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2

3 **West Timor: a key for the Eastern Indonesian geodynamic evolution**

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6

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14

15 *Key-words.* - Indonesia, Timor, Sulawesi, Sumba, Tectonic nappes, Overthrusts, Eocene, Oligocene and
16 Pliocene collisions, Neogene events, Palaeogeographic reconstructions.

17

18 *Abstract .* - Timor Island was at time considered as an example of “accretionary prism” linked to the collision
19 between the Australian block and the Banda arc. However, its geological evolution is more complex. Five
20 main superimposed structural units are distinguished in West Timor. The ~~today~~ structure is the result of three
21 main tectonic events that occurred during the Late Oligocene, Late Early Pliocene and Late Pliocene-Early
22 Pleistocene times, respectively. Our field investigations in the 1990 to 2000 decade completed with
23 geochemical analyses and K-Ar datings (Jurassic and Miocene ages) of magmatism allow to precise the
24 geodynamic evolution of Timor that can be summarized as follows: a first block was detached from
25 Gondwana (unit 2) and drifted to the Asiatic margin until the Late Oligocene when it collided with the
26 Asiatic active margin (unit 3). Then, the new block formed by ~~both 2 and 3 units~~ drifted to the South during
27 the Miocene and the Early Pliocene until it collided with the Australian margin (ASM), by the Late Early
28 Pliocene. Then, the Australian and Timor blocks moved together towards the North-North East during the
29 Late Pliocene until they collided with the Banda fore-arc (unit 4). Later on (Pleistocene), Timor Island was
30 capped by the “Autochthon” (unit 5) and then on (Quaternary?) by the Banda volcanic arc northward
31 thrust over the South Banda basin. Taking in consideration its close relationships with both the Australian

32 plate and the Eurasian one: Timor may be considered as a key area for building this geodynamical scenario
33 of Indonesia.

34

35 **Timor occidental : une clé de l'évolution géodynamique de l'Est Indonésien**

36

37 L'île de Timor **qui** a souvent été considérée comme un « prisme d'accrétion » lié à la collision entre
38 l'Australie et le bloc de Banda. Mais son évolution est bien plus complexe. Nous avons distingué cinq unités
39 structurales superposées dans Timor Ouest. Sa structure actuelle résulte de trois événements tectoniques
40 principaux intervenus respectivement : à la fin de l'Oligocène, à la fin du Pliocène inférieur et à la fin du
41 Pliocène ou au début du Pléistocène. Nos travaux de terrain effectués entre 1990 et 2000 complétés par des
42 analyses géochimiques et des datations Ar/K sur différentes roches magmatiques (du Jurassique et du
43 Miocène) nous ont permis de préciser l'évolution géodynamique de Timor.

44 Celle-ci peut être résumée ainsi : un premier bloc (Unité 2) s'est détaché du Gondwana au Jurassique et a
45 dérivé vers le Nord-Ouest pour entrer en collision avec la marge active asiatique (unité 3), vers la fin de
46 l'Oligocène. Ensuite, le bloc issu de la réunion des unités 2 et 3 a dérivé vers le Sud, du Miocène au Pliocène
47 inférieur, grâce à l'ouverture des bassins de Banda (Nord puis Sud) et ce jusqu'à ce qu'il entre en collision
48 avec la marge Nord du bloc australien (ASM), vers la fin du Pliocène inférieur. Puis l'ensemble formé par
49 l'Australie et Timor se déplace en direction Nord-Nord Est durant le Pliocène supérieur jusqu'à ce qu'il
50 rencontre le **fore-arc** de Banda (unité 4). Au Pléistocène, l'île de Timor est partiellement recouverte par de
51 dépôts de bassins (unité 5 autochtone). Enfin au Quaternaire, l'ensemble est charrié sur le bassin de Banda
52 Sud qui commence à « subduire » sous Timor.

53 Ainsi l'île de Timor qui contient des terrains appartenant à la fois au Gondwana et au bloc asiatique peut être
54 considérée comme une des clefs géologique pour la reconstitution géodynamique de l'Indonésie orientale.

55

56 *Mots-clés.* -Indonésie, Timor, Sulawesi, Sumba, Nappes, Charriages, Collisions, Eocène, Oligocène et
57 Pliocène, événements tectoniques au Néogène, Reconstructions paléogéographiques.

58

59 **INTRODUCTION**

60 Timor Island is located in the southern part of East Indonesia [Fig. 1a] south of the Banda volcanic arc. This
61 island is politically separated in two parts: the western part belonging to the Indonesian country and the
62 eastern part which has been detached from the Portuguese colonial domain since 1976. Thus, these two parts
63 were always geologically investigated separately. The study area, which corresponds to the current
64 Indonesian province, extends over 170 km from Kupang, to the West, to Atambua, to the East, and 100 km
65 from Wini, to the North, to Kolbano, to the South.

66 At first, the very complicated structure pointed out the island as a huge "tectonic melange" [Hamilton 1979].
67 But the Asiatic origin of some "terrane" [Villeneuve et al. 2004, Harris 2006], does not favour a simple
68 "accretionary prism" between the Australian block and the Banda volcanic arc. Since the beginning of the
69 20th century, an "overthrust structure" has been evidenced by Dutch geologists and three different terranes
70 have been distinguished: the "Allochthon", the "Para-autochthon" and the "Autochthon" units.

71 Our geological investigations have been carried out in the frame of "French Indonesian programs" including
72 studies both on land and sea basins over the eastern part of Indonesia including Kalimantan, Sulawesi and the
73 "Banda" basins and islands. These "cooperative programs" lasted ten years, from 1990 to 2000 and bring a
74 lot of new data recently summarized by Villeneuve et al. [2010], but the main results concerning the Western
75 Timor area have not been published yet excepted the stratigraphic data [Harsolumakso et al. 1995,
76 Villeneuve et al. 2005] and the origin of units [Villeneuve et al. 2004]. The structural framework and its
77 geodynamical interpretation supported by new data, are the main topic of the present paper.

78

79 **PREVIOUS WORKS**

80 The first investigations in West Timor were conducted by Wanner [1913], Molengraaff [1915], Tappenbeck
81 [1939] and De Waard [1955] which confirmed the "thin skin thrust structure" of "metamorphic massifs" over
82 the sedimentary units. On the contrary, Fitch and Hamilton [1974] proposed a "tectonic mélangé structure".
83 On the other hand, Carter et al. [1976a and b] and Barber et al. [1977] favoured a "low angle thrust fault" on
84 the Australian margin. Indonesian geologists from the GRDC [Research and Development Centre, Bandung]
85 or from the ITB [Institute Technology Bandung] work there from 1974 to 1986 under control of Rosidi et al.
86 [1979]. Many graduate students from the London University choose West Timor for their theses: Earle
87 [1981], Charlton [1987], Bird and Cook [1991], Harris [1991] and Barkham [1991]. Australian geologists
88 from the Flinders University also devoted their attention to the geology of West Timor as Chamalaun

89 [1977a], Hailé et al. [1979]. Harris [1991] provided a new tectonic model for the “overthrust” and Sawyer et
 90 al. [1993] published the “Amoseas Indonesia Inc.” geological researches. Other investigations were
 91 performed during the 1982 Snellius II Dutch-Indonesian program [Sopaheluwakan, 1990, De Smet et al.
 92 1990 and Van Marle 1991] by the Santa Cruz University program and by the French-Indonesian cooperative
 93 program [Harsolumakso 1993, Villeneuve et al. 1999]. Since this time only Martini et al. [2000], Harris and
 94 Long [2000], Villeneuve et al. [2004 and 2005] and, Harris [2006] published some papers on West Timor.

95 A lot of papers dedicated to the geology of East Timor and its adjacent areas highlighted the Banda outer
 96 arc geodynamic model, such as: Gageonnet et Lemoine [1958], Lemoine [1959], Audley-Charles [1968],
 97 Carter et al. [1976b], Charlton [2002], Kaneko et al. [2007], Ishikawa et al. [2007], Haig et al. [2008],
 98 Standley and Harris [2009], Charlton et al. [2009], Rosmawati and Harris [2009], Kadarusman et al. [2010],
 99 Keep and Haig [2010]. Despite some ~~consequent~~ stratigraphic results a large discussion arose concerning the
 100 pattern and the chronological setting of the nappes, the timing of tectonic events, the origin of the different
 101 units and the integration in a geodynamic model.

102 Three geodynamic models have been proposed: an “imbricated model” [Fitch and Hamilton, 1974;
 103 Hamilton, 1979], an “overthrust model” [Wanner 1913, Carter et al. 1976a, Barber 1979, Harris 1991] and a
 104 “rebound model” proposed by Chamalaun and Grady [1978] taking into account a lot of vertical faults.

105 Our investigations performed in the framework of the “Geobanda group”, lead to propose a different
 106 scenario for the West Timor evolution.

107

108 **STRUCTURAL FRAMEWORK**

109 New geological data and six new dating on Timor island ~~allows us~~ to present a new structural sketch map
 110 and an original North-South synthetic cross-section.

