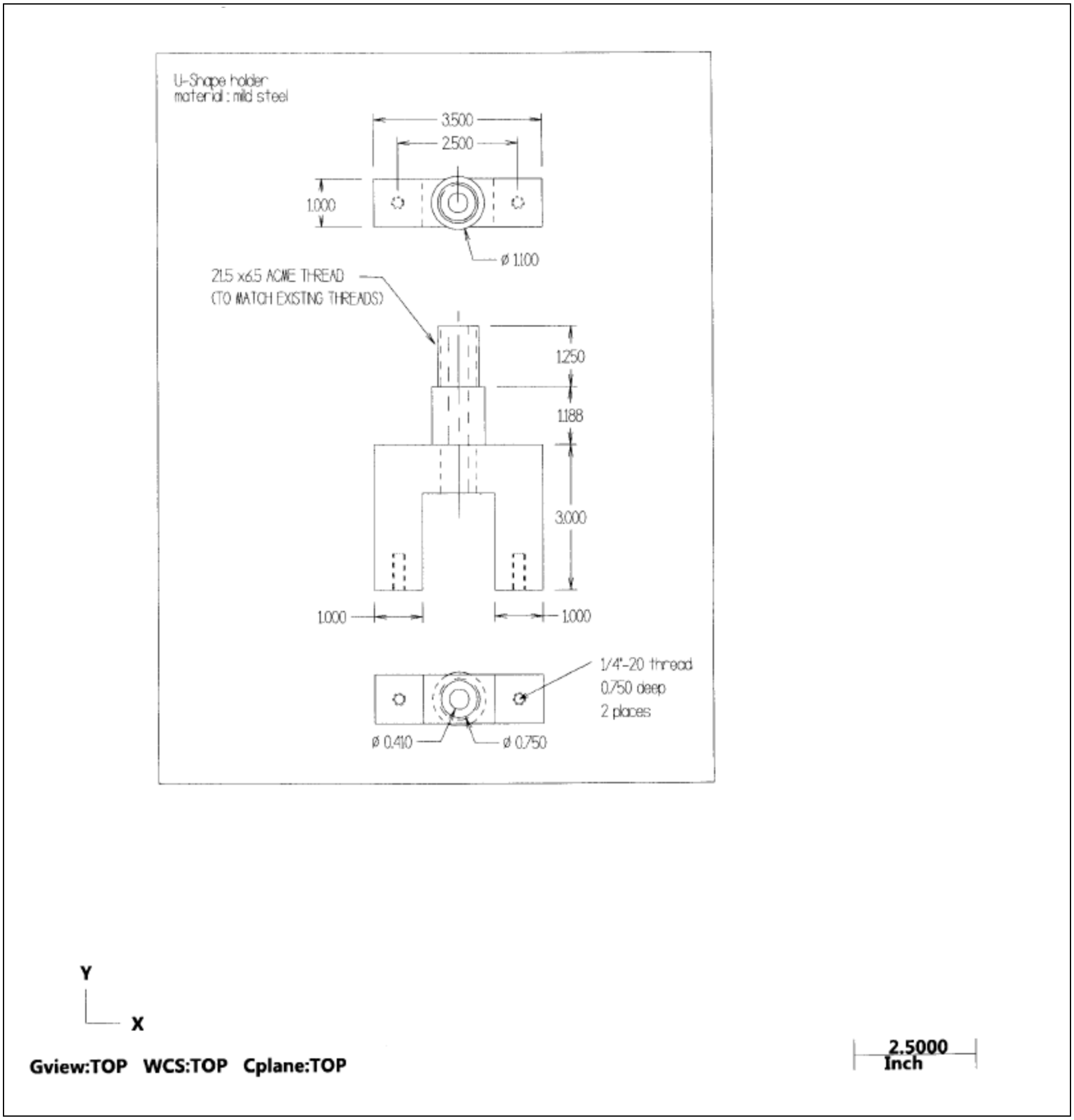


Figure A1. Technical drawing of the U-shaped steel screw adaptor for connection of threaded drive rods to the top of the Tech-Ops gravity corer (3 views)

