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Contact Profile Analysis of Resource Estimation Domains: A Case Study on a Laterite Nickel Deposit †

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Abstract: Resource estimation is commonly performed in separate domains that are defined using different criteria depending on the type and geometry of the deposit, the mining method used, and the estimation method applied. The validity of estimation domains can be critical to the quality of produced resource estimates as they control various steps of the estimation process, including sample and block selection. Estimation domains also affect statistical and geostatistical analyses because they define what estimation practitioners will consider as statistically separate distributions of data. Sometimes, samples from different estimation domains share similar grade properties close to the contact between domains, a situation known as a soft boundary. In such cases, it can be useful to include samples from different domains at short distances from the boundary. Contact profile analysis is a technique that allows for the measurement of the relationship between grades on either side of the contact between two estimation domains. As discussed in the study presented in this paper, contact profile analysis can help validate the defined estimation domains and control the application depth of any soft boundaries found between domains.

Keywords: contact profile analysis; soft boundaries; estimation domains; resource estimation; geostatistics

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1. Introduction

The resource estimation of mineral deposits is based on three-dimensional models of geology, the success of which depends on the quality of the used relational database. The estimation approach is always stepwise and can be based on the explicit or implicit modelling of geology. Regardless of the method used to produce it, the geological model to a large extent controls the quantities reported as resources and reserves, as it will define the volumes that are considered to potentially host ore and are thus estimated using a geomathematical method such as ordinary kriging. In certain deposits, ore can exist across multiple zones or domains of lithological or grade-controlled character, and in some cases, these domains can be in contact with each other and not separated by totally sterile material. Identifying these domains and modelling their boundaries is a time-consuming process, and the estimation practitioner needs to be able to validate them before moving on to their estimation.

The modelling of multi-domain deposits and the analysis of the statistical and geostatistical behaviour of samples across domain boundaries has been the subject of extensive research in the past [1–5]. The contact profile analysis (CPA) technique, discussed in this paper, is a useful tool for investigating the behaviour of the transition from one geological unit to another and can be used to improve the use of samples from neighbouring units to estimate the grades of a given geological unit. Allowing for the exchange of samples between neighbouring domains when supported by CPA can help increase the confidence of estimates near their boundaries, improve resource classification, and guarantee the smoother transition of estimated grades across their boundaries.

2. Geological Background

The nickeliferous mineralization in Greece is related to the geotectonic zones of Almopia, Pelagonian, and Sub-Pelagonian—the main metalliferous regions are situated in Locris, Euboea, and Kastoria. In Central Euboea—the location of the Tsouka laterite nickel deposit of our study (Figure 1)— sedimentary iron and nickel ores of the Cretaceous age occur, consist of stratified lenses and layers, are overlain by Upper Cretaceous limestones, and are underlain by ophiolites (and in exceptional cases by Jurassic limestones). The mineralization is either pisolitic or compact with silcretes developed within the ore, the development of lenticular intercalations or siliceous layers is also common, and silcretes are also found in the bedrock. Many significant deposits exist in the Psachnon area, the Akres, Katsikiza, and Isomata, as well as the Katavolo-Fterada in Kimi's area [6].

Figure 1. Location of the Tsouka deposit in central Greece.

In the area of Agios Ioannis, there are large laterite deposits developed and mined by LARCO GMMSA that belong to the Sub-Pelagonian zone. The Tsouka Ni-laterite deposit is characterized by a 1 m thick saprolite zone and then a 4 m thick pelitic–pisolitic horizon, the upper part of which comprises transported material. Lower Cretaceous limestone layers alternating with Ni-laterite ore conformably overlie the mineralized horizon [6–11]. The mining of the Tsouka deposit started before WWI using an underground room and pillar process. LARCO began the surface mining of the deposit in the 1990s.

The resource estimation procedure applied to all Fe–Ni deposits of LARCO was described by Kapageridis et al. [12]. The modelling and estimation of the Tsouka deposit was based on a dataset consisting of 218 drillholes that provided a total of 12,473 one-metre composite samples (Figure 2). Samples were assigned to different domains based on lithology and Fe–Ni grades. The boundaries between domains were modelled using a mostly stratigraphic approach and were used to flag blocks in the model before resource estimation. Figure 3 shows a typical section of the deposit and the relative location of the estimation domains.

