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FOSSIL SUBDUCTION ZONES EXAMPLES IN THE SOUTH-WEST PACIFIC

J. RECY, J. DUBOIS, J. DANIEL, J. DUPONT and J. LAUNAY [1]

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INTRODUCTION

Since the notion of subduction zone based on the configurations of the seismic zones linked with island arcs has been suggested by Oliver and Isacks (1967), many studies have aimed at giving more precise details to their characteristics and consequences. The question about evolution in time of still active island arcs was several times raised, especially about the study of remnant arcs set backward to the active arcs (Karig 1972, Dickinson 1973). On the other hand, the survey of subduction fossil zones raises, with the lack of any seismicity to mark the subduction plane, the problem of selection amidst the significative characteristics which have been preserved. Kienle (1971) compared the characteristics of the general morphology and of the magnetic and gravity anomalies surveyed across the Bower Chain and the basin associated with it (in the Bering Sea) to those surveyed on active island arc systems and this author assumed in conclusion that those structures might be representative of remnant arcs connected with an ancient subduction zone.

In the South West Pacific where the evolution of plate boundaries has been particularly complex, this notion of fossil subduction zone was previously raised several times (Chase 1971, Karig 1972, Halunen and von Herzen 1973) but most of the structures have not yet been studied in details. As for Recy et al, 1975, the Rennell Basin and its chains present, with regard to their morphologies, their ways of filling and the shapes of their magnetic anomalies, some characteristics fitting with structures in connection with the subduction.

In addition to the seismological criteria we shall restrain this paper to the study of some of the characteristics given by a series of bathymetric, magnetic and continuous seismic profiles. We shall then draw a comparison between the observable characteristics derived from these investigating means about active island arcs and those observed on some of the structures in the South West Pacific (Fig. 1).

I - REVIEW AND DISCUSSION ABOUT THE STUDIED CHARACTERISTICS OF ACTIVE ISLAND ARCS

A) Criteria of seismicity :

- The configuration of the seismicity constitutes the main criterion to define active subduction zones. It was suggested (Barazangi et al, 1973) that seismic activity did not stop at the very end of the subduction and seemed to go on at the level of the underthrusting plate slabs, detached from the original plate.

- The pP waves observed underneath some active island arcs are decreasing in intensity while this phenomenon is not observed underneath other active island arcs (Barazangi et al, 1975). Therefore this characteristic

(1) Office de la Recherche Scientifique et Technique Outre-Mer, B.P. A5, Noumea Cedex, New Caledonia

cannot be representative of an available criterion of identification.

- In the same way, the finding out of remains linked with the residual underthrusting lithosphere, through a method nearing that used by Davies and MacKenzie (1969) when applied to the residual times of the volume waves has not allowed the assumption of convincing results about the supposed fossil zones (Dubois J. and Pascal G. pers. com.).

B) Morphology :

- The morphology of the structures in connection with active subduction zones has been yet largely defined. One can remember :

- The generally arched shape, especially of the trench, either regularly arched or only at its extremities, with a convexity facing the underthrusting plate.

- The dissymmetry of the trench (the flank with a gentler slope connected with the underthrusting plate) with a relative narrowness (from 50 to 100 km wide).

- The great depth of the trench (7.000 to 10.000 m) and the great fall in level (frequently more than 4.000 m) from the trench bottom to the underthrusting plate top.

- The existence of an island arc, outlined by islands along the inner side of the trench convexity.

- The cross section of a typical island arc presents a group of characteristical features whose nomenclatures were recently renewed (Karig and Sharmann, 1975, Fig. 2).

- A representative feature in connection with the subduction is the bulge of the underthrusting lithosphere evidenced by topographical surveys of the sea bottom, the uplifting of atolls and the existence of a gravity anomaly (Lliboutry 1969, Hanks 1971, Dubois et al 1973, 1974, 1975, 1976 Watts and Talwani 1974). The profile surveyed across the New Hebrides (Fig. 3) is fitting well with the model of an elastic plate except for the part neighbouring the trench (at 80 km from the trench axis) where the observed flexure is abnormally accentuated and seems to be under laws belonging to the visco-elastic domain (Dubois et al, 1976).

C) Way of filling :

- The sediments, when the trench gets some, are found generally as horizontal layers ; on the continuous seismic reflection records these layers appear in disconformity with the inclined layers of the outer flank so important and brutal are the lateral variations in thicknesses of the filling layers (Scholl 1974). The inclined layers of the outer flank represent ancient horizontal deposits which had been brought by the plate migration to the level of the flexure in the vicinity of the trench.

D) Magnetic characteristics :

Other characteristics bring further arguments of identification but none of them is determining by itself.

