Paléoécologie/*Paleoecology*

# First study of *in situ* fossil woods from the Upper Cretaceous of Livingston Island, South Shetland Islands, Antarctica: palaeoecological investigations

Marc PHILIPPE, Georges BARALE, Teresa TORRES and Vladimir COVACEVICH

***Abstract*** – *In situ* fossil woods of the Upper Cretaceous of Livingston Island, South Shetland Islands, are investigated for the first time. They give evidence for an open mixed type forest and for a climatic gradient through the Antarctic Peninsula at this time.

## Première étude de bois fossiles *in situ* dans le Crétacé supérieur de l'île Livingston, Shetland du Sud, Antarctique; déductions paléoécologiques

***Résumé*** – *Pour la première fois des bois fossiles* in situ *du Crétacé supérieur de l'île Livingston, Shetland du Sud, ont été étudiés. Ils suggèrent une forêt mixte ouverte et un gradient climatique à travers la Péninsule Antarctique à cette époque.*

***Version française abrégée*** – La Pointe Williams (62°36′S; 60°30′W) de l'île Livingston, Shetland du Sud, Péninsule Antarctique (*fig.*), est connue pour ses gisements à plantes fossiles (Orlando, 1968; Lacey, 1981; Lemoigne, 1987; Banerji, 1987; Lemoigne, 1988; Rees, 1989; Torres, 1989; Chapman, 1992). Les données paléoécologiques sur cette région avant l'ouverture du détroit du Drake sont d'un grand intérêt, notamment pour la modélisation des climats (Barron, 1984). Malheureusement l'étude de ces gisements de l'île Livingston, basée essentiellement sur du matériel dispersé, est limitée par de fortes incertitudes stratigraphiques et paléobotaniques (Rees, 1989).

Durant l'Expédition Antarctique Chilienne de janvier 1993 nous avons pu récolter de nombreux bois fossiles *in situ* dans le gisement P1806 (*fig.*), daté par palynologie du Cénomanien-Campanien précoce (Chapman, 1992). Notre étude remet en cause les résultats obtenus à partir des échantillons dispersés en surface. Parmi eux nous montrons la présence d'éléments allochtones. Les données acquises *in situ* donnent une image complètement renouvelée de la paléoécologie du site P1806.

Au site P1806 (*fig.*) affleure un tuf volcanique, riche en bois fossiles, inséré dans la série volcano-sédimentaire dite « Williams Point Beds » (Smellie, 1984). Un demi-mètre carré a été dégagé. A partir de 10 cm de profondeur la présence de bois en contact avec leur contre-empreinte et de fusains friables non brisés montrent l'absence de remaniement. Au-delà de cette profondeur et jusqu'à 20 cm, 141 échantillons *in situ* ont été récoltés. 22 ont pu être étudiés.

Quatre types de Gymnospermes sont reconnus, ainsi que deux d'Angiospermes et *Sahnioxylon antarcticum* Lemoigne et Torres (tableau I). Ce dernier pourrait ne pas être le bois d'une Bennettitale (Torres, 1990; Suzuki, 1991), mais plutôt d'une Angiosperme primitive. Les études précédentes, sur des échantillons dispersés, semblent avoir surestimé la part des Gymnospermes (tableau II).

Les bois n'ont pas été transportés. Environ 9,19 $m^3$ de bois ont été fossilisés dans le gisement, ce qui correspond à un taux de 27 t de bois par hectare seulement (pour une densité moyenne du bois sec de 0,75 $t/m^3$). Les cernes sont le plus souvent indistincts.

Note présentée par Michel DURAND-DELGA.