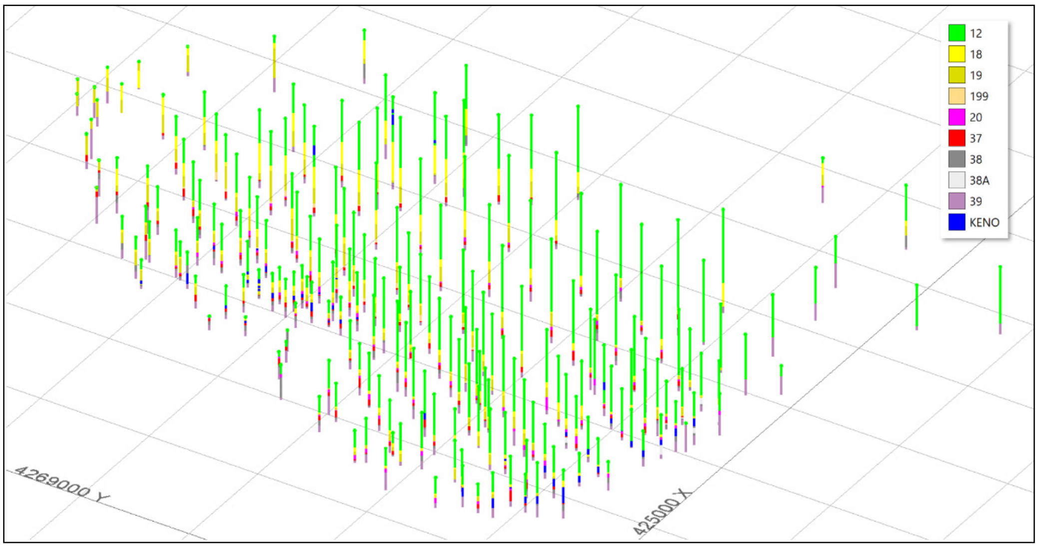

Figure 2. Drillholes from the Tsouka deposit coloured by domains with a 100 × 100 m grid overlay.

The following domains were identified and modelled in the Tsouka deposit according to the domain naming system used by LARCO:

- 12 (Roof): overburden—limestone.
- 18: conglomerate.
- 19: poor clay horizon.
- 199: poor mineralisation with slightly higher Fe concentration than 19.
- 20: poor mineralisation with high Fe content.
- 37 (Ore): main mineralisation.
- 38: red ophiolite with some rich spots.
- 39: green ophiolite (bedrock).
- KENO (Void): old underground workings (room and pillar).

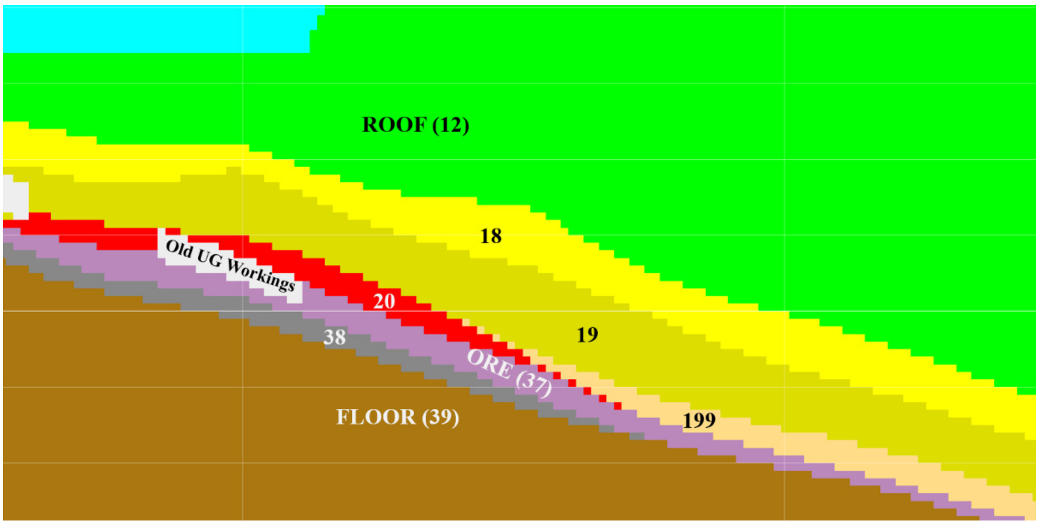

Figure 3. Cross section of Tsouka block model colour-coded using modelled domains.