- Thus a typical magnetic profile (Fig. 4) made across an old active arc (Tonga) and a young active arc (New Hebrides) allows the following observations, from the outer to the inner part :

- 1) a series of anomalies of short wavelength and low amplitude on the inner wall and on the frontal arc.

- 2) anomalies with short wavelength and high amplitude (500 to 800 γ) at the level of the volcanic arc.

II - DESCRIPTION OF SOME STRUCTURES REPRESENTATIVE OF FOSSIL SUBDUCTIONS

We shall successively speak about structures whose seismic activities are not completely interrupted (Vitiaz trench, Solomon trench) and structures presenting a morphology which can be compared to that of subduction zones (Solomon, Pocklington and Rennell trenches).

A) The area of the Vitiaz trench (Fig. 1)

This gently arched trench stretches along more than 1.000 km. Its western extremity shows a remarkable curvature towards South. Its maximal depth reaches 6.000 m. Its difference in level from the sea floor located North of the trench, is never up to 2.000 m generally. Some considerations about global tectonics led Chase (1971) to assume that trench to be the remains of a subduction zone of the Pacific plate which was active between 20 and 10 M.y. The profiles of continuous seismic bathymetry we have, do not show morphological characteristics comparable to those observed in the active subduction zones. They are more approaching, especially in the eastern part, to the characteristics observed on the transition zone and the transform fault (Daniel et al, in this volume). The spreading of the North Fiji Plateau (Chase 1971) might have modified the morphologies of the nearings of the trench. Barazangi et al (1973) observed under the North Fiji Plateau a series of deep earthquakes which they attributed to a detached lithospheric slab. Isacks (pers. com.) observes, thanks to a recent determination of new deep earthquake focuses, that those focuses define, from 550 to 650 km deep, a plane dipping southward. With regard to the present knowledge, it looks logical to emphasize this isolated lithospheric slab to originate from an ancient subduction at the level of the Vitiaz trench and would have been detached as pursueing a downgoing movement after the subduction stopping.

B) The North Solomon trench area :

Halunen and von Herzen (1973) emphasize the existence of a subduction zone active to the end of Miocene, located North of the present active subduction zone. These authors deduce their assumptions from the measure of the heat flow, from geological studies about the Solomon islands after Coleman (1970) and from the presence of a deep seismicity under the seismic activity of the present subduction zone.

The North Solomon trench which borders Northly the Solomon archipelago presents a regularly arched structure with its convexity facing the Pacific plate. It appears as a continuation of the Vitiaz trench forming with the Western extremity of the latter a bold recess (such a feature is not without reminding that observed along the successions of active island arc systems especially that found between the South Solomon and the New Hebrides trenches).

More recent determinations on deep earthquakes beneath San Cristobal island, neatly distinct from the seismicity in surface connected with the South Solomon present subduction zone, point out that the detached lithospheric slab spotted under the North Fiji Plateau seems to be found beneath the Solomon archipelago (B. Isacks, pers. com.). We said previously that this slab would originate from an ancient subduction of the Pacific Plate. The North Solomon trench appears in terms of general morphology, as the only structure liable to represent a remnant structure in connection with a subduction zone.

On the three profiles surveyed along the North Solomon trench we present here (Fig. 5) We can observe that the North Solomon trench is affected by a bold dissymmetry. North the Ontong Java Plateau whose depth never reaches more than 1.700 m shows an horizontal sedimentary cover of 2 t.w.t. which begins to bend at 70 km from the trench axis, the bending of the formations is increasing as far as it gets nearer to this axis.

The South flank of the trench (entirely seen across an only profile : Glomar Challenger leg. 30, Fig. 5) presents an abrupt raising up to 1.500 m and is prolongated by a series of small chains with decreasing depths. On the AUS 410 profile alone we can observe in the trench a sedimentary filling in, less than 1 t.w.t. thick, formed with horizontal layers clearly in disconformity with, on one hand, the regularly inclined formations of the North flank of the trench, on the other hand, with the irregular reflectors, not easily detected on the South flank of the trench. The maximal depth of the trench found on our profiles (under the sedimentary filling when it occurs) is never less than 4.000 m and this depth does not seem in any place to be exceeded (see map after Scripps).

The characteristics observed over the structures presumed to be connected with the North Solomon fossil subduction zone, point out lot of fittings with those observed in active subduction zones.

One can notice :

- The arched general pattern of the trench with its convexity facing the ancient underthrusting plate.

- The dissymmetry of the trench flanks, with its outer flank showing a progressive flexure originated at 70 km from the trench axis. Such a flexure is quite comparable to a non-elastic type deformation of the lithosphere as observed by Dubois et al (1976) in the vicinity of the trench.

