

This report and software are for the sole use of CCG members.

This ninth report may be distributed to non-members for the purpose of advertisement. The report may be circulated and disposed of at your discretion; however, the following copyright notice must be adhered to.

Copyright, 2007, Centre for Computational Geostatistics

All rights reserved. No part of this report may be used or reproduced without written permission, except for members of the *Centre for Computational Geostatistics*.

Ninth Annual Report of the Centre for Computational Geostatistics

SEPTEMBER 2007

- Introduction, List of CCG Sponsors, List of CCG Staff / Students / Researchers

Geostatistical Modeling

- 101 Some Developments Towards Best Practice, *C.V. Deutsch*
- 102 Calculating Distance in the Presence of Locally Varying Anisotropy, *J.B. Boisvert, J.G. Manchuk and C. V. Deutsch*
- 103 Kriging and Simulation in the Presence of Locally Varying Anisotropy, *J.B. Boisvert, J.G. Manchuk and C. V. Deutsch*
- 104 Prediction in Presence of a Nonstationary Histogram, *J.A. McLennan and C. V. Deutsch*
- 105 Methods for Integrating Conditional Probabilities for Geostatistical Modeling, *S. Hong and C. V. Deutsch*
- 106 A Second Generation Gibbs Sampler for Simulation with Multiple-Point Statistics, *S. Lyster*
- 107 An Intrinsic Model of Coreginalization that Solves Variance Inflation in Colocated CoKriging, *O. Babak and C.V. Deutsch*
- 108 Modeling Multiple Coal Seams Using Volume Functions, *B. J. Wilde and C. V. Deutsch*
- 109 Merging Multiple Secondary Data for Collated Cokriging (recall of super secondary variable idea), *O. Babak and C. V. Deutsch*
- 110 Wide Array Declustering for Representative Distributions (The Ultimate DECLUS Program), *B. J. Wilde and C. V. Deutsch*
- 111 Linear and Non Linear Estimation Based on Training Images, *D.F. Machuca Mory and C. V. Deutsch*
- 112 Determination of Locally Varying Direction Through Mass Moment of Inertia Tensor, *R. M. Hassanpour and C. V. Deutsch*
- 113 Artifacts Near Conditioning Data in MPS Gibbs Sampling, *S. Lyster and C. V. Deutsch*
- 114 Theoretical Justification for Iterative Simulation Methods such as Gibbs Sampler, *S. Lyster*
- 115 Variability of Multiple-Point Statistics, *S. Lyster*
- 116 Comparison of Cokriging with a LMC Versus The Intrinsic Model, *O. Babak and C. V. Deutsch*
- 117 Non Stationary Variograms Based on Continuously Varying Weights, *D.F. Machuca Mory and C. V. Deutsch*
- 118 Estimation with Non Stationary First and Second Moments, *D. F. Machuca Mory and C. V. Deutsch*
- 119 Successive Kriging for Estimation and Simulation in a Finite Domain, *O. Babak and C. V. Deutsch*
- 120 Distance Constrained Kriging Weights to Correct Large Weights to Data at the End of Strings, *O. Babak and C. V. Deutsch*
- 121 Methodology for Choosing the Optimal Tolerance Parameters for Variogram Calculation, *S. H. Derakhshan, C. V. Deutsch and O. Leuangthong*

- 122 Application of Optimal Tolerance Parameters for Variogram Calculation , *S. H. Derakhshan, O. Leuangthong and C. V. Deutsch*
- 123 Inference of the Nugget Effect and Variogram Range with Sample Compositing, *D. F. Machuca Mory and C. V. Deutsch*
- 124 Variogram Range Estimation from Experimental Variograms with Significant Tolerance, *S. H. Derakhshan, O. Leuangthong and C. V. Deutsch*
- 125 A Practical Approach to Validate the Variogram Reproduction from Geostatistical Simulation, *J. M. Ortiz. and O. Leuangthong*
- 126 The Proportional Effect of Spatial Variables, *J. G. Manchuk, O. Leuangthong and C. V. Deutsch*
- 127 A Distance Function Based Algorithm to Quantify Uncertainty in Areal Limits, *A. H. Hosseini and C. V. Deutsch*
- 128 Data Integration for Characterization of Spatial Distribution of Residual Hydrocarbon at a Contaminated Site, *A. H. Hosseini*
- 129 Large Scale Modeling by Bayesian Updating Techniques, *W. Ren*

