GEOLOGY OF A FOREARC MANTLE-CRUST SEQUENCE: THE SOUTHEAST BOHOL OPHIOLITE COMPLEX, VISAYAS, PHILIPPINES

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ABSTRACT

A reconnaisance geologic mapping and reinterpretation of existing information suggest the existence of a complete ophiolite complex in Southeast Bohol. This crust-mantle sequence is made up of residual harzburgites, layered harzburgites-dunites-clinopyroxenites, layered to massive gabbros, sheeted diabase-gabbro dike complex/ swarms and pillow basalts. The amphibolite schist, previously included as part of the regionally metamorphosed Alicia Schist, is reinterpreted as the associated metamorphic sole of the ophiolite. Analyses of available regional fault structures, focal mechanism solutions, and the lithological distributions suggest the existence of a proto-Southeast Bohol Trench. The Southeast Bohol Ophiolite Complex could be the associated forearc ophiolite. The Cebu Cretaceous magmatic arc-SE Bohol forearc ophiolite-proto-Southeast Bohol Trench is interpreted to be one Cretaceous trench-arc system.

INTRODUCTION

The Philippines is considered a good laboratory for the study of the various geologic and tectonic processes that had actually shaped the earth in the past. Aside from its being made up of several autocthonous and allocthonous terrains of varying origin (e.g., oceanic, continental, island arc), the interplay of several tectonic processes, as manifested by the presence of several major fault and trench systems, are very evident in the rock records (Balce et al., 1979; Yumul et al., 1993).

It is in this context that a preliminary study of a crust-mantle sequence in Southeast Bohol is made. The presence and significance of these possibly related suites of rocks in Bohol Island have not been fully recognized and understood

(BMG, 1982; JICA, 1985; Diegor and Matos, 1986). It is the purpose of this paper to characterize the different rock units of a probable ophiolite sequence found in Southeast Bohol and determine its tectonic significance. It is hoped that from this characterization, the over-all contribution of the ophiolite complex to the geologic evolution of the Philippine island arc system will be elucidated.

BRIEF GEOLOGIC OUTLINE

Southeast Bohol has for its basement the Cretaceous-Paleogene Alicia Schist and Ubay Volcanics. The Alicia Schist is dominantly made up of chlorite schists and quartz schists (Arco, 1962) (Fig. 1). The amphibolite schists that are found in Aliawan River, Jagna and which were formerly considered to be a part of the Alicia Schist, are actually believed to have been generated through a different mechanism. The Alicia Schist could have resulted from regional metamorphism whereas the amphibolite schists may correspond to the associated metamorphic sole of an ophiolite. The amphibolite sole was produced during the emplacement of the hot residual peridotites, through thrust faulting, on top of an oceanic crust made up of pillow basalts and associated sediments (Ghent and Stout, 1981; Gnos and Peters, 1993). On the other hand, the Ubay volcanics are made up of agglomerates, basalts, andesites, and dacites which have also undergone varying ranges of metamorphism (Arco, 1962). Some portions of the Ubay Volcanics may turn out to be part of the ophiolite sequence in Southeast Bohol. Future work is needed to verify this.

In thrust contact with the Alicia Schist is a peridotite unit called the Boctol Serpentinite (JICA, 1985; David et al., 1994) (Fig. 1). The Boctol Serpentinite is considered to correspond to the residual peridotite unit of the exposed crust-mantle sequence which is collectively called here as the Southeast Bohol Ophiolite Complex (SBOC). Although the different lithological boundaries among the various units of the SBOC are not observed, thrust fault contacts are encountered in several outcrops. The different rock units of the SBOC will be discussed in detail in the next section.

The Jagna Andesite, which consists of andesitic rocks, is dated Middle Miocene and is unconformably overlain by the Sierra Bullones Limestone (Javelosa, 1994).

The Carmen Formation, dated as Middle Miocene, is characterized by a shale – sandstone sequence which appears to be a marine shallow shelf deposit (Javelosa, 1994). On the other hand, the Sierra Bullones Limestone is a thick coralline limestone ranging from a well-bedded, thin to massive, and recrystallized limestone (BMG, 1986; Javelosa, 1994).

In general, the rock succession from the metamorphic basement complex and ophiolite sequence all the way to the clastic sedimentary rocks and capping limestone unit suggests either lowering of the sea level or the consistent rise of this part of Bohol island. Measurement of uplift rates in Bohol Island is consistent with this (Javelosa, 1994).