0764-4450/93/03170103 $ 2.00 

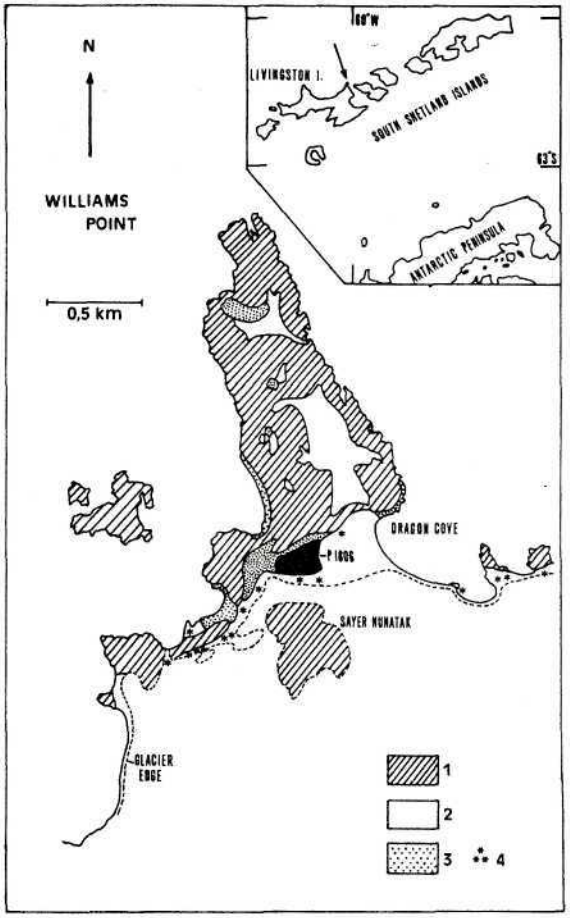
Sinon, avec une épaisseur moyenne de 2,02 mm, ils caractérisent une croissance modérée (Chaloner, 1989), très variable.

La xyloflore cénomanienne de la Péninsule Byers de cette même île Livingston (Torres, 1982 et 1990) est moins évoluée que celle de P1806. Un âge Turonien-Santonien peut être proposé pour P1806. Trouvé *in situ*, *Sahnioxylon antarcticum* est ainsi daté avec certitude pour la première fois.

Le dépôt semble correspondre à une forêt mixte, dont on pourrait trouver l'équivalent dans les forêts actuelles sur pentes volcaniques au Guatemala vers 1 500 m. Si l'on suppose que les bois fossiles représentent l'enfouissement d'une seule forêt, la faible biomasse estimée dénoterait une formation ouverte (Lanier, 1986). Les cernes indistincts ne caractérisent pas forcément un climat stable (Jacoby, 1989). Nos données, celles de Jefferson (1982) et de Francis (1986), sur la « Mean-Sensitivity », montrent qu'au Crétacé, la variabilité du climat est nettement plus élevées sur la face ouest de la péninsule que sur sa face est.

---

INTRODUCTION. – The fossil wood rich outcrop "P1806" of Williams Point, Livingston Island, South Shetland Islands (*fig.*), is one of the major sources of continental palaeoecological data for the Upper Cretaceous of West Antarctica, insofar as the age of the other plant macrofossil assemblages is still much debated (work in progress). Paleofloras and




The Williams Point of Livingston Island, South Shetland Islands, Antarctica. (1) intrusions and vent deposits; (2) fluvio-glacial deposits; (3) volcano-sedimentary rocks of Williams Point Beds (in black the P1806 outcrop, also of these Beds, rich in fossil woods); (4) scattered fossil woods.

*La pointe Williams de l'île Livingston, Shetland du Sud.* (1) *roches intrusives;* (2) *dépôts fluvio-glaciaires;* (3) *série volcano-sédimentaire dite « Williams Point Beds » (en noir le gisement P*1806, *de cette série, riche en bois fossiles);* (4) *bois fossiles dispersés.*

paleoclimates of this time, prior to the opening of the Drake Passage, are of great interest, especially for climate modelling (Barron *et al.*, 1984).

The first investigations at P1806 were done by Lemoigne (1988), Torres (1989) and Chapman (1992). However, until now, fossil wood had never been found *in situ* at this locality and the number of samples taken into account was quite small (always less than 20).