111

112 **Geological scheme** (fig. 1)

113 The geological scheme of West Timor (fig. 1b) modified from Rosidi et al. [1979] shows the main geological
 114 units together with the main thrusts. Three major geological structures have been distinguished:

115 1 The northern Banda terranes (“Manamas and Atapupu complex”) located in the northern part of the
 116 island and corresponding to the “Banda” formations, that were recently (Late Pliocene-Pleistocene) thrust
 117 over the Island (T5, T6 and T7).

118 2 The “Timor belt” that comprises several sedimentary and metamorphic complexes ranging from the
 119 Permian to the Mid-Pliocene is strongly deformed and largely thrust (T1, T2, T3, T4) at several periods.
 120 The geological scheme (fig. 1b) points out two sets of thrusts: the “Oligo-Miocene” thrusts (T3 and T4) and
 121 the “Plio-Pleistocene” thrust (T2). The East-West thrust (T2) ~~affects~~ both the Miocene and the Early Pliocene
 122 (possibly the Late Pliocene?) sediments, together with older units and thrusts (T3 and T4). T3 and T4 thrusts,
 123 cut by the Plio-Pleistocene thrusts (T5, T6 and T7), are older and likely of Late Eocene or Early Oligocene
 124 period.

125 3 The “Central basin” that covers a large part of the area is composed by ~~non~~ deformed or ~~locally slightly~~
 126 ~~deformed~~ sediments deposited since the Late Miocene. Several unconformities have been distinguished
 127 between the deformed and the undeformed sediments.

128 North-South elongated fault, the “Beli fault”, ~~is limiting~~ the East and West Timor countries. Owing the
 129 geological map a sinistral strike-slip motion is suspected [Snyder et al. 1996].

130 Classically three main “terrane” have been distinguished in the Timor Island: the Autochthon, the
 131 “Allochthon” and the “Para-autochthon”. However, each “terrane” includes many other subdivisions named
 132 “units”. At least six lithostructural units, including nine groups and several formations, have been evidenced
 133 (see after).

134

135 **The interpreted geological cross section** (fig. 2)

136 The schematic cross section between Wini [to the North] and Kolbano [to the South] points out the main
 137 complexes, groups, formations and thrusts.

138 From North to South, we successively recognize: the “Manamas complex” thrust over the “Mutis and
 139 Boi metamorphic complex” and the “Palelo” formations themselves thrust over the “Maubisse and
 140 Kekneno–Tumu groups”. All these units are supposed to rest on an old metamorphic basement that does not
 141 presently crop out. To the South, the Maubisse and Kekneno-Tumu groups were thrust over the Kolbano
 142 group. North of Kolbano (fig. 2c), a part of the Kekneno-Tumu group is thrust over the Kolbano group and
 143 to the North, several gabbro-dioritic “plots” intruded the “allochthon” terranes.

144 In the Noil Toko (or Noetoko) river (fig. 2b), the “Noetoko” group of Lower to Middle-Miocene age is
 145 stressed between two metamorphic massifs: the “Miamoffo” and the “Booi” (Boie or Boii) massifs belonging

146 to the “allochthon terranes”. Several post tectonic oolitic limestones klippen (Cablac limestones) set
147 unconformably on top of the “allochthon terranes”.

148 Finally, outcropping between Niki-Niki and the Sabau River, the flat central basin (Autochthon unit) is
149 limited by normal faults. This cross-section shows several “normal” faults likely related to the Timor trough
150 and North Banda basin opening.

151

152 **ADDITIONAL DATA**

153

154 **Geochronological data**

155

156 Excepted five Neogene apatite fission tracks ages recorded from sedimentary rocks of the northern Kekneno
157 inlier [[Harris et al. 2000](#)], only five radiometric data have been performed on West Timor previously (table
158 2). mainly on metamorphic rocks collected in the Booi and Mutis massifs.

159 According to [Sopaheluwakan \[1990\]](#) these results express an ophiolitic “obduction” or basement thrusting
160 ages rather than the protolith ages.

161 K-Ar results which are listed in table 1 have been carried on six magmatic rocks collected:

162 in the volcanic complex in the Metan formation (sample BP 9);

163 in the Mutis massif (sample T 23);

164 south of Wini (sample T 109b from the Manamas basaltic complex and sample T 111 from a gabbro-dioritic
165 body, south of the volcanic formation of Oecusse);

166 and in the Atapupu ultrabasic complex (sample ATTP1 and sample ATTP2)

167 Finally, four groups of ages have been evidenced: during the Mesozoic (at 157 to 149 Ma and circa 118 Ma),
168 in Late Eocene to Early Oligocene (37 to 32 Ma), in Middle to Late Miocene (14 to 10 Ma) and in Pleistocene
169 (1.59 Ma).

170

171 **Geochemical data**

172

173 Geochemical analyses for major and trace elements by ICP except for Rb by AAS have been performed. One
174 may note that all these magmatic rocks have a loss on ignition (wt. % LOI) varying between 1.6 % for the
175 freshest ones (ATTP lavas) and up to 6 % for the most altered (T 23).

176 BP9: This basic lava (wt% SiO₂ at 56.2) is a normal CA andesite, which shows the typical negative
177 niobium anomaly may be considered as the witness of an arc activity.

178 T 23: This basalt (wt% SiO₂ at 45.5) contains normative nepheline (13%) Its spidergram with a
179 positive niobium anomaly may be interpreted as that of a “continental” alkaline basalt. These two
180 “Jurassic” rocks show different affinities that can be related to probably two different geodynamical
181 contexts.

182 T 109B: This basic lava (wt% SiO₂ at 52.0) contains normative quartz and hypersthene and is K₂O-poor
183 (wt.% at 0.39). Its spider diagram shows a positive niobium anomaly.

184 T 111: This gabbro-diorite (wt% SiO₂ at 50.1) with normative quartz and hypersthene normative. is K₂O-
185 poor (wt.% at 0.31). It shows a flat REE diagram and no niobium anomaly.

186 ATTP 2: This K₂O-poor (wt.% at 0.25) lava which is more differentiated (wt% SiO₂ at 57) than T 109
187 B or T 111 shows quite similar concentrations for trace elements.

188 ATTP 1: is a K-rich (wt.% at 3.88) CA basic lava (wt% SiO₂ at 53.3), rich both in strontium (1045
189 ppm) and baryum (1650 ppm), that can be classified among the shoshonitic lavas encountered as in a
190 arc or a back-arc framework.

191 Geochemical analyses indicate different geodynamical origins. Apart T23 most of them can be related
192 to volcanic arc or back arc basins.

193

194 **Metamorphic data**

195

196 Most of the formations consist of sedimentary rocks and few of them were affected by metamorphism. [Harris](#)
197 [et al. 2000](#) applied the “vitrinite reflectance”, “Illite cristallinity, “conodont alteration” and “apatite fission
198 track” to these sedimentary rocks. Most of them are in the diagenetic zone and do not exceed 100° in
199 temperature that is consistent with the peak temperatures for the Gondwana sequences [100-150°]

200 So, only the allochthon massifs evidenced by [Brouwer \[1942\]](#) and [Barber and Audley-Charles \[1976\]](#)
201 suffered a metamorphic event but only three of them: Booi, Miomaffo and Mutis were deeply investigated
202 respectively by [Earle \[1981\]](#) and [Sopahuluwakan \[1990\]](#).

203 In the Booi massif: [Earle \[1980\]](#) reported a “basement” composed of pelitic and “mafic gneisses overlies
204 by a dismembered “ophiolite” including peridotite and “metagabbros” stacked in reverse order. [Barber and
205 Audley-Charles \[1976\]](#) reported a high proportion of pyrope in almandine garnets indicating a granulite
206 facies.

207 In the Mutis and Miomaffo massifs main rocks are: metabasites and metatuffs (Amphibolitic to
208 greenschist facies), metapelites (greenschist facies with staurolite and garnet zone), peridotite and granulite
209 (or garnet-mica-staurolite –kyanite schists) with few gabbros. Bluechists are associated to these rocks. Due to
210 numerous tectonic contacts, relationships between them are unknown. [Sopaheluwakan \[1990\]](#) considered
211 an inverted metamorphic zonation (albitic, chloritic, biotitic, garnet and staurolite zone) from the base to the
212 top. Despite a lot of strong tectonic contacts, he concluded to a metamorphism generated by an obduction of
213 peridotites (part of ophiolitic sheet) over metapelites or schists. Age of this “obduction” was around 37-32
214 Ma. But, the metamorphic age (118 Ma) recorded in gneisses of the Booi massif does not favoured the
215 [Sopaheluwakan \[1990\]](#) interpretation. However, [Barber and Audley-Charles \[1976\]](#) favoured an Australian
216 basement origin. They also talked of a possible “Sundaland” origin but previous hypotheses taking into
217 account an Indian Ocean piece trapped in the Banda area prevented to consider a Sundaland origin.

218 Another high grade metamorphism was related to the emplacement of Atapupu complex by [Helmerts et al
219 \[1989\]](#). After that, pelitic and mafic rocks located underneath the peridotite suffered a metamorphism to over
220 800°C at 6 to 7 Kbar. The lustrous slates in the Aileu massif (Maubisse group) in East Timor, dated by [Berry
221 and Mac Dougall \[1986\]](#) between 8 and 5.5 Ma, are linked to the Atapupu peridotitic emplacement.