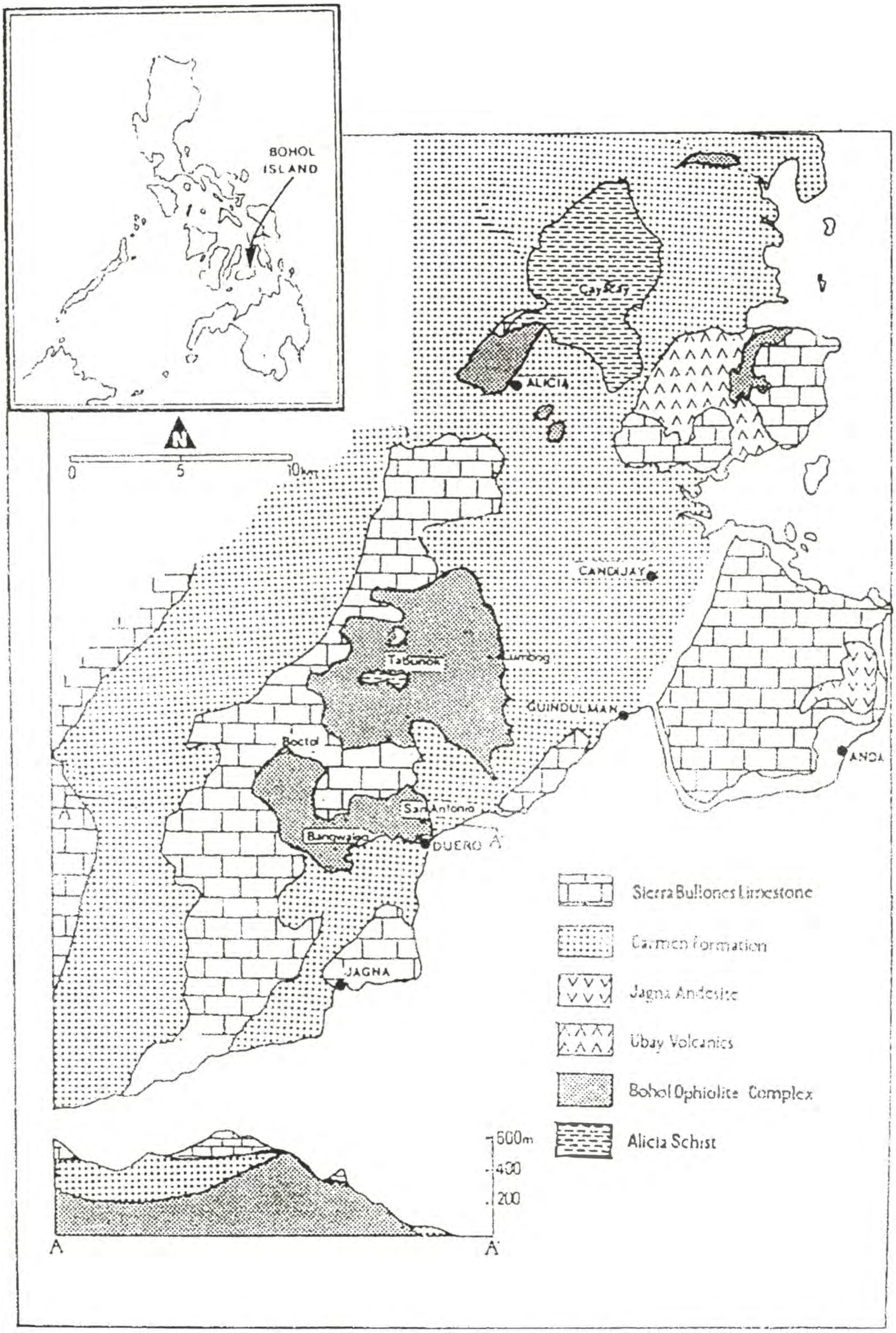


Figure 1. Geologic map of Southeast Bohol adopted from David et al. (1994).

LITHOLOGICAL UNITS OF THE SOUTHEAST BOHOL OPHIOLITE COMPLEX

A. Residual Harzburgites

Exposures of the residual harzburgites, disposed in a northeast direction, can be found in Duero, Guindulman, and Alicia (formerly Batuanan) (Arco, 1962; Diegor and Matos, 1986; David et al., 1994) (Figs. 1 and 2). Fresh dark-green harzburgite outcrops are encountered although intensely serpentinized ones, characterized by hob-nailed texture and bastites, predominate. The harzburgites, believed to be of residual origin, are associated with fine-grained, black to dark green-colored dunites. Based on the intimate field relationship of the harzburgites and dunites, these dunites may also be of residual origin (e.g., Quick, 1981; Arai, 1994). Later mineral chemistry analysis will have to bear this out. The outcrops encountered range from massive to intensely sheared especially in the vicinity of thrust faults.

Surprisingly, in Barangay Cantiguas, Alicia, two round mounds which look exactly like the limestone mounds of the Bohol Chocolate Hills (=limestone mounds), turned out to be harzburgites. The harzburgites and dunites, although both black to dark green in color, are differentiated on the basis of the percentage of orthopyroxenes or bastites present.

Gabbro, anorthosite, epidote, and serpentinite dikes cut several residual harzburgite-dunite outcrops. The epidote dikes are altered feldspar-rich dikes while ultramafic rocks are the protoliths of the serpentinite dikes. Whether all of these dikes are late stage intrusives, brought about by crustal melting or mantle – derived magmatism, or are unextracted frozen melts will have to be verified in future geochemical work (e.g., Benn et al., 1988; Girardeau and Mercier, 1991; Laurent, 1992).

In Barangay Tabunok, Duero, a series of NE-trending, SE-dipping thrust faults had emplaced harzburgites on top of pillow basalts. These pillow basalts themselves are thrusted over tuffaceous to cherty mudstones which could be the associated capping sediments of the ophiolite sequence (Fig. 3). Magnesites are noted on some sheared portions of the fractured harzburgite outcrops.

B. Layered Harzburgites – Dunites – Clinopyroxenites

In the Payao Road of Barangay San Antonio, Duero, an exposure reveals the presence of interlayered harzburgites, dunites, and clinopyroxenites (Figs. 1 and 2). A harzburgite horizon is noted within the clinopyroxenite layer. Although not very distinct, the apparent cumulate layering is N65E; 70SE.

The clinopyroxenites are coarse grained, ranging in color from olive green through yellowish green to black in color. The dunites are fine grained and black in color. The harzburgites, together with the dunites, are intensely serpentinized. The harzburgites have the characteristic bastite occurrence in a black matrix of