During the last Chilean-Antarctic Expedition (1992/1993) it was possible for us to study the P1806 fossil wood rich outcrop. As snow had melted more extensively than in previous years, large new areas were exposed to research and the structure of the outcrop was clearer. This allowed us to collect more than 800 samples, 141 of them found *in situ*. This paper deals with the contribution of *in situ* wood, which casts a whole new light on the deposit.

MATERIAL AND METHODS. – Numerous fossil plant outcrops are known at Williams Point (62°36'S; 60°30'W) of Livingston Island (Orlando, 1968; Lacey, 1981; Lemoigne, 1987; Banerji, 1987; Rees, 1989; Chapman, 1992). Five of them, with unclear stratigraphical relations, give leaf impressions and some poorly preserved woods. At P1806 (Chapman, 1992) only fossil wood is to be found, but it is abundant there.

On the other hand, dispersed fossil woods are frequent at the foot of the glacier, among the moraine and fluvio-glacial deposits (*fig.*). Different types of fossilization indicate that different source layers are highly probable for those woods. Even at P1806 outcrop some obviously allochthonous samples are to be found. Therefore, sampling had to be done cautiously.

At the P1806 an ash-flow bed crops out. It is included in a volcano-sedimentary succession, known as Williams Point Beds (Smellie, 1984), gently dipping eastward. Its place within the sedimentological succession is well determined. According to palynological investigations (Chapman, 1992) it can be dated as Cenomanian-Early Campanian. The western border is cleared of glacial deposits by a torrent, whereas the easternmost part is covered with raised beach deposits. Elsewhere extensive fluvio-glacial deposits limit, and locally cover, the P1806 ash-flow bed. Isolated marine boulders (including some of fossil wood) can be found on the major part of the outcrop. Through cryoturbation, allochthonous elements are frequently mixed with the deeply alterated upper layer of the ash-flow bed.

First of all 626 weathered samples were collected on the surface of the P1806 outcrop (Lot 1), in a part devoid of any obviously allochthonous element. Then a half square-metre, chosen in what seemed the more characteristic part, was dug 20 cm deep. Below 10 cm, six pieces of silicified wood were found in contact with their counterparts in the rock and four others with attached remains of matrix. Friable, untouched pieces of charcoal were found in the rock as well as within the alterite. We consider this part of the bed to be undisturbed and its woods as *in situ*. 141 silicified wood samples (Lot 2) were found in it.

The gymnosperms-angiosperms ratio for both lots was calculated in the field by magnifying-glass sorting. At the same time reasonably well preserved samples (respectively 75 and 27) were kept for further investigations. These woods were studied by the classical way of optical sections.

LOT 2 (141 *IN SITU* SAMPLES) ANALYSIS RESULTS. – According to field sorting, nine samples belong to angiosperms, 18 to gymnosperms and 114 are of indeterminate

TABLE I

Taxonomy of the woods found at P1806, Williams Point, Livingston Island, South Shetland Islands. The 10 wood types correspond to our interpolation of the datas from Torres (1989) and Chapman (1992). Both studied scattered samples, while our Lot 2 was collected *in situ*. Some angiosperms woods of previous studies may be allochthonous.

*Taxonomie des bois trouvés à P1806, Pointe Williams, Ile Livingston, Shetland du Sud. Les 10 types de bois correspondent à notre interpolation des données de Torres* (1989) *et Chapman* (1992). *Les deux ont étudié des échantillons dispersés, alors que notre Lot 2 a été collecté* in situ. *Certains bois d'Angiospermes des études précédentes pourraient être allochtones.*

| Wood type | Torres (1989) | Chapman (1992) | Lot 2, this study |
|---|---|---|---|
| a | *Araucarioxylon floresii* | clustered pits | 3 samples |
| b | not found | spaced pits | 10 samples |
| c | *Podocarpoxylon sp.* | not found | 1 sample |
| d | not found | low rays | 3 samples |
| e | *Sahnioxylon antarcticum* | not found | 1 sample |
| f | *Dicotyledoxylon sp* 1 | multiserirays | 1 sample |
| g | *Dicotyledoxylon sp* 2 | not found | 3 samples |
| h | *Dicotyledoxylon sp* 3 | ?dumpirays | not found |
| i | *Dicotyledoxylon sp* 4 | not found | not found |
| j | not found | heterorays | not found |

