Synthetic Study of Pentalenolactone F

Shota Sato

Doctoral Program in Advanced Materials Science and Technology
Graduate School of Science and Technology
Niigata University

Abbreviations

Ac	acetyl
acac	acetylacetonyl
AIBN	2,2'-azo *bis*isobutyronitrile
aq.	aqueous
AZADO	azaadamantane N-oxyl
Bn	benzyl
Bu	butyl
Bz	benzoyl
CSA	camphorsulfonic acid
DBU	1,8-diazabicyclo[5.4.0]undec-7-ene
DCC	dicyclohexylcarbodiimide
DCE	1,1-dichloroethane
DET	Diethyl tartrate
DIBAL	diisobutylaluminum hydride
DMAP	N,N-4-dimethylaminopyridine
DME	dimethyl ether
DMF	N,N-dimethylformamide
DMPU	N,N-dimethyl propylene urea
DMSO	dimethylsulfoxide
d.p.	desired product
Et	ethyl
eq.	equivalent
FPP	Farnesyl diphosphate
HMPT	hexamethylphosphorous triamide
LDA	lithium diispropylamide
m-CPBA	meta chloroperbenzoic acid
Me	methyl

MOM	methoxymethyl
MPM(PMB)	*p*-methoxybenzyl
Ms	mesyl(methanesulfonyl)
MS	molecular sieves
NaHMDS	sodium *bis*(trimethylsilyl)amide
NMO	N-methylmorpholine oxide
NMR	nuclear magnetic resonance
NOE	nuclear overhauser effect
NOESY	nuclear overhauser effect spectroscopy
PCC	pyridinium chlorochlomate
PDC	pyridinium dichromate
Ph	phenyl
PPTS	pyridinium *p*-toluenesulfonate
Pr	propyl
rec.s.m.	recycle starting material
r.t.	room temperature
TBAF	tetra-*n*-butylammonium fluoride
TBDPS	*t*-butyldiphenylsilyl
TBHP	*t*-butyl hydroperoxide
TBS(TBDMS)	*t*-butyldimethylsilyl
TEA	triethylamine
Tf	trifluoromethanesulfonyl
THF	tetrahydrofuran
TMS	trimethylsilyl
TPAP	tetra-*n*-propylammonium perruthenate
Ts	*p*-toluenesulfonyl
TSA	toluenesulfonic acid

Table of Contents

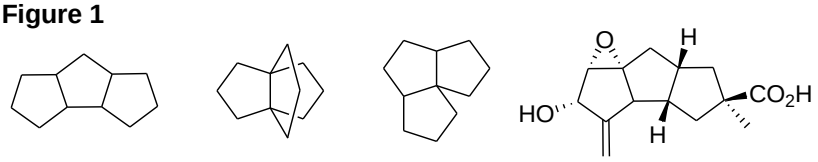
Chapter 1

Introduction

1-1 : Angular Triquinane Group Comprised in Sesquiterpene

Sesquiterpenes, which go through farnesyl diphosphate (FPP) consisting of three isoprene units as a common precursor, are one of the isoprenoids produced by biosynthetic conversion. Various cyclization patterns provide a lot of sesquiterpene frameworks such as mono, di and tricyclic skeletons, and they are regarded as important biochemical intermediates or bioactive natural products. These ideas have driven new methodology and strategy to develop over last four decades. Among sesquiterpenes, a polyquinane family which possesses carbocyclic framework composed of fused five membered rings has been regarded as an important class of natural products, and have been in nature since olden days and revealed to chemical scientists only in the second half of 20th century. Firstly, the isolation and structural determination were accomplished with hirsutic acid (**1**)[1)]. Since then, many polyquinane natural products were found out from plant, marine and microbial sources. Among the polyquinane family, triquinane framework is more abundant natural product skeleton (Figure 1). According to some literatures, nearly eighty such types have been discovered. Based on the type of ring fusion, they can be broadly classified into three types: linear[2)], propellane[3)], and angular[4)].

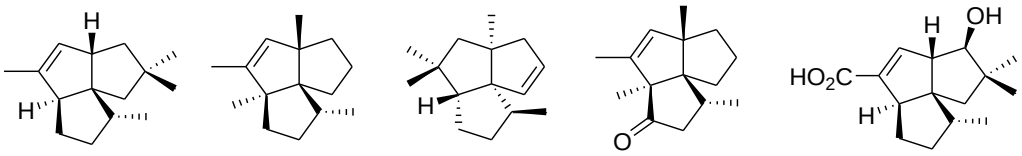
Figure 1



Linear Propellane Angular Hirsutic acid (**1**)

Among them, the angular triquinane type, which has unique structure composed of three cyclopentane rings sharing a quaternary carbon, is the most abundant in nature. For example, pentalenene (**2**)[5)], isocomene (**3**)[6)], silphinene (**4**)[7)], arnicenone (**5**)[8)] and pentalenic acid (**6**)[9)] have a common angular triquinane framework (Figure 2). Many scientists have been considered this type as attractive ring structure consisting of significant interests and promising bioactivity. Therefore, a lot of investigations have been done by many scientists.

Figure 2

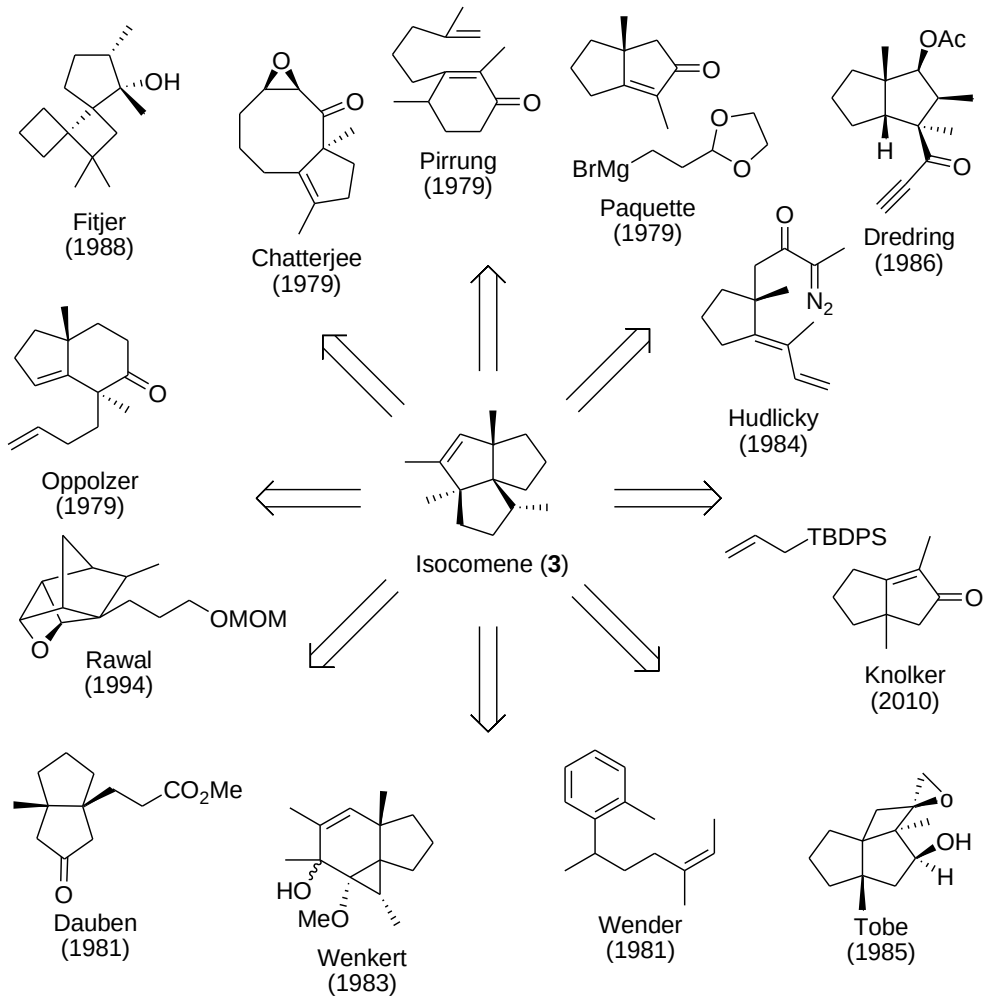


Pentalenene (**2**) Isocomene (**3**) Silphinene (**4**) Arnicenone (**5**) Pentalenic acid (**6**)

