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ABSTRACT

Two types of offshore phosphate deposits could conceivably occur in the southwest Pacific: guano-derived deposits and marine phosphorites. Submerged guano deposits may be present in places, as a result of eustatic sea-level rises or vertical tectonics. Any such deposits would most likely be found near to known onshore deposits. Possible locations of offshore phosphorites may be delineated by the use of bathymetric, bio-productivity, phosphate content, ocean current, and water temperature data. The most promising area for phosphorites is the region extending from Nauru to the Line Islands. At this stage, prospecting should be concentrated on seamounts occurring within this region.

INTRODUCTION

The recent rise in the price of Moroccan phosphate rock from \$US 18.50 a tonne to a current price of \$US 75.00 a tonne, makes offshore phosphorites such as those off southern California look economically more attractive at the present time. It is highly unlikely that the present high prices will continue because of the vast onshore deposits in North Africa, North America and Australia. Nevertheless, phosphate-deficient countries are likely to be prepared to pay a significantly higher price than that prevailing up to 12 months ago, in order to secure long-term contracts which will ensure a more certain supply and a stable price. In an economic climate such as this the time is perhaps ripe for focussing our attention on offshore phosphate deposits, and this paper will examine the potential for finding such deposits in southwest Pacific waters (Fig 1).

PHOSPHATE DEPOSITS AND THEIR GENESIS

There are three basic types of phosphate ores, igneous apatite accumulations such as those of southern Africa and the Kola Peninsula (Deans, 1966; 1968), guano-derived deposits, such as those of the southwest Pacific area (White and Warin, 1964), and sedimentary deposits (phosphorites) such as those of North Africa. Phosphorite deposits constitute the bulk of the worlds phosphate reserves but locally, small high grade guano-derived deposits such as those of Nauru (Fig 2), can be extremely important. The igneous apatite bodies will not be considered here, as none are known from the southwest Pacific region and it is highly unlikely that any are present offshore.

The guano-derived deposits may, in some instances, be formed directly from the droppings of birds (or in caves, bats), but the majority are composed of phosphatized coralline material; where phosphatization has resulted from mobilization of phosphate from the primary guano during weathering and leaching. Their formation is discussed in some detail by Hutchinson (1950) and Warin (1968). Such deposits can only form under sub-aerial conditions and therefore at first sight may seem outside the scope of this conference. However, there may conceivably be a number of guano deposits, Pleistocene or older, which are now submerged as a result of eustatic sea-level changes or tectonics. Their additional importance to this study lies in their value as indicators of nutrient-rich waters.

Pelletal and nodular phosphorites are almost invariably marine deposits. They are widespread and range in age from Precambrian to Recent. Offshore phosphorites have been reported from the continental shelves in various regions: those of southern and south-western Africa, the southeastern and western United States, the west coast of South America, and the east coasts of New Zealand and Australia are amongst the best known.

Many of these deposits are located in areas of upwelling and as a consequence of this, geologists correlate phosphate formation with upwelling although the precise nature of this association is the subject of much discussion and an extensive literature. For many years the ideas first enunciated by Kazakov (1937) were widely accepted.

He proposed that phosphorites are formed in areas where cold currents are forced to ascend, producing a decrease in the pH of those waters, and resulting in the precipitation of first calcite and then apatite. Later experimental work by Smirnov et al (1962), cast some doubt on this theory of inorganic precipitation. The discovery by Kolodny (1969) that none of the offshore phosphorites examined by him were forming at the present day, also strongly suggested that the phosphorite-upwelling hypothesis was no longer valid. However, the recent discovery of contemporary phosphorites off the Peruvian coast by Veeh et al (1973) and in the Walvis Bay region of southwest Africa (Baturin et al, 1972), both areas of strong upwelling, has once again suggested that the phosphorite-upwelling association is indeed a genetic association. This association is not as envisaged by Kazakov, for Baturin (1971) has shown that there is a marked phosphatization of sediments below the sediment water interface.

The mechanism for the formation of pelletal phosphorites is summarized by Cook (1974) in a six-stage genetic scheme consisting of:-

1. Influx of nutrient-rich waters, generally by upwelling, into shallow marine waters (ranging in depth from hundreds of metres to tens of metres), with a slow rate of terrigenous and calcareous deposition.