- The existence of a relatively steep inner flank where the existence of irregular reflectors at its base looks like a structure of accretionary prisms.

- A sedimentary filling with layers in conformity with one another, but in disconformity with the layers of the flank.

Finally, the magnetic anomalies connected with the three small chains which border the trench

North, are affected with short wavelengths and low amplitudes where a series of anomalies of higher amplitudes and short wavelengths appears at 50 km from the trench axis (profile GC 30), marking volcanic intrusions just as in the active island arcs.

- On the other hand one can notice :

- The elastic-type lithospheric bulge observed on the underthrusting plates in active subduction zones does not appear to be conserved.

- The maximal depth of the Trench (4.000 m) is highly lesser than that of the active trenches.

- The difference in level from the trench to the upper part of the underthrusting plate (2.500 m) is lesser than the difference in level observed in the active zones.

- The depth of the upper part of the underthrusting plate is lesser too than that observed over the active zones. This observation is fitting with the suggested hypothesis about the end of the subduction caused by the coming of a thick crust with a low density. This low density of the crust may explain also the shallow depth of the trench.

The study of the structures connected with the North Solomon fossil subduction zone points out that the main morphological sedimentological and magnetic characteristics observed on active zone are easily known. Thus, they seem to represent a sum of arguments available enough to determine the origins of other structures, themselves completely inactive.

C) Pocklington trench and chain areas :

That seismically inactive structure, after Karig (1972), might represent a fossil subduction zone, with regard to the existences there of later Eocene metamorphic and intrusive rocks and of a trench with an upper apron flank.

The western part of this structure which stretches along more than 1.000 km, presents an arched general morphology. From the two transverse profiles AUS 412 and 318 (Fig. 6) one can deduce the following characteristics :

- A narrow trench with dissymmetrical flanks whose depths under the sedimentary filling reach 5.000 m.

- A steep inner flank (with regard to the convexity), with at its base warped formations.

- An outer flank with a much more gentle slope with a curvature beginning at 100 km from the trench axis.

- A chain on its inner side, approximately 70 km wide and which might represent the island arc. The relief of this chain is decreasing towards East.

- Inside the trench, a sedimentary filling whose layers warped towards the inner flank are in conformity between themselves. The filling depth is about 2 t.w.t.

All those characteristics support the hypothesis of a fossil subduction zone ; the convexities of the structures facing South indicate that the ancient underthrusting plate was that located South of the trench. In fact, this structure seems more complex and its evolution towards East looks like that described by J. Daniel et al (in this book) about the transition zones and the transform faults, ending the subduction zones. Sea-bottoms at the surface of this plate do not reach 1.600 m deep ; this shallow depth is representative of a thick, little dense crust, may be the cause of the end of the subduction.

D) Rennell Basin and Chain, Indispensable Chain :

We have to deal here with seismically inactive structures whose general morphologies are different from those studied previously since they are rectilinear and their longitudinal extensions do not reach 300 km ; the morphological and sedimentological characteristics in their whole allowed to Recy et al (1975) to suggest thereafter the hypothesis that those structures would mark a fossil subduction zone.

The transverse profile GEORSTOM 104 (Fig. 7) allows to point out some characteristical features : progressive flexure of one of the flank at 70 km from the trench axis, opposite steep flank in which one can distinguish startings of reflector, filling consisting in layers in conformity, lack of magnetic anomalies with a high amplitude along the part of the chain represented by the frontal arc, existence of anomalies with a high amplitude at 50 km from the trench at the level of what might be the ancient volcanic arc. The depth in the trench down to the sedimentary filling base reaches 5.500 m, the difference in level with the oceanic bottom of the outer side reaching more than 2.500 m deep.

The lack of convexity and the small length of the structures raise the incertitude about their origins. One can suggest that a mechanism of subsidence originated that trench. But we can observe (Fig. 7) that the sedimentary filling layers are recorded in conformity between them, and because of the sharp variation in thickness at the level of the outer flank, in disconformity with the inclined formations forming the outer flank ; the latter are in conformity between them with a constant thickness : then at their origins they deposited horizontally. That cannot afford their inclination to be originated by a mere subsidence because the latest layers of the filling would then be found in disconformities between them as a function of the subsidence. Only the subduction mechanism implying the progressive accretion of the filling to the inner wall when the filling is going on inside the trench in the same conditions, may explain the observed facts. If the filling is subsequent to the active period of the subduction, the trench acts as a pre-existing collector and the conditions of deposits are identical to those existing during the active period. The way of filling constitutes therefore a criterion which makes up the observed characteristics across the transverse profiles ; those characteristics in their whole allow to assume that the Rennell structure though its rectilinear strike and its small length, marks a fossil subduction zone.