1-2 : Constructive Method for Angular Triqinane Framework

Skeletal construction methods of the angular triquinane framework have been reported by many scientists (Figure 3): for example, Hudlicky's report[10] by [4+1] cyclopentene annulation, Wender's report[11] by photochemical arene-alkene meta cycloaddition followed by [3+2] cycloaddition, Lee's report[12] by intramolecular Michael addition, Snider's report[13] by intramolecular ketene cycloaddition followed by Caroll rearrangement and Grieco's report[14] by intramolecular cationic [5+2] cycloaddition. In this research, it is the most important and fascinating task to install the quaternary carbon for construction of the angular triquinane framework.

Figure 3

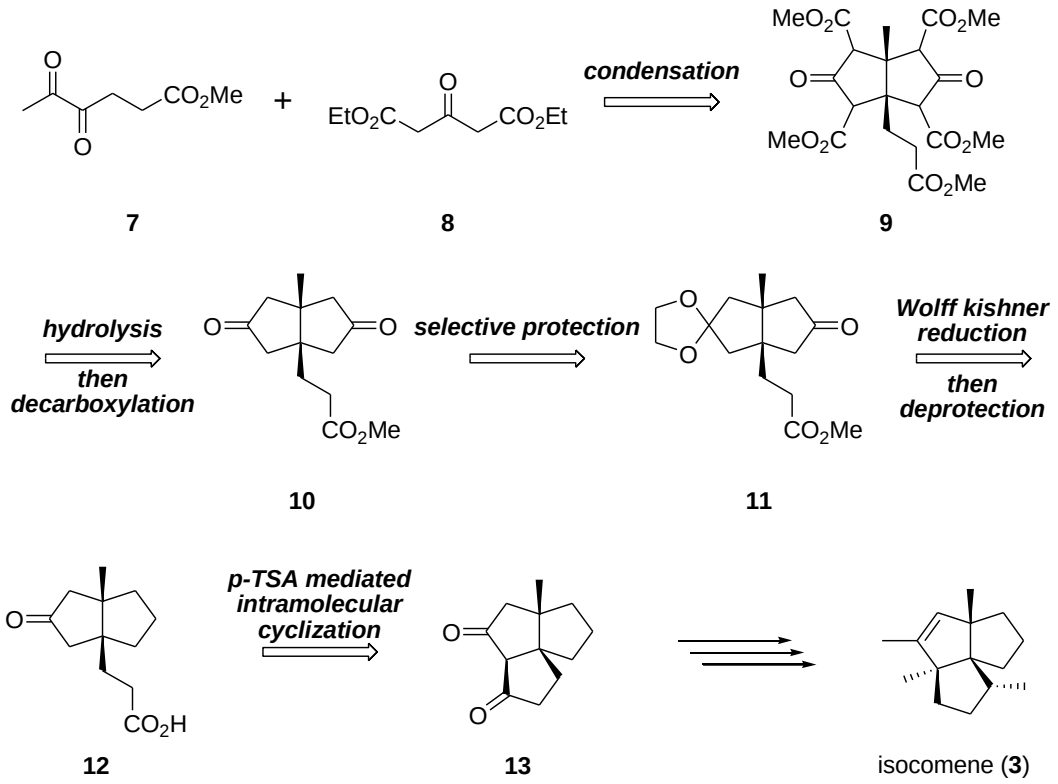


1-3 : Previous Reports

1-3-1 Methodology by Dauben's group[6c)]

In synthetic study of Isocomene (1981), construction procedure of angular triquinane framework was reported by Dauben and co-workers (Scheme 1). At the outset, they achieved the synthesis of **9** composed of diquinane framework by condensation with 1,2-diketone (**7**), which was obtained from ethylene dithiotosylate and 2,4-pentanedione, and 2 equiv of dimethyl 1,3-acetonedicarboxylate (**8**). Subsequently, resultant **9** was hydrolyzed and decarboxylated in refluxing aqueous acid to give **10**. A crucial step, differentiation of the two carbonyls in diketone **10** was achieved by the following sequence; 1) protection of both carbonyl groups with 3,3-dimethyl propane-1,3-diol, 2) partial hydrolysis of the result diacetal. Wolff-Kishner reduction of **11** followed by deprotection of ketal gave **12**. Finally, *p*-TSA mediated intramolecular cyclization accomplished the construction of the desired angular triquinane framework **13**.

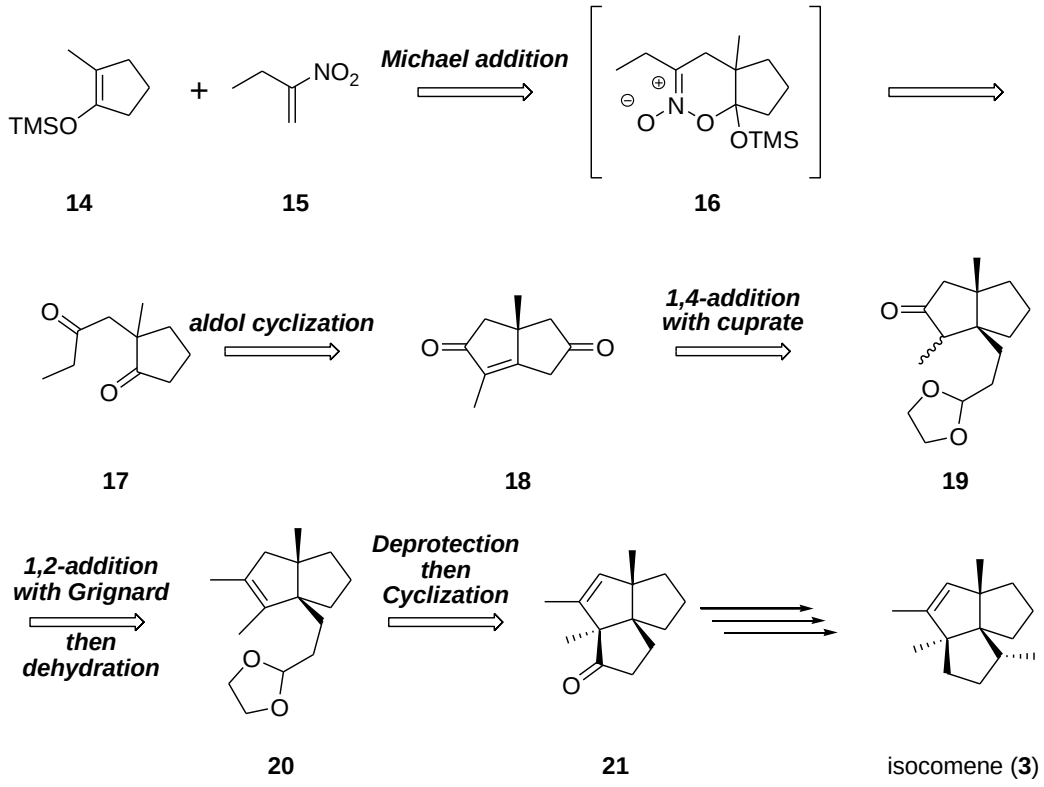
Scheme 1



1-3-2 Methodology by Paquette's group[6b)]