Petroleum Related

- 201 Calculation of Permeability Tensors for Unstructured Grid Blocks, *R. M. Hassanpour, O. Leuangthong and C. V. Deutsch*
- 202 Summary Statistics for Geologic Continuity, Grid Geometry and Permeability Tensor Characterization, *R. M. Hassanpour and C.V. Deutsch*
- 203 Multivariate Distribution Modeling of Geologic Variables, *J. G. Manchuk and C. V. Deutsch*
- 204 On Geostatistical Simulation of Permeability Tensors, *J. G. Manchuk and C. V Deutsch*
- 205 Data Integration for 2-D Areal Proportions of Facies, *S. Hong and C. V. Deutsch*
- 206 High Resolution Facies Modeling in Presence of Large-Scale Probabilistic Data, *S. Hong and C.V. Deutsch*
- 207 Data Integration for 3-D Porosity Modeling, *S. Hong and C. V. Deutsch*
- 208 Advances in Stochastic Surface Modeling of Deepwater Depositional Systems, *X. Zhang M. J. Pyrcz and C. V. Deutsch*
- 209 Facies Modeling in Presence of High Resolution Surface-based Reservoir Models, *X. Zhang*
- 210 Automatic High Resolution Surface Picking for Geostatistical Modeling, *X. Zhang*
- 211 Scale Consistent Modeling for Reservoir Characterization, *W. Ren*

Mining Related

- 301 Feasibility Grade Control (FGC): Simulation of Grade Control on Geostatistical Realizations, *B. J. Wilde and C. V. Deutsch*
- 302 A Short Note Comparing Feasibility Grade Control with Dig Limit Grade Control, *B. J. Wilde and C. V. Deutsch*
- 303 Flexible Change of Support Model Suitable for a Wide Range of Mineralization Styles, *D. F. Machuca Mory, O. Babak and C. V. Deutsch*
- 304 Local Recoverable Reserves Prediction with Block LU Simulation, *J. M. Ortiz and C. V. Deutsch*
- 305 Multivariate Block LU Simulation, *J. Boisvert and C. V. Deutsch*

- 306 A Methodology for Geometric Modeling of Kimberlite Deposits with Uncertainty, *J. Boisvert, P. Oshust and C. V. Deutsch*
- 307 Estimation of Heavy Mineral Resources in Oil Sands Tailings, *C. Neufeld and C. V. Deutsch*
- 308 A Simulation Approach to Account for the Information Effect, *C. Neufeld, O. Leuangthong, C. V. Deutsch*
- 309 On the Challenge of Estimating Recoverable Reserves with Sequential Indicator Simulation, *D. F. Machuca Mory, J. M. Ortiz and C. V. Deutsch*
- 310 Why Choosing One Realization for Mine Planning is a Bad Idea, *C. Neufeld and C. V. Deutsch*
- 311 The Slope of Regression for Kriging Estimators, *C. V. Deutsch*

Software Related

- 401 Robust Solution of Normal (Kriging) Equations, *J. G. Manchuk and C. V. Deutsch*
- 402 Programming Tips for Plugins, *C. Neufeld and C. V. Deutsch*
- 403 Petrel Plugins for Declustering and Debiasing, *J. G. Manchuk, C. Neufeld, and C. V. Deutsch*
- 404 A Recall of Factorial Kriging with Examples and a Modified Version of `kt3d`, *C. V. Deutsch*
- 405 Improved Factorial Kriging for Feature Identification and Extraction, *S. Hong and C. V. Deutsch*
- 406 Estimating Conditional Moments with Inverse Distance Weights in Sequential Gaussian Simulation, *O. Babak and C. V. Deutsch*
- 407 A Comparison of Z Variograms Obtained by Transformation Using Hermite Polynomials and Monte Carlo Simulation, *B. J. Wilde, C. Neufeld and C. V. Deutsch*
- 408 Uncertainty as the Overlap of Alternate Conditional Distributions, *O. Babak and C.V. Deutsch*

Introduction

Welcome to the ninth CCG report! It has been a great year and we are sure you will find something of interest. Significant theory, algorithms, code and applications have been created and demonstrated. Our cumulative summary statistics:

Report		Members	Papers	Length (pages)
1	1999	6	15	257
2	2000	7	21	415
3	2001	10	23	356
4	2002	8	28	481
5	2003	13	42	727
6	2004	17	41	548
7	2005	20	40	560
8	2006	29	55	800
9	2007	33	59	596
Total:			324	4740

The list of members and current active students/staff can be found on pages vii to x. Our target for this report was no more than 600 pages. We mercilessly cut the length of most papers. In many cases, there is a full thesis supporting the results. Those theses, electronic copies of all papers, the latest software catalogue, presentations and other resources are available on the CCG server. Talk to your CCG contact or ask one of us for your company login information.

