Chapter 8

Conclusions

Acknowledgement of Contributions

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8.1 Summary of the thesis conclusions

A summary of the conclusions is presented for each chapter of the thesis that concerned the three geological studies presented. The general research question and main purpose of the thesis, was an evaluation of how modern computational techniques and quantitative geology can substantially improve our understanding of a geological system. The thesis results have confirmed the benefit obtained by utilisation of modern computational tools in solving classical geological problems. WofE Modeller, GoCAD and FLAC have extended my interpretation of the various features and geological patterns observed leading to better, multi-scale classification. This has been demonstrated by the following results concerning the predictive modelling undertaken in (Chapter 3): (1) Favourability KD models produced for SEDEX mineralisation and VS ores suggests that most of the known mineral deposits and prospects occur in areas that are more favourable to the formation of SEDEX style ore; (2) KD models indicate favourable stratigraphic intervals based upon expert driven scores assigned; (3) the DD-modelling showed that fault intersections appear to be more favourable sites for the deposition of Pb-Zn mineralisation of any style. However, fault intersections were also among the most troubling patterns when assessing conditional independence; (4) the data driven model suggests that new Pb-Zn prospects may be localised in proximity of the Termite Range Fault; (5) moreover the DD model indicates new areas that were not previously considered prospective (e.g. north of the Edith cluster and in the northern part of the Kamarga Dome area); (6) the integration of KD-models with DD-models allowed definition of degree of favourability for SEDEX and VS mineralisation in areas proximal to the Termite Range Fault. Potential for SEDEX has been outlined by the favourability map north of the Edith cluster of vein style deposits/prospects.

Favourability and probabilistic models offer the advantage of integrating the information and synthesising it in map format to facilitate exploration. Favourability KD models can be also used to assess the relationship between characters typical of certain styles of mineralisation and their relative association to known mineral occurrences.

In Chapters 4 and 5, the problem of ore genesis at Century was investigated and tested using 3D geometrical and 2D numerical techniques providing insights on how the ore deposit might have been evolving in time. Results from structural modelling developed at camp- to deposit-scale have outlined the possible interaction between regional structures and local structures modelled inside the mineral deposit. This suggests that some of the regional vein style mineralisation may have been the product of remobilisation of metals. This may explain the relatively high tonnage observed at Silver King (proximal to Century) compared to other lodes that could be linked to regional scale redistribution of base metals from Century. However, this could not be proved. Locally (at the deposit-scale) internal faults were classified broadly in three sets NE to ENE, NW and E-W. NE and ENE faults were possibly active since early stages of deposition according to the thickening observed form reconstructed isopach-maps. Regional scale thickening interpreted from seismic profiles north of Century in the

Elizabeth Creek Fault Zone is consistent with the role of ENE faults as growth faults that controlled sedimentary patterns in the Lawn Hill Region.

Two dimensional fluid flow modelling indicated that local extension may allow lateral infiltration of fluids. However, the models encountered significant problems after several steps of extensional deformation due to the limitation of the Mohr-Coulomb constitutive model in the simulation of relatively unconsolidated materials (e.g. unlithified argillaceous sediments). On the other hand, the models run for the compressional scenario (Broadbent, 1999) have clearly illustrated how fluid flow tends to be focused in more permeable domains – the faults, and is distributed vertically rather than the horizontal, lateral flow required for the replacement model. This led to the conclusion that a replacement model could not readily be applied to the Century case, at least during compression.

