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Kuwae (≈1425 A.D.): the forgotten caldera

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Abstract

In Vanuatu, Tongoa and Epi islands once formed part of a larger landmass, Kuwae, which was partly destroyed during a cataclysmic seismo-volcanic event that is recorded in local folklore. It led to the formation of a 12-km-long and 6-km-wide oval-shaped submarine caldera with two distinct basins and a total area of ~60 km^2 at the level of the rim.

The age of this eruption, 1420–1430 A.D., and the structure of the related collapse are discussed and a composite log (143 m) of the pyroclastics surrounding the caldera is presented. They comprise thick hydromagmatic deposits belonging to a terminal hydromagmatic phase of the pre-caldera edifice, which grade upwards into two major sequences of pyroclastic flow deposits, clearly related to the caldera event. Collapse near the caldera edge was at least in the range 650 to 950 m, and may have been as much as 800 to 1100 m. The volume of rocks engulfed during the caldera formation is ~32–39 km^3, suggesting the same volume of magma was erupted.

Even if two coalescent collapse structures were formed, it is worth noting that the Kuwae caldera is not a reactivated structure, but the result of a single event of short duration which occurred in the first half of the Fifteenth century. This event is one of the seven biggest caldera-forming events during the last 10,000 years, and is comparable with the Santorini Minoan eruption and the Crater Lake eruption.

1. Introduction

In central Vanuatu (Fig. 1) there is a local legend that Tongoa and Epi islands once formed part of a larger landmass, Kuwae, partly destroyed during a cataclysmic seismo-volcanic event (Garanger, 1966, 1972; Hébert, 1966; Espirat et al., 1973). When embellishments common to oral folklore are filtered out, it appears that after several strong earthquakes of increasing magnitude, Kuwae tilted and broke into pieces while a gigantic eruption was occurring. Many people escaped death, fleeing southward as far as Efate island at the first signs of the cataclysm. Most inhabitants remaining on Kuwae were killed, but a few were able to return to Tongariki island (Fig. 2), and among them was the young Ti Tongoa Liseiriki who first resettled Tongoa shortly after the eruptions ceased.

This cataclysmic event has been well known to archaeologists and ethnologists, as well as to geologists over the last few decades. Nevertheless, inadequate geological data and a lack of knowledge and the misinterpretation of ^{14}C dates quoted by archaeologists have previously prevented the determination of the age and size of the event, the nature and volume of the erupted products, and the precise morphology of the re-

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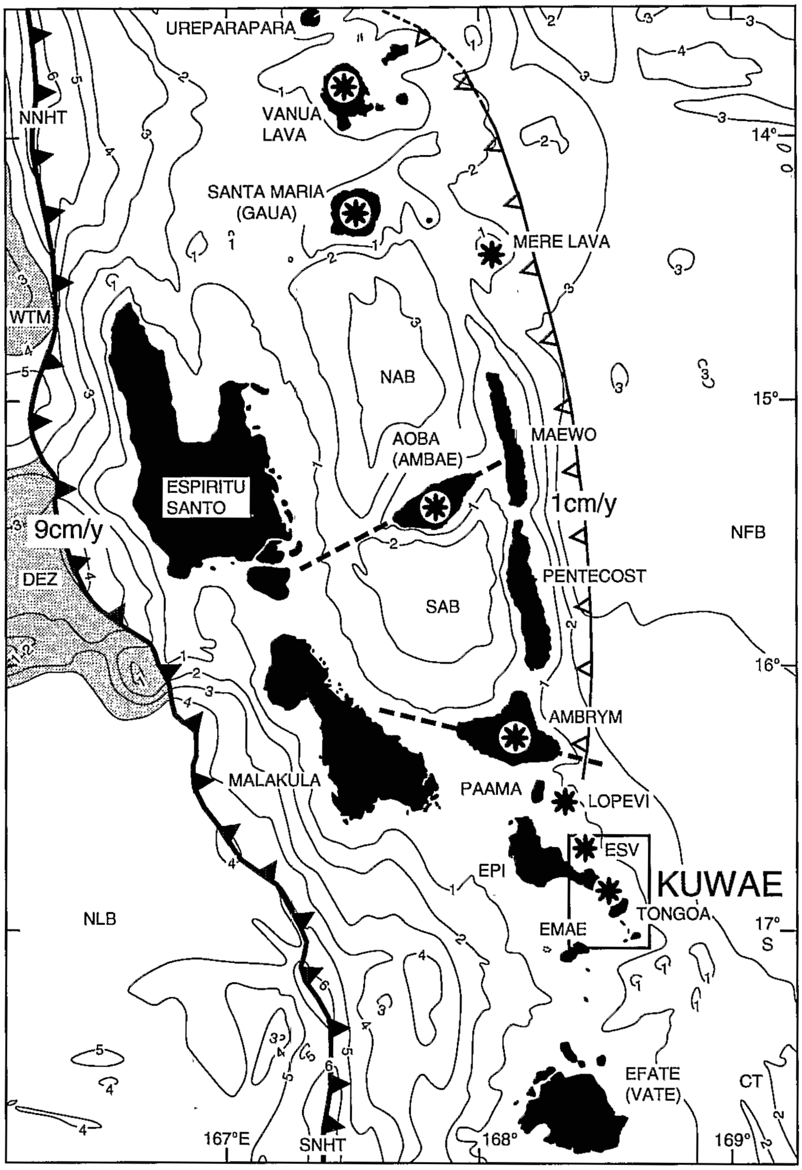