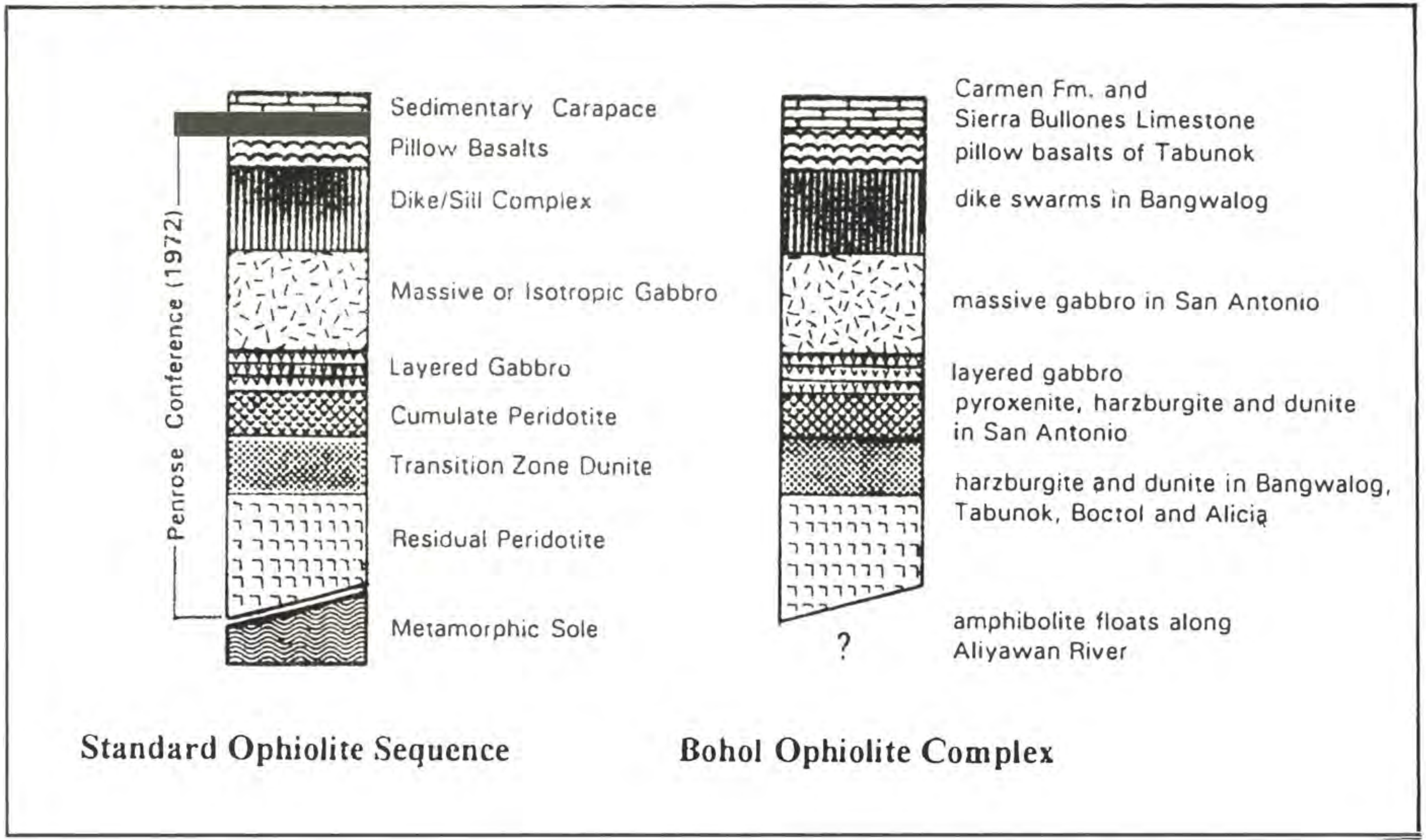


Figure 2. Comparison of the Southeast Bohol Ophiolite Complex with the Penrose-defined (Anonymous, 1972) oceanic crust-mantle sequence.