APPENDIX B – DEPTH CONTROL RING SPECIFICATIONS

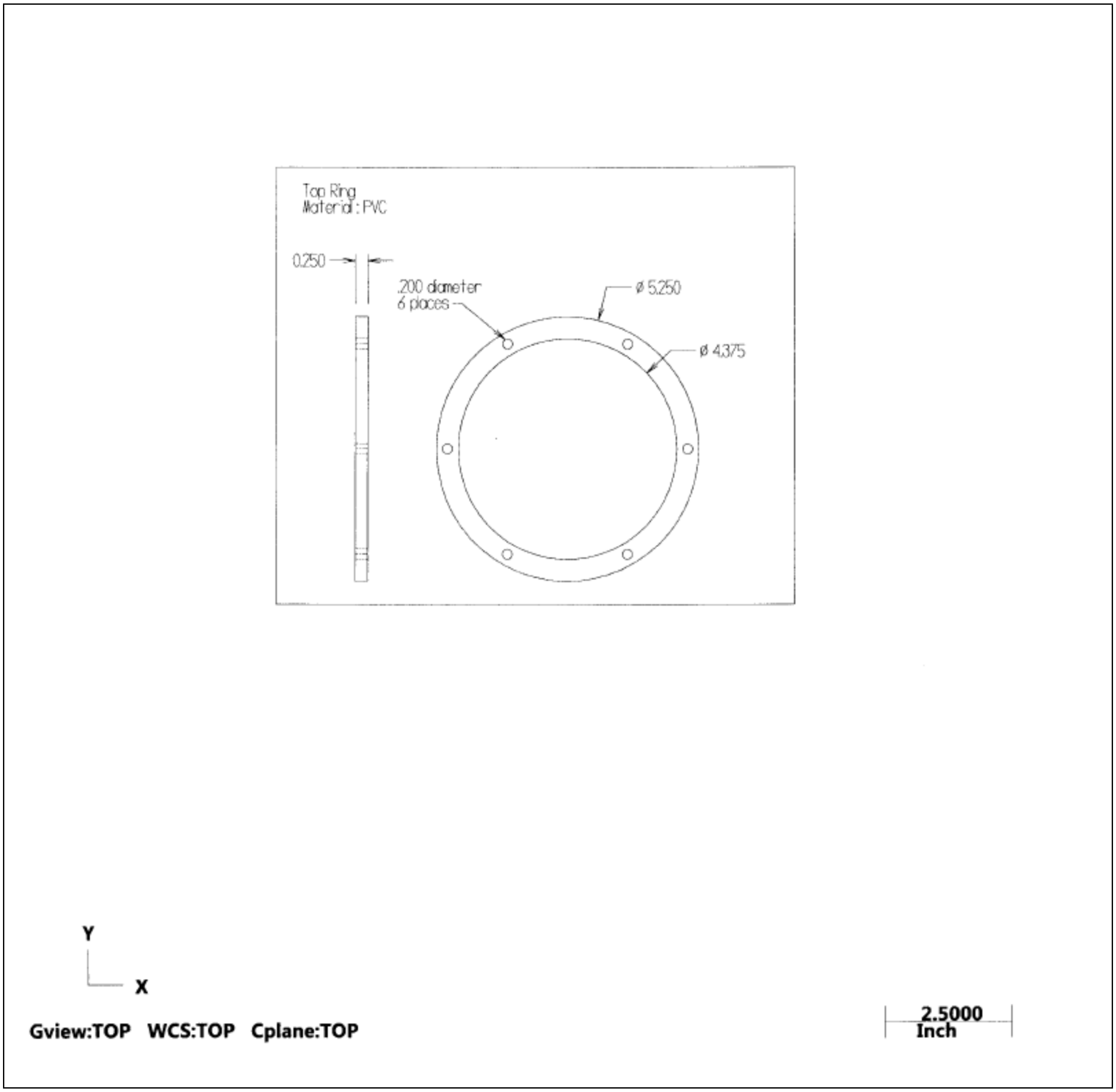


Figure B1. Technical drawing of the top ring of the depth control ring assembly (2 views)