2. Development of a prolific fauna.

3. Formation of anoxic, organic-rich sediments, and loss of C, N and H.

4. Enrichment of pore waters rich in phosphorus below the sediment-water interface.

5. Development of patches of collophane by the phosphatization of sediments by the phosphate-rich pore waters.

6. Reworking of the sediments in response to changes in the current pattern, or sea level, resulting in winnowing out of the fine matrix, leaving a lag gravel of the coarser phosphatized pellets.

OFFSHORE PHOSPHATE DEPOSITS IN THE SOUTHWEST PACIFIC

Having summarized very briefly the current state of knowledge on the genesis of phosphate deposits let us now turn to the southwest Pacific region and examine the potential for finding offshore phosphate deposits there.

As previously mentioned, the only known offshore phosphate deposits in the region occur off the east coast of Australia (von der Borch, 1971; Marshall, 1971), off the west coast of Tasmania, and on the Chatham Rise (Watters, 1968) (Fig 2). It appears at the present time that all of these are relict deposits of Tertiary age, and that their location may be related to ancient patterns of oceanic circulation. Although areally extensive they are generally low grade and are unlikely to be worked commercially in the foreseeable future.

In the Oceania region the sole source of phosphate rock to date has been onshore guano-derived deposits which are comparatively small but generally high-grade. There is abundant evidence of vertical tectonics throughout the southwest Pacific in the form of raised terraces (indicating possible uplift) and flat-topped guyots (suggesting possible subsidence). In addition, eustatic sea-level changes have occurred during the Holocene and earlier. Therefore, it is not unreasonable to suggest that some guano islands have been submerged as a result of these relative sea-level changes. Offshore deposits possibly of the guano-derived type have recently been reported from the vicinity of Christmas Island in the Indian Ocean (Bezrukov, 1973). Obviously then the place to prospect for such submarine deposits is on sea mounts in the general region of known sub-aerial deposits.

A complication to this comparatively simple story is posed by the fact that within the euphotic zone there will be reef growth. This situation was found for example at Gascoyne Guyot (Davies and Marshall, 1972) where phosphatic sediments are overlain by up to 50 m of non-phosphatic calcareous sediments. The thickness of the carbonate capping will vary with the length of time that the seamount has been submerged and also with the depth of submergence. Drilling information from the Great Barrier Reef and Bikini Atoll, suggest that if the submergence is entirely a function of the Holocene eustatic sea-level rise there will be a maximum of 10 m of carbonate, and possibly very much less. If the top of the seamount has been below the euphotic zone for long periods of time (i.e. below 50 m) then there is likely to have been little or no reef growth, and prospects for finding submerged guano-type deposits, will be better. The prospects will be best in those areas known to have been subject to Cenozoic vertical tectonics and in which there are present-day sub-aerial guano-derived deposits.

Turning now to phosphorites; it has previously been pointed out that phosphorites generally form in nutrient-rich areas. Again modern guano-type deposits are useful for delineating areas of abnormally high nutrient values in the surrounding seas. This is exemplified by the area around Nauru which is a region of exceptionally high zooplankton productivity (Fig 2); other areas of high zooplankton productivity where there are guano deposits, or offshore phosphorites, occur to the north of Papua New Guinea, and off the east coasts of Australia and New Zealand.

In the equatorial region there is oceanic upwelling associated with the equatorial divergence. Upwelling of the dynamic type may be equally important; this occurs when currents are forced upwards by a topographic high. The southwest Pacific current pattern is shown in Figure 3. The equatorial and the trade wind-associated currents are the two most prominent current systems, (in the southern extremities, west-wind drift also impinges on the southwest Pacific). Wherever such currents meet a topographic high there is potential for upwelling. The upwelling indicated to the north of Fiji is likely to be of this type. If the ascending currents are also abnormally cold (Figs 4 & 5) then such upwelling will produce particularly intense nutrient concentrations and organic productivity. These cold waters will have the dual effect of inhibiting reef growth and increasing the phosphate content of the sediments. Therefore, ideal circumstances for the formation of offshore phosphorites in the south west Pacific will comprise (1) an elongate topographic high, lying at right angles to the prevailing current; (2) a sufficient depth to prevent reef growth (greater than 50 m) but not so deep as to make mining prohibitively expensive (taken as an arbitrary 1000 m); (3) deeper waters will be colder than normal; (4) upwelling may have previously been noted in the area; (5) organic productivity will be high, and (6) there may be guano deposits in the vicinity.

