

IN MEMORIAM

Professor D.G. Krige FRSSAf

R.C.A. Minnitt^{1*} & W. Assibey-Bonsu²

¹School of Mining Engineering, University of the Witwatersrand, South Africa

²Group Consultant, Geostatistics and Evaluation, Gold Fields Limited, Perth, Australia

*Author for correspondence email: Richard.Minnitt@wits.ac.za

Daniel Gerhardus ("Danie") Krige, whose name is world-renowned in the field of mineral resource estimation and evaluation, passed away peacefully on Sunday morning, 23 March 2013; he was 93 years old. The funeral at Constantia Kloof Dutch Reformed Church on 28 March was attended by more than 200 family members, friends and colleagues from industry and universities, with eulogies by Oscar Steffen, Richard Minnitt and Winfred Assibey-Bonsu. Such was the renown of Daniel Krige that his death is recorded together with that of Margaret Thatcher in Wikipedia (Deaths in April, 2013).

Born in Bothaville, Free State, on the 26 August 1919, Daniel G. Krige grew up in Krugersdorp, matriculating from Monument High School in Krugersdorp in 1934 at the age of 15. He graduated with a BSc(Eng) degree in mining engineering from the University of the Witwatersrand at the end of 1938 (aged 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 eight years before returning to industry as Group Financial Engineer of the Anglovaal Group. He held this post until 1981, after which he spent 10 years as Professor of Mineral Economics at the Witwatersrand University. He remained a registered Professional Engineer although his activity as a consultant naturally diminished.



Danie Krige learning the trade, 1939.

HONOURS AND AWARDS

His contributions were recognised by the Witwatersrand University through the award of the DSc(Eng) degree in 1963 and a DIng(HC) degree in 1981 by the University of Pretoria. He received further honorary doctorates from the University of South Africa in April 1996 and from the Moscow State Mining University in September 1997. He received many merit awards from the SA 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 the Institute's highest award, 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 Suid Afrikaanse 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, the Daniel Jackling Award, and in 1988 he was made a 'Distinguished Member'; in both cases he was the first, and to date, the 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.

In February 2010 his distinguished contributions to engineering were acknowledged by the United States National Academy of Engineering (NAE) and he was elected a Foreign Associate, Section 11, Earth Resources engineering. Danie was the first South African to ever receive this award from the NAE. In December 2010 he received an Honorary Doctorate from the University of the Witwatersrand, and in 2011 he was awarded the Order of the Baobab (Kremetart Silver), by President Jacob Zuma.

CAREER ACCOMPLISHMENTS

During his period in government service Danie Krige 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 worldwide at that stage but which had already

been initiated in South Africa by Herbert 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. This paper introduced, inter alia, the basic geostatistical concepts of 'support,' 'spatial structure,' 'selective mining units' and 'grade-tonnage curves.'



Danie Krige with Herbert Sichel.

As the Anglovaal Group's Financial Engineer, 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. Apart from ore evaluation, his career led to significant contributions in the fields of investment and financial analysis and mining taxation. This is evidenced by his contributions to the establishments of 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 one of the first papers on risk analysis for new mining investments.

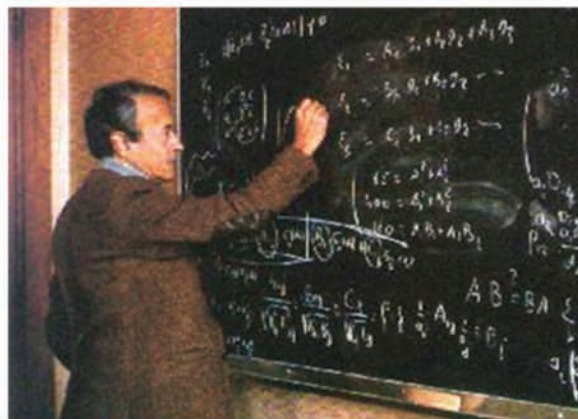
As Professor of Mineral Economics in the Mining Engineering Department of the University of the Witwatersrand he was responsible mainly for postgraduate courses in geostatistics and mining economics and supervised many masters and doctoral theses. After retirement from the university he continued his research, lecturing and publication activities and remained 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 international mining and consulting companies. He presented courses in geostatistics and/or lectured at local universities (Pretoria, UNISA, RAU and Rhodes) and overseas (Australia, Germany, Taiwan, Chile, Russia and China). He has participated in, and contributed to, many international mining congresses in South Africa, the USA, Canada, Germany, Spain,

Chile, Colombia, Slovenia, Australia, the UK, Russia, France and China; in several cases as the keynote speaker.

OUTCOMES

Krige's work led directly, or contributed largely, to the following:

1. His recognition worldwide in mining circles as the principal pioneer in modern statistical methods of ore evaluation, or geostatistics as it is now called.
2. Since the early 1960s his surname has been used to describe the geostatistical techniques of 'kriging.' The term was coined by Georges Matheron and is now applied worldwide mainly in the fields of exploration and ore evaluation, but the environmental, petroleum, hydrology, agriculture and other disciplines.
3. The teaching of geostatistics in graduate and postgraduate mining engineering and other courses at universities worldwide.
4. The establishment of the now world-renowned French school of ore evaluation in Fontainebleau, Le Centre de Géostatistique de l'Ecole des Mines de Paris.



Professor Georges Matheron.

PUBLICATIONS

Danie Krige published some 90 technical papers both locally and overseas, including Russia. 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. A 1951 paper, based on his MSc(Eng.) thesis submitted to the Department of Mining Engineering to the University of the Witwatersrand, expounded his pioneering work in geostatistics in more detail. His 1978 publication was the first Monograph (Geostatistics) in the monograph series of the SA Institute of Mining and Metallurgy.