These metrics are updated every CCG report. They have been listed, presented as a GSLIB-format data file, and plotted with the oil and copper price. We all know that such measures do not tell the whole story. There are other measures including degrees granted (10 last year), students admitted (6 this fall), research revenue (better check with Amanda), leveraging with governmental sources (over 6 major scholarships leveraged with CCG membership fees), citations (according to Google Scholar™ we have more citations than virtually all other research groups), and so on. In the end, all of these metrics are trumped by notions of *quality*, *reputation* and *impact* of research. These more consequential soft notions are not directly measureable.

Convincing others of success in these soft areas seems to be done with anecdotes. Stories are told of the success of one student, a practitioner affected by an inspiring short course, a new algorithm integrated in commercial software that impacts an important decision, or a theoretical breakthrough that permits improved prediction. We have our success stories and anecdotes. Many students have graduated from CCG and have moved on to academia and industry; many making important contributions. Virtually all geomodeling software has implemented a CCG algorithm; these algorithms have, undoubtedly, contributed to important development decisions. The theoretical contributions of CCG are many and varied; some have improved estimates and uncertainty. We may collect some of these success stories for our next Newsletter.

The preparation of our annual report marks our research year end. It is a time to reflect on the health of the research group; hence our interest in metrics of success. CCG is in the prime of its life – old enough to be over growing pains and adolescent mistakes; young enough to have energy and enthusiasm for the future. Working with a steady supply of young and eager students helps keep us in shape (although we could work out more).

The students of CCG have delivered a great annual report. A number of students have finished degrees. **Jason** completed his Ph.D. on the decision of stationarity including the nature of

geological boundaries and trend modeling. **Weishan** also completed his Ph.D. on the topic of large-scale modeling and scale-consistent high resolution modeling. **John** completed his M.Sc. on various aspects of optimization for underground mine planning. **Jeff's** M.Sc. related to the generation of training images for a variety of geological settings. **Deepak** completed his M.Sc. on a comparative study of resource estimation techniques. **Zhou** completed his M.Sc. on multiscale facies modeling. **Xingquan** (Kevin) documented a number of enhancements to process-mimicking geological modeling in his M.Sc. **Hadi** completed an M.Sc. on the optimal choice of tolerance parameters for variogram calculation. Finally, **Mehran** completed an M.Sc. related to the calculation of tensors for permeability and directions of continuity.

Regarding current students, **Olena** has made interesting developments in cokriging, estimation in a finite domain and other areas. **Hadi** and **Mehran** just finished their Master degrees and have launched into Doctorate degree programs this month. **Jeff** has devised interesting techniques for modeling with anisotropy. **Sahyun** has made many contributions toward data integration. **Steve** has made many contributions related to generating simulated realizations with multiple point statistics. **David** has made a number of practical contributions related to variogram inference and non-stationary variograms,. **John** has contributed his mathematical and programming skills to many research areas. **Brandon** spent the summer with us again and made valuable contributions.

Regarding the permanent staff, **Amanda** continues to provide vital administrative support. **Chad** remains at CCG as a Research Engineer providing important assistance. A number of alumni remain actively involved including **Julián** and **Michael**.

We are at an all-time high in terms of member companies – thirty three! We would like to welcome Golder, Husky, NovaGold and Inco to CCG. A list of all members is shown on the following two pages. The research at CCG is driven by our members. We strive to keep each member organization engaged in CCG activities. The level of interaction, however, is quite variable over time and between member companies. We strongly encourage member companies to seek out opportunities to be involved in our research. Site visits to Edmonton and dissemination of CCG deliverables throughout your company are important.

This coming year of research will be our tenth. We are thinking of widespread changes. We will be speaking with our member companies and the University administration.



CCG Sponsors:

AMEC E & C Services Inc.
2020 Winston Park Drive
Oakville, ON, Canada L6H 6X7
contact: Ian Crundwell

AngloAmerican
45 Main Street
Johannesburg 2001, South Africa
contact: Christina Dohm

Apache Corporation
2000 Post Oak Blvd, Suite 100
Houston, TX, USA 77056
contact: Kelly Haizlip

Barrick Gold Corporation
760 E. Pusch View Lane, Suite 100
Tucson, AZ USA 85737
contact: Jean Francios Metail

BHP Billiton Corporation
#8 – 2604 Enterprise Way
Kelowna, B.C., Canada V1X 7Y5
contact: Peter Oshust

Chevron Petroleum Technology Co.
1500 Louisiana Street, 17042A
Houston, TX USA 77002
contact: Michael Pyrcz

Conoco Phillips
600 N Dairy Ashford
Houston, TX, USA 77079
contact: Helen Farrell

De Beers Consolidated Mines
Private Bag X01, Southdale 2135
Johannesburg, South Africa
contact: David Bush

Encana Corporation
150 – 9th Avenue SW
Calgary, AB, Canada T2P 3H9
contact: Tarun Kashib

Newmont Mining Corporation
10101 East Dry Creek Road
Englewood CO, USA 80112
contact: Ian Douglas

