

## Keynote Address: A tribute to Prof. D.G. Krige for his contributions over a period of more than half a century

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Born in Bothaville (OFS) on the 26th August 1919, Daniel G. Krige grew up in Krugersdorp on the West Rand. He matriculated from Monument High School in Krugersdorp in 1934 at the age of 15 and graduated with a B.Sc. (Eng.) degree in mining engineering from the University of the Witwatersrand at the end of 1938 (age 19). In 1938 he joined Anglo Transvaal where he worked on a number of gold mines until 1943, gaining a wide range of valuable practical experience in surveying, sampling and ore valuation. He then joined the Government Mining Engineer's Department where he worked for 8 years during which time he participated in the uranium negotiations with the British and American authorities and designed the uranium pricing formula for the contracts which led to the establishment of South Africa's profitable uranium industry in the early 1950s.

During the same period he began his pioneering work in the application of mathematical statistics to the valuation of new gold mines using a limited number of boreholes and of ore reserves for existing mines. His early papers in the application of mathematical statistics, some republished in French, created world-wide interest that led to the development of the science and concepts that surround the spatial evaluation of mineral resources and reserves known as geostatistics. This technique has contributed to improved ore evaluation techniques as well as the reduction of the financial risks associated with investment in mining enterprises. Furthermore, it led to the recognition of his contributions to the evaluations of mineral deposits through the coining of the term 'kriging' that is used to describe a spatial mineral evaluation process known and practised in international mining circles. He continued his work in geostatistics throughout his career as Group Financial Engineer of the Anglovaal Group until his retirement in 1981 and afterwards for ten years as Professor of Mineral Economics at the Witwatersrand University. He is still active as a consultant and is a registered Professional Engineer.

He has published some 90 technical papers both locally and overseas, some in Russia, and has lectured and participated in international congresses in many countries. His contributions were recognized by the Witwatersrand University through the award of the D.Sc. (Eng.) degree in 1963, by three honorary degrees (from the universities of Pretoria, UNISA and Moscow State Mining University), by many awards from the South African Institute of Mining and Metallurgy, the International Association for Mathematical Geology, Die Suid Afrikaanse Akademie vir

Wetenskap en Kuns, the SME of the American Institute of Mining Engineers, the International APCOM Council in 1999, the University of Antofagasta in Chile, and by the South African President (Order for Meritorious Service, Class 1, Gold).

He has served on various Government committees, notably that for State Aid for gold mines (1967/8) and designed the State Aid formula which enabled many mines to survive a period of low gold prices; also various taxation committees, and the mining mission to Iran in 1974. He is a fellow and/or honorary life member of various technical societies locally and overseas, including the Royal Society of South Africa.

During the period in the Government service he also handled several of the post-war lease applications in the Free State and Klerksdorp goldfields. The fact that decisions on new gold mines of critical importance to the State and the economy as a whole, were being taken on a limited number of drillholes without any scientific analysis of the risks of failure, stimulated him to start basic research into ore evaluation. His approach was based on the application of Mathematical Statistics to these problems, an approach of which very little was known world-wide at that stage but which had already been initiated in South Africa by Sichel via the lognormal frequency distribution model. In Krige's 1951 paper published in the Journal of the Chemical, Metallurgical and Mining Society of South Africa he covered the statistical explanation of the conditional biases in ore block valuations and stimulated the use by several gold mines of regression corrections for routine ore reserve valuations, a technique which, in effect, was the first use on an elementary basis of what is now known as kriging. His 1952 paper introduced, *inter alia* the basic geostatistical concepts of 'support', 'spatial structure', 'selective mining units' and 'grade-tonnage curves'.

His 1951 paper was based on his M.Sc. (Eng.) thesis submitted in the Department of Mining Engineering to the University of the Witwatersrand, and expounded his pioneering work in geostatistics in more detail. His early research papers that had stimulated interest in several mining circles overseas, were republished in French in 1955, resulting in a major research effort by French mining engineers in this field. This, in turn, led to the establishment of the now world-renowned French school of ore evaluation in Fontainebleau, Le Centre de Geostatistique de l'Ecole des Mines de Paris.

As the Group's Financial Engineer at the Anglovaal Head Office until his retirement in 1981, he was responsible for

the Group's ore evaluation, mine surveying, financial analyses of mining projects and negotiations, share valuations and technical computing facilities. During the early 1960s he implemented geostatistical kriging procedures on the two large gold mines of the Group. This was the first routine application of the kriging of ore reserves in the world on a routine basis. His research especially in the field of practical applications to ore evaluation, continued unabated as evidenced by some 90 world-wide publications to date. His publications and work in this field led directly or contributed largely to the following.