Fig. 1. Central and northern Vanuatu islands (in black). Bathymetry in km from Chase and Seekins (1988). *NLB*=North Loyalty Basin; *DEZ*=D'Entrecasteaux Zone (dotted); *WTM*=West Torres Massif (dotted); *SNHT*=Southern New Hebrides Trench; *NNHT*=Northern New Hebrides Trench; *NAB*=North Aoba Basin; *SAB*=South Aoba Basin; *ESV*=Epi Submarine volcanoes; *NFB*=North Fiji Basin; *CT*=Coriolis troughs. Heavy line with filled triangles emphasizes the New Hebrides convergence. Line with open triangles shows reverse back-arc thrusting. Relative motions are in cm/yr (Louat and Pelletier, 1989). Volcanoes with activity during the last five centuries are marked by a black star (Simkin et al., 1981). Rectangle around the Kuwae caldera corresponds to Fig. 2.

sulting caldera. As a consequence, there is no report of this major eruption, which was probably of the same order of magnitude as that of the Santorini Minoan event in 3600 y.B.P. or that of Mount Mazama (Crater Lake) in 6845 y.B.P.

On the basis of recent marine and field observations and new ^{14}C dates, this paper describes the morphology of the collapse area and its age,

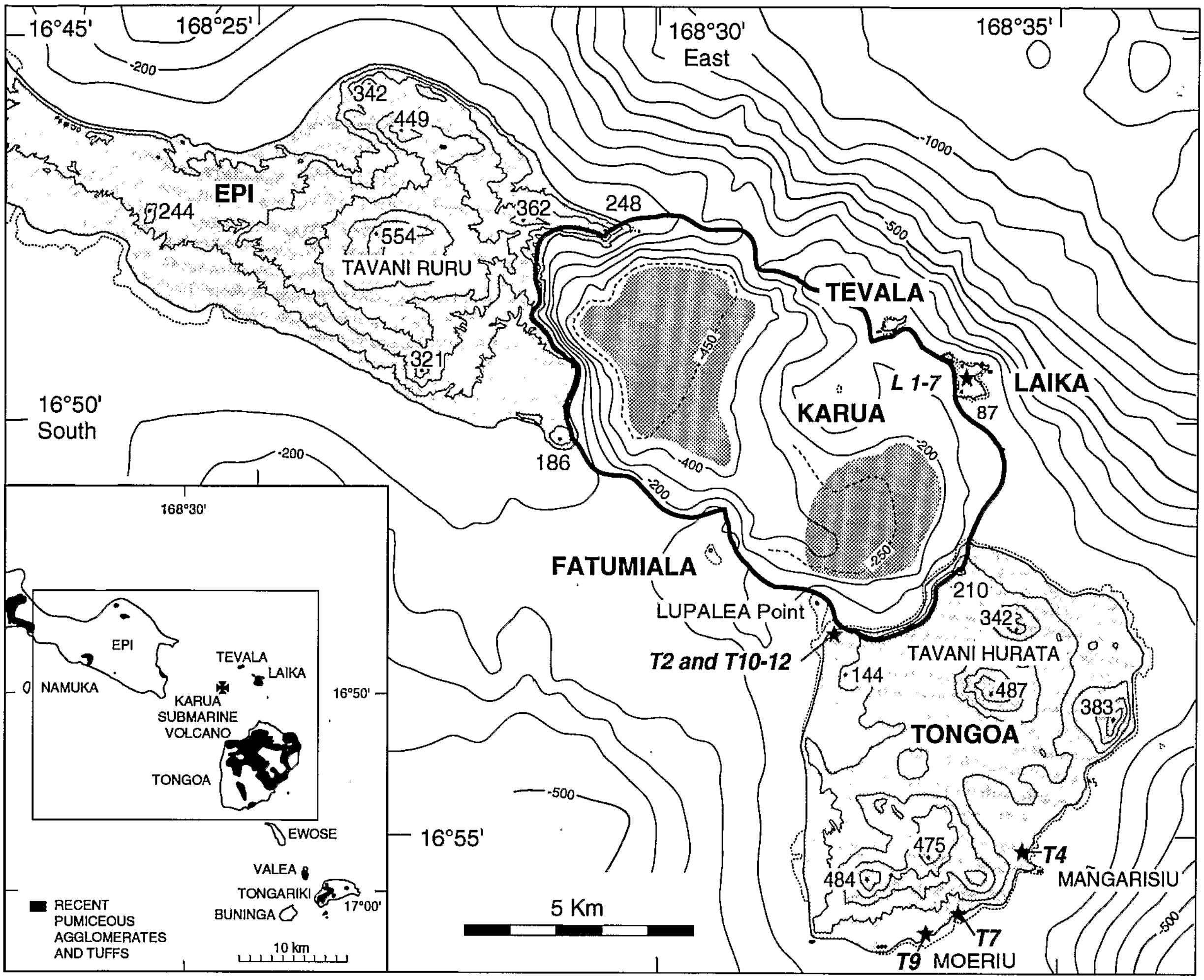


Fig. 2. The Kuwae sumarine caldera and its two basins (medium dotted area), and the surrounding islands (light dotted). Topographic or bathymetric contour interval is 100 m. Stars: location of cross sections and reference sites of sampling. Inset: extent of recent pumiceous agglomerates and tuffs (in black) according to Warden et al. (1972).

and gives a summarized description of the syn-caldera pyroclastic deposits. The short duration of the event and the two resulting coalescent collapse structures are also discussed.