Using the maps which illustrate these variables (Figs 1-5), it is now possible to suggest areas where the chances of finding offshore phosphorites are greatest. It appears, from all the available data, that the region extending from Nauru through the Gilbert and Ellice Islands, the Phoenix Islands and as far east as the Line Islands should be regarded as having the greatest potential (Fig 6). It lies within the zone of the south equatorial current, the deeper water (at 400 m) is cold, producing a temperature difference between the surface waters and those at 400 m depth, of 15°C - 20°C: there is high productivity (zooplankton productivity of greater than 100 $cm^3/1000\ m^3$) throughout much of the area, and the phosphate content of the surface waters is relatively high. The Gilbert and Ellice Islands and the Line Islands trend at right angles to the dominant current direction. There are also a number of comparatively shallow seamounts (indicated on Figure 6), which would make suitable prospecting targets. It is likely that more detailed bathymetric surveys in the high priority area shown in Figure 6 will reveal the presence of further seamounts which may also form promising targets.

A lower priority area is shown to the north of the Admiralty Islands extending east to the Solomon Islands (Fig 6). Although having some of the features shown by priority area 1, ocean waters in priority area 2 has lower phosphate values for the surface; in addition the nearby land areas are large and likely to contribute a significant amount of fine terrigenous sediment to the adjacent sea-floor. This terrigenous sediment would produce dilution of any chemical or biochemical sediments such as collophane.

Phosphorites may conceivably also exist in the vicinity of the Marquesa Islands and the Tuamotu Archipelago where some upwelling occurs as a result of the trade wind drift and where deeper waters are cold. However, bio-productivity appears to be comparatively low for the area and consequently its priority as a phosphorite area is regarded as somewhat less than that of the two previously-discussed areas at the present time, although further information could modify this assessment.

CONCLUSIONS

In this brief review of prospects for finding offshore phosphate deposits a regional view of the southwest Pacific has been taken. Submerged guano-type deposits may exist in places and the obvious place to look for them is on seamounts at depths of 50 m or more in the vicinity of known major sub-aerial deposits (Fig 6).

In the search for phosphorites it is recommended that work be concentrated for the present in the region between Nauru and the Line Islands. As a first step more detailed bathymetric surveys should be undertaken. Simultaneous temperature, salinity phosphate and bioproductivity surveys will also help to identify areas of intense upwelling and high productivity, (much of the information obtained for the phosphate search program will have direct relevance to the development of fishing industries in the region, and perhaps also to thermal energy programs). Bottom sampling should be undertaken in these areas, on seamounts which rise to within 1000 to 50 metres of the surface. Free-fall corers could be employed for bottom sampling but phosphorites are commonly strongly indurated, resulting in little or no penetration by free-fall corers. Therefore, it is likely that in many places, more satisfactory results will be achieved by dredging. An additional prospecting tool may be a submersible scintillation counter.

Finally it should be pointed out that although there is no possibility of offshore phosphorites or submerged guano-type deposits competing economically with the island guano deposits, without exception these insular deposits have small reserves and a relatively short life. Few, if any, are likely to be still in production by the end of the century. It is therefore important that countries in this region consider now alternative local sources of this important primary product.