- He is known and recognized world-wide in mining circles as the principal pioneer in modern statistical methods of ore evaluation, or geostatistics as it is now called.
  - Since the early 1960s, his surname has been used to describe the geostatistical techniques of 'kriging'. These techniques are now applied world-wide mainly in the fields of exploration and ore evaluation, but have also extended into the environmental, petroleum, hydrology, agriculture and other disciplines.
  - The teaching of geostatistics in graduate and post-graduate mining engineering and other courses is now established at universities world-wide.
  - The D.Sc. (Eng.) degree was awarded to him by the University of the Witwatersrand in 1963 and the D.Ing. (H.C) degree in 1981 by the University of Pretoria. He received a further honorary doctorate from the University of South Africa in April 1996 and a third honorary doctorate from the Moscow State Mining University in September 1997.
  - He has received many merit awards from the S.A. Institute of Mining and Metallurgy including two gold medals in 1966 and 1980 and two silver medals in 1979 and 1993. In 1984 he received this Institute's highest award, i.e. the Brigadier Stokes platinum medal. He was awarded the William Krumbein medal from the International Association of Mathematical Geology in 1984, the Gold Medal for Scientific and Technical Achievements from the S.A. Akademie vir Wetenskap en Kuns in 1982, the Distinguished Achievement Award from the APCOM International Council in 1989 and in the same year the Percy Fox Foundation Award in South Africa. In 1987 he received from the American Society of Mining Engineers one of its highest awards, i.e. the Daniel Jackling Award and in 1988 he was made a 'Distinguished Member'; in both cases the first and only South African to receive these honours. In 1992 the University of Antofagasta in Chile also honoured him with a special award.
- The South African State President awarded him with the Order for Meritorious Service Class 1, Gold in 1989. In 1998 The Royal Society of South Africa awarded him the John F. Herschel Medal for outstanding contributions to science in South Africa.
- The publication of several of his papers in French and Russian; also the publication in 1978 of the first Monograph (Geostatistics) in the monograph series of the S.A. Institute of Mining and Metallurgy.

He has presented courses in geostatistics and/or lectured at local universities (Witwatersrand, Pretoria, UNISA, RAU

and Rhodes) and overseas (Australia, Germany, Greece, Taiwan, Chile, Russia and China). He has participated in or contributed to many international mining congresses in South Africa, the U.S.A., Canada, Germany, Spain, Italy, Chile, Colombia, Slovenia, Australia, the United Kingdom, Russia, France and China; in several cases as the keynote speaker. He was South Africa's representative on the International APCOM Council since its inception until recently and initiated the arrangements for that Symposium to be held in South Africa in 1972, again in 1987, and assisted in the preparation of this Symposium in Cape Town. He served as Chairman of the International APCOM Council, the first non-USA member to be elected to this position, from 1990 to 1993.

Apart from ore valuation, his career also led to significant contributions in the fields of investment and financial analysis and mining taxation. This is evidenced by his contributions to the original South African uranium contracts and by a substantial number of local and overseas publications in his field. These include the publication in 1955 in Afrikaans of what was probably the first, or one of the first, papers locally and overseas on risk analysis for new mining investments.

In this same field he served on the sub-committee of the Prime Minister's Economic Advisory Council which investigated State Aid for marginal gold mines in 1967/8. He designed the State Aid formula which was enacted in 1968 and which assisted a large number of gold mines to survive the period of low gold prices. This scheme was a significant contribution to the stabilization and growth of the gold mining industry and the economy as a whole during a difficult period. He also served for many years on various committees of the Chamber of Mines. In 1974, he was a Chamber-nominated member of the joint Government-Chamber mining mission to Iran which investigated aspects of a closer co-operation with Iran on mining matters. More recently, he served as a member of the Marais Committee on mining taxation and on the Melamet Commission of Enquiry into further State aid for the E.R.P.M. gold mine; he was also an observer on behalf of the State on this mine's Management Committee and Board of Directors until early 1994.

He is a Professional Engineer and served for many years on the mining committee of the Engineering Council of South Africa. He served, for an extensive period, as honorary treasurer on the Council of the S.A. Institute of Mining and Metallurgy and is now an honorary life member. He is also a mining engineering member of the Income Tax Special Court, a founder-member of the International Association for Mathematical Geology and of the Geostatistical Association of Southern Africa, a founder-member and honorary life Fellow of the S.A. Statistical Association, an honorary life member of the Institute of Mine Surveyors of South Africa and a Fellow of the Royal Society of South Africa. He also served as a director of several mining companies for extended periods as well as the South African Development Trust, the Lebowa Development Corporation and the Lebowa Mineral Trust, Lebowa being part of the present Limpopo province.

On retirement from the mining industry in 1981, he was appointed Professor of Mineral Economics in the Mining Engineering Department of the University of the Witwatersrand and occupied this chair until 1991. He was

responsible mainly for postgraduate courses in geostatistics and mining economics and supervised many masters and doctoral theses. After retirement from the university he has continued his research, lecturing and publication activities and is still active as a consultant in the valuation of resources and reserves of mineral deposits and financial analysis for several of the Mining Houses and various local and international mining and consultant companies. He has also been a member of the SAMREC Working Committee which developed the South African Code for reporting of Mineral Resources and Reserves as published in 2000.

Some 70 selected publications and a complete record of all the publications by Danie Krige have been cut onto a CD disc that is available at this Symposium. The selected papers are presented under the following headings:

- Original basic concepts and developments
- Routine block kriging on mines
- Geostatistical techniques, Simple kriging vs. Ordinary kriging, Conditional biases
- Bayesian approach

- Valuation of new mines from drillholes
- Reference works
- Reviews
- Economic and Financial.

The outstanding feature of Danie Krige's contributions has been his focus on, and dedication to the basic tenets of geostatistics and the use, wherever practical, of large databases to undertake practical follow-up studies. This style of approach to statistical and geostatistical research became apparent in his initial 1950/2 work and has consistently underpinned his research. His rigorous practice of verifying new geostatistical techniques using large data sets, allowed him to test and audit their applicability and interrogate alternative approaches. His high standards of research have contributed significantly to the advancement of the science of geostatistics and provided many fruitful avenues for future research. His contributions are a tribute to his lifetime of dedication making him a worthy leader and example for all who practice and research in the field of geostatistics.