In synthetic study of Isocomene (1979), construction method of the angular triquinane framework was reported by Paquette and co-workers (Scheme 2). In the beggining, they carried out Michael addition with silyl enol ether **14** prepared from 2-methyl cyclopentanone to nitroolefine **15** obtained by an aldol-type condensation of formaldehyde and 2-nitro-1-butene, to give **17**. The reaction proceeded via nitronic acid intermediate **16**. Subsequently, construction of diquinane **18** was achieved by intramolecular aldol cyclization with KOH in aqueous EtOH under reflux condition. Conjugate addition of Grignard reagent prepared from *β*-bromopropionaldehyde ethylene ketal in the presence of the cuprous bromide dimethyl sulfide complex gave **19**. 1,2-Addition of Grignard reagent followed by dehydration afforded **20**. Finally, deprotection of the ketal followed by intramolecular cyclization in the presence of acetic acid accomplished the construction of the desired angular triquinane framework **21**.

Scheme 2



Reference

(1) (a) Heatley, N. G.; Jennings, M. A.; Florey, H. W. *Br. J. Exp. Pathol.* **1947**, 28, 35; (b) Comer, F. W.; Trotter, J. *J. Chem. Soc. B.* **1996**, 11-18; (c) Banwell, M. G.; Austin, K. A. B.; Willis, A. C. *Tetrahedron.* **2007**, 63, 6388-6403.

(2) (a) Singh, V.; Thomas, B. *Tetrahedron*. **1988**, 54, 3647-3692. (b) Veretenov, A. L.; Koltun, D. O.; Smit, W. A. *Tetrahedron Lett*. **1995**, 36, 4651-4654; (c) Srikrishna, A.; Beeraiah, B. *Tetrahedron: Asymmetry.* **2008**, 19, 884-890.

(3) Kotha, S.; Ali, R.; Chinnam, A. K. *Tetrahedron Lett*. **2014**, 55, 4492-4495.

(4) (a) Enholm, E. J.; Jia, Z. J. *Tetrahedron Lett*. **1996**, 37, 1177-1178; (b) Pierre, M. C.; Tenaglia, A.; Maurice, S. *Tetrahedron*. **1998**, 54, 14803-14810. (c) Srikrishna, A.; Gowri, V. *Tetrahedron: Asymmetry*. **2011**, 22, 1553-1559.

(5) (a) Seto, H.; Yonehara, H.; *J. Antibiot*. **1980**, 33, 92; (b) Hatanaka, M.; Ueno, F.; Ueda, I.; *Tetrahedron Lett.* **1996**, 37, 89-90; (c) Miesch, M.; Gross, L.; Neumann, M. *Tetrahedron*. **1997**, 53, 2111-2118; (d) Ishii, S.; Zhao, S.; Mehta, G.; Knors, C. J.; Helquist, P. *J. Org. Chem*. **2001**, 66, 3449-3458; (e) Pallera, M. K.; Fox, J. M. *Org. Lett*. **2007**, 9, 5625-5628.

(6) (a) Kaneda, M.; Takahashi, R.; Iitaka, Y.; Shibata, S. *Tetrahedron Lett*. **1972**, 13, 4609-4611; (b) Paquette, L. A.; Han, Y, K.; *J. Org. Chem*. **1979**, 44, 4014-4016; (c) Dauben, W. G.; Walker, D. M. *J. Org. Chem.* **1981**, 46, 1103-1108.

(7) (a) Bohlmann, F.; Jakupovic, *J. Phytochemistry.* **1980**, 19, 259; (b) Paquette, L. A.; Bay, A. *J. Am. Chem. Soc*. **1983**, 105, 7352-7358; (c) Sternbach, D. D.; Hughes, J. W.; Burdi, D. F.; Banks, B. A. *J. Am. Chem. Soc*. **1985**, 107, 2149-2153.

(8) (a) Schmitz, R.; Frahm, A. W.; Kating, H. *Phytochemistry*. **1980**, 19, 1477; (b) Iura, Y.; Sugahara, T.; Ogasawara, K. *Org. Lett*. **2001**, 3, 291-293.

(9) (a) Seto, H.; Sasaki, T.; Uzawa, J.; Takeuchi, S.; Yonehara, H. *Tetrahedron Lett*. **1978**, 4411; (b) Crimmins, M. T.; Deloach, J. A. *J. Org. Chem.* **1984**, 49, 2076-2077; (c) Agnel, G.; Negishi, E. *J. Am. Chem. Soc*. **1991**, 113, 7424-7426.

(10) Ranu, B. C.; Kavka, M.; Higgs, L. A.; Hudlickyl, T. *Tetrahedron.* **1984**, 25, 2447-2450.

(11) Paul, A. Wender.; Geoffrey, B. Dreyer.; *Tetrahedron*. **1981**, 37, 4445.

(12) H. M, Lee.; J. H, Lee.; I. C, Lee. *Bull Korean. Chem. Soc.* **1991**, 12, 392.

(13) B. B, Snider.; R. B, Beal. *J. Org. Chem.* **1988**, 53, 4508.

(14) P. A, Grieco.; J. K, Walker. *Tetrahedron*. **1997**, 53, 8975.

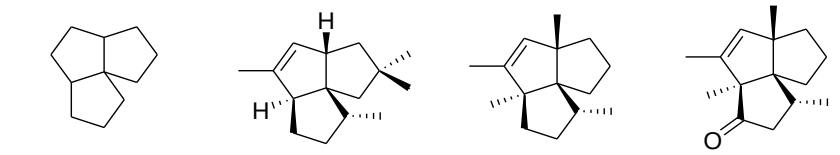
Chapter 2

Synthesis of the Triquinane System

2-1 : Eu(OTf)$_3$ Mediated 5-*exo*-Cyclization of Epoxy Malonate

In polyquinane natural products which were encountered among plant, marine and microbial sources, angular triquinane compounds has unique structure composed of three cyclopentane rings around one carbon and promising bioactivity (Scheme 1). These features have received adequate attention from many scientists and a lot of investigations have been done by them.

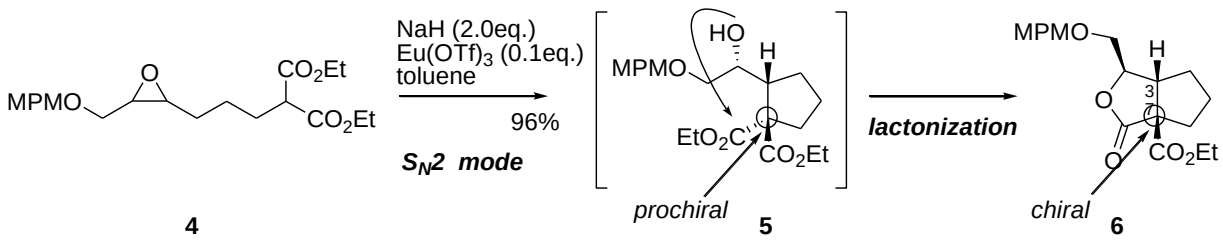
Figure 1



Angular triquinane Pentalenene (**1**) Isocomene (**2**) Arnicenone (**3**)

In association with synthetic study of the angular triquinane framework, our laboratory have developed intramolecular addition of malonate anion to epoxide by addition of Eu(OTf)$_3$ in the past several years (Scheme 1). This reaction proceeds via S_N2 and modes to give the intermediate **5**, which successively lactonized to afford bicyclic lactone **6**, in which three consecutive chiral centers were introduced. In the first step, the presence of Eu(OTf)$_3$ plays an important role to obtain higher reactivity and excellent yield. In the second step, lactonization of intermediate **5** proceeds stereoselectively by means of more stable *cis*-5, 5-system. As a result, a prochiral quaternary carbon in intermediate **5** was converted to a chiral one in lactone **6**. The bicycle lactone **6** consists of three consecutive chiral centers containg the desired chiral quaternary carbon and functionalities for construction of the angular triquinane framework.