East to the trench, the shallow depth of the ocean bottom marks the existence of a thick crust which might have originated the subduction stopping.

Finally, Recy et al (1975) note that the existence of a thick reef cover overlying the chains, marks a subsidence of these chains after the subduction ended.

The uplifting of part of the thus created atolls is a recent phenomenon which could be linked to the lithospheric bulge at the level of the South Solomon present subduction zone after a mechanism already established for the Loyalty Islands (Dubois et al 1973, 1974, 1975, 1976).

CONCLUSIONS :

The seismic activities of detached lithospheric slabs are going on after the subduction ended, which allows to use the criterion of seismicity to define very recent fossil subduction zones as Vitiaz and Solomon zones active at least till the upper Miocene. The results established through this study have shown up that most of the morphological and sedimentary characteristics observed on the structures connected with active subduction zones are conserved after the subduction ended except the action of new stresses. Those characteristics thus allow to define the origins of structures close to which no seismic activity either in depth nor in surface could be recorded.

One can schematically classify those characteristics into three groups :

- Characteristics of general morphology :

The trench remains neatly marked : generally it is affected with an arched shape and it stretches along several hundreds of kilometers ; its width being never more than 50 to 80 km. It is bordered along the inner side of the convexity by a continuous chain about 50 km wide for the structures we are studying in this paper. Its convexity faces the underthrusting plate. The trench depth is less than those of active trenches and does not reach more than 6.000 m deep ; the difference in level between the trench bottom and the underthrusting plate top is less than those observed in active trenches.

- Different structural features :

On the transverse profiles, one can observe a bold dissymmetry of the trench, the outer flank to the convexity being the smoother. The flexure of the lithosphere of the underthrusting plate observed on active subduction zones does not appear as completely conserved in inactive zones as previously assumed by Recy et al. Effectively the elastic-type deformation (lithospheric bulge) does not appear there ; on the other hand the non-elastic deformation, which takes its origin at 80 km from the trench axis and whose curvature is increasing as far as getting closer to the trench axis, appears as well conserved. While the sea bottoms exceed currently 4.000 m on the outer side of the trench in active zones, in fossil zones one can observe practically always deeps which do not reach 2.000 m.

The inner abrupt flank where one can

find warped layers, and the island arc too, are not very different from the inner flank of active arcs. Magnetic anomalies, with a low amplitude on the frontal arc, are only devellopped at the level of the ancient volcanic arc. On the other hand the general relief of this fossil arc seems neatly less marked than in the active island arcs.

- Way of filling :

When the filling of the trench exists, the sedimentary layers seem to be in conformity between them and, as a result of the brutal variation in depth at the levels of the trench flanks, they appear in disconformity with the inclined layers forming the trench outer flank. This characteristic observed on the active subduction zones constitutes for the fossil subduction zones a very important selection test, the filling having occurred either before the active period or after it.

We observe the convexity of the structure does not represent a necessary criterion since its origin may be determined through the other characteristics. The lack of sedimentary filling too, does not rule the determination of a structure if it owns the characteristics described in the both first groups.

The shallow depths of the sea-bottoms surveyed over the ancient underthrusting plates point out zones of crust thicker and less dense than those of the active subduction zones : the existence of this less dense crust is assumed to have caused the subduction stopping.

The absolute shallow depth of the trench is assumed to be related with the shallow depth of the ancient underthrusting plate upper part. It could mark too a movement of positive isostatic readjustment after the stopping of the stresses, a movement which could be interfered with a swift filling of the trench.

The small difference in level from the trench to the underthrusting plate upper part might be resulting from a positive isostatic readjustment of the underthrusting plate, or from a partial readjustment of the visco-elastic deformation of the underthrusting plate after the subduction stopping.

The less uneven relief of fossil island arcs and the subsidence observed along some of these island arcs may be explained by a negative isostatic readjustment of the island arc after the stopping of the stresses.

The aim of this paper was only to make a comparison between well conserved structures pointing out fossil subduction zones and structures marking active zones, and to assume that the end of the subduction does not cause swift and radical modifications in these structures. It is obvious that the time factor and the external influences induce far more important modifications ; fossil structure identifications must then use different criteria of investigations, which implies the use of methods in complementarity with those used here by us.

