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Chatham Rise nodular phosphate — Modelling the prospectivity of a lag deposit (off-shore New Zealand): A critical tool for use in resource development and deep sea mining

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ABSTRACT

After almost five decades of episodic exploration, feasibility studies are now being completed to mine the deep-water nodular phosphate deposit on the central Chatham Rise. Weights of evidence (WofE) and fuzzy logic prospectivity models have been used in these studies to help in mapping of the exploration and resource potential, to constrain resource estimation, to aid with geotechnical engineering and mine planning studies and to provide background geological data for the environmental consent process. Prospectivity modelling was carried out in two stages using weights of evidence and fuzzy logic techniques. A WofE prospectivity model covering the area of best data coverage was initially developed to define the geological and environmental variables that control the distribution of phosphate on the Chatham Rise and map areas where mineralised nodules are most likely to be present. The post-probability results from this model, in conjunction with unique conditions and confidence maps, were used to guide environmental modelling for setting aside protected zones, and also to assist with mine planning and future exploration planning. A regional scale fuzzy logic model was developed guided by the results of the spatial analysis of the WofE model, elucidating where future exploration should be targeted to give the best chance of success in expanding the known resource. The development work to date on the Chatham Rise for nodular phosphate mineralisation is an innovative example of how spatial data modelling techniques can be used not only at the exploration stage, but also to constrain resource estimation and aid with environmental studies, thereby greatly reducing development costs, improving the economics of mine planning and reducing the environmental impact of the project.

1. Introduction

The New Zealand agricultural sector relies heavily on imported rock phosphate-based fertilizer for farming efficiency, resulting in an opportunity for the production of locally based sources of phosphate. Sources of rock phosphate in the SW Pacific region have been depleted over the last 60 years, leading to rising imports of phosphate from further afield and adding to the urgency of exploring the potential of local sources (Cullen, 1979; Von Rad, 1984).

The only known phosphate mineralisation with economic potential in New Zealand is a limestone gravel lag-based nodular phosphate deposit that is located in open waters at a depth of up to 400 m, more than 400 km offshore off the east coast of the Canterbury region of the South Island (Fig. 1). The phosphate deposit is located on the crest of the Chatham Rise, a structurally simple bathymetric high rising over the Hikurangi Plateau to the north and the Bounty Trough to the south. It has been described as a replacement deposit comprising a mix of Late Oligocene and Late Miocene chalk pebbles and hardground rubble phosphatised in the Late Miocene and subsequently concentrated by erosion and selective removal of non-indurated chalk as the crest of the Rise was karstified (Cullen, 1987; Kudrass and von Rad, 1984).

The Chatham Rise stretches due east from the Banks Peninsula as a single structural entity for over 1000 km. The crest of the central Rise plateaus at 400 m water depth, stepping down to more than 1000 m east of the Chatham Islands (Wood et al., 1989). The slope to the north to the Hikurangi Plateau and Trough has a relatively constant gradient, while the southern slope to the Bounty Trough appears as a series of steps into what may be the failed rift arm of the Bounty Trough (Fig. 1).

The Chatham Rise phosphate deposit has been subject to episodic exploration since its discovery in the 1950s (Reed and Hornibrook, 1952). In the late 1960s Global Marine Inc. spent several weeks dredging on the Chatham Rise (Pasho, 1976), using the results from an initial wide-ranging survey to target a second survey on the area with highest nodule concentrations. The bulk of the exploration took place in the late