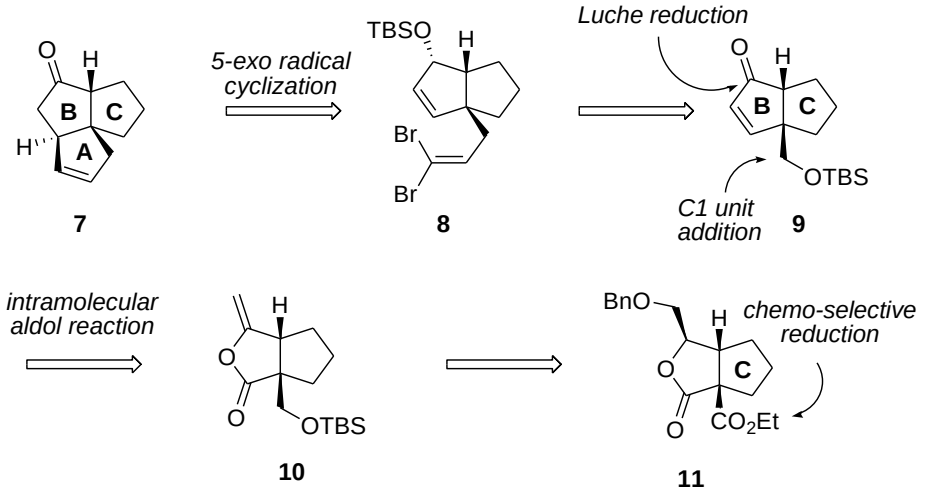
Scheme 1



2-2 : Synthetic Strategy

Synthetic strategy involving the bicyclic lactone **11** as a key precursor is shown in scheme 2. I envisaged that diquinane **9** would be synthesized by chemoselective reduction of **11** and subsequent intramolecular aldol condensation of **10**. The angular triquinane skeleton **7** would be constructed via 5-exo radical cyclization of dibromoalkene **8**, which would be obtained from **9** by Luche reduction and C-1 unit homologation.

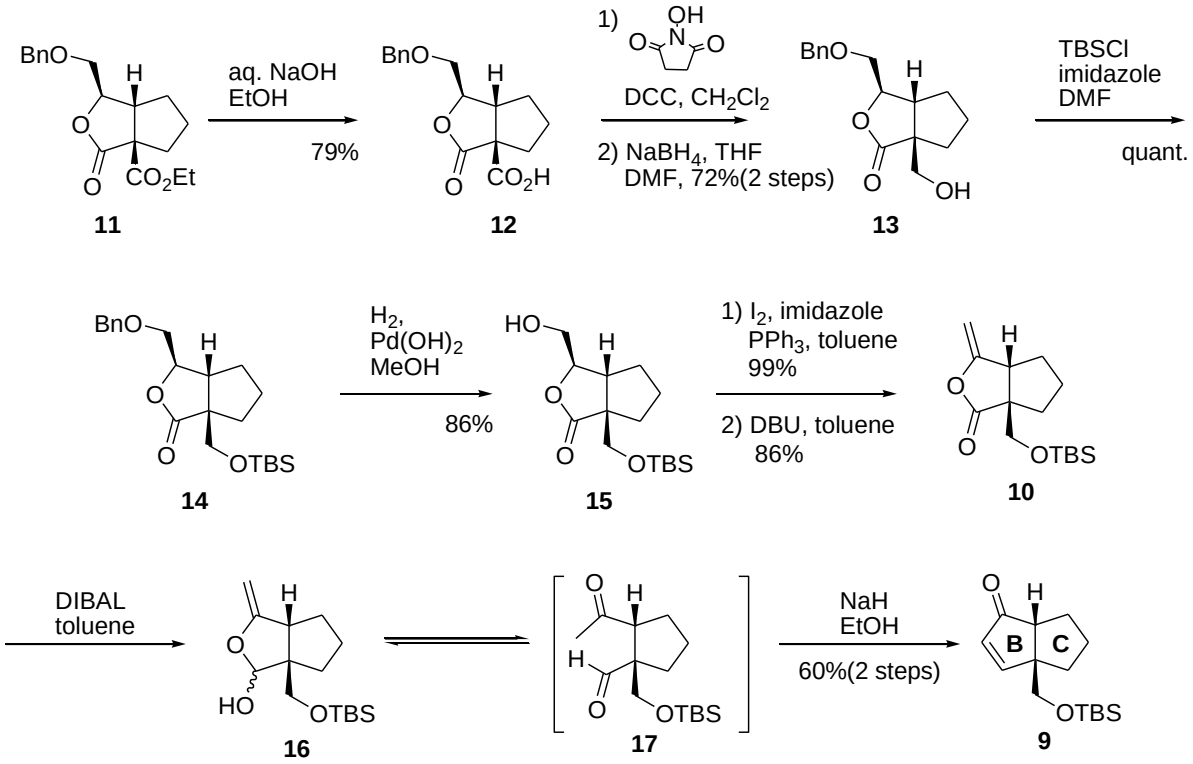
Scheme 2



2-3 : Transformation of Bicyclic Lactone into Diquinane Framework

In the beginning of the research, I focused on the construction of diquinane framework. Hydrolysis of **11** under basic conditions proceeded smoothly to produce **12** in 79% yield. I envisaged that chemoselective reduction could be done by condition using borane dimethyl sulfide complex, however, this attempt was failed. This problem was solved by reduction with $NaBH_4$ via an active ester. Namely, esterification of **12** with DCC and N-hydroxysuccinimide[1)] followed by reduction with $NaBH_4$ afforded **13** in good yield. After protection of the resulting hydroxy group as a TBS ether, benzyl ether was cleavaged under hydrogenation conditions to afford **15**. Subsequently, **15** was converted to **10** by iodination followed by elimination conditions. Finally, reduction of lactone in **10** with DIBAL and intramolecular aldol condensation was conducted by treating **16** with EtOH and catalytic NaH to furnish **9** possessing of diquinane framework without isomerization.