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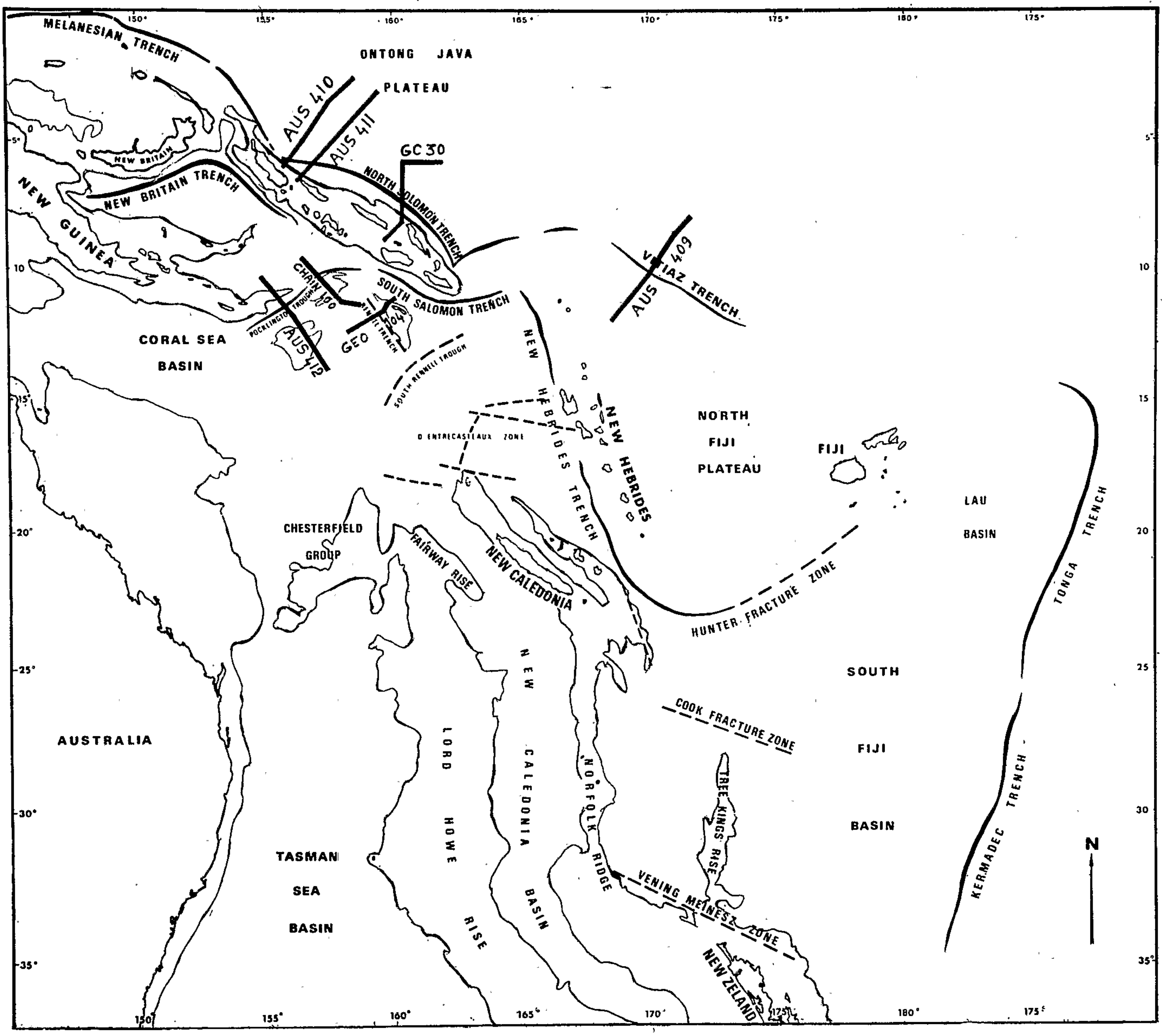


Fig. 1 - Localisation map of the studied structures and profiles.

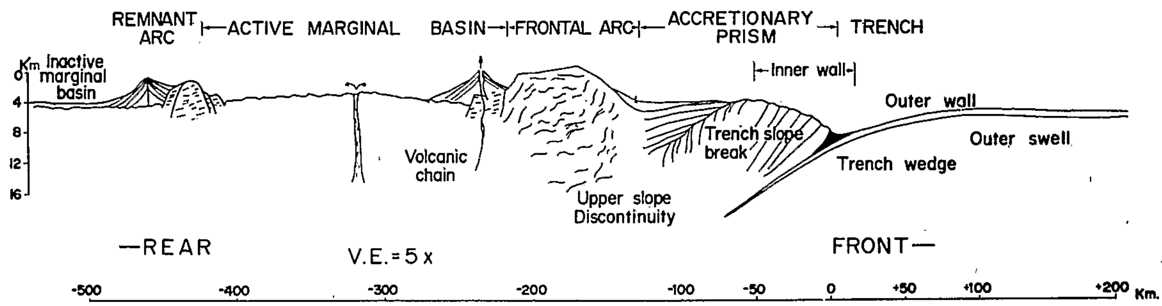


Figure-2. CROSS SECTION OF A TYPICAL ISLAND-ARC SYSTEM SHOWING TECTONIC UNITS AND TERMINOLOGY USED IN THIS PAPER (REVISED AFTER KARIG, 1970, 1971 1 a') (FROM KARIG AND SHARMAN 1975)