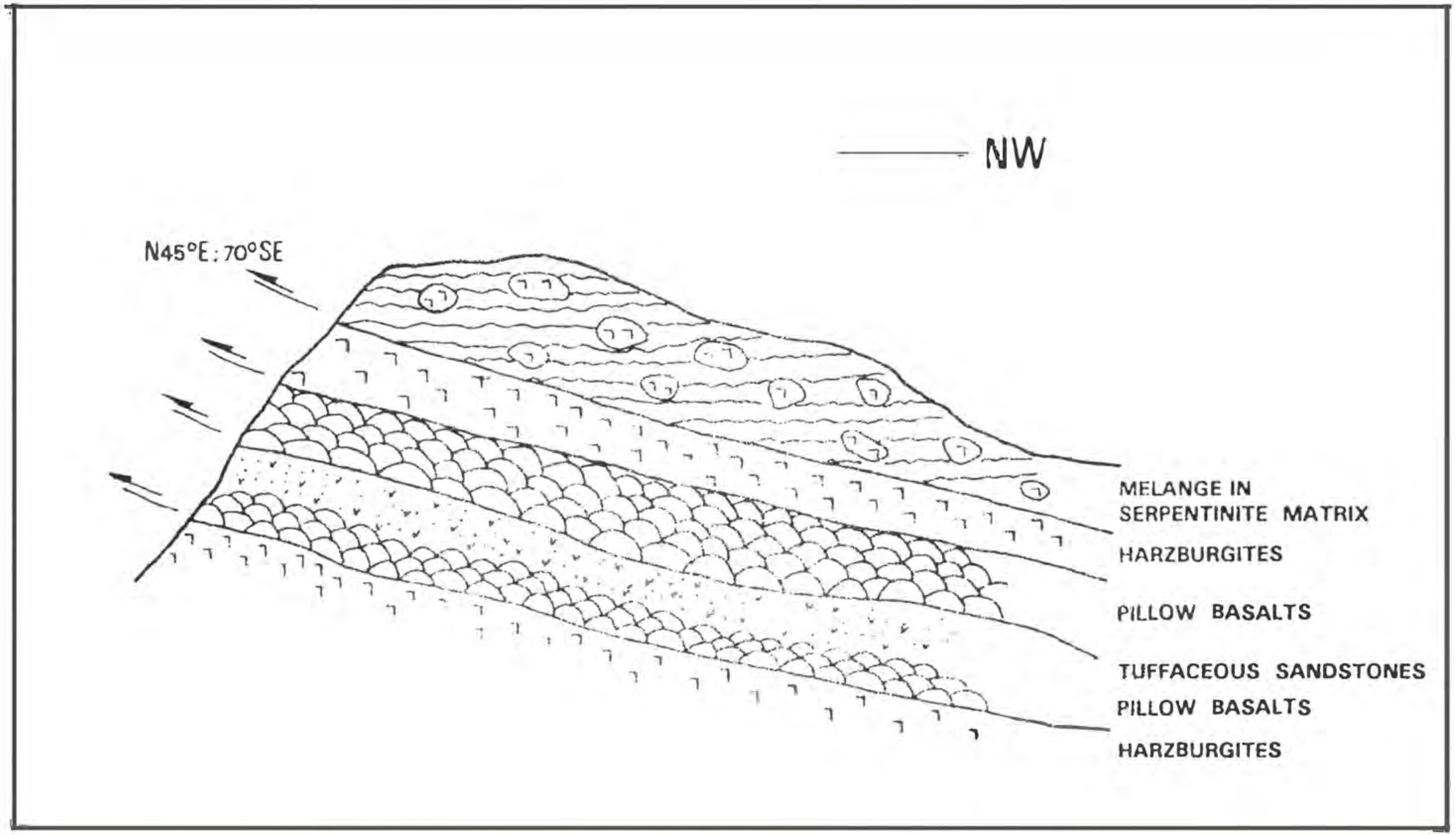


Figure 3. Schematic drawing showing the structural configuration of the thrusted harzburgites, pillow basalts, and sediments.

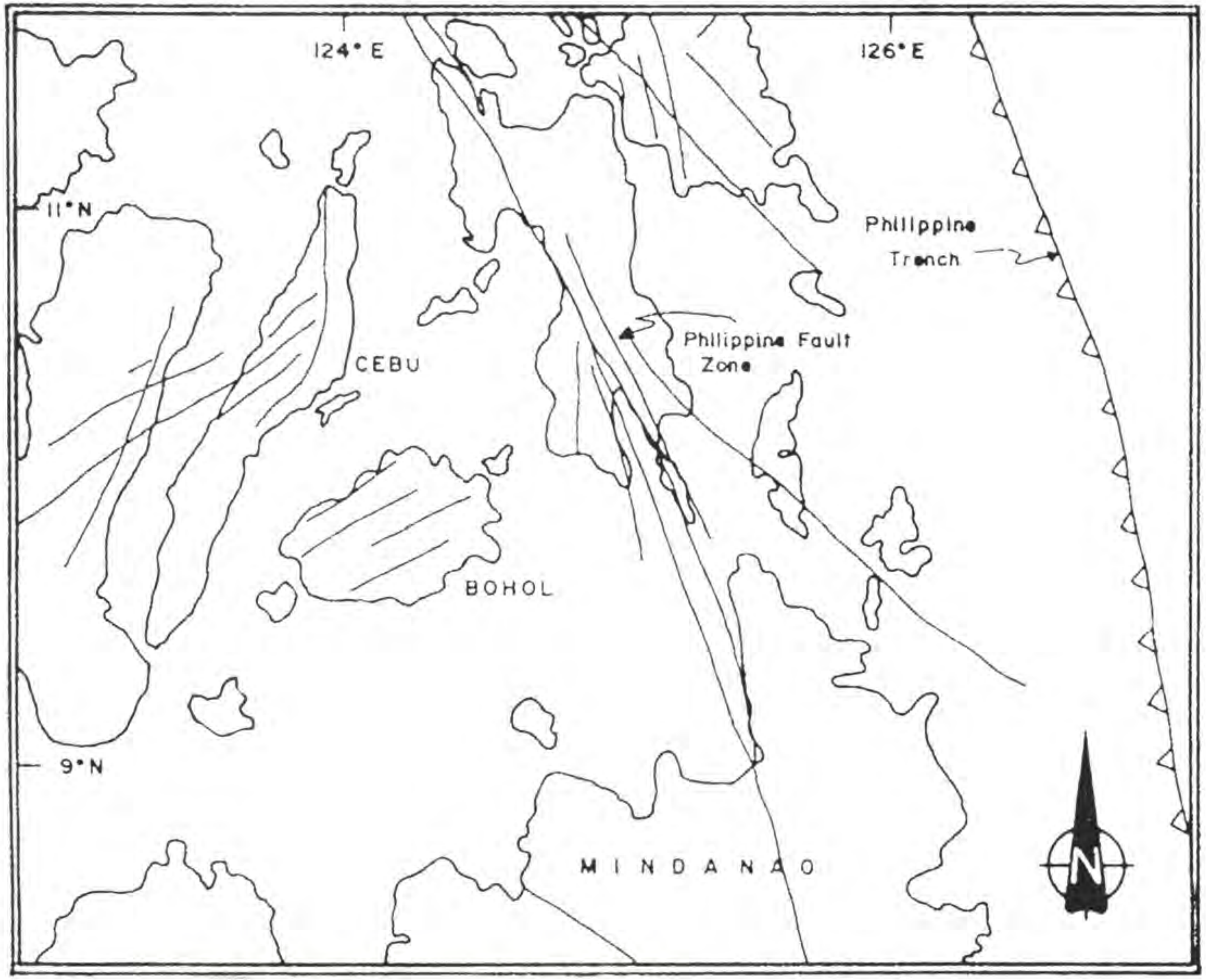
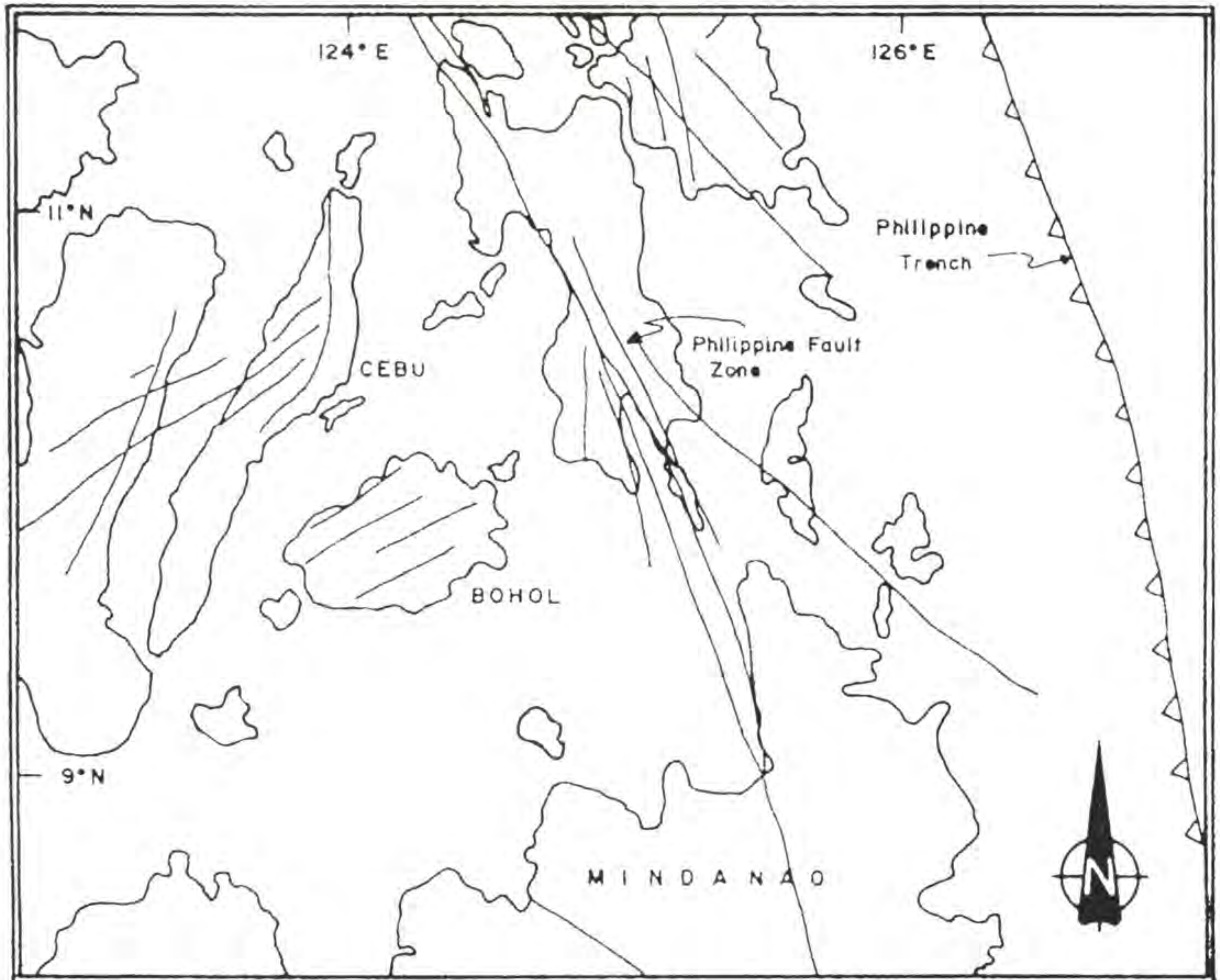