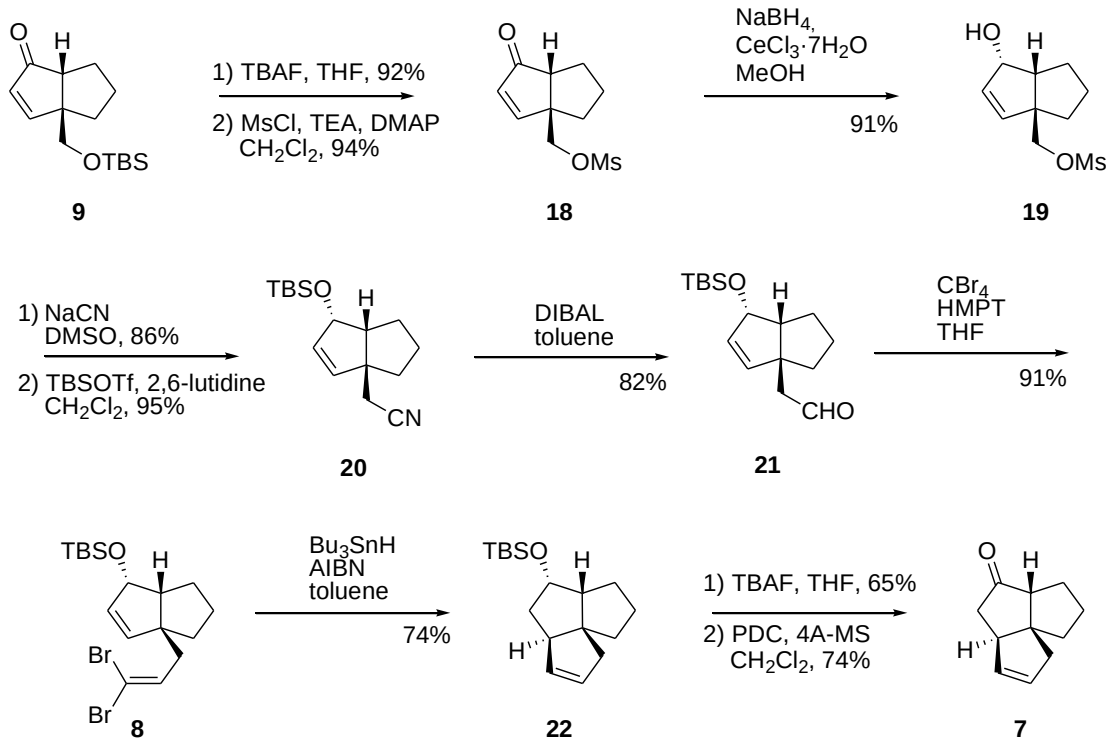
Scheme 3



2-4 : Construction of the Angular Triquinane Framework

With the requisite diquinane **9** in hand, the next task in 5-*exo* radical cyclization of bromoalkene **8** for the purpose of the construction of the angular triquinane framework (Scheme 4). Removal of TBS group with TBAF followed by mesylation gave **18**. Subsequently, Luche reduction[2)] of an enone moiety in **18** afforded desired **19** as a single isomer. Introduction of a cyano group to **19** for the homologation of C-1 unit and subsequent protection of secondary alcohol with TBSOTf gave desired **20**. After that, DIBAL reduction of **20** to provide aldehyde **21**, followed by dibromoolefination with tetrabromomethane and hexamethyl phosphorous triamide (HMPT)[3)] gave **8**. Finally, **8** was successively treated for 5-*exo* radical cyclization[4)] with tributyltin hydride and AIBN to give **22** having the angular triquinane framework in 83% yield and subsequently removal of TBS group followed by PDC oxidation provided desired ketone **7** in moderate yields.

Scheme 4



9 **18** **19** **20** **21** **8** **22** **7**

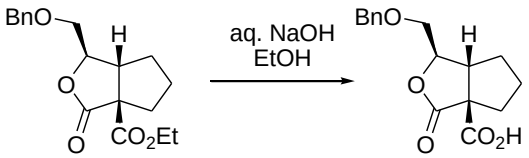
Experimental Section

General

IR spectra were recorded on a JASCO FT/IR-4200 spectrometer. Oily products were measured directly, solid products were diluted with chloroform and then measured. ^{1}H and ^{13}C NMR spectra were obtained for solutions in dueteriochloroform with VARIAN 400MHz and 700MHz spectrometer with residual solvent as the internal standard. Mass spectral data were run on JEOL GC-mate. Optical rotation was measured on a HORIBA SEPA-200 spectrometer. Thin layer chromatography (TLC) was carried out on MERCK Silica gel 60 F_{254} plates employing *n*-hexane/ethyl acetate as the mobile phase. KANTO Silica gel 60 N 40-50 μm was employed for flash column chromatography. THF and Et_2O were distilled from sodium/benzophenone ketyl. Benzene, CH_2Cl_2, toluene, CH_3CN, 2,6-lutidine, and TEA were distilled from CaH_2. Commercialized MeOH, EtOH, DMSO and DMF were used as reaction solvent. Simple distillation was carried out about ethyl acetate and *n*-hexane.

2-3 : Experimental Section

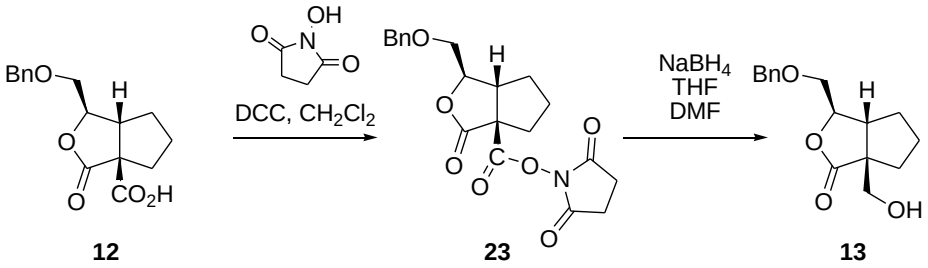
Carboxylic Acid 12



11 **12**

To a stirred solution of bicyclic lactone **11** (510.0 mg, 1.602 mmol) in EtOH (16 ml), 1N NaOH aq. (9.6 ml, 9.612 mmol) was added at room temperature under air atmosphere. After being stirred for 4 h at 50 ℃, the reaction was quenched by addition of 1N HCl aq.(9.6 ml, 9.612 ml). After being diluted with ethyl acetate, aqueous layer was checked to be acidic property with pH paper and then extracted with ethyl acetate two times in the presence of solid NaCl. The organic layer was dried with Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (80 g, CH_2Cl_2/MeOH = 10: 1) to give carboxylic acid **12** (365.6 mg, 1.259 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.38-7.25 (m, 5H), 4.59 (d, *J* = 12.1 Hz, 1H), 4.53 (d, *J* = 12.1 Hz, 1H), 4.33 (ddd, *J* = 3.6, 3.4, 3.4 Hz, 1H), 3.66 (dd, *J* = 10.5, 3.4 Hz, 1H), 3.58 (dd, *J* = 10.5, 3.6 Hz, 1H), 3.18 (br-ddd, *J* = 8.5, 3.4, 2.9 Hz, 1H), 2.35 (br-ddd, *J* = 13.2, 6.6, 3.7 Hz, 1H), 2.26 (ddd, *J* = 13.2, 10.5, 6.4 Hz, 1H), 2.16-2.05 (m, 1H), 1.94-1.85 (m, 1H), 1.81-1.74 (m, 1H), 1.69-1.56 (m, 1H).

Alcohol 13

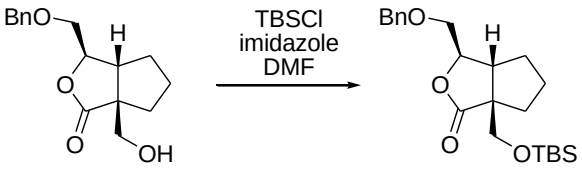


12 **23** **13**

To a stirred solution of carboxylic acid **12** (365.6 mg, 1.259 mmol) in anhydrous CH_2Cl_2 (6 ml), N-hydroxy succinimide (221.8 mg, 1.889 mmol) and then DCC (393.7 mg, 1.889 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 30 min, DCC (131.2 mg, 0.6295 mmol) was added because of incomplete esterification. Subsequently, removal of solvent by decompression and then filtration through a celite pad (ethyl acetate/hexane = 2:1) were carried out. After concentration, the residual oil was used in next step.