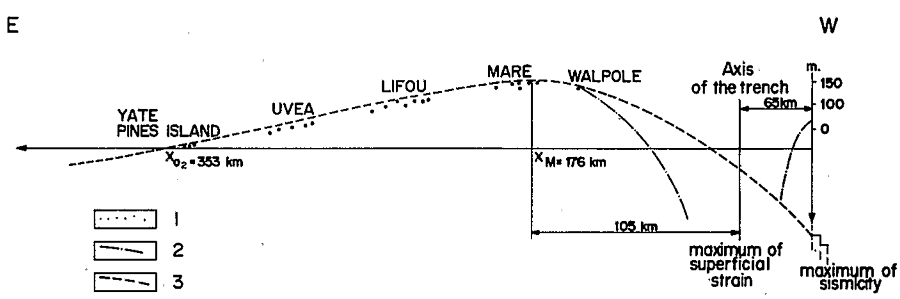


Figure- 3. TOPOGRAPHIC PROFILE PERPENDICULAR TO THE TRENCH AXIS AND THEORETICAL DEFLECTION CURVE_ CORAL REEFS (1) BATHYMETRIC PROFILE OF THE TRENCH (2) THEORETICAL DEFLECTION CURVE (3)

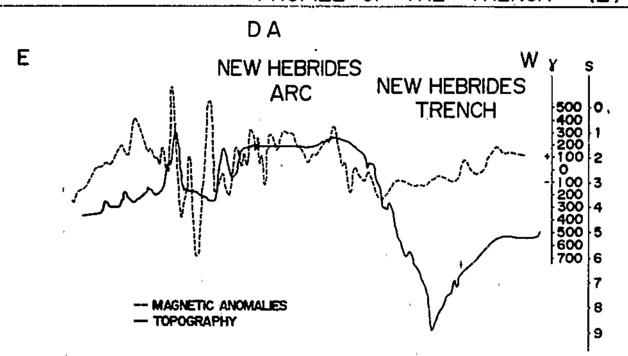
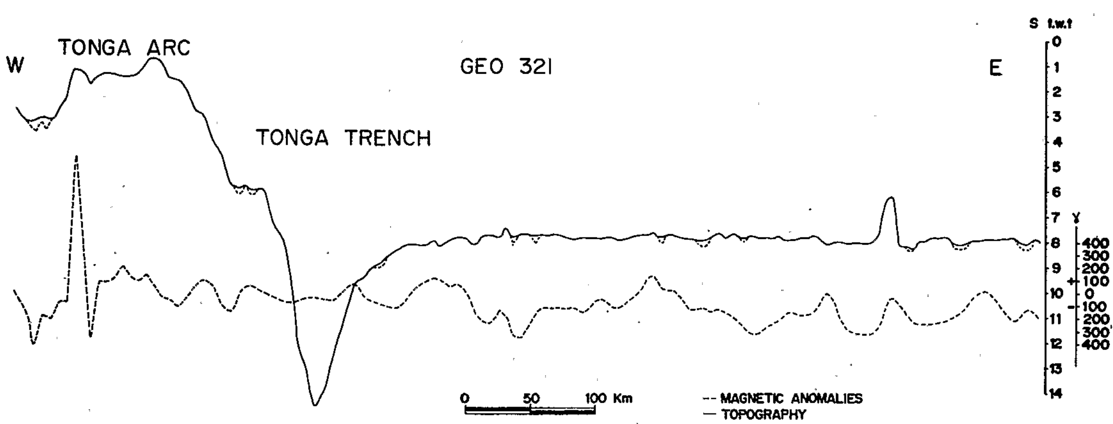


Figure-4. TOPOGRAPHY AND MAGNETIC ANOMALIES ACROSS A YOUNG ISLAND ARC (NEW HEBRIDES) AND AN OLD ISLAND ARC (TONGA)