Results from Chapter 5 represent an extension of the results obtained in Chapter 4. In Chapter 5 all datasets become fully three-dimensional both in the structural property model and also in the numerical simulations. From the analysis of 2D projection maps of grade and thickness variability we step into a multi-layer model coupled with a 3D deformed S-grid that was used as a base for DSI 3D interpolation of mineral grades. A better understanding of how remobilisation could work after lithification of relatively impermeable layers lead to the following interpretations: (1) the deposit was locally influenced by later hydrothermal fluids that (re)mobilised Pb-Zn ores at least at the metre scale along some fault/fractured domains; however, the extent of remobilisation processes is difficult to ascertain for the larger scale; (2) the deposit zoning varies depending upon the scale of observation considered. At small scale below a diameter of 100 m there is a rapid variation of mineral grades (either sharp increase or decrease of mineral grades depending upon the stratigraphic interval and base metal pattern considered). In particular, across adjacent horizons the vertical correlation of depletion and enrichment in shale/siltstone layers of Pb-Zn ore supports the role of faults as (re)mobilising agents; (3) (re)mobilisation therefore was interpreted as a restricted process - permeability driven, and also a function of the hydraulic gradients established between the bedded sulphides, the feeder/fault zone and other barren, and ideally more permeable horizons, within the mineral deposit; (4) If the (re)mobilisation is governed by permeability patterns, then when the permeability structure changes during basin evolution also (re)mobilisation would change accordingly; (5) moreover, base metals would be more likely remobilised early when the host rock is not yet lithified, because permeability is higher; (6) this consideration also provided a model for the different zoning observed. The broad zoning of Pb-Zn-Mn, which is a typical character of SEDEX deposits, more likely would form during early stages and therefore can be considered of an exhalative nature; (7) In a later stage after compartmentalisation the permeability structure of a mineral deposit is better defined and therefore any modification is confined to areas that have sufficient permeability to allow fluid percolation and therefore facilitate fluid assisted chemical (re)mobilisation. Also mechanical remobilisation is a possible alternative although limited in scale and to softer sulphides, such as galena; (8) on the basis of all considerations made I concluded that Century is more likely an exhalative system. However, the mineral deposit may have experienced additional input of base metals, for example during inversion or when later vein style ore was emplaced. Although the veins themselves may represent a remobilised product of early synsedimentary stockworks, Pb-Pb ages on galena support a model in which at least some additional Pb was introduced well after diagenesis and lithification of the host.

3D FLAC models displayed negligible variations in the pore pressure distributions if compared with 2D models, confirming the results obtained in the initial simulations. 3D numerical modelling results showed that fluid flow could not laterally move through the shale intervals, unless significant secondary permeability enhancement (developed by hydro-fracturing) would allow these units to reach the same order of magnitude of permeability assigned to the faults – a case not observed in the available exposures of the mineral deposit, which displays scarce abundance of mineralised veins. When shortening is applied to the models, also relatively impermeable units (shales), tend to become overpressured causing expulsion of fluids, which might explain the presence of localised sub-vertical cracks sealed by sulphide and carbonate/quartz precipitates. Numerical models were integrated with the results obtained from the 3D geometrical and property modelling to illustrate also that fluid flow changes accordingly to the permeability structure evolution.

In Chapter 6 a third geological problem concerning the timing and genesis of the Lawn Hill Megabreccia was addressed. The observations collected in the field coupled with spatial analysis led to the following conclusions. The timing of the Lawn Hill Megabreccia is constrained to be synchronous with the depositional age of the

Thorntonia Limestone. The structural features (slumps, truncated folds etc.) coupled with the paragenetic study of the distribution of flow breccia dikes (CBX) paragenetic relationships with the flow breccia (MB), and isotopic data, support a model in which the source of the breccias were originally part of the sedimentary sequence and were subsequently reworked and redeposited or injected in reactivated faults. These processes may be explained easily by simple gravity driven failure of the platform, assisted by tectonic destabilisation of the margin, in the eastern part of the Georgina Basin. However, a sub-marine meteoritic impact is also a plausible alternative. (4) The integration of qualitative and computational/quantitative models provides invaluable feedback regarding validation of modelling results. In other words, the two approaches should be combined to avoid oversimplification and misinterpretations.

In Chapter 7 we considered the complexity of a geological system from an alternative perspective: fractals and self-organisation are viable non-linear models of geological complexity. The chapter reflects a purely theoretical approach to geological complexity. Complex systems or chaotic systems can ideally be reduced to simple laws repeated in time and space (e.g. fractals, attractors). I concluded the thesis suggesting future directions using these approaches, which hitherto have not been applied by geologists because of the high-level mathematical background required. However, new software tools such as Matlab can substantially assist in the usage of non-linear approaches such as Neural-Net learning and classification of geological complexity. The advantage of these techniques is essentially their capability of exploring the deterministic component of a chaotic system. To conclude, these methods may provide better prediction in mineral potential mapping and also help understanding ore genesis, and other complex geological scenarios such as the Lawn Hill Megabreccia.

8.2 General concluding remarks

A general conclusion can be made concerning computational modelling and quantitative geology. They certainly extend our capability of analysis, however I believe that understanding of geological objects is still largely based on the geologist's intuitions. Models must be then validated using either additional quantitative methodologies, but also integrating geological observations.