The crude active ester **23** in anhydrous THF (10 ml) and DMF (2 ml), $NaBH_4$ (41.4 mg, 1.007 mmol) was added at 0 ℃ under nitrogen atmosphere. After being stirred for 45 min, the reaction was quenched by addition of AcOH (288 μl, 5.036 mmol) and sat.NH_4Cl aq. at 0 ℃. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/benzene = 1: 3) to give alcohol **13** (251.6 mg, 0.9105 mmol) as a white solid. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.39-7.28 (m, 5H), 4.60 (d, *J* = 12.0 Hz, 1H), 4.57 (d, *J* = 12.0 Hz, 1H), 4.17 (ddd, *J* = 4.5, 4.5, 3.5 Hz, 1H), 3.83 (d, *J* = 10.8 Hz, 1H), 3.70 (dd, *J* = 10.7, 3.5 Hz, 1H), 3.63 (dd, *J* = 10.7, 4.5 Hz, 1H), 3.60 (d, *J* = 10.8 Hz, 1H), 2.72-2.66 (m, 1H), 2.13-2.06 (m, 1H), 1.91-1.70 (m, 4H), 1.65-1.50 (m, 1H).

TBS Ether 14

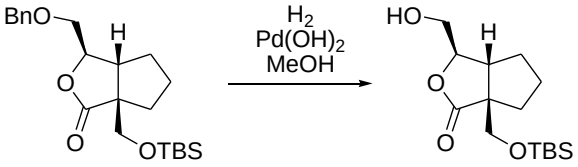


13 **14**

To a stirred solution of alcohol **13** (251.6 mg, 0.9105 mmol) in anhydrous DMF (9 ml), imidazole (186.0 mg, 2.732 mmol) and TBSCl (212.2 mg, 1.366 mmol) were added at room temperature. After being stirred for 2 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1:7) to give TBS ether **14** (358.5 g, 0.9178 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz,

$CDCl_3$): δ = 7.35-7.25 (m, 5H), 4.58 (d, J = 12.0 Hz, 1H), 4.53 (d, J = 12.0 Hz, 1H), 4.13 (ddd, J = 6.0, 4.9, 4.9 Hz, 1H), 3.89 (d, J = 9.5 Hz, 1H), 3.62 (dd, J = 10.3, 6.0 Hz, 1H), 3.58 (dd, J = 10.3, 4.9 Hz, 1H), 3.41 (d, J = 9.5 Hz, 1H), 2.66-2.60 (m, 1H), 2.00-1.93 (m, 1H), 1.85-1.67 (m, 4H), 1.57-1.47 (m, 1H), 0.84 (s, 9H), 0.00 (s, 3H), 0.00 (s, 3H).

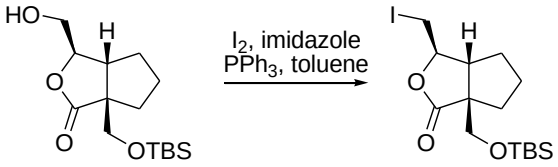
Alcohol 15



14 **15**

To a stirred solution of TBS ether **14** (358.5 mg, 0.9178 mmol) in MeOH (9 ml), $Pd(OH)_2$-C (35.9 mg, 10Wt%) was added at room temperature, and then purged with hydrogen. After being stirred for 30 min under a balloon of hydrogen, the heterogeneous mixture was filtered through a celite pad with ethyl acetate and concentrated. Subsequently, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:2) to give alcohol **15** (235.7 mg, 0.7844 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.10 (ddd, J = 6.2, 4.9, 3.4 Hz, 1H), 3.97 (d, J = 9.6 Hz, 1H), 3.80 (ddd, J = 12.2, 7.7, 3.4 Hz, 1H), 3.73 (ddd, J = 12.2, 6.2, 5.1 Hz, 1H), 3.45 (d, J = 9.6 Hz, 1H), 2.71-2.66 (m, 1H), 2.22-1.98 (m, 1H), 1.90-1.72 (m, 3H), 1.62-1.43 (m, 2H), 0.89 (s, 9H), 0.07 (s,3H), 0.07 (s, 3H).

Iodide 24

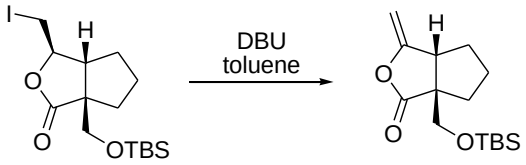


15 **24**

To a stirred solution of alcohol **15** (235.7 mg, 0.7844 mmol) in anhydrous toluene (8 ml), imidazole (120.2 mg, 1.765 mmol), PPh_3 (315.0 mg, 1.177 mmol) and then I_2 (299.2 mg, 1.177 mmol) were added at room temperature under nitrogen atmosphere. Subsequently, the mixture was warmed to 70 ℃. After being stirred for 30 min, the reaction was quenched by addition of aq.Na_2SO_3 and then filtered through a silica pad with ethyl acetate/hexanes = 1:10. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1:10) to give iodide **24** (317.8 mg, 0.7744 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.20 (ddd, J = 9.5, 4.9, 3.8 Hz, 1H), 3.97 (d, J = 9.5 Hz, 1H), 3.41 (d, J = 9.5Hz, 1H), 3.38 (dd, J = 9.5,

4.9Hz, 1H), 3.27 (dd, *J* = 9.5, 9.5 Hz, 1H), 2.68 (br-ddd, *J* = 8.2, 3.8, 2.8 Hz, 1H), 2.03-1.91 (m, 2H), 1.83-1.71 (m, 2H), 1.60-1.43 (m, 2H), 0.88 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H).

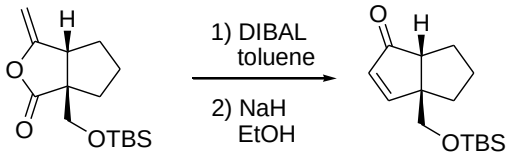
Vinyl Ether 10



24 **10**

To a stirred solution of iodide **24** (317.8 mg, 0.7744 mmol) in anhydrous toluene (8 ml), DBU (356 μl, 0.7744 mmol) was added at room temperature under nitrogen atmosphere and then warmed to 110 ℃. After being stirred for 8 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on florisil (15 g, ethyl acetate/hexanes = 1:20) to give vinyl ether **10** (188.7 mg, 0.6681 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.69 (dd, *J* = 2.5, 2.0 Hz, 1H), 4.27 (dd, *J* = 2.5, 1.7 Hz, 1H), 3.95 (d, *J* = 9.6 Hz, 1H), 3.47 (d, *J* = 9.6 Hz, 1H), 3.37 (br-dddd, *J* = 8.4, 2.0, 1.9, 1.7 Hz, 1H), 2.05-1.92 (m, 2H), 1.78-1.70 (m, 1H), 1.62-1.47 (m, 2H), 0.85 (s, 9H), 0.03 (s, 3H), 0.03 (s, 3H).

Enone 9



10 **9**

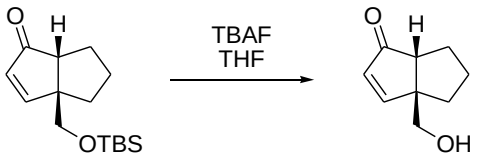
Firstly, azeotropic dehydration of vinyl ether **10** (188.7 mg, 0.6681 mmol) with anhydrous toluene was carried out. To a stirred solution of **10** in anhydrous toluene (7 ml), DIBAL (1.0 M in toluene, 675 μl, 0.6815 mmol) was added at -78 ℃ under nitrogen atmosphere. After being stirred for 30 min, additional DIBAL (1.0 M in toluene, 66 μl, 0.06681 mmol) was added four times. Subsequently, the reaction was quenched by addition of aq.Rochell's salt and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was used in the next step.