Figure 4. Major NE-SW trending fault structures in Bohol and Cebu islands together with available focal mechanism solutions.



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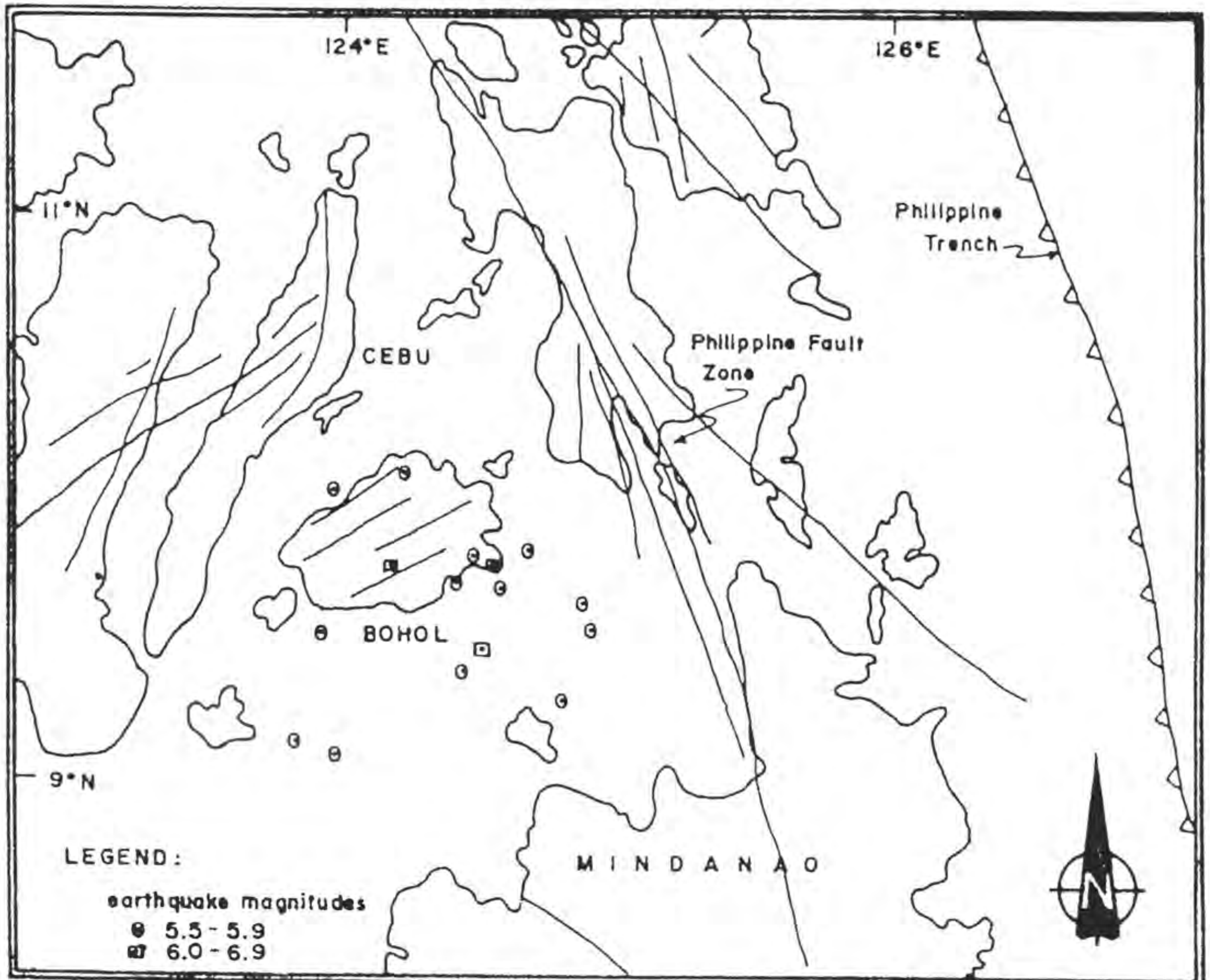

Figure 5. Focal mechanism solutions generally offshore of Bohol Island define a NE-SW trend.