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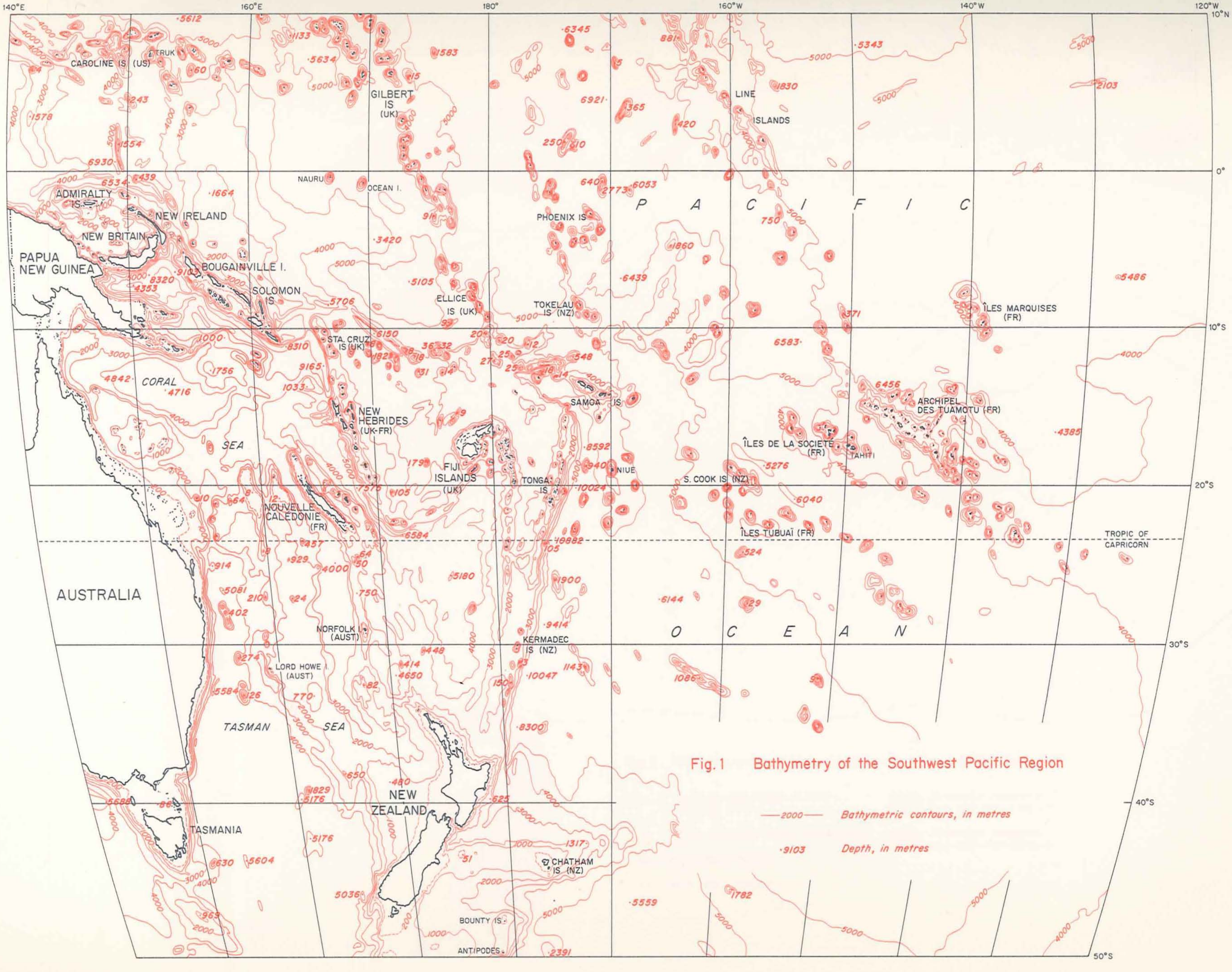