222 So there are, at least, three main metamorphic events: around 118 Ma in the Booi massif, around 37-32 Ma in
223 the Mutis and Miomaffo massifs and around 8-5.5 Ma at the base of the Atapupu complex. The last two ones
224 can be clearly associated to different “ophiolitic” obductions.

225

226 **Paleomagnetical data.**

227 Several paleomagnetic investigations have been carried out on Timor, by Wensink and Chamalaun.

228 Chamalaun [1977a] evidenced a paleoposition for the Permian Cribas formation [base of the Kekneno Tumu
 229 group] very consistent with the Permian Australian position. Then Chamalaun [1977b] found a similar
 230 paleoposition for the Permian part of the Maubisse group, which prevents the Audley-Charles hypothesis
 231 [1968] on the Sundaland origin for this group. Wensink et al. [1987] evidenced a paleopole located 1200km
 232 south of the present position for the Nakfunu formation [Lower Cretaceous part of the Kekneno-Tumu
 233 group]. That was also the location of the Northern Australian continent. Later on [Wensink and
 234 Hartosukohardjo, S., 1990] propose a paleoposition at 17° in the northern hemisphere for the Metan volcanics
 235 and finally an in situ paleoposition for the Late Miocene Manamas volcanics. In addition, this volcanic
 236 complex suffered a 40 to 60° counterclockwise rotation since the Late Miocene. Unfortunately they are the
 237 only paleomagnetic results known on West Timor.

238 **THE MAIN LITHOSTRUCTURAL UNITS (fig. 3)**

239
 240 Most of the groups and formations mentioned above come from the literature. But there are a lot of non
 241 mentioned stratigraphic groups and formations bearing local names.

242 Accordingly, three main “terranes” have been distinguished, from North to South:

243 -The “Banda terranes” (BT) to the North including the Quaternary deposits (autochthonous deposits).

244 -The “Timor terranes” (TT) including all the others formations outcropping in Timor Island.

245 -The “Northern Australian terranes” (AT) also called Timor Gap (TG); never outcrop in the area are deduced
 246 from the geodynamic context. They belong to the current Australian margin which is currently “subducting”
 247 beneath the Timor Island and the Banda volcanic arc [Crostella, 1977]. The metamorphic basement of the
 248 Australian margin and its sedimentary cover are drawn in figure 3. The T1 thrust located on top of the
 249 Australian passive margin sedimentary cover can be considered as an equivalent of the “subducted” plane on
 250 top of the trench.

251 Five units (1 to 5) have been distinguished in the Banda and Timor “terranes”, each one including several
 252 groups and formations. A diagram (fig. 3) presents these main structural units with from the top to the base:

253 Unit 5 (Autochthon unit) is formed by 1500 m of marine and clastic sediments (the “Noele” group-G9)
 254 mainly deposited in the central basin (Soe basin) and along the coasts. It includes reefs limestones and
 255 Quaternary sediments.

256 Unit 4 (Sub-autochthon) which is separated from the unit 5 by the D4 structural unconformity, includes
 257 several groups, formations and complexes. Three “groups” have been distinguished:

258 The volcano sedimentary group (Viqueque group G8) including the “Viqueque formation” of Upper Pliocene
 259 age, which is locally deformed.

260 The northern volcanic and metamorphic group (Wini group G7), including the “Manamas basaltic complex”
 261 dated at 10.35 ± 2.20 Ma (basalt T109 B, table 1) (Upper Miocene) and the “Atapupu ultrabasic complex”
 262 dated at 14.10 ± 1.00 Ma (basalt AATP2 table 1) (Middle Miocene) and the “Aileu metamorphic complex”
 263 in East Timor. The latter includes material originated from the “Maubisse group” [Permian to Cretaceous
 264 deposits] but metamorphosed during the Lower to Middle Miocene [Berry and Grady, 1981]. The “contacts”
 265 between the different “complexes” belonging to the G7 group are tectonic (T6 and T7 thrusts).

266 The G6 group (“Batuputih group” includes the “Batuputih” formation consisting of white calcarenites,
 267 calcilutites and calcareous sandstones and the “Bobonaro” formation consisting of breccias and
 268 conglomerates that were deposited during the Upper Miocene to Lower Pliocene. This group is separated
 269 from the “Viqueque formation” by the D3 unconformity. The “Batuputih formation” is involved in the
 270 Middle Pliocene thrusts while the Manamas, Atapupu and Aileu complex were thrust over Timor (T5)
 271 either during the Middle-Pliocene or at the end of the Pleistocene. The second hypothesis seems to be more
 272 valuable taking in consideration direct covering by the Quaternary group G9.

273 Unit 3 (Allochthon) is represented by two groups (G4 and G5) separated by the D1 angular
 274 unconformity. The Noetoko group (G5) is separated from the “Bobonaro breccias” and Batuputih calcilutites
 275 by the D2 unconformity. It includes the “Miamoffo” volcanic tuffs and the “Cablac” oolitic limestones.
 276 Barber [1979] included the “Cablac” limestones in the “Noetoko” sedimentary group (Lower to Middle
 277 Miocene). In fact, the “Cablac” name is properly inappropriate because it corresponds to “oolitic limestones”
 278 with different ages (i.e. Permian, Triassic or Lower Miocene) outcropping mainly in East Timor and firstly
 279 described by Gageonnet and Lemoine [1958]. Recently, Haig et al. [2008] ascribed the “Cablac” limestones
 280 from the “type area”, to the Upper Triassic or Lower Jurassic rocks. The G5 group is intruded by “dioritic”
 281 dykes (T111) displaying an Upper Miocene age (10.55 ± 1.60 Ma) (table 1).

282 The Palelo group (G4) includes several sedimentary and volcano-sedimentary formations as well as
 283 metamorphic complex. It is separated from the G5 by the D1 unconformity.

284 The sedimentary succession (i.e. Palelo, Haulasi and Noni formations) exhibits successively: Upper
285 Cretaceous cherts, Paleocene to Eocene sandstones interbedded with Eocene lava-flows and Eocene
286 Nummulitic limestones.

287 The volcanic complex (Metan formation) consists of basaltic lavas displaying a Late Jurassic age (BP9 dated
288 at 149.7 ± 3.3 Ma, table 1).

289 The “metamorphic complex” well studied by [Sopaheluwakan \[1990\]](#) outcrops in the Mutis, Miamoffo and
290 Booi massifs. The metamorphism is known as Middle Cretaceous [[Earle, 1981](#)] in the Booi massif, but basic
291 rocks from the Mutis massif displays a Jurassic age (162 Ma) according to [Harris \[2006\]](#) and a basalt (T23) is
292 dated at 157.4 ± 3.4 Ma (table 1). The main tectonic event (T4 thrusting) related to the “Mutis” massif
293 “obduction” over the “Maubisse group” occurred at the end of the Eocene or during the Oligocene
294 [[Sopaheluwakan, 1990 and Villeneuve et al., 1999](#)]. [Harris \[2006\]](#) delivers a lot of new ages which support
295 an exhumation of these massifs, from 550 m (below surface) to the surface, between 36-28 Ma. This
296 “allochthon” unit is sealed by the “Noetoko formation” belonging to the Batuputih group (G5).

297 Unit 2 (Para-allochthon) includes two groups (G3 and G2). The Maubisse group (G3) contains several
298 sedimentary rocks (Permian and Triassic limestones, Jurassic and Cretaceous shales, radiolaritic and volcanic
299 rocks). The Kekneno-Tumu group (G2) is characterized by Permian pelitic sandstones and Triassic shales
300 associated with Cretaceous to Paleocene-Eocene radiolaritic rocks. G3 and G2 are separated by the T3 thrust.

301 Unit 1 (Para-autochthon) is represented by the Kolbano group which contains limestones, shales and
302 calcilutites ranging from the Jurassic to the Lower Pliocene. It is tectonically overlain (T2 thrust) by the 2
303 and 3 units and parts of the 4 unit and sealed by the “Viqueque” group (G7)

304 Lithostratigraphic units (fig. 3) also reflect the geological evolution of Timor, and from the older to the
305 younger one, successively: T4 (Oligocene), T2 (Late Pliocene) and T5 (Late Pleistocene) thrusts are
306 displayed..

307

308 **DISCUSSION and GEODYNAMIC EVOLUTION**

309

310 Comparisons with adjacent areas (mainly Sulawesi) should be necessary to understand the origin of the
311 different “terranes” that have built Timor Island.

312

313 **Origin of Units**

314 Apart the modern Australian margin and the unit 5 (Autochthon unit), other units were displaced with respect
315 to the present position of Timor.

316 ***Unit 4 (Sub-autochthon)***

317 The Viqueque group (G8) (Upper Pliocene) was deposited after the collision with the Kolbano group (G1,
318 unit B). Taking into account a northward motion of the Australian continent, this deposition should occurred
319 to the south of the Timor present position.