DISCUSSION

A. Regional Fault Structures, Focal Mechanism Solutions, and the Southeast Bohol Ophiolite Complex: Evidence for a Proto-Southeast Bohol Trench?

An ophiolite sequence is an exhumed oceanic crust-mantle sequence that is emplaced on land through a variety of geologic and tectonic processes. From the bottom to the top, an ophiolite sequence is made up of residual harzburgites/ lherzolites, transition zone dunites, layered ultramafic to mafic cumulates, high level/ isotropic gabbros, sheeted dike/sill complex, and pillow basalts (Anonymous, 1972) (Fig. 2). Preliminary mapping and a reinterpretation of the existing geologic data of Bohol Island support the presence of a complete ophiolite sequence (e.g., BMG, 1982; Diegor and Matos, 1986; David et al., 1994).

The distribution and trends of the major fault structures in Bohol and, for that matter, in Cebu reveal that the general strike of these structures is NE-SW (Lanuza, 1994) (Fig. 4). In addition to this, the distribution of the available offshore focal mechanism solutions-earthquake hypocenter data also show a NE-SW direction (Fig. 5). Although this may be fortuitous, this is consistent with the NE-SW trend of Cebu Island, and to a certain degree, Negros and Bohol Islands, which obviously does not follow the NNW-SSE trend/ tectonic grain of this part of the Philippine archipelago. The islands of Samar, Masbate, Leyte, to name a few, and the trends of the Philippine Fault and the Philippine Trench all show a NNW-SSE direction (Fig. 4) (e.g., Barrier et al., 1990; Aurelio et al., 1991).

Assuming that there was no major rotation of Bohol and Cebu Islands, one way to account for the NE-SW trending fault structures in these islands and that of the focal mechanism solutions will be to have a major NE-SW trending structural break. This structure could have initiated the formation of these faults and earthquake records. Assuming present-day configuration, it is interpreted that the structures and earthquake data in Bohol and Cebu suggest the presence of a NE-SW trending proto-Southeast Bohol Trench (Fig. 6). This proto-trench is obviously at an angle with the present-day, major NNW-SSE structures in this part of the Visayas. Furthermore, it is possible that the generation and subsequent emplacement of the SBOC in its present position was intricately related to the past existence of a proto-Southeast Bohol Trench.

B. Cebu Cretaceous Arc – Southeast Bohol Forearc Ophiolite Complex – Proto Southeast Bohol Trench: Related Trench Arc System?

Assuming that a NE-SW trending proto-Southeast Bohol Trench was already in existence during the Cretaceous, this could have been responsible for the Cretaceous magmatism in Cebu Island (Balce et al., 1979; BMG, 1982; Mitchell et al., 1986) (Fig. 7). This magmatic arc body in Cebu is host to a major porphyry copper deposit (Divis, 1980). Should this scenario be correct, this places Bohol Island in