Fig. 1 Bathymetry of the Southwest Pacific Region

—2000— Bathymetric contours, in metres

·9103 Depth, in metres

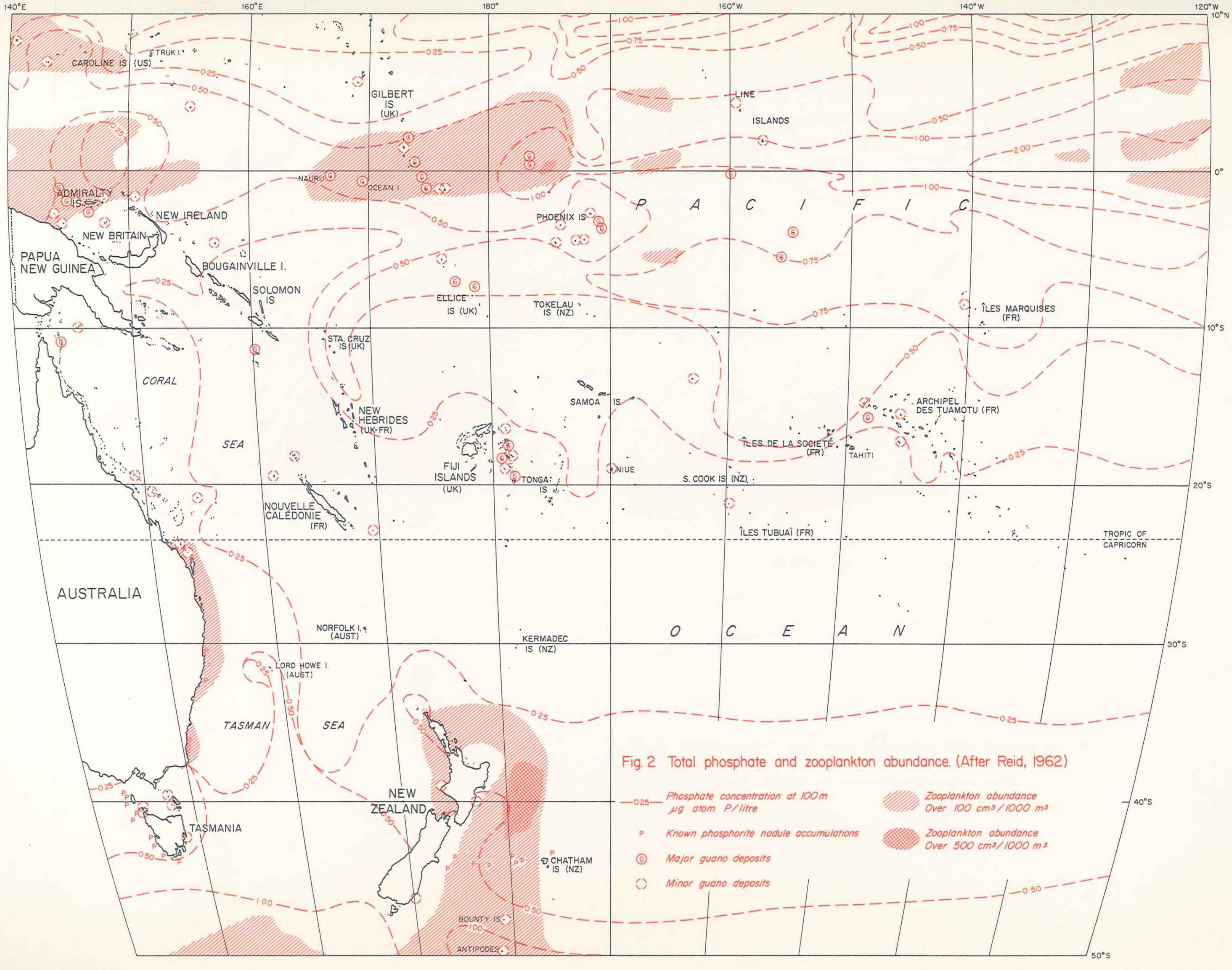

Fig. 2 Total phosphate and zooplankton abundance. (After Reid, 1962)