320 The northern volcanic and metamorphic group (G7) is related to the “Banda” terranes. The “Manamas
321 basalts” T 109 B have been dated at 10.35 ± 2.20 Ma (table 1) and basalts from the “Atapupu ultramafic
322 complex” display an whole rock age of 14.10 ± 1.00 Ma (table 1). Gabbro dioritic intrusions (T 111) dated at
323 10.55 ± 1.60 Ma (table 1) were piercing the Maubisse group (G3), thus indicating that a Late Miocene
324 volcanic arc was operating there. Part of this volcanic arc was thrusting onto the Maubisse formations, at least
325 after the “Viqueque formation” deposition (Upper Pliocene or Early Pleistocene?). Consequently, the
326 “Manamas” basalts should be in a more northern position than presently but not so far from this latter,
327 according to [Wensink and Hartosukohardjo S. \[1990\]](#). Previous datings from Flinders University [[Rosidi et](#)
328 [al. 1979](#)] and from [Abbot and Chamalaun \[1981\]](#) provide several ages between 6 and 4 Ma. These ages are
329 consistent with a South Banda Neogene volcanic arc [[Honthaas et al. 1998](#)]. According to [Berry and Grady](#)
330 [[1981](#)] similar formations in East Timor were thrusting on the mainland Timor around 5 to 4 Ma.

331 The 1.59 ± 0.07 Ma age for the ATT P1 basaltic dykes (table 1) postdate the thrusting.

332 The Batuputih group (G6) capping the Noetoko group, is involved in the tectonic event which affected the
333 Kolbano group. Its location at the time of deposition is unknown.

334 ***Unit 3 (Allochthon unit).***

335 The G5 group (Miocene), deposited before the Kolbano group deformation, is related to the southern Banda
336 volcanic arcs and consequently should be in a northern position with respect to the Miocene Timor mainland.

337 The origin of the Palelo group (G4) has long been discussed, and specially its metamorphic complex. Most of
338 the authors supposed a local origin [[Tappenbeck 1939](#), [Barber 1979](#)] or a sub-local origin [[Sopaheluwakan](#)
339 [1990](#)]. Only [Haile et al. \[1979\]](#) pointed out a possible relationship between the Mesozoic “cherts” of Timor

340 and Sulawesi. However, owing to a lack of information concerning the Banda Sea origin [first considered as
 341 an Indian Oceanic fragment by Lapouille et al. 1985] they were unable to link Sulawesi and Timor islands.
 342 Then, new dating [Réhault et al. 1994, Honthaas et al. 1998] on the Banda Sea floors [Upper Miocene to
 343 Pleistocene] allows us to propose a direct connection between West Sulawesi and Timor before the Banda
 344 seas opening [Villeneuve et al. 2004, 2005, 2010]. This hypothesis has then been enhanced by Harris [2006]
 345 and Standley and Harris [2009]. Therefore, taking into account:

346 1- the Neogene occurrence of Banda Sea basins [North and South Banda basins],
 347 2- the similarities between the Western Sulawesi volcanic rocks and those of the Palelo group [G4], we again
 348 support an Asiatic origin for the G4 rocks.

349 The similarities to what we refer are:

350 -The “Booi” metamorphic complex [Earle 1981, Brown and Earle 1983] and the West Sulawesi metamorphic
 351 substratum [Sukanto 1975] which display comparable metamorphic ages, at respectively 118 Ma and 110
 352 Ma

353 -The “Metan” volcanic formation in Timor (table 1) and the Lamassi-Bajo basaltic complex in Sulawesi
 354 [Priadi 1993] display a Jurassic age.

355 -The “Palelo” formation presents some close similarities with the Mesozoic succession of western Sulawesi.

356 -Finally, the Tertiary nummulitic limestones from the Timor “allochthon unit” [unit D] exhibits a terrestrial
 357 mammal [*Anthrocothere*] of Asiatic origin [Ducrocq 1996].

358 All these similarities enhance an Asiatic origin [close to Sulawesi] for the Timor unit 3 [“Allochthon”].

359 ***Unit 2 (Para-allochthon unit)***

360 The origin of Maubisse G3 and Kekneno-Tumu G2 groups is more discussed. The G2 group presents a
 361 similar stratigraphic succession than the Australian margin, from the Permian to the Jurassic time. But,
 362 the post Jurassic stratigraphic successions of the two areas differ from the Cretaceous to the Eocene
 363 [Harsolumakso et al. 1995]. However, Chamalaun [1977a and 1977b] indicates palaeomagnetic
 364 accordance between Timor and the northern Australian margin [including the G2 and G3 groups] by
 365 the Permian and Triassic times. Moreover, a palaeontological [pollens] and sedimentological study of
 366 the Upper Triassic [G2 group] in Timor reveals its high latitudinal position at the depositional time
 367 [Martini et al. 2000]. This high latitude is consistent with the position of the Australian plate during

368 the Upper Triassic time. It is important to be notice that [Wensink \[1987\]](#) pointed out the deposition of
369 Early Cretaceous sediments in G2 in an area situated at 1200 km to the North of the Early Cretaceous
370 Northern Australian margin palaeoposition. On the contrary, the palaeoposition of the Permian and
371 Triassic rocks of the Maubisse formation was discussed. [Audley-Charles \[1968\]](#) supposed a more
372 equatorial palaeoposition, according to the microfossils palaeoclimatic records, but the [Chamalaun
373 \[1977b\]](#) palaeomagnetic data confirmed by [Wensinck \[1988\]](#) indicate high latitude consistent with the
374 Triassic palaeoposition of the North Australian margin. Taking into account the lack of oceanic
375 remnants between the G2 and the G3 groups, we favour the Wensink's conclusion and propose a
376 common origin and evolution for the two groups. On the other hand, the trusting of this U 3 unit, of
377 Asiatic origin, let us to suppose a strong connection between Timor Island and the Asian active margin
378 at the thrusting time from Late Eocene to Early Miocene.

379 In conclusion, this part of Timor was first detached from the Australian margin (by the Jurassic
380 time) and then connected to the Asiatic margin at least by the Early Neogene.

381 **Unit 1 (*Para-autochthon*)** (e.g. the Kolbano group G1) is considered as a part of the current Australian
382 margin by [Crostella \[1977\]](#) even if the Australian margin sediments have likely incorporated the southern
383 Timor Neogene accretionary prism. Anyway, it should not be far from the present position of Timor Island
384 by the Mid-Pliocene time [[Villeneuve et al. 1999](#)].

385

386 **Main stages of the evolution of West Timor**

387

388 Taking into account the structure, the timing of events and the supposed origin of the units we
389 confidently propose a new scenario for the West Timor evolution (fig. 4).

390 ***From the Permian to the Eocene*** (fig. 4a), the northern Gondwana margin (A1) splitted in several
391 blocks by the Jurassic time. The Timor block, including the Kekneno-Tumu deposits (G2 group), the
392 Maubisse sediments (G3 group), and the Triassic to Jurassic basaltic lavas drifted away from the
393 Australian margin until it collided with the Asiatic margin (Unit 3 = Allochthon).

394 ***By the late Eocene to the Early Miocene*** (fig. 4b), the Unit 3 (Allochthon) was thrust over the
395 Maubisse group (G3), thrust itself over the Tumu-Kekneno group (G2). According to
396 [Sopaheluwakan \[1990\]](#) this thrust (T4) occurred around 37.5 Ma (Late Eocene). However, we cannot
397 know if the thrust separating the Maubisse formation from the Kekneno–Tumu formation (T3) is
398 contemporaneous with the T4 thrust. Then, the Timor area was covered by sedimentary rocks of the
399 “Noetoko group” (G5) together with volcanism likely related to a Miocene volcanic arc. That probably
400 has lasted until the Upper Miocene, when a set of calc-alkaline diorites (T 111 at 10.55 ± 1.60 Ma)
401 intruded the new Timor block.

402 ***By the end of Early Pliocene*** (fig. 4c) the new Timor block, including the Unit 3 (Allochthon)
403 collided with the Timor Gap formations (A2). Consequently, the whole new Timor block was thrust
404 (T2) over the Kolbano formation. As a result, the previous thrusts were rejuvenated and the Miocene
405 and Lower Pliocene sediments were likely folded and thrust during this collision.

406 ***By the Late Pliocene*** (fig. 4d) a period of extensive tectonic gave way to the central and marginal
407 basins as exemplified by the “Savu” basin and the “Timor” trough which were filled by sediments of
408 the “Viqueque” group G8.

409 ***By the Late Pliocene-Pleistocene boundary*** a new uplift was evidenced by [Van Marle \[1989\]](#).
410 This uplift should be related to the thrusting of the “Sub-autochthon unit” (“Manamas” and “Atapupu”
411 complexes] over the contemporaneous Timor block (T6 and T7). The “Viqueque group” (G8) was
412 likely deformed at that time, noticeably in the Mina area (West of Soe).

413 We notice that, during the Early Pleistocene, sediments were deposited in the central basin previously
414 to the current Timor Island uplift [[Jouannic et al. 1998](#)].

415

416 **Geodynamics**

417

418 We attempt to illustrate the geodynamic evolution of Timor and adjacent areas since the Eocene to the
419 present time. Because Timor can be considered as a “go between” for the Australian and Eurasian plates, it
420 is a “masterpiece” in the east Indonesian “puzzle”.

421 ***During the Eocene time*** (fig.5a), the northern part of the Indian Ocean [IO] was subducting underneath
 422 the Asiatic margin [AAM] until the collision between “Initial Timor” [tm1] and AAM, elsewhere south of
 423 Sulawesi and close to Sumba, by the Late Oligocene or the Early Miocene (fig.5b).