3. Contact Profile Analysis

The contact profile analysis (CPA) tool, included in Maptek Vulcan™ mine planning software, was used to investigate the relationship between grades when moving from one estimation domain to another to validate the domains and possibly justify and control the use of samples from neighbouring domains during estimation. Samples from each domain were paired with samples from a neighbouring domain based on separation distance. The pairs were constructed over an increasing separation distance. For each separation distance, the average grade of the first domain was plotted against the average grade of the second. Average grades from the first domain were plotted on negative distances so that differences could be observed within the graph (Figure 4). The careful examination of the produced graphs allowed for the determination of the type of boundary (soft or hard) and a safe distance or width in the case of a soft boundary between estimation domains for sharing samples. The different scale of each of the contact profile graphs should be considered when comparing them.

Starting from the top, the contact profile between overburden material (12) and the conglomerate layer (18) was constructed (Figure 4a). The values near the interface between the two domains were considerably different, producing a sudden jump in Ni grade when moving from domains 12 to 18 (more than 0.25% Ni) and a similar change in Fe grade (more than 10% Fe) in less than a meter of distance. This was considered a hard boundary, and no samples from 12 were used to estimate domain 18. The basic sample statistics shown in Tables 1 and 2 (first two rows) also supported the exclusion of any domain 12 samples when estimating domain 18. The clear difference between samples from the two domains near their interface and the produced contact profile graph were considered evidence of the validity of the modelled boundary between them.

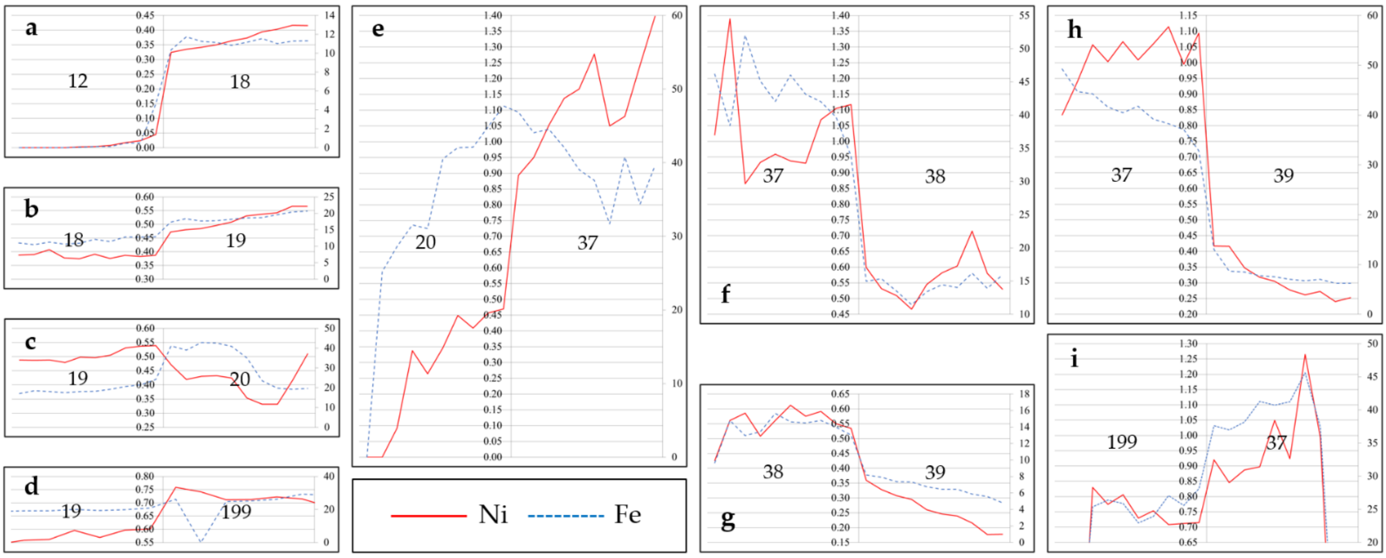

Figure 4. Contact profile graphs between various domains of the Tsouka deposit. The middle vertical axis shows mean Ni% grades of distance intervals on either side of the contact, while the right vertical axis shows corresponding mean Fe% grades. The horizontal axis starts and ends 10 m before and after the boundary between the two domains.