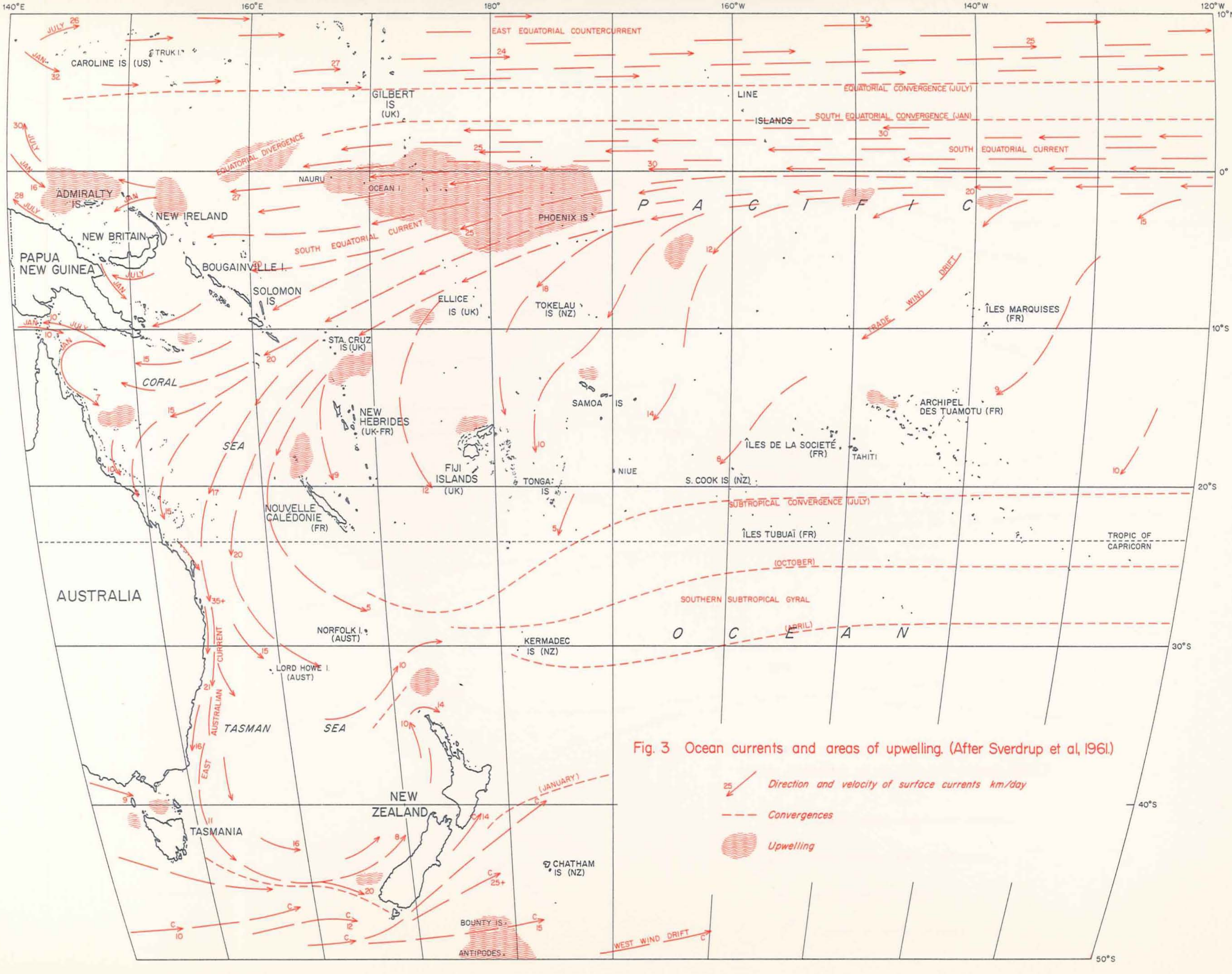

Fig. 3 Ocean currents and areas of upwelling. (After Sverdrup et al, 1961.)