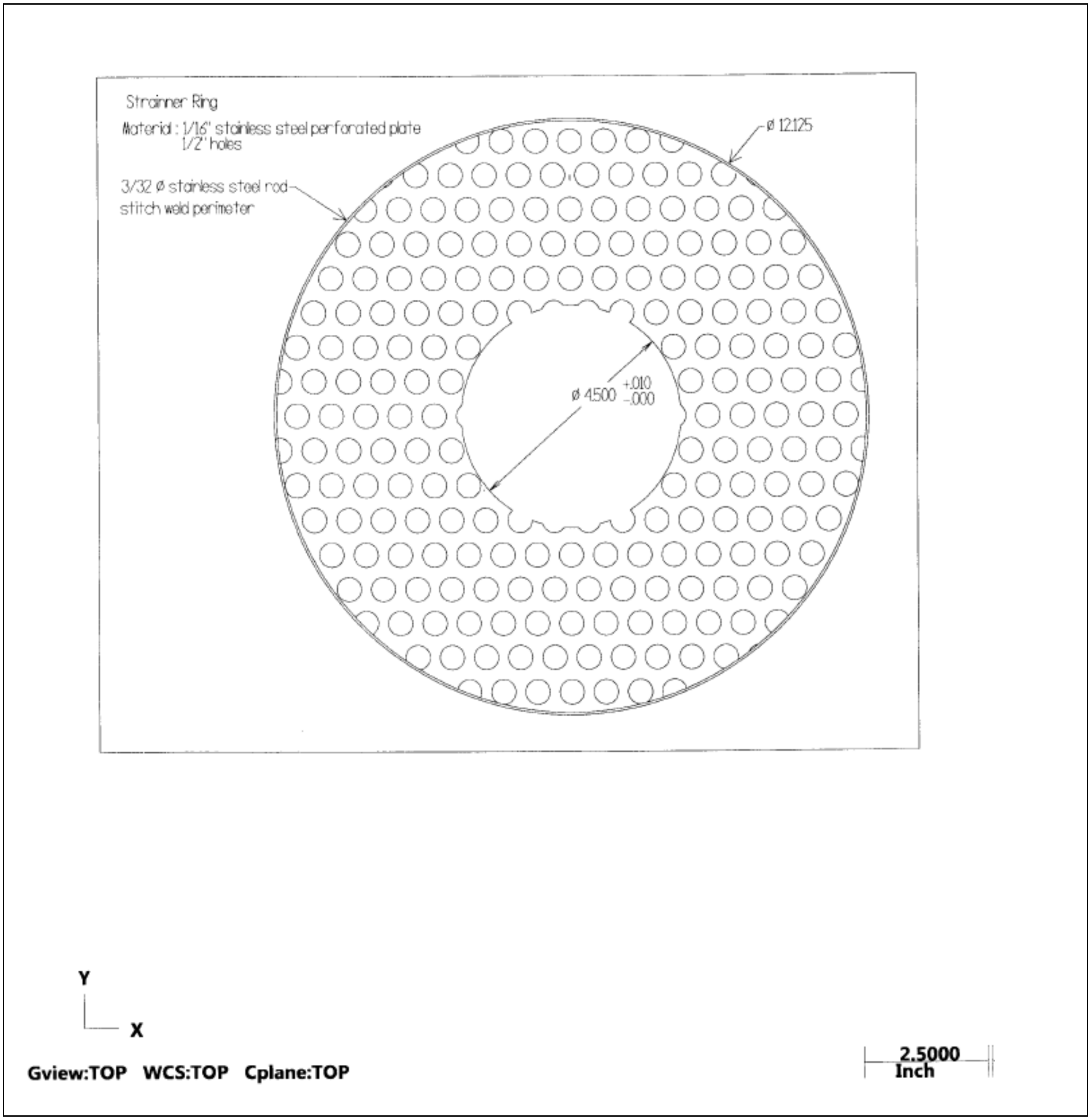


Figure B2. Technical drawing of the perforated depth control ring, sandwiched between the top ring (Figure B1) and the body collar (Figure B3)