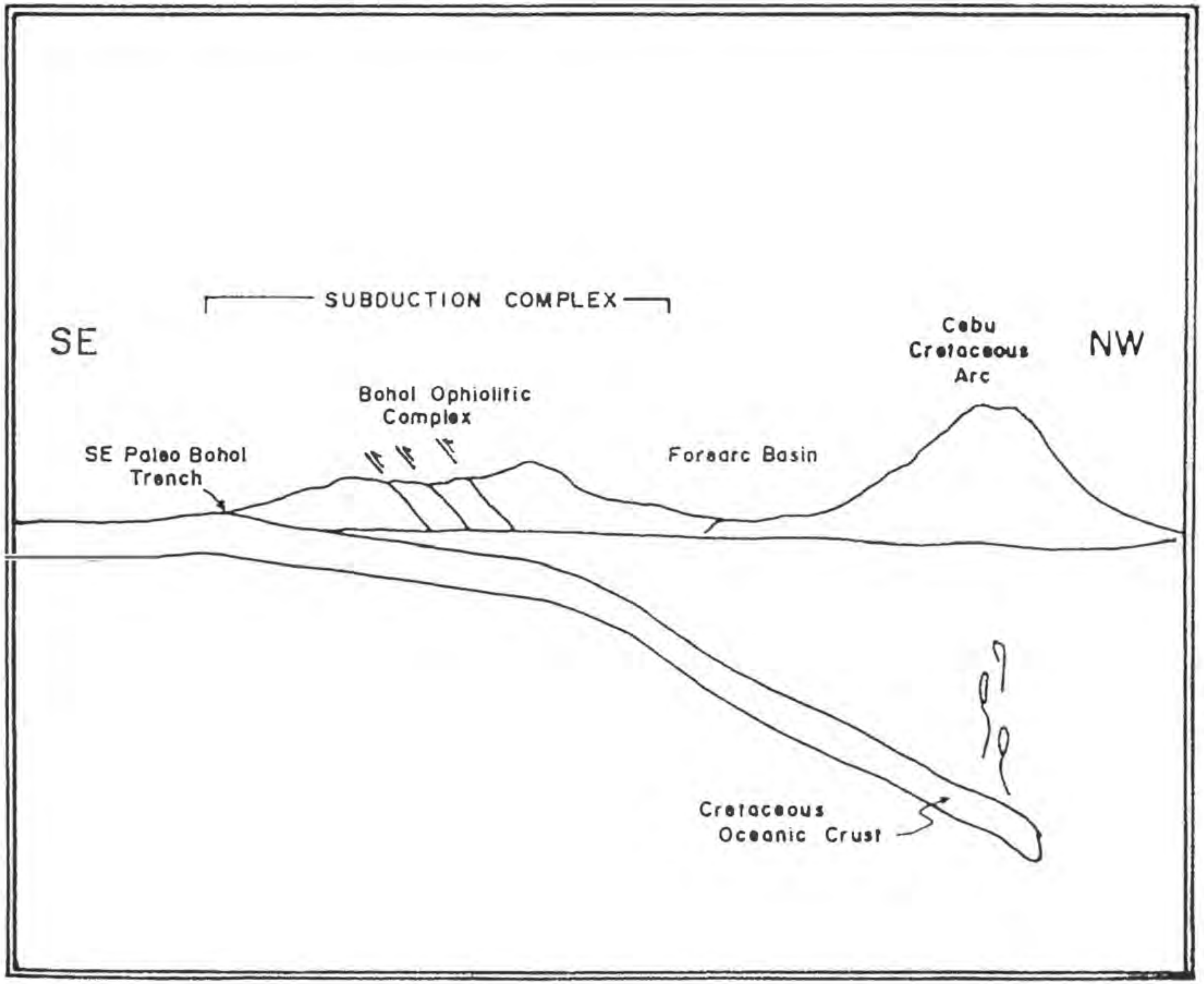

Figure 6. The presence of a NE-SW trending proto-Southeast Bohol Trench is inferred based on available fault and focal mechanism solution data.

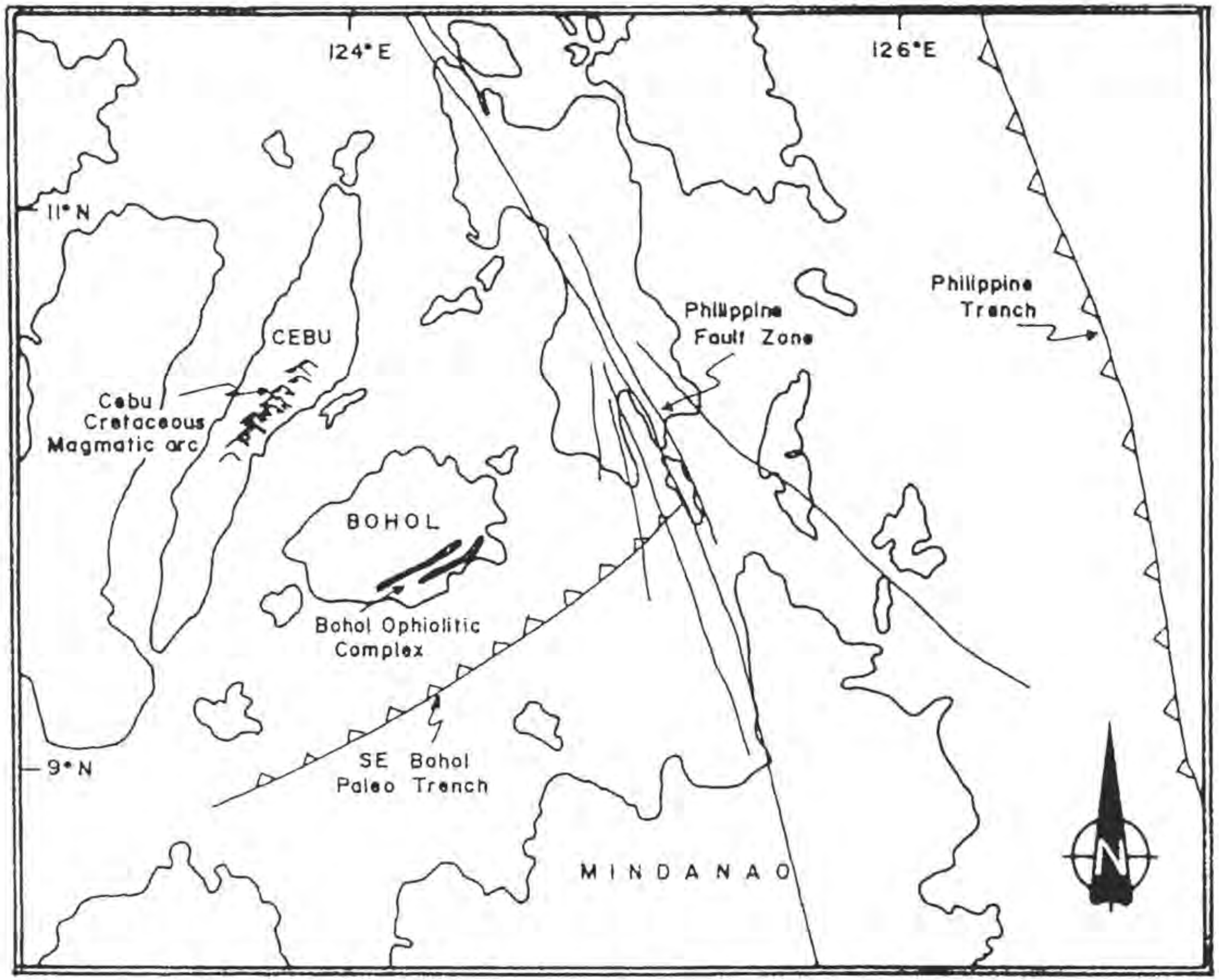

Figure 7. Schematic diagram showing the Cebu Cretaceous arc – Southeast Bohol forearc ophiolite complex – proto-Southeast Bohol Trench arc – trench system.