A complete record of all Krige's publications is available on a CD disc from the SA Institute of Mining and Metallurgy. They are presented under the following headings:

1. Original basic concepts and developments
2. Routine block kriging on mines
3. Geostatistical techniques, Simple kriging versus Ordinary kriging, Conditional biases
4. Bayesian approach
5. Valuation of new mines from drillholes
6. Reference works
7. Reviews
8. Economic and Financial.

OTHER PROFESSIONAL CONTRIBUTIONS

As a Professional Engineer, Danie Krige served for many years on the mining committee of the Engineering Council of South Africa. For an extensive period he was honorary treasurer on the Council of the SA Institute of Mining and Metallurgy and became an honorary life member. He was 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 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, as well as for the South African Development Trust, the Lebowa Development Corporation, and the Lebowa Mineral Trust.

Danie 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 assisted a large number of gold mines to survive the period of low gold prices. This scheme significantly contributed to the stabilisation and growth of the gold mining industry and the economy as a whole during a difficult time. He also served for many years on various committees of the Chamber of Mines. In 1974 he was a Chamber-nominated member of the Government-Chamber mining mission to Iran which investigated aspects of a closer co-operation 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 ERPM gold mine; he was also an observer for the State on this mine's Management Committee and Board of Directors until early 1994. He was also a member of the SAMREC Working Committee which developed the South African Code for reporting of Mineral Resources and Reserves as published in 2000.

He was South Africa's representative on the International APCOM Council from its inception and initiated the arrangements for the Symposia held in South Africa in 1972 and in 1987, and he assisted in the preparation of this Symposium in Cape Town in 2003. He served as Chairman of the International Council, the first non-USA member to be elected to this position, from 1990 to 1993.

The outstanding feature of Danie Krige's contributions was 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 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 contributed significantly to the advancement of the science of geostatistics and provided many fruitful avenues for future research. His lasting contributions are a tribute to a lifetime of dedication and he was a worthy leader and an example to all who practice and research in the field of geostatistics.

DANIE KRIGE'S ACKNOWLEDGEMENT OF THE GRACE GIVEN TO HIM

Thoughts from an interview he gave to Richard Minnitt during 2012

With his weight of achievement and a life of distinguished contributions to science and engineering behind him, Professor

Danie Krige was a devout Christian who also recognised and acknowledged that he had been the recipient of gifts of grace from the Creator. He drew attention to six specific areas in which he could identify the grace of the Almighty at work in his life and career. The first was a tribute to his parents for the practical application of a godly lifestyle, the establishment of a firm foundation, and a life philosophy that was modelled by them in every area of life. An example of this was that even with the limited resources of a pastor, his parents saw to it that seven of the nine siblings received a tertiary education.

The second of the gifts of grace that Danie acknowledged was the support he had received from his two spouses. He was happily married for 45 years to his first wife (until her death), and for 20 years to Ansie, his second wife.

The third gift of grace was the way in which his career developed, and the various turns in direction that it took as his research unfolded. Having graduated from Wits he was employed in the sampling and survey departments of the Anglovaal Group. In the interview Danie stated that the most important event of his career occurred when an extensive prospecting programme of deep drilling was launched to determine the extent and value of the extensions of the Witwatersrand gold deposits westwards to Klerksdorp and the Orange Free State. Mining companies involved in exploration applied to the Government Mining Engineer for mining leases which led to the opening up of the new goldfields. The GME enrolled additional Mining Engineers to handle this work and he was one of the lucky ones to be chosen. Danie was involved full time in collecting, analysing, and using statistical modelling of the data to determine the underlying patterns of the gold distribution in the widening fields. These patterns proved to be adaptable to modern statistical programmes and these were in turn developed to yield improved grade estimation procedures. This work was successfully submitted for a Master's thesis at the University of the Witwatersrand and a technical paper that was published here and overseas, raised interest. A French team under Professor Georges Matheron in Paris translated the publication and republished it in French. Professor Matheron insisted for the worldwide acceptance of the term KRIGING for this new valuation method, a term for a practice that is now accepted internationally.



Danie and Ansie at Danie's 90th birthday party.

The fourth gift of grace was that when Danie returned to work at Anglovaal, they began to apply these advanced methods of valuation on their mines. Comparisons with later

follow-up values demonstrated the advantages of the new methods. Following the clear demonstration of the validity of the new methods, Anglovaal fully supported the application of Danie's methods on their mines, as well as the publication of these findings, both locally and internationally, particularly at international conferences. In addition, Wits University awarded Danie a DSc(Eng) degree in recognition of this work. This led to the award of two Honorary Doctorate degrees in South Africa, from the University of Pretoria and the University of South Africa (UNISA), and a third from the Moscow State University, in addition to numerous other awards both locally and overseas.

The fifth gift of grace Danie acknowledged was that on retirement from Anglovaal at the age of 60, he accepted the

unexpected opportunity of taking up the chair of Professor of Mine Economics at Wits University, which he occupied for the next 10 years. This enabled him to teach and undertake extensive consulting work for mining companies both locally and internationally, and was, in his opinion, a great blessing.

The final gift of grace that Danie recognised was that after his retirement from Wits University he was able to undertake extensive national and international consulting work which he believed kept him occupied and young for the following 20 years. Danie also acknowledged, with deep gratitude, that while the opportunities presented themselves to him, his was the responsibility to make good use of them, and that without these gifts of grace his life's work would not have been possible.

Acknowledgement

This paper which was first published in August 2013 is republished with the permission of the Royal Society of South Africa, <http://dx.doi.org/10.1080/0035919X.2013.826748>.