424 Then a new “subduction system” of the Indian Ocean skip over the new Timor Island given way to a Lower
 425 to Middle Miocene volcanic arcs (fig.5c), until the South Banda sea back arc basin (SBB) was opened in
 426 Late Miocene. Then a new volcanic arc took place to the South (fig.5e). In East Timor, [Keep and Haig](#)
 427 [\[2010\]](#) support a collision between the Banda arc and the Australian continent after 10.9- 9.8 Ma.

428 ***By the Middle Pliocene***, Timor and the northern Australian margin were connected and then the southern
 429 part of the South Banda basin (SBB) was thrust over the northern Timor (fig.5f).

430 ***Nowadays***, according to [Snyder et al. \[1996\]](#), the whole Timor block, including the southern Banda arc, is
 431 thrusting over the Banda basin floor owing to the north-eastward motion of the Australian block (fig.5g).

432

433 **Palaeogeography**

434 A palaeogeographic reconstruction of eastern Indonesia since the Late Miocene is shown in Figure 6.

435 ***Late Miocene*** (fig. 6a). At that time Timor was incorporated to the Asiatic margin and new subduction
 436 zones were operating to the South (2 and 3 in fig. 6a). This volcanic arc was extended to the Tukang Besi and
 437 Lucipara blocks which have collided Sulawesi around 13 Ma [[Silver et al. 1985](#)]. However, the North Banda
 438 Basin (NBB) was opened by the Early Late Miocene (10-9 Ma) according to [R hault et al. \[1994\]](#).

439 ***Late Miocene-Early Pliocene*** (fig.6b). This volcanic arc splitted and a new back-arc basin (the South
 440 Banda basin = SBB) opened and grew until the Middle-Pliocene [[Honthaas et al. 1998](#)]. The Late Miocene
 441 volcanic arc was operating in the southern part of the South Banda basin including the northern part of
 442 Timor. Another “subduction” zone was operating beneath the western margin of “Irian Jaya” (4 in fig. 6b).
 443 This time coincide, more or less, with the tectonic quiescent period (5-5-4.5 Ma) evidenced by [Keep and](#)
 444 [Haig \[2010\]](#). The Banda volcanic arc migrated to the North separating the “Savu basin” from the “South
 445 Banda basin”. This event approximately coincides with the post 4.5 Ma phase of uplift evidenced by [Keep](#)
 446 [and Haig \[2010\]](#).

447 ***Late Pliocene*** (fig. 6c). The “Sahul shelf” [current Australian margin] joined the Timor mainland and the
 448 Indian Ocean slab collapsed providing a regional extensional trend underlined by several sedimentary basins

449 within Timor. We suspect a new collisional event between the Timor block and the Southern part of the
450 South Banda basin (SBB) by the end of the Pliocene, when the “Viqueque formation” was locally folded and
451 the northern part of the U4 unit (G7) thrust over the Timor mainland.

452

453 **CONCLUSIONS**

454 Timor Island includes at least five different lithostratigraphic “units”. Thus, apart the current Australian
455 margin (A), the Pleistocene to Holocene sediments ascribed to the Unit 5 (Autochthon) and the Unit 3
456 (Allochthon unit) which includes some parts of the Asiatic margin, three others units have been evidenced:
457 Unit 1 (Para-autochthon), Unit 2 (Para-allochthon) and Unit 4 (Sub-autochthon). This Timor “assemblage”
458 results from a long and complex geological history.

459 At least three collisional tectonic events were involved in the Timor polyphased structure. Each one is
460 sealed by volcanic or volcano-sedimentary rocks. Because Timor was a kind of “shuttle” between the
461 Australian continent and the Asiatic margin, we consider this block as a geological “masterpiece” for the
462 geodynamic evolution of Eastern Indonesia.

463 The Late Eocene-Oligocene tectonic event is linked to the collision of the “initial” Timor block (Unit 2,
464 previously detached from the Jurassic Gondwana margin) with the active Asiatic margin (Unit 3).

465 The Mid-Pliocene event is linked to the collision of the enlarged Oligocene “Timor block” newly
466 detached (Late Miocene) from the Asiatic margin, with the Northern Australian margin (A).

467 The third event (Late Pliocene / Early Pleistocene) may be linked to the collision between the Australian
468 margin [including the new Pliocene Timor Island] and the southern part of the South Banda basin.

469 Nowadays, according to [Snyder et al. \[1996\]](#), the current Timor block, including the southern Banda arc, is
470 thrusting over the South Banda Sea floor.

471 A further collision could be expected within the next millions years, between the present Timor block and
472 the Northern Banda islands (Seram, Buru...) owing to the present north-eastward motion of the Australian
473 block [[Michel et al. 2000](#), [Bock et al. 2003](#), [Nugroho et al. 2009](#)]. This motion allows us to forecast a
474 “southward subduction” of the Banda basin floor beneath the Australian margin until the Australian block,
475 including Timor, will collide with the northern Banda islands.

476 Finally, Timor Island has registered the main geological events that occurred in this part of Southeast
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478
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485

486 REFERENCES

487

488 Abbot, M.J., Chamalaun, F.H. 1981. Geochronology of some Banda arc volcanic. In: A. J. BARBER & S.
 489 WIRYOSUJONO [Editors], the geology and tectonics of Eastern Indonesia. *Geol. Res. Dev. Centre*, Bandung,
 490 Spec. Publ., 2, 253-272.

491

492 Audley-Charles, M.G., 1968. The geology of Portuguese Timor. *Memoir of the Geological Society of London*, 4, 76.

493

494 Barber, A.J., Audley-Charles, M.G. and Carter, D.J., 1977. Thrust Tectonics in Timor. *J. geol. Soc. Aust*, 24, 51-62.

495

496 Barber A.J. and Audley-Charles ,1976. The signifiante of the metamorphic rocks of Timor in the development of the
 497 Banda arc, Eastern Indonesia. *Tectonophysics*, 30, 119-128.

498

499 Barber, A.J., 1979. Structural interpretation of the island of Timor, Eastern Indonesia, *Proc. Southeast Asia, Petrol. Soc.*,
 500 4, 9-21.

501

502 Barkham, S.T. 1991. The structure and stratigraphy of the Permo-Triassic carbonates formations of West Timor, Indonesia.
 503 University of London, Unpublished PhD. Thesis.

504

505 Berry, R F. and Grady, A.E.-1981. Deformation and metamorphism of the Aileu formation, North coast, East Timor and
 506 its tectonic signifiante. *J. of Structural Geology*, 3, 2, 143-167.

507

508 Berry, R.F and Mac Dougall, I., 1989, Interpretation of $^{40}\text{Ar}/^{39}\text{Ar}$ and K/Ar dating evidence from the Aileu formation,
 509 East Timor, Indonesia. *Chemical Geology* , 59, 43-58.

510

511 Bird, P.R. and Cook, S.E., 1991. Permo-Triassic successions of the Kekneno area, West Timor: implications for
 512 palaeogeography and basin evolution. *Journal of South East Asian Earth Sciences*, 6, 359-372.

513

- 514 Bock, Y, Prawiridirdjo, L., Genrich, J.F, Stevens, C.W., Mc Caffrey, R., Subarya, C., Puntodewi, S.S.O, Calais E., 2003.
 515 Crustal motion in Indonesia from global positioning system measurements. *Journal of Geophysical Research*, **108**,
 516 B8, 2367.
- 517
- 518 Brouwer, H.A., 1942, Summary of the geological results of the expedition. Geol. Exped. Lesser Sunda Islands, Univ.
 519 Amsterdam, 4, 345-402.
- 520
- 521 Brown, M., Earle, M.M., 1983. Cordierite bearing schists and gneisses from Timor, eastern Indonesia: P/T conditions of
 522 metamorphism and tectonic implications. *Journ. Metam. Geol*, **1**, 183-203.
- 523
- 524 Carter, D.J., Audley-Charles, M.G. and Barber, A.J., 1976a. New Kolbano-Timor Trough accretionary complex, eastern
 525 Indonesia. PhD thesis, University of London [unpubl.], 374p.
- 526
- 527 Carter, D.J., Audley-Charles, M.G. and Barber, A.J., 1976b. Stratigraphical analysis of Island arc-continental, margin
 528 collision in eastern Indonesia. *Journal of the Geological Society of London*, **132**, 179-198.
- 529
- 530 Chamalaun, F.H, 1977a. Palaeomagnetic evidence for the relative positions of Timor and Australia in the Permian. *Earth
 531 and Planetary Science Letters.*, **34**, 107-112.
- 532
- 533 Chamalaun, F.H, 1977b. Palaeomagnetic evidence reconnaissance results from the Maubisse Formation, East Timor and
 534 its tectonic implication. *Tectonophysics*, **42**, T17-T26.
- 535
- 536 Chamalaun, F.H, Grady, A.E., 1978. The tectonic development of Timor: a new model and its implications for petroleum
 537 exploration. *Austr. Petrol. Explor. Assos. Journ.* **18**, 102-108.
- 538
- 539 Charlton, T.R., 1987. The tectonic evolution of the Kolbano-Timor trough accretionary complex, Eastern Indonesia, PhD.
 540 Thesis, University of London, 374p.
- 541
- 542 Charlton, T.R., 2002. The structural setting and tectonic significance of the Lolotoi, Laclubar and Aileu metamorphic
 543 massifs, East Timor. *Journal of Asian Earth Science*, **20**, 851-865.
- 544
- 545 Charlton, T.R., Barber, A.J., McGowan, A.J., Nicoll, R.S., Roniewicz, E., Cook, S.E., Barkham, S.T., Bird, P.R., 2009.
 546 The Triassic of Timor: Lithostratigraphy, chronostratigraphy and palaeogeography. *Journal of Asian Earth
 547 Sciences*, **36**, 341-363.
- 548
- 549 Crostella, A, 1977. Geosynclines and Plate Tectonics in Banda arcs, Eastern Indonesia. *AAPG Bull.*, 61, **12**, 2063-2081.
- 550
- 551 De Smet, M.E.M, Fortuin, A R., Troelstra, A., Van Marle, L.J Karmini, M., Tjokrosapöetro, S and Hadiwisartra, S.,
 552 1990. Detection of related vertical movements in the outer Banda Arc [Timor, Indonesia], using
 553 micropaleontological data. *J. Southeast Asian Earth Sci.*, **4-4**, 337-146.