2. Previous geological work

Warden (1967) and Warden et al. (1972) related the dacitic pumiceous agglomerates which cover most of the high ground of Tongoa, Laika, Tongariki, and Valea islands and also the south-eastern part of Epi island (Fig. 2) to the major volcanic event recorded in oral tradition. Previous workers (Aubert de la Rüe, 1956; Espirat, 1964; Gèze, 1966) postulated that this cataclysm might correspond to the formation of a large-scale caldera, somewhere between Epi and Tongariki islands. Warden (1967) disputed this hypothesis, but Carney and Macfarlane (1977) recognized an oval-shaped caldera between Epi and Tongoa from new bathymetric data. Crawford et al. (1988) defined five large, mainly submerged calderas between Epi and Efate islands and proposed that Kuwae was destroyed and largely submerged during paroxysmal eruptions of one or more of the adjacent calderas, between 3,000 and 400 years ago. Lastly, on the basis of scarce and questionable ^{14}C dates, Macfarlane et al. (1988) proposed a regional event of caldera collapses along the Central Chain of the New Hebrides island arc, some 2,000 years ago.

3. Morphology of the caldera

During the CALIS (May 1991) and VOLVAN (July 1992) cruises (R/V ALIS of ORSTOM), a survey of the submarine morphology between Epi and Tongoa was carried out, and a new bathymetric map has been produced (Fig. 2). The scalloped rim of the caldera is conspicuously delimited by Epi, Tevala, Laika, Tongoa and Fatumiala (Sail Rock) islands. As a whole, the caldera is a NW–SE-elongated depression, 12 km long and 6 km wide, with an area of ~60 km^2 at the level of the rim and a floor 250–450 m below sea-level, from southeast to northwest.

The inner wall of the caldera is steep, from about 200 m high south of Laika to 700 m high along the shore of Epi. From seismic reflection data, "*well layered, flat lying reflectors*" that partly fill the structure (Crawford et al., 1988) — i.e. the ignimbrites (and minor ash from the intra-caldera Karua active volcano; see below) trapped within the caldera — are 225 m thick, a value agreeing well with observations made in the Santorini Minoan caldera (Druitt and Francaviglia, 1992). If the "*basinward dipping and chaotically bedded reflectors*" observed below are also part of the pyroclastic series, the fill reaches 380 m in thickness. Thus, the minimum estimate for collapse near the caldera edge ranges from 650 m along the Tongoa coastline to 950 m along the southeastern shore of Epi, and may range from 800 to 1100 m.

For volume calculation, a simplified caldera shape is considered to take into account probable slope modification during collapse, which enlarged the caldera to its present size and created its scalloped outline (Bacon, 1983; Self et al., 1984). This simplified shape, 45 km^2 in area, comprises: a NW half-cylinder, 5 km in diameter and 0.6 km high, a central truncated parallelepiped of 5×5 km and respectively 0.45 and 0.25 km high, and a SE half-cylinder, 5 km in diameter and 0.33 km high. On this basis, the volume of the depression is estimated to be 17 km^3 and the volume of the intracaldera tuffs is in the range 10 to 17 km^3. In addition, an undocumented volcanic edifice vanished during the eruption. Considering a hypothetical previous topography, quite similar to that of Epi and Tongoa islands (i.e. 500–600 m in elevation; see discussion below), of two cones 5 km in diameter and respectively 0.5 and 0.6 km high, the volume of this edifice was ~7 km^3. Part of this volume (~2 km^3, based on a rough estimate) can be accounted for as lithics in the proximal pyroclastic deposits. Thus, a total of ~32–39 km^3 of rock were engulfed during the caldera formation.

4. Age

Frederick (1893) first mentioned the cataclysm and Hébert (1966), summarized information collected by European missionaries and travellers about the tectono-volcanic event. Rough estimates based on the number of generations of chiefs place the event between 1540 and 1654 A.D. According to Garanger (1972), these estimates appear too recent in view of two ^{14}C age determinations carried out on burned wood included in deposits related to the cataclysm, and one collagen age determination carried out on the skeleton of Ti Tongoa Liseiriki, suggesting that the cataclysm occurred in the Fourteenth or Fifteenth century; Table 1; Fig. 3). An age of 2300 years B.P. has been proposed by Carney and Macfarlane (1977) but these authors misinterpreted previous archaeological data and ^{14}C dates reported by Garanger (1972).