systematic position. Of the first two groups, 22 samples were sectioned to produce optical sections, five being too small for cutting. Taxonomic results are given in table I with, for comparison, the results of previous studies on scattered samples. For the moment, we have not made any nomenclatural choices as we prefer to await the results of systematic investigations in order to have a more complete view.

There are four wood types of gymnosperms, two of angiosperms and one corresponding to *Sahnioxylon antarcticum* Lemoigne and Torres. Table II gives the percentages of

TABLE II

Homoxylous and heteroxylous wood percentages at P1806, Williams Point, Livingston Island, South Shetland Islands, taking into account only determinable samples. Chapman's samples and Lot 1 were collected at the surface, whereas Lot 2 was collected *in situ*. The difference *in situ* versus scattered is significant. The study of Torres (1989) is not taken in account as samples were not collected at random.

*Pourcentages de bois homoxylés et hétéroxylés à P1806, Pointe Williams, Ile Livingston, Shetland du Sud, en ne prenant en compte que les échantillons déterminables. Les échantillons de Chapman et le Lot 1 ont été récoltés dispersés, le Lot 2* in situ. *Les données de Torres* (1989) *ne sont pas prises en compte car l'échantillonnage ne fut pas aléatoire.*

| | Chapman (1992) | Lot 1 | Lot 2 |
|---|---|---|---|
| Number determined | 20 | 243 | 27 |
| Homoxylous (%) | 75 | 81 | 67 |
| Heteroxylous (%) | 25 | 19 | 33 |

homoxylous and heteroxylous woods for previous studies and both lots. Surface collecting may overestimate the contribution of homoxylous woods.

Sample sizes range from some millimetres to 60 mm in length. These samples correspond to fragments of axes of at least 20 mm in diameter. They are arranged without any particular orientation. No branch or trunk can be followed in strata; samples are always isolated pieces. They are sharp and the breakup as morphological ratio is typical of a segmentation of original axes by desiccation. There is no trace of rolling prior to fossilization. All types of morphology are present (except branchlets under roughly 2 cm in diameter). Therefore, there must have been little or no sorting before sedimentation.

The volume of wood found in the hole is 495 $cm^3$, for a volume of rock of $5 \times 10^{-3}$ $m^3$. The outcropping upper layer of the ash-flow deposit at P1806 is estimated to be $70 \times 35 \times 0.75$ m, that is 1,837.5 $m^3$ of rock. So roughly 9.19 $m^3$ of wood has been

fossilized in this exposed layer. With an average wood density of 0.75 t/m$^3$ this gives a ratio of 27 t of wood per hectare.

Obviously the number of samples is too small for the statistical approach needed for growth-ring analysis. Yet some points can be made. Growth-ring type is strongly correlated to taxonomy. Most of the time growth-rings are indistinct and difficult to follow laterally. Many false rings occur. Two taxa show more distinct rings. For type "*b*" the ring width ranges from 0.8 to 4.0 mm, with an average of 2.02 ($n=21$). For type "*g*" the ring width ranges from 0.9 to 4.2, with an average of 2.02 ($n=5$). These values are strikingly similar. The strong variability of this width is also worth pointing out: average Mean-Sensitivity = 0.395.

Discussion. – From a systematic point of view lot 2 shows seven types of wood. It is highly probable that the four conifer types correspond in fact to two species, one of the *Araucariaceae* (type "*a*") and one of the *Podocarpaceae* (types "*b*", "*c*" and "*d*"). It may, however, be that one at least of these belongs in fact to the group *Taxodiaceae-Cupressaceae*. *Sahnioxylon antarcticum* is frequently attributed to *Bennettitales*; but it also shares many xylological features with primitive angiosperms (Torres, 1990; Suzuki, 1991), for example *Trochodendraceae* or *Tetracentraceae*. *In situ* collecting shows a lesser diversity among angiosperms than previously estimated from weathered samples.