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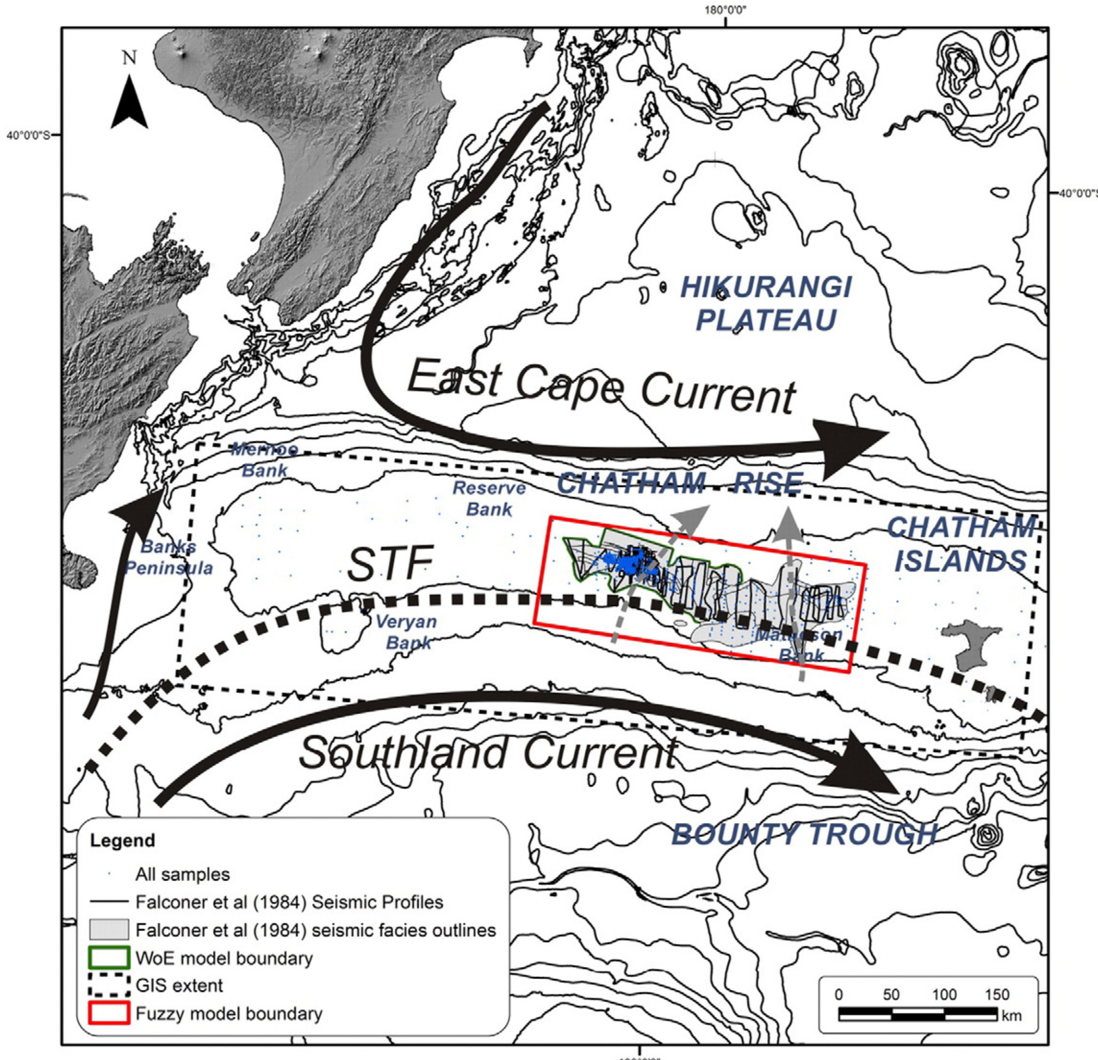

Fig. 1. Chatham Rise overview map, with the Rise and surrounding basins indicated by bathymetric contours and local bathymetric highs indicated by their names. Mainland New Zealand can be seen in the upper left corner. STF = Subtropical Front (simplified from Hayward et al., 2004). Grey arrows represent potential deepwater flow paths across the crest of the Rise.

1970s and early 1980s by collaborating German and New Zealand scientists onboard the research vessels *Valdivia* (Kudrass and Cullen, 1982) and *Sonne* (von Rad and Kudrass, 1984). The surveys focussed on the areas previously determined to be the most prospective.

Renewed interest by Chatham Rock Phosphate Ltd. in the 2010s led to a series of surveys in 2011/2012, revisiting the areas surveyed by the *Valdivia* and the *Sonne*. Subsequently, prospectivity and resource studies based on new and historical data were undertaken. A 20-year seabed mining permit was granted in the late 2013, and feasibility studies are in the final stages of completion. The aim of these studies is to integrate geological prospectivity with environmental studies and resource assessment, to effectively develop the resource with minimal environmental impact, as well as plan future exploration where it is most likely to increase the current resource and show a positive economic return.

Computer-based geographical information systems (GIS) provide a variety of tools and statistical techniques that allow the mapping of mineral prospectivity to be carried out and combined with environmental and economic risk analysis. Such techniques and tools have been used by the petroleum industry for a number of years, and the mineral exploration industry has taken this further with the help of spatial data modelling using GIS (Bonham-Carter et al., 1989; Carranza, 2014; Deng, 2009; Harris et al., 2001; Lusty et al., 2012; Mejía-Herrera et al., 2014; Partington and Sale, 2004).

A mineral system model adapted for phosphate deposition on the Chatham Rise phosphate has been developed from the mineral system concept normally applied to a range of hydrothermal and magmatic styles of mineralisation (Hronsky and Groves, 2008; Lord et al., 2001; Wyborn et al., 1994). This adapted model has been used to constrain the modelling of the prospectivity of the central Chatham Rise through the development of a range of predictive maps as proxies for the physical and chemical processes that have been combined to form the phosphate mineralisation. While the factors leading to the formation of phosphatised lag gravels are obviously different from those leading to many metallogenic ore deposits, the components of the mineral system model are similar: There need to be a source of phosphate, a means to transport it to the site of deposition, a trap to allow the phosphate rich fluids to replace chalk pebbles and hardground rubble, and means to concentrate and preserve the deposit.

The mineral system approach used with spatial data modelling differs from conventional ore deposit models by focussing on the similarities rather than on differences between deposit-types. Since the mineral system approach is process based, it is not restricted to particular settings or mineral type, and has here been adapted to a mixed sedimentary and chemical process system. When applied to mineral deposits, the mineral system approach requires identification at various scales of the critical deposit-forming processes that can be mapped and that are