4.1. New ^{14C} data

The sequence of deposits related to the caldera collapse includes two thick pumice-rich flow deposits which occur extensively on Tongoa. Three radiocarbon dates on pieces of charcoal from sites T4, T7 and T9 (Fig. 2) have been determined at the Centre des Faibles Radioactivités (Gif sur

Table 1
^{14}C data

	1	2	3	4	5	6
Source:	T4D (this study)	T7D (this study)	T9A (this study)	Garanger, 1972	Garanger, 1972	Garanger, 1972
No. analysis:	Gif-8958	Gif-8959	Gif-8960	B-742	No. not reported	GX-0291
Radiocarbon age:	430±50BP	560±50 BP	430±40 BP	630±80 BP	490±37 BP	475±85 BP
Calibrated age (A):	1445 AD	1401 AD	1445 AD	1300 AD or 1365 AD or 1374 AD	1427 AD	1432 AD
Age range 2Σ (B)	1414–1619 AD	1295–1430 AD	1420–1611 AD			
Age range 2Σ (C)	1410–1624 AD	1290–1440 AD	1417–1611 AD	1250–1430AD	1399–1451AD	1290–1630AD
Age range 2Σ (D)	1405–1524 AD (1564–1630 AD)	1294–1431 AD	1409–1518 AD	1254–1433AD	1394–1463AD	1293–1529AD (1552–1633AD)

Calibrated ages A and age ranges C and D based on 2Σ (C from intercepts method, D from probability distribution method) are according to Stuiver and Pearson (1986), and calculated using the radiocarbon calibration program 1987 of the Quaternary Isotop Lab. (University of Washington); age ranges B are based on 2Σ, calibration according to Pazdur and Michczynska (1989).

Yvette, France) (Table 1, Fig. 3). Completely carbonised tree trunks are abundant in the lower deposit near Moeriu (sites T7 and T9).

- T4D, is a completely carbonised pandanus trunk, 7 cm in diameter, from the upper pumice flow deposit at Mangarisiu, with a conventional radiocarbon age of 430±50 y.B.P. (Gif-8958), that reduces to a calibrated date of CAL A.D. 1414–1619 (calibration according to Pazdur and Michczynska, 1989; 95% confidence level, range based on 2 sigmas).

- T7D, is a completely carbonised "ironwood" trunk, 20 cm in diameter, from the lower pumice flow deposit at Moeriu, with a conventional age of 560±50 y.B.P. (Gif-8959), or CAL A.D. 1295–1430.

- T9A, is a completely carbonised "ironwood" trunk, 25 cm in diameter, from the lower pumice flow deposit at Moeriu, with a conventional age of 430±40 y.B.P. (Gif-8960), or CAL A.D. 1420–1611.

In order to constrain more precisely the age of

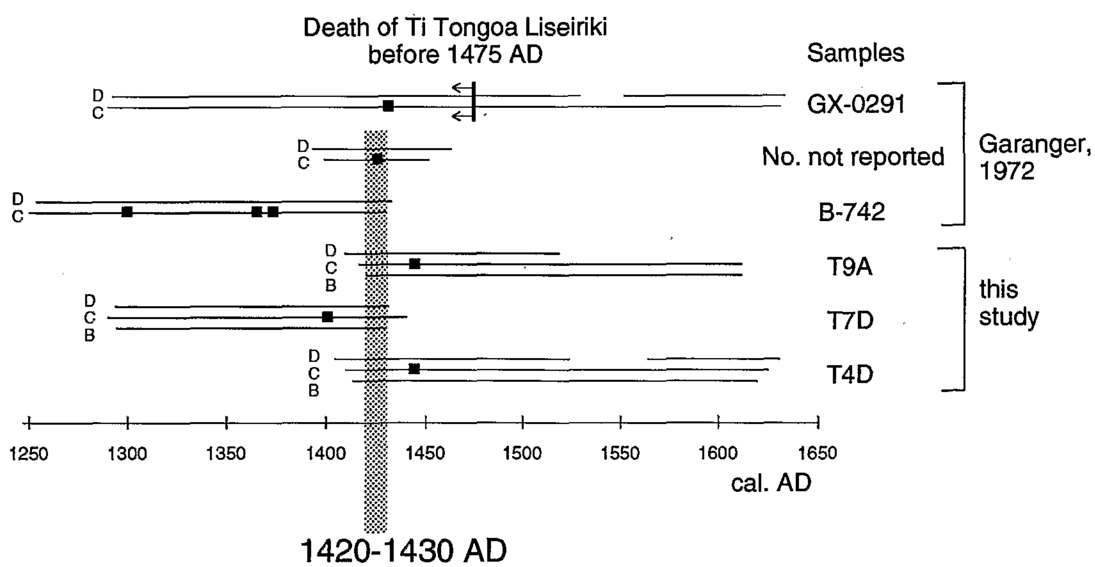


Fig. 3. ^{14}C diagram. Black squares are calibrated ages; for B, C, D on age ranges, see legend of Table 1.

the event, we have calculated the calibrated age and age ranges for all the samples, including those reported by Garanger (1972) (Table 1). As age ranges for charcoal samples only coincide between 1420 and 1430 A.D., the cataclysmic eruption of Kuwae probably took place at this time (Fig. 3). This date agrees well with the collagen age range calculated for the skeleton of Ti Tongoa Liseiriki, as it is considered improbable that his death post dates the cataclysmic event by more than 50 years.

5. Products

Effusive and strombolian, mainly basaltic, products characterize the pre-caldera edifice (Warden 1967; Warden et al., 1972).