From a stratigraphical point of view, the P1806 xyloflora is different to, and younger than, the one known at Byers Peninsula (Torres, 1982), also in Livingston Island. This is devoid of angiosperms and is actually dated (by radiometry and fauna) as Cenomanian (Torres, 1990). Consistently with this, P1806 may be Turonian-Santonian (or Early Campanian?) in age. *Sahnioxylon antarcticum*, previously of uncertain age, has been found *in situ* at P1806.

The present could be the key to the past. A present-day landscape is strongly reminiscent of the P1806 deposit. At Fuentes Georginas (1,500 m), Quetzaltenango, Guatemala, the slopes of a volcano are covered by clear mixed forest. In the zones with fumaroles, trees are killed by volatiles and stripped of their small branches. On the ground, they break into sharp pieces with an appearance typical of desiccation. Toxic volatiles prevent the wood from rotting, but sulfuric acid partially dissolves the lignin of cell walls. There is very little transportation and apparently no size sorting. Pieces are dispersed on the ground without continuity (M. P., pers. obs., 1992). An ash-flow may well overwhelm all these. The main features of this present-day phenomenon are consistent with the ones observed at P1806.

Sedimentation of an ash-flow is nearly instantaneous and its wood content can be considered as being overwhelmed by a single volcanic event. In our opinion the calculated ratio of 43 t/ha corresponds to only one forest growth. This is quite small as, according to the growth-ring width average (2.02 mm), the forest annual productivity should have been average (Chaloner, 1989). For such a forest type, the trunk and branch biomass is circa 250 t/ha (Lanier, 1986). Either the rate of wood fossilization is very low or, more probably, as the preservation is often good, the original biomass of the forest was lower, which means rather scattered trees.

The picture arises of a rather open forest with two or three species of the conifers and an equivalent number of Angiosperms, with a medium to low productivity, subject to strong growth variations (climatic or volcanic events?). Indistinct growth-rings are not necessarily related to low seasonality or a stable climate (Jacoby, 1989). It should be pointed out that, for the Cretaceous, the known Mean-Sensitivities on the west coast of

the Antarctic Peninsula are always much higher than those on the eastern coast: 0.42 (Aptian-Albian, Alexander I., Jefferson, 1982), 0.210 (Cenomanian, Byers Peninsula, Livingston I., Francis, 1986) and 0.395 (this study), versus 0.125 (Aptian-Albian, James Ross I., Francis, 1986) and 0.192 (Senonian-Campanian, James Ross I., Francis, 1986). It may be that there was a climatic gradient through Antarctic Peninsula at this time. This, together with other results, indicates the value of "P1806" *in situ* fossil woods for the reconstruction of paleoclimates and for general circulation modelling.

We are grateful for provision of research facilities by the Instituto Antarctico Chileno (Proyeto 017, Estudios Paleobotanicos de las Islas Shetland del Sur), to H. Galleguillos for valuable help during field collecting and to J. and R. Ward for the preparation of the English version.

Note remise le 26 avril 1993, acceptée après révision le 14 mai 1993.

REFERENCES

J. BANERJI, Y. LEMOIGNE and T. TORRES, Significant additions to the Upper Triassic flora of Williams Point, Livingston Island, South Shetland (Antarctica), *Ser. Cient. INACH*, 36, 1987, pp. 33-58.

E. J. BARRON and W. M. WASHINGTON, The role of geographic variables in explaining paleoclimates: results from Cretaceous climate model sensitivity studies, *J. Geophys. Res.*, 89, 1984, pp. 1267-1279.

W. G. CHALONER and G. T. CREBER, The phenomenon of forest growth in Antarctica: a review, *Geol. Soc.*, spec. publ., No. 47. 1989, pp. 85-88.