A different contact profile was presented between domains 18 and 19 (Figure 4b). A jump in the Ni grade was still present, but the difference was less than 0.1% in less than a meter of distance. Fe presented similar behaviour across this boundary, so a choice was made to allow for the exchanging of samples between these two domains during the estimation of both Ni and Fe. The contact profile between domains 19 and 20 confirmed the lower Fe content of the first and the higher Fe content of the second. The opposite behaviour was present regarding the Ni grades, with domain 19 having a more constant and overall higher Ni grade than domain 20. As there was a rapid change at the boundary between the two domains in both elements, the boundary was considered valid and no samples were exchanged between the two domains during the estimation of Fe and Ni.

Figure 4d shows that the Ni and Fe grades seemed to be similar either side of the boundary between domains 19 and 199. Unlike the previously seen boundaries, this was considered to be a soft boundary and samples were exchanged between the two domains during estimation up to 6 m from the boundary. The boundary between domains 20 and 37 presented a smooth transition of Fe grades, with a peak at the boundary, while the Ni grades seemed to constantly increase from domains 20 to 37 (Figure 4e). Thus, the contact between these two domains was considered a soft boundary for both Fe and Ni grades, though with different ranges of sample exchange—6 m for Fe and 4 m for Ni. The same consideration was made for the boundaries between domains 199 and 37 shown in Figure 4i.

The contact profile between domains 37 and 38 (Figure 4f) and domains 37 and 39 (Figure 4h) led to the consideration of their boundary as a hard one, and no exchange of samples was allowed during their estimation. The statistics and first interval correlation values for the two domains shown in Tables 1 and 2 also supported this choice, as well as the contact estimation between domains 38 and 39 (Figure 4g).

Table 1. Basic statistics of Ni samples near the interfaces between neighbouring domains and first interval correlation.

Domain	Domain Total Samples Count	Mean of Totals	Domain Intervals Samples Count	Mean of Intervals	First Interval Correlation	Type of Boundary
12 18	7116 1140	0.00 0.38	1727 865	0.01 0.36	0.00	hard
18 19	1140 1436	0.38 0.53	833 1101	0.38 0.52	0.31	soft
19 20	1436 311	0.53 0.41	472 246	0.51 0.43	0.11	hard
19 199	1436 82	0.53 0.73	288 82	0.56 0.73	0.02	soft
20 37	311 455	0.41 1.04	198 269	0.42 1.07	0.03	soft
37 38	455 376	1.04 0.56	296 230	1.04 0.54	0.08	hard
37 39	455 1323	1.04 0.28	437 587	1.04 0.30	0.03	hard
199 37	82 455	0.73 1.04	72 92	0.73 0.95	0.00	soft

Table 2. Basic statistics of Fe samples near the interfaces between neighbouring domains and first interval correlation.

Domain	Domain Total Samples Count	Mean of Totals	Domain Intervals Samples Count	Mean of Intervals	First Interval Correlation	Type of Boundary
12 18	7116 1140	0.07 11.46	1727 865	0.21 11.26	0.31	hard
18 19	1140 1436	11.46 18.36	833 1101	12.03 18.55	0.43	soft
19 20	1436 311	18.36 36.42	472 246	19.91 39.92	0.07	hard
19 199	1436 82	18.36 25.92	288 82	19.24 25.92	0.06	soft
20 37	312 456	36.42 39.91	200 270	42.64 42.34	0.39	soft

Table 2. *Cont.*

Domain	Domain Total Samples Count	Mean of Totals	Domain Intervals Samples Count	Mean of Intervals	First Interval Correlation	Type of Boundary
37 38	456 376	39.91 13.98	297 230	40.28 13.92	0.13	hard
37 39	456 1323	39.91 6.71	442 581	39.79 7.69	0.03	hard
199 37	82 456	25.92 39.91	72 92	26.12 39.79	0.22	soft

4. Conclusions

Contact profile analysis is a technique that can be used to investigate the relationship between grades on either side of the boundaries between neighbouring domains. The results of CPA were used to increase confidence in the estimation of boundaries themselves and how efficiently they separate sample distributions, choose the type of the boundary (soft or hard), and control the depth of sample exchange between domains considered to have soft boundaries, thus leading to improvements of the resource category of estimates close to these boundaries with the inclusion of samples from neighbouring domains. Overall, the study presented in this paper demonstrates the practice and benefits of CPA when applied to a laterite Fe–Ni deposit consisting of multiple domains.

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