In Figure 4, three sections from Tongoa and Laika are summarized on a log showing the tephrostratigraphy of the whole series of tuffs surrounding the caldera. Two sections are located on the caldera wall, at Lupalea Point on Tongoa (sites T2 and T10-12, Fig. 2) and on the small

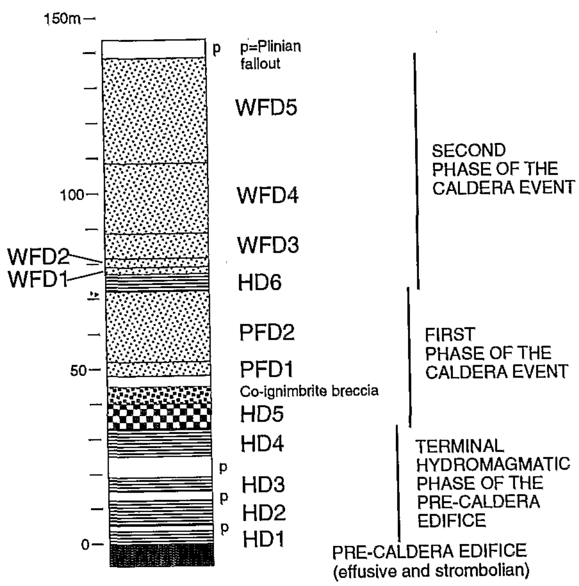


Fig. 4. Summarized log of the whole tuff series related to the caldera event. *HD*=Hydromagmatic Deposit; *PFD*= unwelded Pumice Flow Deposit; *WFD*=Welded ash Flow Deposit.

island of Laika (L1–7), and the third is a composite section from the SE coast of Tongoa, near Moeriu and Mangarisiu (T4 and T7–9).

The sections are as follows:

(1) At Lupalea Point, the first 33 m of deposits which overlie the pre-caldera lava flows show a complex association of pyroclastics which correspond to alternating hydromagmatic deposits (HD 1–4) including fine ash-falls, and basaltic fallout lapilli (layers "p" Fig. 4). At the base, a first sequence of hydromagmatic deposits (HD 1), 3.5 m thick, consists mainly of surge layers grading upward into ash flow deposits bearing juvenile basaltic scoriae. This sequence is followed by a rhythmic 1.5-m-thick sequence of ash and lapilli fallout layers. Above, two sequences of yellowish layered hydromagmatic deposits, HD 2 (7.5 m thick) and HD3 (4 m thick) are intercalated with two massive (2.5 and 6 m) beds of airfall grey lapilli. Ash layers showing conspicuous cross bedding or wavy fine "laminites", intercalated with ash and vitric lapilli layers cemented by a coarse or fine muddy matrix consisting of sideromelane clasts with palagonite, mainly basaltic andesite in composition, are interpreted as surtseyan deposits. A sequence of 8 m of yellowish layered hydromagmatic deposits HD4, quite similar to HD 2–3, ends these 33 m of deposits, which may be interpreted as a terminal hydromagmatic phase of the pre-caldera edifice, and which includes drier fallout episodes. Deposits of the sequence HD4 grade upwards into two major sequences of pumice-rich pyroclastic flow deposits, clearly related to the caldera event.

The upper parts of the Lupalea Point section (26 m) expose:

(a) 7 m of massive yellow hydromagmatic tuffs, with quenched, black, vitric blocks and flattened bombs, dacitic in composition, in an indurated muddy matrix of coarse ash cemented by fines (layer HD 5);

(b) a 5-m-thick co-ignimbrite breccia, consisting essentially of accidental blocks and including about 10% of juvenile clasts (vitric blocks and pumice); the latter grades into:

(c) a 4-m-thick lithic- and pumice-rich unwelded flow deposit (PFD 1);

Table 2
Selected whole-rock analyses

Stratigraphy: Sample no.:	PFD1 T4A	PFD2 T2N	WFD4 L7F	WFD5 L7B
SiO_2	64.43	62.49	65.68	64.38
TiO_2	0.60	0.61	0.56	0.59
Al_2O_3	15.53	16.00	15.29	15.47
FeO^*	6.25	6.69	5.69	6.12
MnO	0.15	0.16	0.14	0.15
MgO	1.68	2.05	1.46	1.82
CaO	4.80	5.73	4.33	4.74
Na_2O	3.80	3.77	4.03	4.03
K_2O	2.50	2.27	2.58	2.46
P_2O_5	0.25	0.23	0.25	0.24
LOI 1050°C	0.10	−0.02	−0.10	0.57
Initial tot.	98.96	99.03	99.25	99.05
Mg#	0.35	0.38	0.34	0.37

Major-element geochemistry in wt.% summed to 100% volatile free; FeO^* = total iron as FeO; LOI = loss on ignition; Mg# determined on the basis of $Fe^{2+}/(Fe^{2+}+Fe^{3+})=0.9$. Analyst: J. Cotten, Brest. Prefix in the sample number: T = Tongoa, L = Laika; see Fig. 2 for location of sites of sampling.