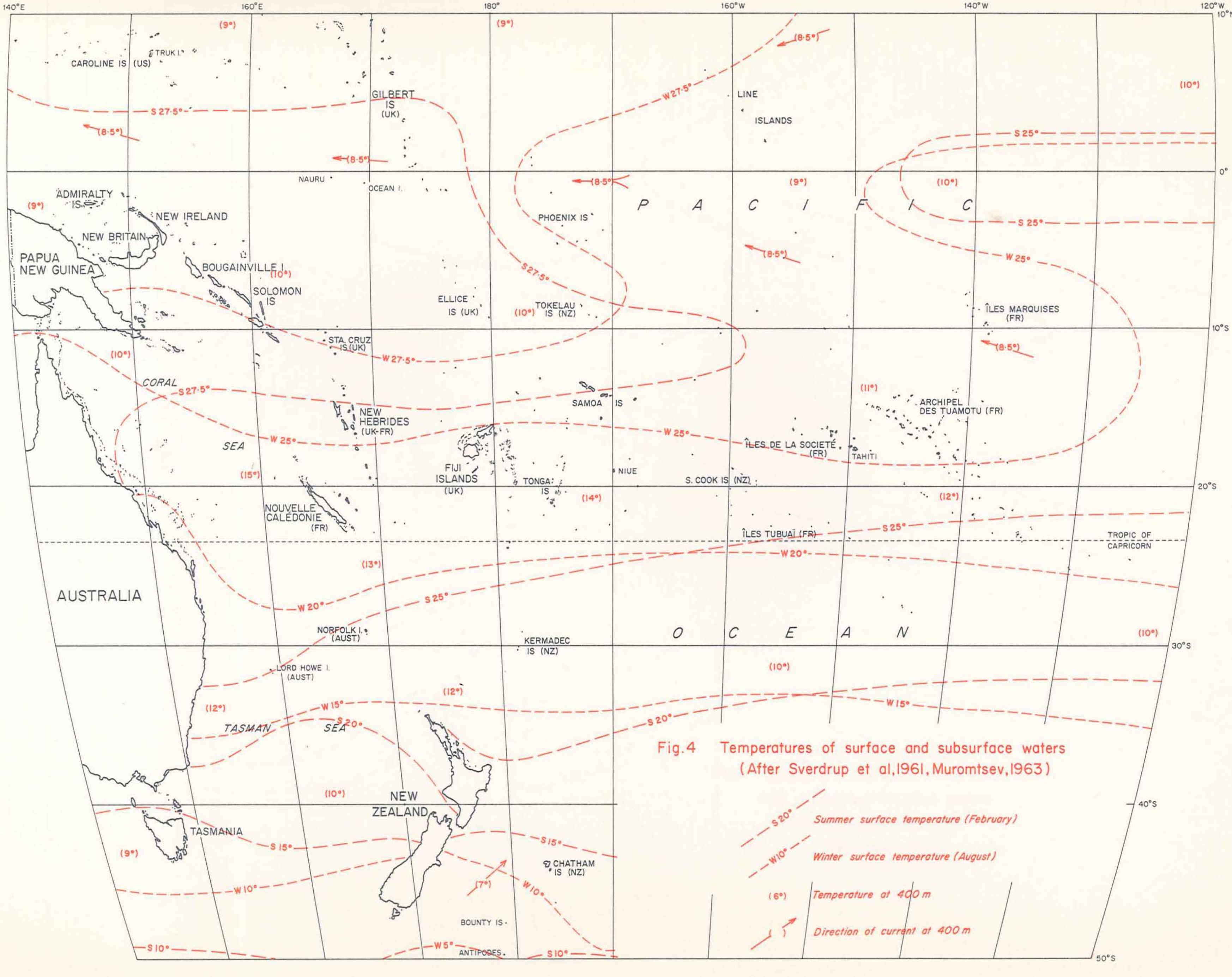

Fig. 4 Temperatures of surface and subsurface waters (After Sverdrup et al, 1961, Muromtsev, 1963)

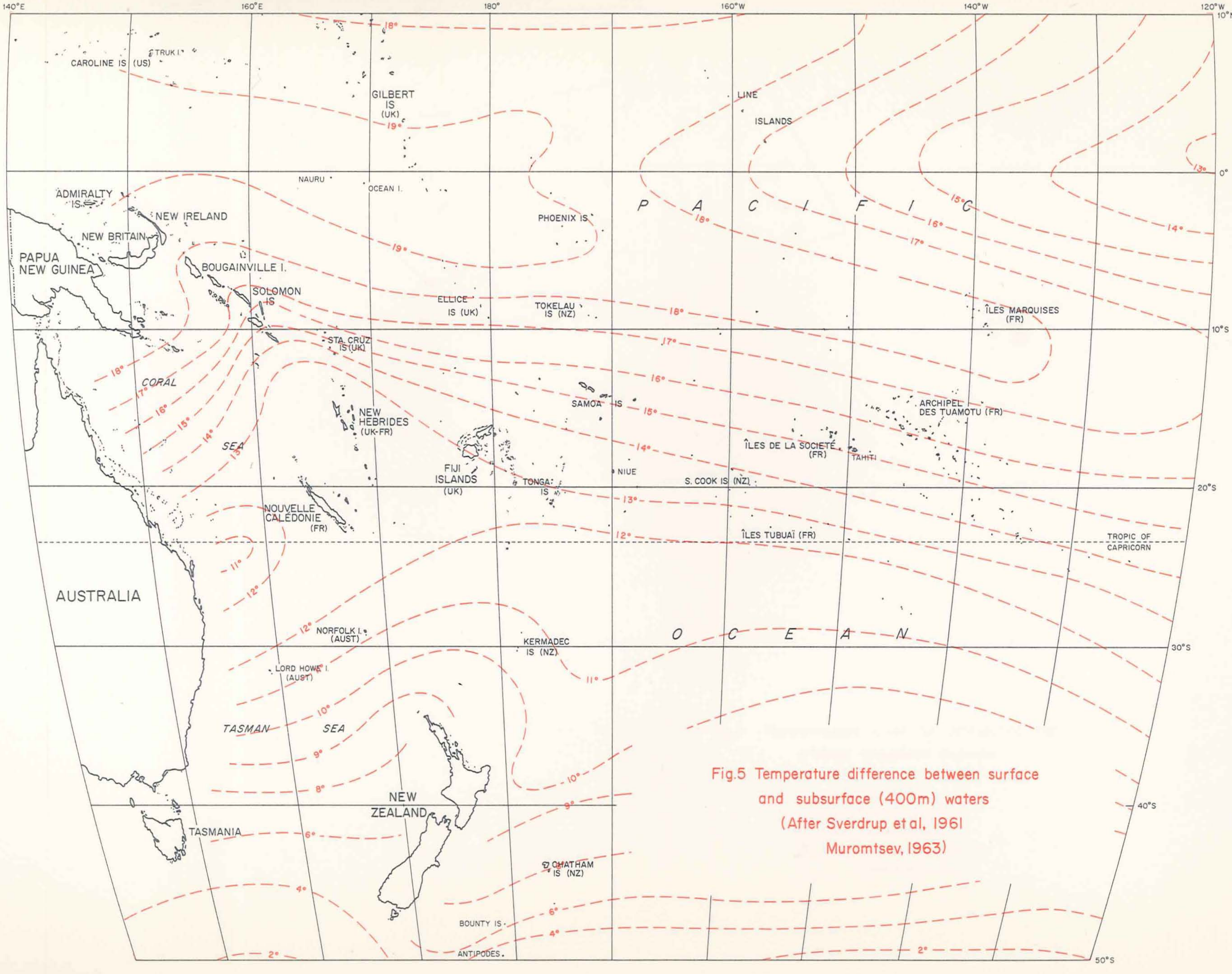

Fig.5 Temperature difference between surface and subsurface (400m) waters (After Sverdrup et al, 1961 Muromtsev, 1963)