GEO 321

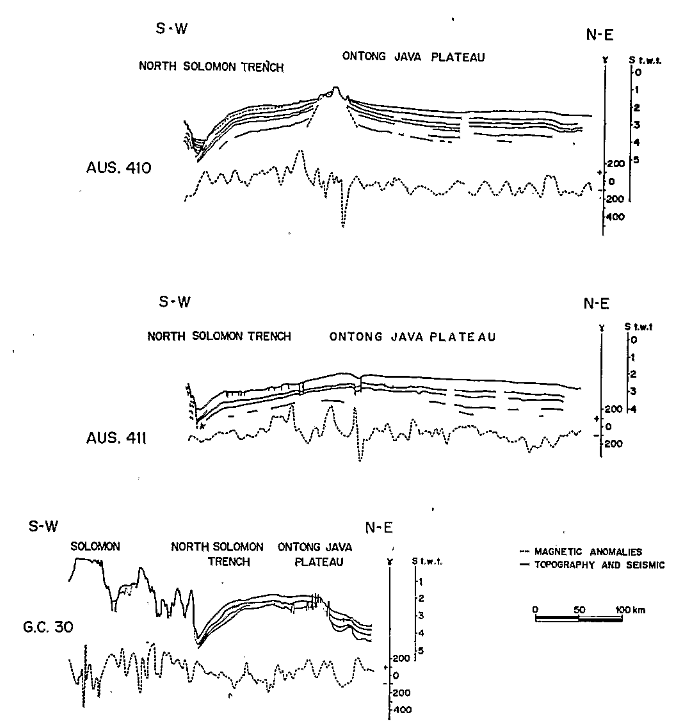


Figure-5. SEISMIC REFLECTION PROFILES AND MAGNETIC ANOMALIES ACROSS NORTH SOLOMON TRENCH

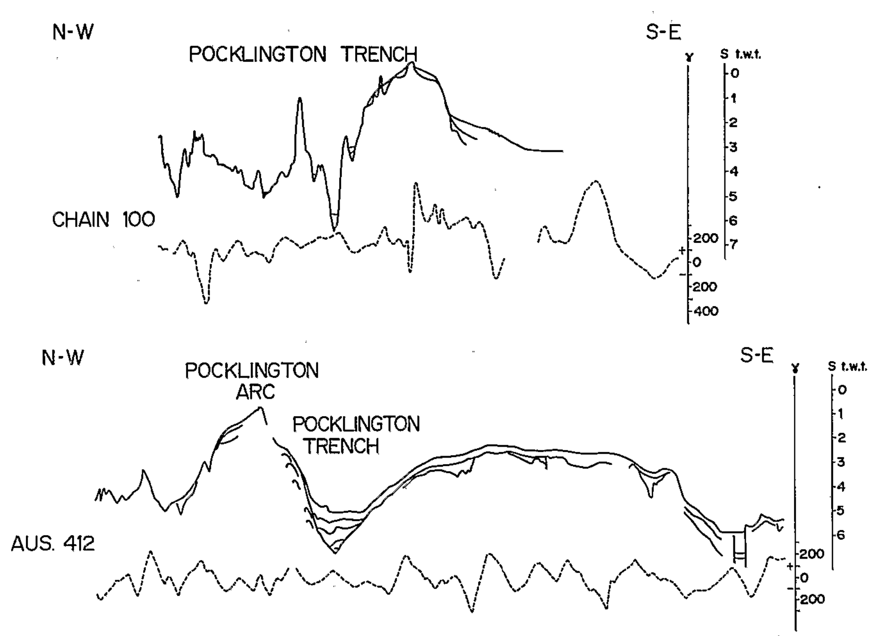


Figure-6. SEISMIC REFLECTION PROFILES AND MAGNETIC ANOMALIES ACROSS POCKLINGTON TRENCH

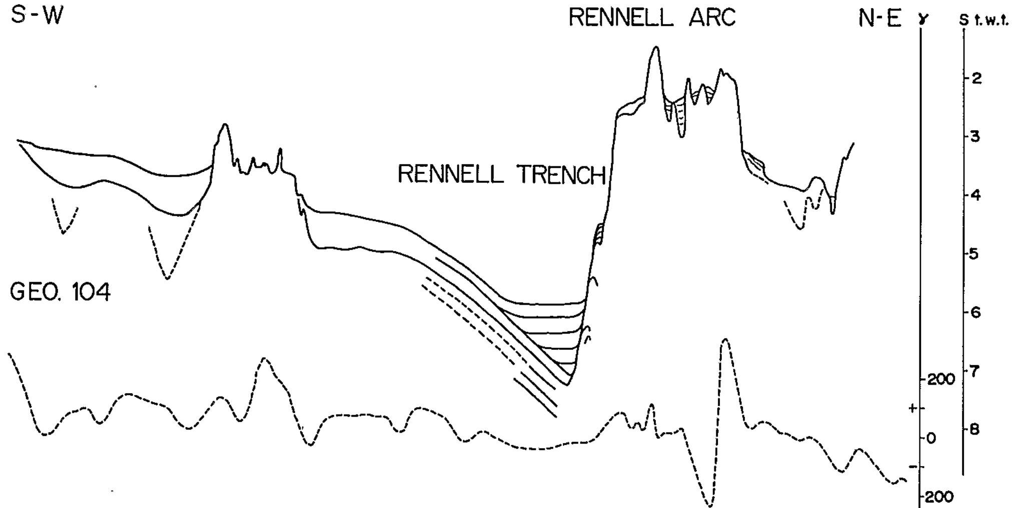