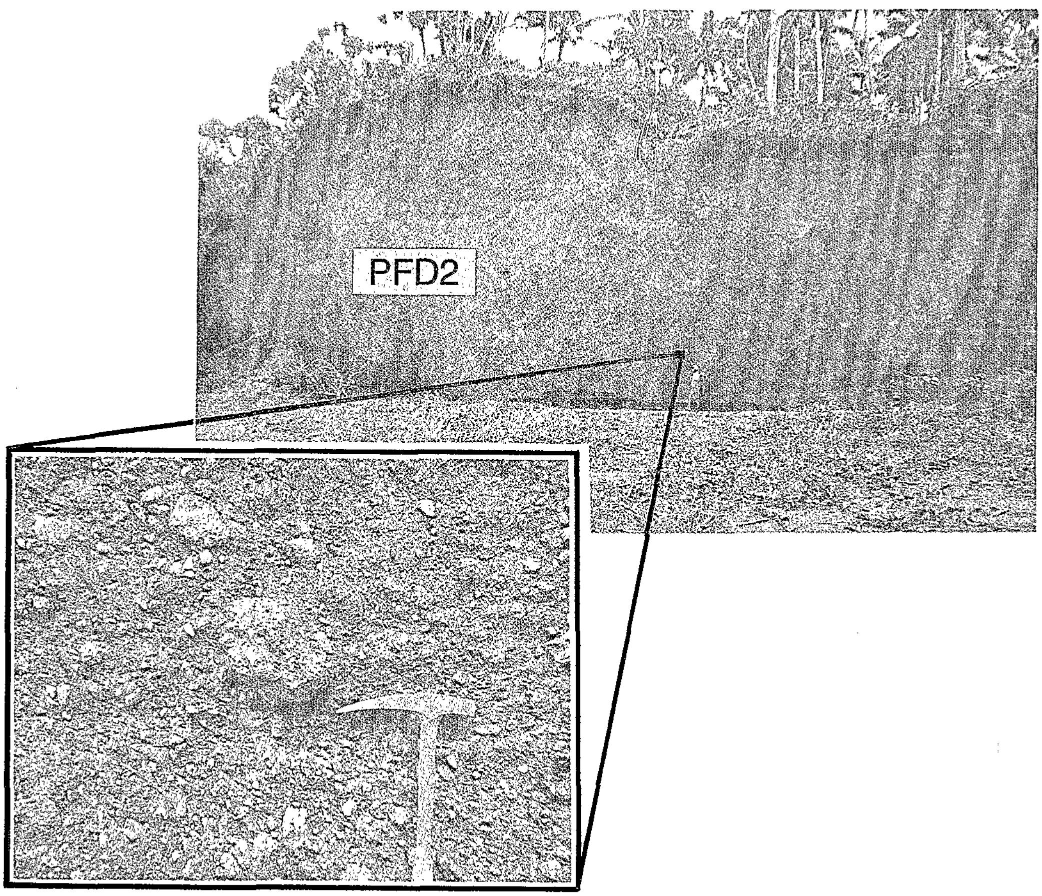
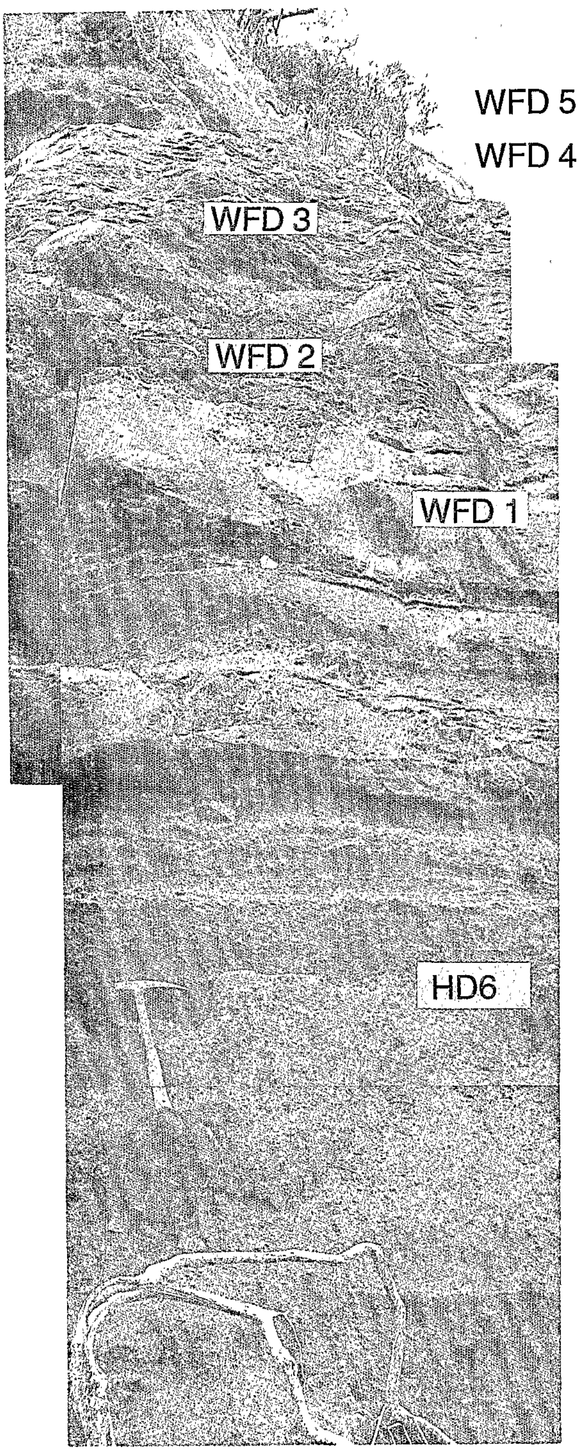


Fig. 5. The ignimbrite unit PFD2 near Mangarisiu, Tongoa.