- 554
 555 De Waard, D., 1955. Tectonic of the Sonnebait overthrust unit near Niki-Niki and Basleo in Timor. *Indon. Journ. for Nat.*
 556 *Sci.*, **111**, 144-150.
 557
- 558 Ducrocq, S, 1996. The Eocene terrestrial mammal from Timor. *Geol. Mag.*, **133**, 763-766.
 559
- 560 Earle, M. M., 1981. The metamorphic rocks of Boi, Timor, Eastern Indonesia. In: A. J. BARBER & S. WIRYOSUJONO
 561 [Editors], The geology and tectonics of Eastern Indonesia. *Geol. Res. Dev. Centre, Bandung, Spec. Publ.*, **2**, 239-
 562 251.
 563
- 564 Fitch, T.J. and Hamilton, W., 1974. Reply to the discussion on paper by Fitch, T.J., *J.Geophys. Res.*79, 4982-4985.
 565
- 566 Gageonnet, R, Lemoine, M.,1958.Contribution à la connaissance de la province portugaise de Timor, Portugal,
 567 Monograph, Portugal, Ministerio Ultramar, Junta de Investigacoes do Ultramar, **48**, 7-134.
 568
- 569 Haile, N., Barber, A. J. and Carter, D. J., 1979. Mesozoic cherts on crystalline schists in Sulawesi and Timor. *J. geol. Soc.*
 570 *Lond.*, **136**, 65-70.
 571
- 572 Haig, D.W., Mac Cartain, E.W, Keep, M., Barber, L., 2008. Re-evaluation of the Cablac limestones at its type area, East
 573 Timor: revision of the Miocene stratigraphy of Timor. *Journal of Asian Earth Sciences*, **33**, 5-6, 366-378.
 574
- 575 Hamilton, W., 1979. Tectonic of the Indonesian region, USGS, Prof. Paper, **1078**, pp345.
 576
- 577 Harris, R.A., 1991. Temporal distribution of strain in the active Banda orogen: A reconciliation of rival hypothesis. *Journ.*
 578 *of South. Asian Earth Sci.*, **6**, ¾, 373-386.
 579
- 580 Harris, R.A, 2006. Rise and fall of the Eastern Great Indonesian arc recorded by the assembly, dispersion and accretion of
 581 the Banda Terrane, Timor. *Gondwana Research*, **10**, 207-231.
 582
- 583 Harris R. A., Kaiser J., Hurford A. and Carter A., 2000. Thermal history of Australian passive margin cover sequences
 584 accreted to Timor during Late Neogene arc-continent collision, Indonesia. *Journal of Asian Earth Sciences*, **18**, 47-
 585 69.
 586
- 587 Harris, R.A., Long, T., 2000. The Timor ophiolite, Indonesia: model or myth? In: Dilek Y., Moores E.M., Elthon D.,
 588 Nicolas, A. [Eds.]. Ophiolites and Oceanic Crust: New Insights from Fields Studies and the Ocean Drilling
 589 Program. *Geol. Soc. Amer.*, Spec. Pap., **349**, 330.
 590
- 590 Harsolumakso, A.H., 1993. Etude lithostratigraphique et structurale le long du transect Wini-Kolbano à Timor Ouest
 591 [Indonésie]. Thesis, University of Nice-Sophia-Antipolis, Valbonne [F], [unpubl.], 256p.
 592

- 593 Harsolumakso, A.H., Villeneuve, M., Cornée J. J., De Wever, P., Tronchetti, G., Butterlin, J., Glacon, G., Saint-Marc, P.
 594 [1995]. Stratigraphie des séries para-autochtones du Sud de Timor occidental. *C.R.Acad. Sci. Paris*, **320**, Ila, 881-
 595 888.
- 596
- 597 Helmers, H., Sopaheluwakan J., Tjokrosapoetro,S. and Surya Nila E. [1989]. High-grade metamorphism related to
 598 peridotite emplacement near Atapupu, Timor with reference to the Kaibobo peridotite on Seram, Indonesia.
 599 *Netherlands Journal of Sea Research*, 24, 2-3, 357-371.
- 600
- 601 Honthaas, C., Rehault, J. P., Maury, R. C., Bellon, H., Hemond, C., Malod, J.A, Cornee, J.J, Villeneuve, M., Cotton, J.,
 602 Burhannuddin, S., Guillou, H., Arnaud, N., 1998. A Neogene back arc origin for the Banda Sea basins:
 603 geochemical and geochronological constraints from the Banda ridges, *Tectonophysics*, **298**, 297-317.
- 604
- 605 Ishikawa, A., Kaneko, Y., Kadarusman, A., Tsoyumu, O., 2007. Multiple generations of Forearc-ultramafic rocks in the
 606 Timor-Tanimbar ophiolite, eastern Indonesia, *Gondwana Research*, **11**, 200-217.
- 607
- 608 Jouannic, C., Hoang, C., Hantoro, W.S., Delinom, R.M., 1998. Uplift rate of Coral Reef Terraces in the area of Kupang,
 609 West Timor: Preliminary results. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **68**, 259-272.
- 610
- 611 Kadarusman, A., Maruyama, S., Kaneko, Y., Tsutomu, O., Ishikawa, A., Sopaheluwakan, J., Omori, S., 2010. World's
 612 youngest blueschist belt from the Leti Island in the non-volcanic Banda outer arc of Eastern Indonesia. *Gondwana*
 613 *Research*, **18**, 189-204.
- 614
- 615 Kaneko, Y., Maruyama, S., Kadarusman, A, Tsutomu, O., Idhikawa, M. , Tsujimoro, T, Ishikawa, A., Okamoto Kasuaki,
 616 2007. On-going orogeny in the Outer arc of the Timor-Tanimbar region, eastern Indonesia. *Gondwana Research*,
 617 **11**, 218-233.
- 618
- 619 Keep, M., Haig, D.W., 2010. Deformation and exhumation in Timor: distinct stages of a young orogeny. *Tectonophysics*,
 620 483, **93**-111.
- 621
- 622 Lapouille, A., Haryono, H., Laure, M., Pramumijoyo, S., Lardy, M., 1985. Age and origin of the seafloor of the Banda Sea
 623 [Eastern Indonesia]. *Oceanologica Acta*, **8**, 379-389.
- 624
- 625 Lemoine, M., 1959. Un exemple de tectonique chaotique-Timor. *Rev. Geogr. Phys. Geol. Dyn.*, **2**, 205-230
- 626
- 627 Mahood, G.A., Drake, R.E., 1982. K-Ar dating young rhyolitic rocks: a case study of the Sierra La Primavera,
 628 Jalisco, Mexico. *Geological Society of America Bulletin* 93, 1232-1241.
- 629
- 630 Michel, G.W., Becker, M., Angermann, D., Reigber, C., Reinhart, E., 2000- Crustal motion in E and SE-Asia from GPS
 631 measurements. *Earth Planet Space*, **52**, 713-720.
- 632