Azeotropic dehydration of residual oil with anhydrous toluene was carried out. In the next place, the oil was diluted with anhydrous EtOH (7 ml), and subsequently NaH (2.9 mg, 0.06681 mmol) was added to a reaction mixture at 0 ℃. After being stirred for 2 h at room temperature, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed

with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:10) to give enone **9** (106.0 g, 0.3978 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.45 (d, *J* = 5.6 Hz, 1H), 6.15 (d, *J* = 5.6 Hz, 1H), 3.68 (d, *J* = 9.6 Hz, 1H), 3.62 (d, *J* = 9.6 Hz, 1H), 2.43 (br-d, *J* = 9.8 Hz, 1H), 1.90 (br-dd, *J* = 13.9, 7.5 Hz, 1H), 1.75 (ddd, *J* = 12.3, 9.8, 5.5 Hz, 1H), 1.70-1.58 (m, 3H), 1.37-1.25 (m, 1H), 0.86 (s, 9H), 0.03 (s, 3H), 0.03 (s, 3H).

2-4 : Experimental Section

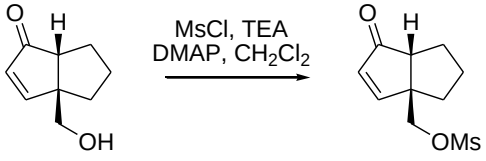
Alcohol 25



9 **25**

To a stirred solution of enone **9** (106.0 mg, 0.3978 mmol) in THF (4 ml), TBAF (1.0 M in THF, 0.8 ml, 0.7956 mmol) was added at room temperature under nitrogen atmosphere. After being stirred for 30 min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 5:2) to give alcohol **25** (55.7 mg, 0.3660 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.50 (d, *J* = 5.6 Hz, 1H), 6.21 (d, *J* = 5.6 Hz, 1H), 3.81 (d, *J* = 10.5 Hz, 1H), 3.69 (d, *J* = 10.5 Hz, 1H), 2.48 (br-d, *J* = 9.7 Hz, 1H), 1.95 (br-ddd, *J* = 12.8, 6.4, 1.4 Hz, 1H), 1.77 (dddd, *J* = 12.6, 9.7, 6.0, 6.0 Hz, 1H), 1.72-1.65 (m, 2H), 1.60-1.52 (m, 1H), 1.38-1.30 (m, 1H).

Mesylate 18

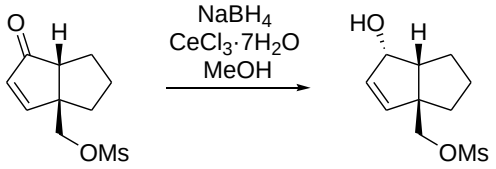


25 **18**

To a stirred solution of alcohol **25** (55.7 mg, 0.3660 mmol) in CH_2Cl_2 (4 ml), TEA (204 μl, 1.464 mmol), MsCl (57 μl, 0.7320 mmol) and then DMAP (4.5 mg, 0.03660 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 30 min, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column

chromatography on silica gel (15 g, ethyl acetate/hexanes = 2:1) to give mesylate **18** (79.4 mg, 0.3448 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.45 (d, J = 5.6 Hz, 1H), 6.25 (d, J = 5.6 Hz, 1H), 4.35 (d, J = 9.7 Hz, 1H), 4.24 (d, J = 9.7 Hz, 1H), 3.02 (s, 3H), 2.51 (br-d, J = 9.6 Hz, 1H), 1.99 (br-ddd, J = 12.9, 6.5, 1.4 Hz, 1H), 186-1.68 (m, 3H), 1.67-1.58 (m, 1H), 1.40-1.30 (m, 1H).

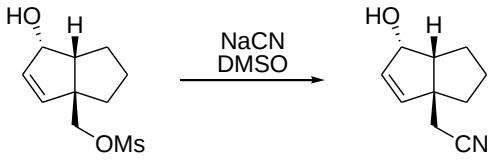
Allyl Aocohol 19



18 **19**

To a stirred solution of mesylate **18** (79.4 mg, 0.3448 mmol) in MeOH (3 ml), $CeCl_3 \cdot 7H_2O$ (192.7 mg, 0.5172 mmol) and then $NaBH_4$ (21.3 mg, 0.5172 mmol) were added at 0 ℃ under nitrogen atmosphere. After being stirred for 30 min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 2:1) to give allyl alcohol **19** (72.6 mg, 0.3125 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.80 (dd, J = 5.6, 1.9 Hz, 1H), 5.66 (dd, J = 5.6, 1.6 Hz, 1H), 4.93 (ddd, J = 8.1, 1.9, 1.6 Hz, 1H), 4.18 (d, J = 9.3 Hz, 1H), 4.10 (d, J = 9.3 Hz, 1H), 3.00 (s, 3H), 2.53 (ddd, J = 8.1, 8.1, 4.1 Hz, 1H), 1.98-1.90 (m, 1H), 1.70-1.50 (m, 5H).

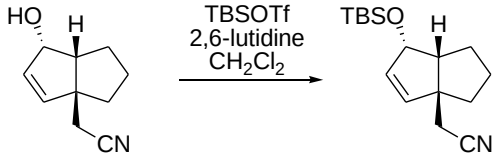
Nitrile 26



19 **26**

To a stirred solution of allyl alcohol **19** (72.6 mg, 0.3125 mmol) in anhydrous DMSO (3 ml), NaCN (47.4 mg, 0.9375 mmol) was added at room temperature under nitrogen atmosphere. The mixture was warmed to 120 ℃. After being stirred for 2 h, the reaction was quenched by addition of H_2O and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:1) to give nitrile **26** (43.6 mg, 0.2671 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.83 (dd, J = 5.6, 1.9 Hz, 1H), 5.67 (dd, J = 5.6, 1.6 Hz, 1H), 5.01 (br-d, J = 7.4 Hz, 1H), 2.55-2.45 (m, 1H), 2.50 (d, J = 1.3 Hz, 2H), 2.04-1.96 (m, 1H), 1.77-1.40 (m, 5H).

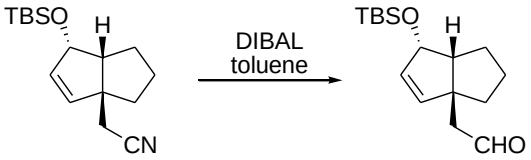
TBS Ether 20



26 **20**

To a stirred solution of nitrile **26** (43.6 mg, 0.2671 mmol) in CH_2Cl_2 (3 ml), 2,6-lutidine (95 μl, 0.8013 mmol) and then TBSOTf (94 μl, 0.4007 mmol) were added at 0 ℃ under nitrogen atmosphere. After being stirred for 20 min, the reaction was quenched by addition of ap.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:10) to give TBS ether **20** (70.4 mg, 0.4313 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.70 (dd, J = 5.6, 1.7 Hz, 1H), 5.57 (dd, J = 5.6, 1.7 Hz, 1H), 4.96 (ddd, J = 7.9, 1.7, 1.7 Hz, 1H), 2.48 (d, J = 1.2 Hz, 2H), 2.42 (ddd, J = 8.1, 7.9, 3.6 Hz, 1H), 2.07-2.00 (m, 1H), 1.73-1.68 (m, 1H), 1.65-1.45 (m, 4H), 0.90 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H).