(d) a 6-m-thick unwelded pumice flow deposit (PFD 2) with 80 to 90% pumice (sample T2N, Table 2).

An 80-cm-thick ashfall layer crowns this section.

(2) The two pyroclastic flow deposits PFD 1 and PFD 2 reached the SE coast of Tongoa. Near Moeriu, PFD 1 is exposed over 9 m at the base of the coastal cliffs (sample T4A, Table 2). Completely carbonised tree trunks are frequently oriented in the direction of flow (NW–SE). Near Mangarisiu, the upper ignimbrite unit PFD2 is 15 m thick (Fig. 5) and is overlain by a 6-m-thick sequence of lahars which rework the ignimbrite.

(3) On Laika island, the base of the western shore cliff exposes a pumice flow deposit, at least 20 m thick, which corresponds unambiguously to the upper ignimbrite PFD 2 recognized on Tongoa. It is overlain by a 5-m-thick distinctive sequence of hydromagmatic deposits (HD 6, Fig. 6). Increasingly welded flow deposits (WFD 1–5) characterize the upper two-thirds of the Laika section which ends in a thick and spectacular sequence of welded tuffs, including about 20 m of black (WFD 4, sample L7F, Table 2) and 30 m of red welded tuffs (WFD 5, sample L7B). Rheomorphic facies are common, as well as quenched and brecciated rocks resulting from interaction between hot flows and seawater. Finally, about 5-m-thick bedded ash and pumice fall deposits complete the Laika section, the total thickness of which is near 90 m.

Post-caldera activity during the last 550 years includes the development of the basaltic Karua cone on the floor of the caldera (Crawford et al., 1988). This cone (4.5×3 km NW–SE oval-shaped base lying at 450–250 m depth, with a top near sea-level, and approximately 1 km^3 in volume) is built against the NE wall of the caldera. Karua has been periodically active since the first documented eruption in 1897 (Warden, 1967;

Fig. 6. Pyroclastic deposits in the the upper two-thirds of the Laika section. Upper hydromagmatic deposits (*HD 6*), then, increasingly welded ignimbrite deposits (*WFD 1–3*), then black (*WFD 4*) and red welded tuffs (*WFD 5*) in the upper part of the cliff (not very visible in this picture, due to the steep angle of the view).

Simkin et al., 1981), and it has frequently emerged temporarily as a small island.

6. Concluding remarks

The segment of the volcanic arc situated between Ambrym and Tongoa (Fig. 1) is at present the most active part of the arc (Simkin et al., 1981) and includes from north to south: the 13-km-wide Ambrym caldera with the two active cones Marum and Benbow (Monzier et al., 1991; Robin et al., 1993), the Lopevi active volcano (Warden, 1967), three active submarine volcanoes near Epi island (Exon and Cronan, 1983; Crawford et al., 1988), the Karua active submarine volcano in the caldera of Kuwae (Crawford et al., 1988) and lastly, some thermal springs on Tongoa (Warden et al., 1972). In addition, recently extinct volcanoes with well preserved cones are frequent on Epi, Tongoa and Emae. In the first decades of the Fifteenth century, a tectono-volcanic cataclysm occurred in the south of this region, leading to the formation of the 12×6 km Kuwae submarine caldera.

6.1. Duration and triggering of the event

The lower part of the pyroclastic series shows increasing amounts of hydromagmatic deposits at the expense of Plinian fallout deposits, both types of deposits being mainly of basaltic andesite composition. Conversely, the upper part of the series exposes a thick pile of dacitic ignimbrites, all emitted during the climactic stage of the eruption. This latter phase was probably short, as similar eruptions such as Tambora in 1815 (Self et al., 1984) seem generally to have lasted for two–three days or less. The time separating the eruption of the hydromagmatic deposits from the climactic stage and the collapse is not known. Nevertheless, the eruption of the whole pyroclastic sequence was of short duration as, in spite of the wet tropical climate, no soils are developed between the different units of tuffs. The numerous episodes that preceed the ignimbrite outpourings suggest at least weeks or months of relatively moderate activity, allowing the inhabitants to flee. As for the ignimbritic sequences on Ambrym and Tanna (Robin et al., 1993; Eissen et al., 1992; Robin et al., in press), the observation of hydromagmatic deposits in the lower part of the pyroclastic series, just below each major sequence of pyroclastic flow deposits, strongly argues for triggering of the cataclysmic eruption by magma–water interaction.

Detailed volcanological and geochemical studies of the pyroclastic series, which are in progress, should enable us to determine the mechanics of the eruption.

6.2. Comparison with other caldera-forming eruptions

The total volume of material released by the Kuwae event cannot be measured as most of its products entered the sea. However, as for the Crater Lake (Bacon, 1983) and Tambora eruptions (Self et al., 1984) the "lost" volume (i.e. the ~32–39 km^3 of rock engulfed during the caldera formation) should equal the DRE (Dense Rock Equivalent) erupted volume. The emission of 4 main units of thick unwelded and welded tuffs (PFD 1, 2 and WFD 4, 5) associated with lesser ash flows agrees well with such a large magma output as ~32–39 km^3 DRE.