J. L. CHAPMAN and J. L. SMELLIE, Cretaceous fossil wood and palynomorphs from Williams Point, Livingston Island, Antarctic Peninsula, *Rev. Paleobot. Palynol.*, 74, 1992, pp. 163-192.

J. E. FRANCIS, Growth rings in Cretaceous and Tertiary wood from Antarctica and their paleoclimatic implications, *Palaeontology*, 29, 1986, pp. 665-684.

G. C. JACOBY, Overview of tree-ring analysis in tropical regions, *IAWA Bull.*, 10, 1989, pp. 99-108.

T. H. JEFFERSON, Fossil forests from the Lower Cretaceous of Alexander Island, Antarctic, *Palaeontology*, 25, 1982, pp. 681-708.

W. S. LACEY and R. C. LUCAS, The Triassic flora of Livingston Island, South Shetland Islands, *Brit. Ant. Surv. Bull.*, 53, 1981, pp. 157-173.

P. LANIER, *Précis de sylviculture*, Engref Ed., Nancy, 1986, 468 p.

Y. LEMOIGNE, Confirmation de l'existence d'une flore triasique dans l'île Livingston des Shetland du Sud (Ouest Antarctique), *C. R. Acad. Sci. Paris*, 304, Series II, 1987, pp. 543-546.

Y. LEMOIGNE and T. TORRES, Paléoxylologie de l'Antarctide : *Sahnioxylon antarcticum* n. sp. et interprétation de la double zonation des cernes des bois secondaires du genre de structure (parataxon) *Sahnioxylon* Bose et Sah, 1954, *C. R. Acad. Sci. Paris*, 306, Series II, 1988, pp. 939-945.

H. A. ORLANDO, A new Triassic flora from Livingston Island, South Shetland Islands, *Brit. Ant. Surv. Bull.*, 16, 1968, pp. 1-13.

P. M. REES and J. L. SMELLIE, Cretaceous angiosperms from an allegedly Triassic flora at Williams Point, Livingston Island, South Shetland, *Antarct. Sci.*, 1, 1989, pp. 239-248.

J. L. SMELLIE, R. J. PANKHURST, M. R. A. THOMSON and R. E. S. DAVIES, The geology of South Shetland Islands. VI. Stratigraphy, geochemistry and evolution, *Brit. Ant. Surv. Sci. Rep.*, 87, 1984, 85 p.

M. SUZUKI, L. JOSHI and S. NOSHIRO, *Tetracentron* wood from the Miocene of Noto Peninsula, Central Japan, with a short revision of homoxylic fossil woods, *Bot. Mag.*, Tokyo, 104, 1991, pp. 37-48.

T. TORRES, Étude paléobotanique du Tertiaire des îles Roi George et Seymour, Antarctique, *Thèse Doctorat*, Lyon-I, No. 247-90, 1990.

T. TORRES, E. VALENZUELA and I. GONZALEZ, Palaeoxilologia de la Peninsula Byers, Isla Livingston, Antartica, *Acta III Congr. Geol. Chileno*, Concepción, 2, 1982, p. 321-342.

T. TORRES and Y. LEMOIGNE, Hallazgos de maderas fosiles de Angiospermas y Gimnospermas del Cretacico Superior en Punta Williams, isla Livingston, islas Shetland del Sur, Antarctica, *Ser. Cient. INACH*, 39, 1989, pp. 9-29.

G. B. and M. P. : *Laboratoire de Paléobotanique du Mésozoïque et URA n° 11 du CNRS*, Bât. 401 A, *Université Lyon-I*, 43, *boulevard du* 11-*Novembre*-1918, 69622 *Villeurbanne Cedex*, *France;*

V. C. : *Servicio Nacional de Geologia y Mineria*, Casilla 10465, *Santiago*, *Chile;*

T. T. : *Laboratorio de Anatomia Vegetal*, *Facultad de Ciencias Agrarias y Forestales*, *Universidad de Chile*, Casilla 1004, *Santiago*, *Chile*.