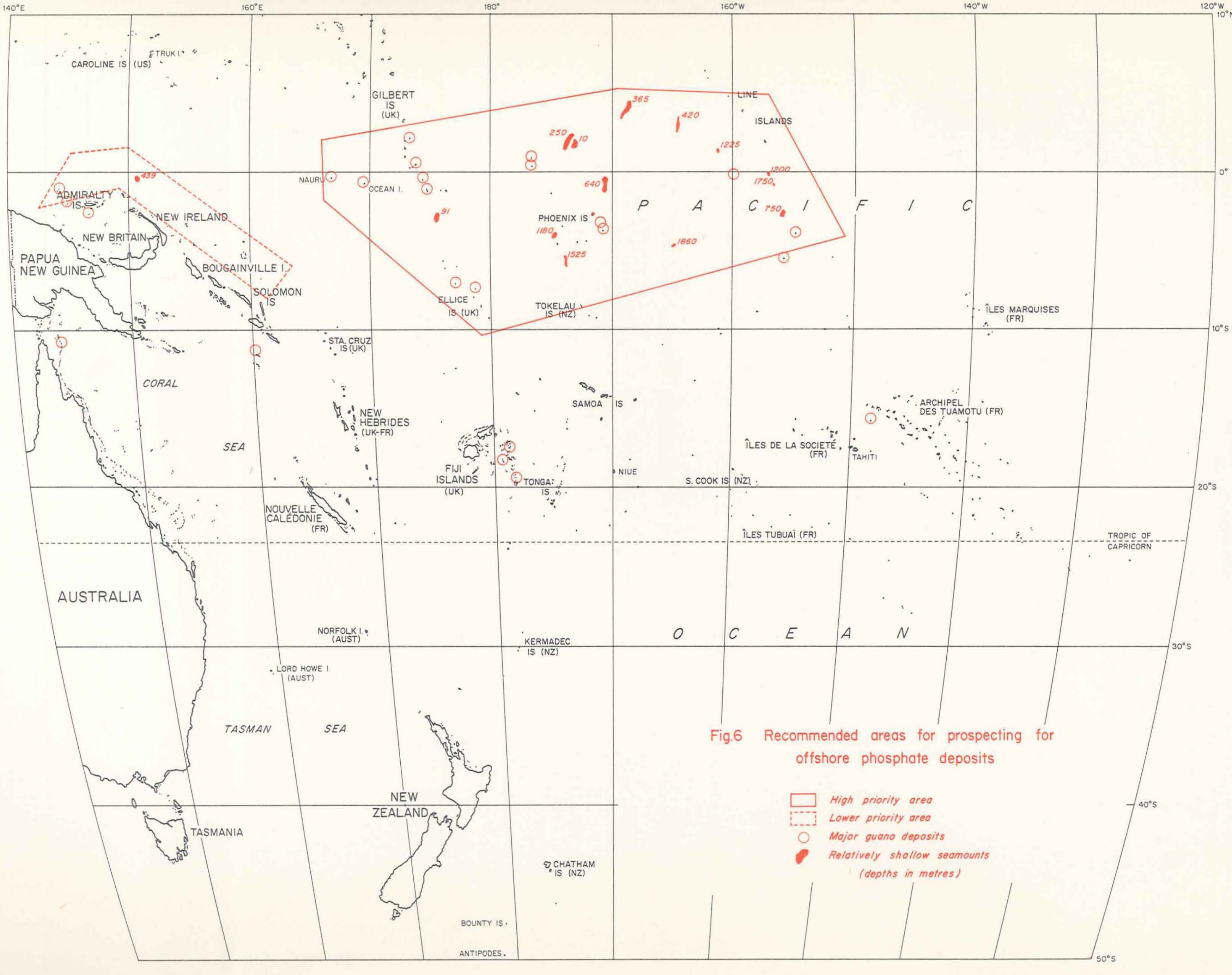

Fig.6 Recommended areas for prospecting for offshore phosphate deposits