A comprehensive idea of the corresponding eruption magnitude may be simply arrived at by comparing this erupted volume with the volume released by the largest eruptions (i.e. exceeding 25 km^3 of magma output) recorded during the past 10,000 years (Table 3). The DRE volume of the Kuwae event, Taupo rhyolitic event (186 A.D.; Walker, 1980) and Santorini Minoan event (3600 y.B.P.; Druitt and Francaviglia, 1992) are quite similar (30–40 km^3), and are only surpassed by those of the Tambora (1815 A.D.; Self et al., 1984; Sigurdsson and Carey, 1989), Kikai-Akahoya (6300 y.B.P.; Machida and Arai, 1983) and Mount Mazama (Crater Lake; 6845 y.B.P.; Bacon, 1983) events (50–60 km^3). The age of the caldera event at Ambrym is not well constrained, but this event should also be included in the list since it is believed to be very young (less than 2,000 y.B.P.; McCall et al., 1970), and

Table 3
Reported eruptions exceeding 25 km^3 of magma output in the past 10,000 years

Volcano	Date	Magma comp.	Erupt. vol. (km^3)	
			Bulk	DRE
Tambora (1)	1815 AD	trachyandesite	~175	~50
Kuwae (2)	~1425 AD	dacite	?	~32–39
Baegdusan (3)	1000–1100 AD	alk. rhyolite	~50	?
Taupo (4)	186 AD	rhyolite	~100	~38
Ambrym (5)	2000 BP?	dacite to basalt	60–80*	19–25*
Santorini (6)	~3600 BP	rhyodacite		~30
Kikai-Akahoya (3)	6300 BP	rhyolite	>150	?
Mazama (7)	6845 BP	rhyol. andesite	~130–140	~51–59

Data from: 1 - Self et al. (1984), Sigurdsson and Carey (1989); 2 - this paper; 3 - Machida and Arai (1983); 4 - Walker (1980); 5 - Robin et al. (1993); 6 - Druitt and Francaviglia (1992); 7 - Bacon (1983). DRE=Dense rock equivalent volume
*=minimum volume taking into account the only deposits on Ambrym island

released at least 19 to 25 km^3 DRE of products (Robin et al., 1993).

Thus, together with the Crater Lake, Kikai-Akahoya, Santorini (Minoan), Ambrym, Taupo and Tambora events, the Kuwae event is among the seven biggest caldera-forming events of the last 10,000 years. Furthermore, the Kuwae eruption appears second in importance amongst the eruptions witnessed during the present era, just after the Tambora eruption (Self et al., 1984). Concerning recent events in the SW Pacific, the great eruption on Long island (11–12 km^3 calculated volume of tephra) which occurred about 250 years ago and provoked a "Time of darkness" in the highlands of Papua New Guinea (Blong, 1982), should also be mentioned. As for Kuwae, oral folklore provides accurate accounts of this eruption.

6.3. Kuwae caldera: two probable coalescent collapse structures

The oval and lobate shape of the depression, with two basins at different depths, does not accord well with the existence of a single large volcano before the cataclysm. In addition, the caldera is located on a very narrow volcanic ridge, where a strip of land, at most 6 km large, previously joined Epi and Tongoa islands, and this also precludes the existence of a large-sized pre-caldera volcano. For comparison, the 12-km-wide Ambrym caldera is at the top of a 35×50 km-wide volcano (Fig. 1) and the caldera of Gaua in the north of the Archipelago, only 6×8-km-wide (Mallick and Ash, 1975), is at the top of a 30-km-wide volcano.

Additional observations are in favour of a previous topography rather similar to that of Epi and Tongoa: the 200-m-high wall along Epi exposes a pile of thin lava flows intercalated with agglomerates (Warden, 1967) which suggest a nearby vent approximately at the center of the NW basin. Along Tongoa, the caldera wall exposes in some places thick sequences of coarse scoria, also suggesting a volcanic center near the present shoreline. Moreover, it is worth noting that both basins on the caldera floor are quite similar in diameter to Mounts Tavani Ruru on Epi and Tavani Hurata on Tongoa (Fig. 2). Thus, two small-sized volcanoes in the same places as the present basins probably produce a good approximation to the pre-caldera morphology. In addition, these volcanic centers would be precisely aligned with the Tavani Ruru and Tavani Hurata cones. The fact that upper ignimbrites WFD 1–5 have never been observed on Tongoa is an additional argument for complex collapse associated with partial emptying of two closely spaced apophyses of an elongate magma chamber beneath the present caldera. This NW–SE magma chamber probably extends over about 25 km, including the areas of the Tavani Ruru and Tavani

Hurata cones. However, even if two coalescent collapse structures were formed, it is worth noting that, in contrast with most of the large-sized calderas, the Kuwae caldera is not a composite structure developed by repeated subsidence over a long time but the result of a single event of short duration. This is demonstrated by: (1) the presence of a continuous landmass between Epi and Tongoa before the cataclysm; (2) the absence of previous volcanic products typical of a caldera forming event, older than those erupted in the Fifteenth century; and (3) no major volcanic event in the area during the last 550 years.

In conclusion, at about 1425 A.D. and after a major seismic crisis, one of the most powerful eruptions of the last 10,000 years occurred near 16°50′S on the axis of the New Hebrides volcanic ridge, partly destroying Kuwae island. During this short duration event which was triggered by magma–water interaction, ~32–39 km^3 of magma was erupted and complex collapse of the roof of two closely spaced apophyses of an elongate magma chamber resulted in the formation of the two coalescent collapse structures of the Kuwae caldera.

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