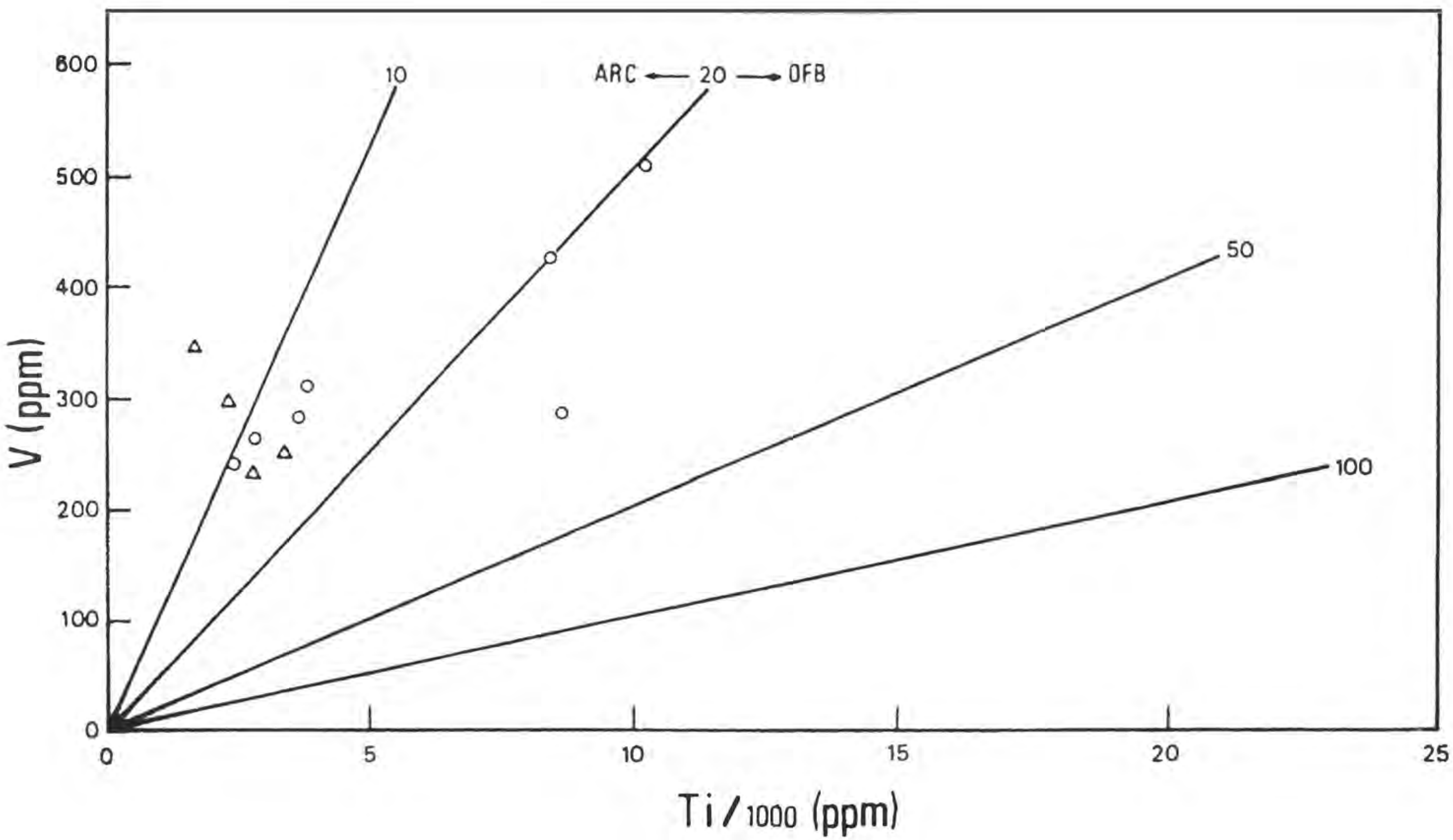

Figure 8. Whole rock Ti versus V diagram of Shervais (1982) shows that the basalts and diabases manifest island arc tholeiite to mid-ocean ridge basalt characteristics. O - basalt; Δ - gabbros.

between the Cebu Cretaceous magmatic are and the assumed proto-Southeast Bohol Trench.

It can then be argued that Bohol Island is in the forearc side of this proposed trench-arc system. Corollary to this, it can be concluded that the SBOC is actually a forearc ophiolite (Fig. 7). The generation and emplacement of this ophiolite complex, through possibly offscraping or lateral accretion, can be intricately related to processes associated with the proto-Southeast Bohol Trench (e.g., Tokuyama et al., 1992). Possible modern day analogues for this type of ophiolite complex and tectonic setting include the Marianas and the Halmahera Ophiolites and their associated trench systems (e.g., Bloomer, 1981; Ishii, 1985; Hall, 1990; Ballantyne, 1992).

Preliminary whole rock geochemical analyses of the basalts and diabases agree with this possible tectonic setting for the ophiolite complex. The analyses of basalts-diabases and gabbros expose a wide range of geochemical signatures characteristic of island arc tholeiites, mid-ocean ridge basalts and within-plate, alkaline basalts (Shervais, 1982) (Fig. 8). This range of rocks is found in other recognized forearc ophiolite complexes. The occurrence of basalts-diabases of varying geochemical signatures is attributed to the combination of spreading, subduction, and possible accretion of seamounts and/or ocean island materials (e.g., Pearce et al., 1984; Ishii, 1985; Hall, 1990; Yumul et al., 1993).

CONCLUSIONS

Reconnaisance geologic mapping of a portion of Southeast Bohol and reinterpretation of existing information suggest the presence of a complete ophiolite sequence in the island. The dominant NE-SW fault structures and distribution of focal mechanism solutions suggest the presence of a NE-SW trending paleo-Southeast Bohol Trench. The Southeast Bohol Ophiolite Complex is modelled here as a forearc ophiolite. The Cebu Cretaceous magmatic arc-Southeast Bohol forearc ophiolite complex-proto-Southeast Bohol Trench may be considered as an associated Cretaceous arc-trench system. Emplacement of the ophiolite complex could have involved various tectonic processes (e.g., offscraping or lateral accretionary processes). Geochemical, paleontological, and a more detailed mapping of the complex will definitely answer a lot of unanswered questions recognized during the preliminary work conducted.

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