Nexen Inc
801 – 7th Avenue SW
Calgary AB, Canada T2P 3P7
contact: Pat Jamieson

NovaGold Resources Inc.
2300 – 200 Granville Street
Vancouver, BC, Canada V6C 1S4
contact: Kevin Francis

Occidental Oil & Gas Corporation
5 Greenway Plaza, Suite 110
Houston, TX USA 77046-0506
contact: Ravi Sharma

Paradigm (formerly gOcad)
11011 Richmond Avenue, Suite #350
Houston, TX 77042, USA
contact: Emmanuel Gringarten

Petrobras/CENPES
Cid. Univ. Quadra 7, Ilha do Fundao
21949-900 Rio de Janeiro, RJ, BRAZIL
contact: Marcelo Costa Monterio

Petro-Canada
150 – 6th Avenue SW
Calgary, AB, Canada T2P 3E3
contact: Paul Morris

Quantitative Group
P.O. Box 1304
Fremantle, WA, Australia 6959
contact: John Vann

RSG Global
1162 Hay Street
West Perth, WA, Australia 6005
contact: Ken Jeffery

Golder Associates S.A.

Av. Once de Septiembre 2353, Piso 2
Santiago, RM, Chile 751 00 58
contact: Paula Larrondo

RWE-Dea Aktiengesellschaft

Überseering 40
22297 Hamburg Germany
contact: Thies Dose

Husky Oil Operations Limited

707 – 8th Avenue SW
Calgary, AB, Canada T2P 3G7
contact: Craig Lamb

Schlumberger Information Solutions

1, rue Henri Becquerel – BP 202
92142 Clamart Cedex, France
contact: Jim Brady

INCO Limited

P.O. Box 5000
Thompson, MB, Canada R8N 1P3
contact: Ian Blakley

Snowden Mining Industry Consultants

87 Colin Street
West Perth, WA 6005 Australia
contact: Ian Glacken

Innovative Petrotech Solutions

6400 N. Cicero, Suite 309
Lincolnwood, IL, USA 60712
contact: Maghsood Abbaszadeh

SRK Consulting

Suite 1000, 25 Adelaide Street East
Toronto, ON, Canada M5C 3A1
contact: Jean-François Couture

Landmark Graphics

2101 CityWest Blvd, Bldg. 2
Houston, TX USA 77042-2827
contact: Jeffery Yarus

Statios LLC

1345 Rhode Island Street
San Francisco, CA USA 94107
contact: Emmanuel Schnetzler

Maptek Sud America

5 Norte 112
Viña del Mar, Chile
contact: Marcelo Arancibia

Talisman Energy Inc.

Suite 3400, 888 – 3rd Street SW
Calgary, AB Canada T2P 5C5
contact: Mark Godlewski

Mintec Inc.

1120 Hamilton Street, Suite 400
Vancouver, B.C., Canada, V6B 2S2
contact: John Davis

Teck Cominco Ltd.

600 – 200 Burrard Street
Vancouver B.C. Canada V6C 3L9
contact: Paul Bankes

Wardrop Engineering Inc.

330 Bay Street, Suite 604
Toronto, ON Canada M5H 2S8
contact: Tim Maunula

CCG Staff / Researchers / Students

Following are the people directly affiliated with the Centre for Computational Geostatistics at the time of writing this report:

- | | | |
|-----|-----------------------------|-----------------------------------|
| • | Clayton V. Deutsch | Professor and Director of CCG |
| • | Oy Leuangthong | Professor and Director of CCG |
| • | Chad Neufeld | Research Engineer |
| • | Julian Ortiz C. | Adjunct Professor |
| • | Amanda Potts | Research Administrative Assistant |
| 1. | Olena Babak | Ph.D. student |
| 2. | Jeff Boisvert | Ph.D. student |
| 3. | Miguel Cuba | new M.Sc. student |
| 4. | Hadi Derakhshan | Ph.D. student |
| 5. | Mehran M. Hassanpour | Ph.D. student |
| 6. | Sahyun Hong | Ph.D. student |
| 7. | Mike Job | new M.Sc. student |
| 8. | Behrang Kushavand | new M. Sc. student |
| 9. | Yupeng Li | new Ph.D. student |
| 10. | Steve Lyster | Ph.D. student |
| 11. | David Machuca | Ph.D. student |
| 12. | John Manchuk | Ph.D. student |
| 13. | Mike Munroe | M.Sc. Student |
| 14. | Eric Niven | new Ph.D. Student |
| 15. | Tong Wang | new M.Sc. Student |
| 16. | Brandon Wilde | Research Intern |

Many others have contributed to this report: (1) contacts from member companies, (2) CCG alumni, and (3) affiliated students from different research groups.