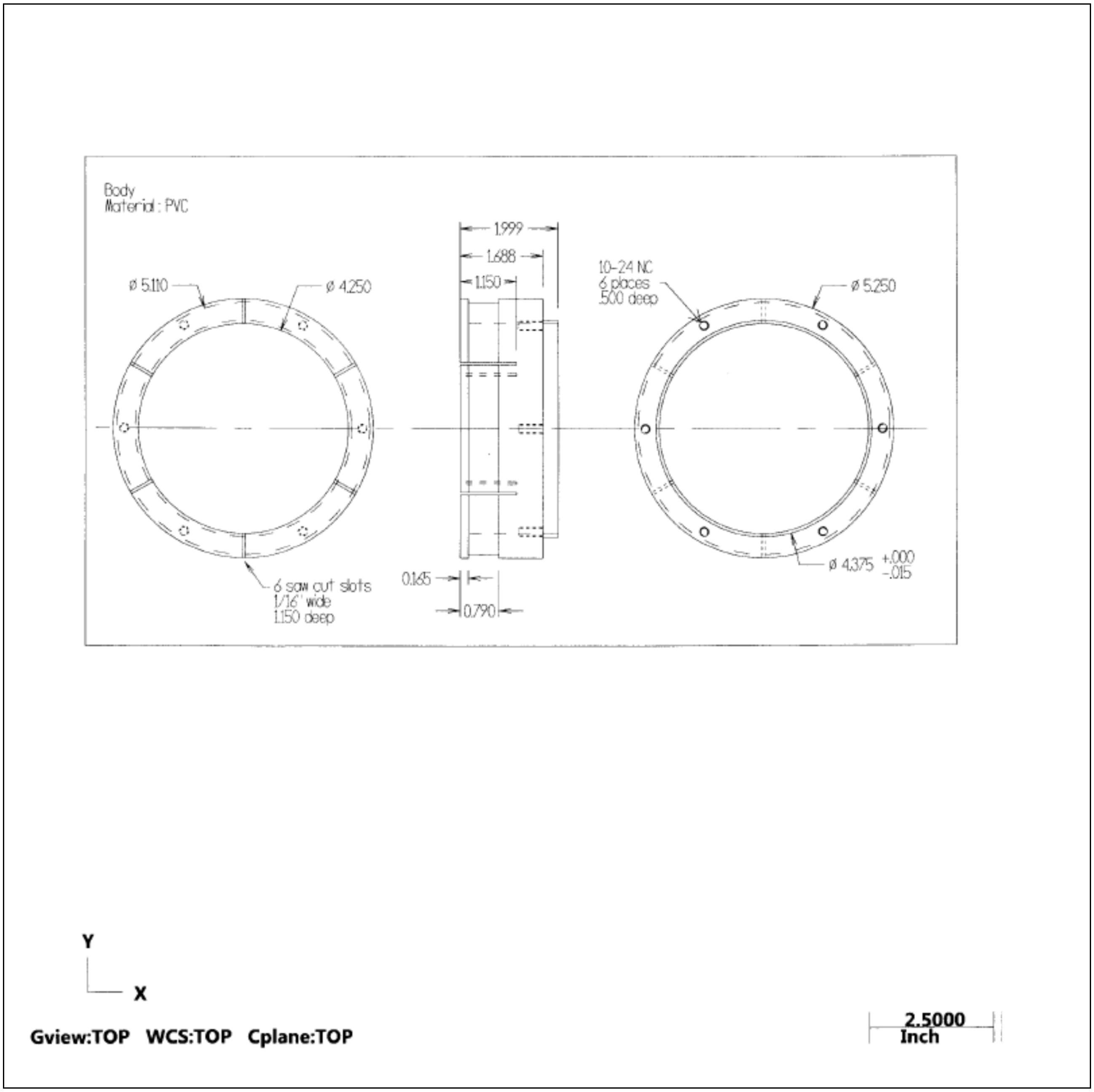


Figure B3. Technical drawing of the body collar which is the bottom attachment in the depth control ring assembly (3 views)