- 633 Martini, R., Zaninetti, L, Villeneuve, M., Cornee, J.J., Krystyn, L. Cirilli, S., De Wever, P, Dumetrica, P. Harsolumakso,
 634 A., 2000. Triassic pelagic deposits of Timor: paleogeographic and sea-level implications. *Palaeogeography,*
 635 *Palaeoclimatology, Palaeoecology*, **160**, 123-151.
 636
- 637 Molengraaff, G.A.F., 1915. Folded mountains chains, overthrust sheets and block-faulted mountains in the East Indian
 638 Archipelago. *C.R. XII, Cong. Intern. Geol.*, Toronto, 689-702.
 639
- 640 Nugroho, H., Harris, R., Lestariya, A.W., Maruf, B., 2009. Plate boundary reorganization in the active Banda Arc-
 641 Continent collision: Insights from new GPS measurements. *Tectonophysics*, **479**, 52-65.
 642
- 643 Priadi, B., 1993. Géochimie du magmatisme de l'Ouest et du Nord de Sulawesi, Indonésie : traçage des sources
 644 et implications géodynamiques, Thèse, Université Paul Sabatier, Toulouse, France. 293p.
 645
- 646 Réhault, J.P., Maury, R.C., Bellon, H., Sarmili, L., Burhanuddin, S., Joron, J.L., Cotten, J., Malod, J.A., 1994. La
 647 Mer de Banda Nord [Indonésie]: un bassin arrière-arc du Miocène supérieur. *C. R. Acad. Sci. Paris*, **318**,
 648 969-976.
 649
- 650 Rosmawati, N., Harris, R.W., 2009. Surface uplift of the incipient Banda arc-continent collision: Geology and synorogenic
 651 foraminifera of Rote and Savu Islands, Indonesia. *Tectonophysics*, **479**, 95-110.
 652
- 653 Rosidi, H.M.D., Suwitodirdjo, K. and Tjokosapoetro, S., 1979. Geological map of Kupang-Atambua quadrangle, Timor,
 654 1:250 000. *Geol. Res. Dev. Centre*, Bandung, Indonesia.
 655
- 656 Sawyer, R.K., Sani, K. and Brown, S., 1993. Stratigraphy and sedimentology of West Timor, Indonesia. *Proceed. Indon.*
 657 *Petrol. Assoc.*, Jakarta, 534-574.
 658
- 659 Silver, E.A., Gill, J.B., Schwartz, D., Prasetyo, H., Duncan, R.A., 1985. Evidence for a submerged and displaced
 660 continental borderland, north Banda Sea, Indonesia. *Geology*, **13**, 687-691.
 661
- 662 Snyder, D.B., Prasetyo, H., Blundell, D.J., Pigram, C.J., Barber, A.J., Richardson, A., Tjokosapoetro, S., 1996. A dual
 663 doubly vergent orogen in the Banda-arc collision zone as observed on deep seismic reflection profiles. *Tectonics*,
 664 **15**, n°1, 34-53.
 665
- 666 Sopaheluwakan, J., 1990. Ophiolite obduction in the Mutis complex, Timor, Eastern Indonesia. PhD. thesis, Vrije
 667 Universiteit te Amsterdam, V.U. University Press. 226p.
 668
- 669 Standley C.E., Harris R.W., 2009. Tectonic evolution of forearc nappes of the active Banda arc-continent collision: Origin,
 670 age, metamorphic history and structure of the Lolotoi complex, East timor. *Tectonophysics*, **479**, 66-94.
 671

- 672 Steiger, R.H., Jäger E., 1977. Subcommittee on geochronology: convention on the use of decay constants in
673 geo- and cosmochronology. *Earth Planetary Science Letters* 36, 359-362.
- 674
- 675 Sukanto R., 1975. Geologic map of Indonesia: Ujung Pandang sheet 1000 000. *Geol. Res. Dev. Centre*, Bandung.
676 Indonesia, 12p
- 677
- 678 Tappenbeck, D., 1939. Geologie des Mollogebirges und einiger benachbarter gebiete [Niederländisch Timor]. Noord.
679 Hollandsch Uitgevers Maatschappig, Amsterdam.
- 680
- 681 Van Marle, L.J., 1989. Benthic foraminifera from the Banda arc region, Indonesia, and their paleobathymetric signifi-
682 cance for the geologic interpretation of the Late Cenozoic sedimentary record. PhD. Thesis, Free University press,
683 Amsterdam
- 684
- 685 Van Marle, L.J., 1991. Late Cenozoic paleobathymetry and geohistory analysis of central West Timor, Eastern Indonesia.
686 *Mar. Petrol. Geol.*, **8**, 22-34.
- 687
- 688 Villeneuve, M. Rehault, J.P., Cornée, J.J, Honthaas, C., Gunawan W. et le groupe Geobanda, 1998. Evolution
689 géodynamique de l'Indonésie orientale, de l'Eocène au Pliocène. *C. R. Acad. Sci., Paris*, **327**, 291-302.
- 690
- 691 Villeneuve, M., Harsolumakso, A.H., Cornée, J.J. and Bellon, H., 1999. Structure of West Timor along a North-
692 South cross section. *Geol. Med. T.***26**, 3/4, 127-142.
- 693
- 694 Villeneuve, M., Cornée, J.J., Martini, R., Zaninetti, L., 2004. Nouvelle hypothèse sur l'origine des formations
695 géologiques de l'île de Timor [Sud-Est Asiatique]. *C. R. Géosciences Paris*, **336**, 1511-1520.
- 696
- 697 Villeneuve, M. Cornée, J.J., Harsolumakso, A.H., Martini, R., Zaninetti, L., 2005. Revision stratigraphique de
698 l'île de Timor [Indonésie orientale]. *Eclogae Geologica Helvetica*, **98**, 297-310.
- 699
- 700 Villeneuve, M, Martini, R., Bellon, H., Réhault, J.P, Cornée, J.J. Bellier O., Burhanuddin, S., Hirschberger, F., Honthaas,
701 C, Monnier, C. 2010. Deciphering of six blocks of Gondwanan origin within Eastern Indonesia [South East Asia].
702 *Gondwana Research*. **18**, 420-437.
- 703
- 704 Wanner, J., 1913. Geologie von West Timor. *Geol. Rundsch.*, **4**: 136-150.
- 705
- 706 Wensink, H., Hartosukohardjo, S and Kool, K., 1987. Paleomagnetism of the Nakfunu formation of Early
707 Cretaceous age, Western Timor, Indonesia. *Geol. en Mijnbouw*, **66**, 89-99.
- 708
- 709 Wensinck, H., 1988. Displaced terranes of Gondwana origin in Indonesia: Paleomagnetic implications. *Ann. Soc.*
710 *Geol. Nord*, **CVII**, 81-87.
- 711

712 Wensink, H., Hartosukohardjo, S.1990. Paleomagnetism of younger volcanics from western Timor. Indonesia.
 713 *Earth and Planetary Science Letters*. **100**, 94-107.

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716 **FIGURES CAPTIONS**

717

718 **Figure 1.**

719 **1a- Location of West Timor in eastern Indonesia.** NBB=North Banda basin, SBB=South Banda basin,
 720 SW=West Sulawesi, SE=East Sulawesi, HL=Halmahera, TB=Tukang Besi platform, LR=Lucipara Ridge,
 721 BA= Savu basin,

722 **1b- Geological sketch map of West Timor** [modified from Rosidi et al. 1979]

723 Legend: 1-Unit 5 [Autochthon unit], 2-Manamas and Atapupu complex [Unit 4, group G8], 3-Batuputih
 724 group [Unit 4, group G6], 4-Late Miocene dioritic intrusions [Unit 4], 5-Palelo Group [Unit 3, group G4], 6-
 725 Maubisse group [Unit 2], 7-Keknenno-Tumu group [Unit 2], 8-Kolbano group, 9-Oligo-Miocene thrusts, 10-
 726 Mid Pliocene and Late Pliocene thrusts, 11-vertical faults. D1, D2 and D3= main unconformities cited in Fig.
 727 3, T2, T3, T4 and T5= main thrusts shown in Fig. 3. The underground D1 is not outcropping.

728 Man=Manamas, Bisn=Bisnain, ATP=Atapupu, ATB=Atambua, W=Wini, Kf=Kefamenanu, NK=Niki-niki,
 729 Kbb=Kolbano, TK=Takari, Cpl=Camplong, Kup=Kupang, Su=Suai,

730

731 **Figure 2.**

732 **2a- Crustal geological cross section of West Timor** (modified from [Villeneuve et al., 2005]). 1-Central
 733 basin (Unit 5, group G9), 2-Manamas complex (Unit 4, group G7), 3-Late Miocene dioritic intrusion (Unit
 734 4), 4-Batuputih group (Unit 4, group G6), 5-Cablac formation (Unit 3, group G5), 6-Metamorphic complex
 735 (Unit 3, group G4), 7-Palelo group (Unit 3, group G4), 8-Kolbano group (Unit 1, group G1), 9-Maubisse
 736 group (Unit 2, group G3), 10-Keknenno-Tumu group (Unit 2, group G2), 11-Supposed Timor metamorphic
 737 basement, 12-Thrusts.

738 **2b- Geological section of the Noiltoko area.** 1-Quaternary deposits, 2-Miocene Noetoko group (G5), 3-
 739 Palelo group [G4], 4-Metamorphic complex [G4], 5-Maubisse group [G3].

740 **2c- The thrust within the Kolbano group,** 1-Lower Pliocene calcilutites (Batuputih group?), 2-black
 741 breccias, 3-Cretaceous or Eocene limestones, 4-Modern breccias.