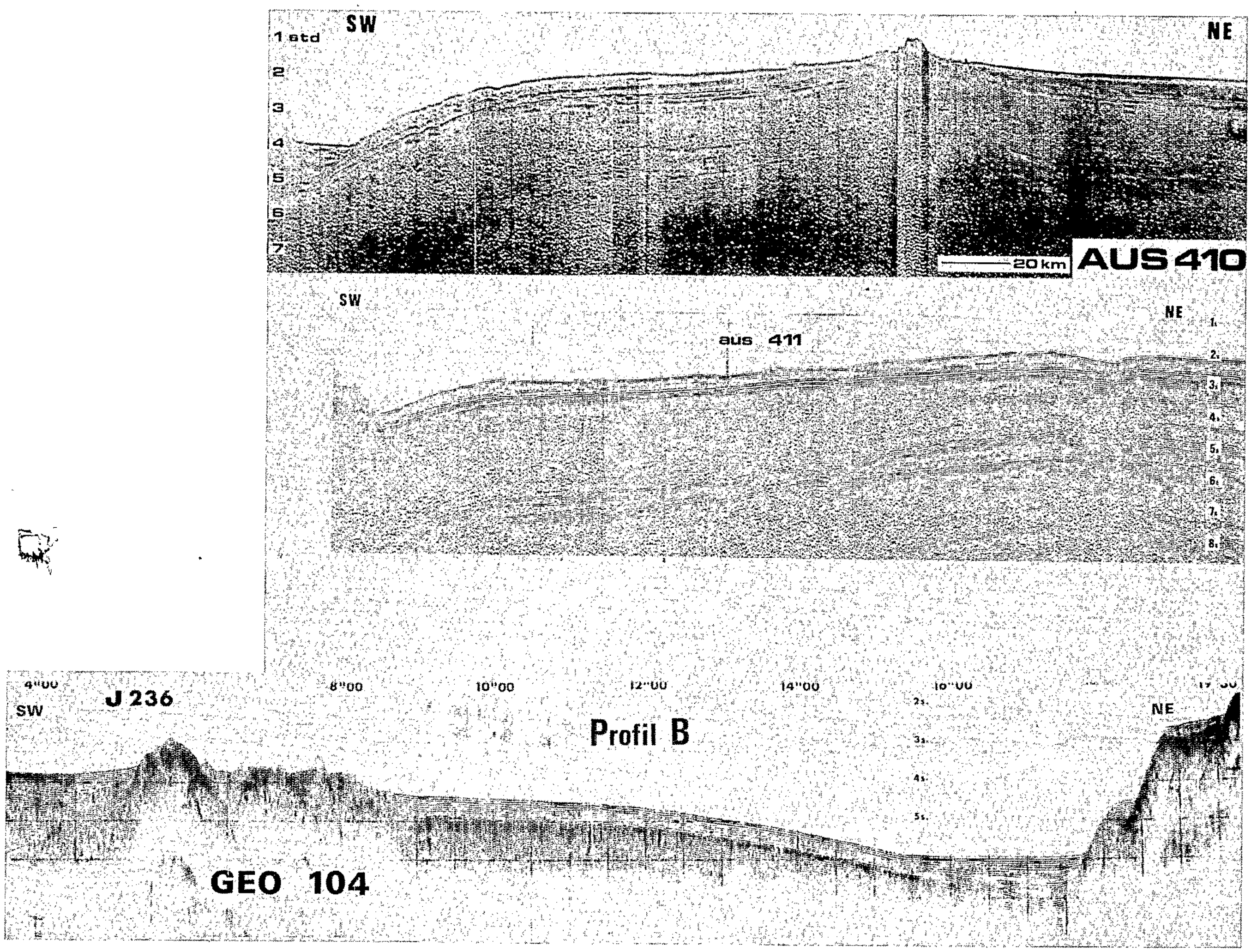


Figure-7. SEISMIC REFLECTION PROFILE AND MAGNETIC ANOMALIES ACROSS RENNELL TRENCH

0 100 200km. ---- MAGNETIC ANOMALIES — TOPOGRAPHY

Original record of profiles AUS 410 - AUS 411 and GEO 1C4 used in figure 5 and 7.



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