742

743 **Figure 3.-Tectono-stratigraphic diagramm of West Timor.** 1-Plio-Quaternary deposits of the Noele group
 744 (Unit 5, group G9, Autochthon), 2-Reef limestones of the Noele group (Unit 5, group G9, Autochthon), 3-
 745 Manamas volcanic complex (Unit 4, group G7, Sub-autochthon), 4-Ultrabasic Atapupu complex (Unit 4,
 746 group G7, Sub-autochthon), 5-Aileu complex of East Timor (Unit 4, group G7, Sub-autochthon), 6-Viqueque
 747 group (Unit 4, group G8, Sub-autochthon), 7-Dioritic intrusions (Unit 4, group G8, Sub-autochthon), 8-
 748 Batuputih formation and Bobonaro conglomeratic complex (Unit 4, group G6, Sub-autochthon), 9-Miomaffo
 749 formation (Unit 3, group G5, Allochthon), 10-Cablac formation (Unit 3, group G5, Allochthon), 11-Palelo
 750 group and Mutis metamorphic complex (Unit 3, group G4, Allochthon), 12-Maubisse group (Unit 2, group
 751 G3, Para-allochthon), 13-Kekneno-Tumu group (Unit 2, group G2, Para-allochthon), 14-Kolbano group
 752 (Unit 1, group G1, Para-autochthon), 15-Australian passive margin cover, 16-Australian metamorphic
 753 basement. T = Main thrusts, D = unconformity, G1 to G8: main groups cited in text. G1=Kolbano group, G2
 754 = Kekneno-Tumu, G3= Maubisse group, G4 = Mutis complex and Palelo group, G7 = Atapupu and
 755 Manamas complex, G8 = G8 group including the “Viqueque formation”.

756 Stratigraphic ages: Gr1 = Jurassic to Early Pliocene, Gr2= Permian to Early Eocene, Gr3=Permian to
 757 Cretaceous, Gr4 = Jurassic to Eocene, Gr5 = Early to Middle Miocene, Gr6 = Late Miocene to Early
 758 Pliocene, Gr7 = Middle to Late Miocene, Gr8 = Late Miocene to Late Pliocene, Gr9 = Pleistocene to
 759 Quaternary.

760

761 **Figure 4. Cartoon depicting the geodynamic evolution of Timor in 4 main steps.**

762 **4a- Triassic period:** Extensive tectonic process on the Northern Gondwana margin. Aus (A1 and A2)-
 763 Australian block, G2-Kekneno Tumu group, G3-Maubisse group, AAM and G4-Asiatic active Margin.

764 **4b- Oligo-Miocene period:** Collision between the Timor Block and the Asiatic active margin (AAM). The
 765 Asiatic volcanic arc is thrust over the Maubisse group and the Maubisse group is itself thrust over the
 766 Kekneno-Tumu group. The Timor Block is separated from the Australia by the Indian Ocean; G4 = Part of
 767 the Asiatic volcanic arc thrust over Timor, AAM = Part of the Asiatic volcanic arc remained at the border
 768 of the Asiatic margin.

769 Legend: IO = Indian Ocean, T3 = thrust between Kekneno–Tumu and Maubisse groups, T4 = thrust
 770 separating the G4 group (Mutis complex and Palelo group) from the U2 unit (Kekneno-Tumu and Maubisse
 771 groups).

772 **4c- Middle Pliocene period:** The Timor block collided with the Australian block. The Kolbano group
 773 contains formations of the Australian margin mixed with Neogene formations from the southern Timor
 774 accretionary prism, G7 = Manamas and Atapupu complexes are related to the south Banda volcanic arc; A1
 775 = basement of the Australian margin, A2 = sediments of the Australian margin, T1 = thrust between the
 776 Kolbano group and the Australian block, T2 = thrust between the Kolbano and the Kekneno-Tumu group],
 777 T5 = thrust between the Aileu complex and the “Maubisse group”.

778 Legend: KTfm = Kekneno-Tumu group, Vqq = Viqueque group, TTr = Timor trough, Aus = Australian
 779 block.

780 **4d- Late Pliocene period:** The Manamas and Atapupu volcanic arc are thrust over the Northern Timor
 781 and a new volcanic arc (the Banda arc) is setting North of the Savu basin.

782 1- Noele group (Unit 5, group G9, Autochthon), 2- Viqueque group (Unit 4, group G8, Autochthon), 3-
 783 Manamas complex (Unit 4, group G7, Sub-autochthon), 4- Atapupu complex, (Unit 4, group G7, Sub-
 784 autochthon), 5- Noetoko group (Unit 3, group G5, Allochthon), 6-Cablac formation (Unit 3, group G5,
 785 Allochthon), 7-Upper Miocene dioritic intrusions (Unit 4, group G8, Sub-autochthon), 8- Aileu complex
 786 (Unit 4, group G7, Sub-autochthon), 9- Palelo group (Unit 3, group G4, Allochthon), 10- Mutis metamorphic
 787 complex (Unit 3, group G4, Allochthon), 11- Maubisse group (Unit 2, group G3, Para-allochthon), 12-
 788 Kekneno-Tumu group (Unit 2, group G2, Para-allochthon), 13- Sedimentary prism of the Australian margin,
 789 14- Kolbano group (Unit 1, group G1, Para-autochthon), 15- Gondwana basement, 16- Volcanoes, 17-
 790 thrusts. T6 = thrust between the Atapupu complex and the Maubisse group, T7 = thrust between the
 791 Manamas and Atapupu complexes, Kbfm = Kolbano group.

792

793 **Figure 5. Cartoon illustrating the geodynamic evolution of Eastern Indonesia.**

794 **fig 5a-** By the Eocene: Tethys ocean is subducting underneath the Asiatic margin. **fig.5b-** By the Oligocene:
 795 the Mutis complex is obducted over the Timor initial. **fig. 5c-** By the Early and Middle Miocene: the
 796 “subduction zone” skipped from North to South of Timor. **fig 5d-** By the Late Miocene: a volcanic arc arose
 797 in northern Timor. **fig.5e-** By the Early Pliocene: The South Banda basin developed. **fig.5f-** By the Middle

798 Pliocene: Australia collided with deformation of the Kolbano prism and by the Pleistocene: the Oecussi and
 799 Atapupu complexes obducted over the northern Timor. **fig. 5g**- Present time: Timor terranes obduct over the
 800 South Banda sea basin.

801 Legend: Aust = Australian block, TG= Timor gap, IO = Indian Ocean, Tm1 = Initial Timor, AAM = Asiatic
 802 active margin, MS = Makassar straits, K= Kalimantan, OP = Obducted part (Mutis complex), Tm2 = Timor
 803 initial + Allochthone, P.Aut = Para-autochthon (Maubisse and Kekneno-Tumu groups), All = (Allochthone),
 804 Kb1 = Kolbano group (Neogene accretionary prism), Kb2 = Kolbano group = part of the Australian
 805 sedimentary prism, Kb = Kolbano group (mix of Kb1 and Kb2), SBB = South Banda basin, BA = Banda
 806 volcanic arc, Ail = Aileu metamorphic complex (with blue schist minerals), Mc = Manamas complex, ATP =
 807 Atapupu complex, TmT = Timor through, Tm3 = Total Timor (Initial + Allochton + Banda arc).

808

809 **Figure 6. Palaeogeographic reconstructions of Eastern Indonesia [Late Miocene].**

810 **6a- Late Miocene.** Timor (Tm) is located on the Asiatic margin, south of Sulawesi and likely to the East of
 811 Sumba.

812 **6b- Mio-Pliocene:** The South Banda basin (SBB) is opened by migration of the Timor-Tanimbar volcanic
 813 arc (Tm-Tan).

814 **6c- Pliocene-Pleistocene:** Following the collision between the Timor-Tanimbar (Tm-Tan) volcanic arc and
 815 the Australian block, the Banda volcanic arc is setting north of the Savu basin. The Weber trough is opened
 816 on the Eastern part of the South Banda basin.

817 **WS**-West Sulawesi, **ES**-East Sulawesi, **Sb**-Sumba island, **KL**-Kalimantan, **MS**-Makassar straight, **Bs**-
 818 Banggai-Sula, **Sbi**-Sulabesi, **HI**-Halmahera, **Pap**-Papouasie, **NBB**-North Banda basin, **Bu**-Buru, **SR**-Seram,
 819 **TB**-Tukang-Besi platform, **LuR**-Lucipara ridge, **FI**-Flores, **Sb**-Sumba island, **FI**-Flores island, **SBB**-South
 820 Banda basin, **WB**-Weber trough, **Tm**-Timor, **Tan**-Tanimbar, **TT**-Timor through.

821 Legend: **1**-Asiatic Volcanic arc, **2**-Kolonodale Timor Block, **3**-Lucipara block, **4**-Emerged islands, **5**-
 822 Volcanoes (Miocene- Pleistocene), **6**-Main subduction zones: (1)-Central Sulawesi subduction thrust, (2)-
 823 North Banda subduction thrust, (3)-South Banda subduction thrust, (4)-Seram-Buru Subduction thrust, **7**-The
 824 Australian block, **8**-Marginal basins, **9**-Miocene–Pliocene metamorphic formations, **10**-Marine escarpments,
 825 **11**- Basins and troughs.

826

827 **Table 1.** K-Ar ages carried on West Timor samples. (Ages were performed in Brest University at UMR
828 CNRS 6538 “Domaines océaniques”).

829 Geographical coordinates: in column 2.

830

831 **Table 2.** K-Ar dating on the Western arm of Sulawesi and on the Timor allochthon and sub-autochthon units.

832 Legend: NRD=New radiometric dating, np = sample number and time error bracket not precised, M =dating

833 on mineral, Horn = Hornblende, wr = K-Ar ages were performed on whole rock.