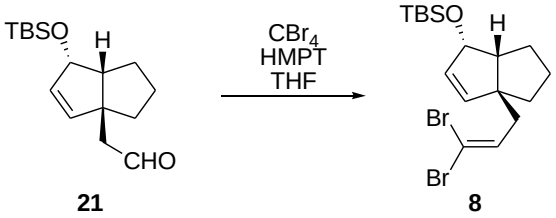
Aldehyde 21



20 **21**

To a stirred solution of TBS ether **20** (70.4 mg, 0.2537 mmol) in anhydrous toluene (3 ml), DIBAL (1.0 M in toluene, 377 μl, 0.3806 mmol) was added at -78 ℃ under nitrogen atmosphere. After being stirred for 30 min, the reaction mixture was warmed to -20 ℃ and then quenched by addition of aq.Rochell's salt. The heterogeneous mixture was diluted with ethyl acetate and then washed with brine. Subsequently, the organic layer was dried over Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:11) to give aldehyde **21** (58.1 mg, 0.2071 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.70 (dd, J = 3.0, 2.6 Hz, 1H), 5.65 (dd, J = 5.6, 1.6 Hz, 1H), 5.60 (dd, J =5.6, 1.7 Hz, 1H), 4.87 (ddd, J = 8.0, 1.7, 1.6 Hz, 1H), 2.62 (dd, J = 15.2, 2.6 Hz, 1H), 2.50 (dd, J = 15.2, 3.0 Hz, 1H), 2.42 (ddd, J = 8.3, 8.0, 3.9 Hz, 1H), 2.07-2.00 (m, 1H), 1.74-1.68 (m, 1H), 1.58-1.40 (m, 4H), 0.90 (s, 9H), 0.07 (s, 6H).

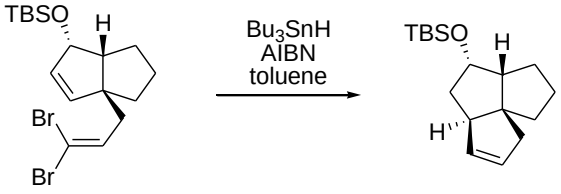
Dibromo Olefin 8



21 **8**

To a stirred solution of CBr_4 (140.2 mg, 0.4142 mmol) and HMPT (155 μl, 0.8284 mmol) in THF (4 ml), aldehyde **21** (0.1 M in THF, 2 ml, 0.2071 mmol) was added at 0 ℃ under nitrogen atmosphere. After being stirred for 20 min, the reaction was quenched by addition of H_2O and then diluted with ethyl acetate. The organic layer was washed with ap.$NaHCO_3$, H_2O and then brine. Subsequently, this layer was dried over Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:20) to give dibromo olefine **8** (82.3 mg, 0.1886 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 6.32 (t, *J* = 7.3 Hz, 1H), 5.58 (dd, *J* = 5.6, 1.6 Hz, 1H), 5.52 (dd, *J* = 5.6, 1.6 Hz, 1H), 4.84 (ddd, *J* = 7.9, 1.6, 1.6 Hz, 1H), 2.30-2.24 (m, 1H), .2.27 (d, *J* = 7.3 Hz, 2H), 2.02-1.95 (m, 1H), 1.61-1.37 (m, 5H).

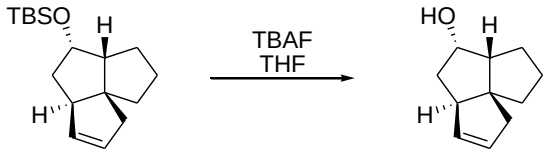
Tricyclic Compound 22



8 **22**

To a stirred solution of dibromo olefine **8** (82.3 mg, 0.1886 mmol) in anhydrous toluene (2 ml), Bu_3SnH (209 μl, 0.7554 mmol) and AIBN (3.1 mg, 0.01886 mmol) were added and then warmed to 100 ℃. After being stirred for 1 h, the reaction mixture was concentrated. The residual oil was purified by short column chromatography on silica gel (10 g, ethyl acetate/hexanes/TEA = 5:200:2) to give tricyclic compound **22** (38.9 mg, 0.1397 mmol) as a colorless oil. Analytical data: ^{1}H NMR (700 MHz, $CDCl_3$): δ = 5.57 (dddd, *J* = 5.7, 2.2, 2.2, 2.2 Hz, 1H), 5.44 (dddd, *J* = 5.7, 2.2, 2.2, 2.2 Hz, 1H), 4.18 (ddd, *J* = 7.8, 7.0, 7.0 Hz, 1H), 2.63-2.59 (m, 1H), 2.47 (dddd, *J* = 17.1, 2.2, 2.2, 2.2 Hz, 1H), 2.44 (dddd, *J* = 17.1, 2.2, 2.2, 2.2 Hz, 1H), 2.06 (ddd, *J* = 9.2, 7.0, 5.2 Hz, 1H), 1.87-1.81 (m, 1H), 1.75-1.68 (m, 2H), 1.66 (d, *J* = 7.8 Hz, 1H), 1.65 (d, *J* = 7.8 Hz, 1H), 1.63-1.51 (m, 3H), 0.87 (s, 9H), 0.01 (s, 3H), 0.01 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 134.4, 129.4, 74.2, 58.2, 57.6, 54.8, 47.6, 42.3, 38.8, 27.3, 26.0, 25.9, 18.2, -4.7, -4.8.

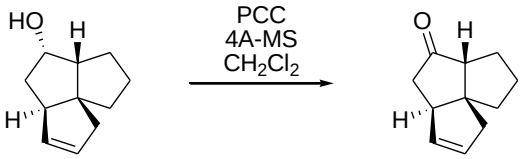
Alcohol 27



22 **27**

To a stirred solution of tricyclic compound **22** (38.9 mg, 0.1400 mmol) in THF (1 ml), TBAF(1.0 M in THF, 280 μl, 0.2800 mmol) was added at room temperature under nitrogen atmosphere. After being stirred for 7 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:4) to give alcohol **27** (15.0 mg, 0.09133 mmol) as a white solid. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.58 (dddd, J = 5.8, 2.3, 2.3, 2.3 Hz, 1H), 5.44 (dddd, J = 5.8, 2.3, 2.3, 2.3 Hz, 1H), 4.27 (ddd, J = 10.5, 6.8, 6.8 Hz, 1H), 2.69-2.63 (m, 1H), 2.51-2.47 (m, 2H), 2.16 (br-ddd, J = 6.8, 6.8, 6.8 Hz, 1H), 1.84-1.55 (m, 8H).

Ketone 7



27 **7**

To a stirred solution of alcohol **27** (15.0 mg, 0.09133 mmol) in CH_2Cl_2 (1 ml), crushed 4A-MS (45.7 mg) and PDC (70.1 mg, 0.1827 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 1.5 h, the reaction was quenched by addition of 2-propanol (70 μl, 0.9133 mmol). The reaction mixture was directly purified by column chromatography on silica gel (10 g, ethyl acetate/hexanes = 1:4) to give ketone **7** (11.0 mg, 0.06780 mmol) as a colorless oil. Analytical data: ^{1}H NMR (700 MHz, $CDCl_3$): δ = 5.72 (dddd, J = 5.6, 2.0, 2.0, 2.0 Hz, 1H), 5.59 (dddd, J = 5.6, 2.0, 2.0, 2.0 Hz, 1H), 3.03-2.99 (m, 1H), 2.57-2.50 (m, 3H), 2.32 (br-d, J = 10.0 Hz, 1H), 2.28 (dddd, J = 18.7, 2.0, 2.0, 2.0Hz, 1H), 1.99-1.50 (m, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 223.3, 134.5, 130.6, 60.2, 57.6, 51.3, 47.0, 43.6, 40.3, 30.7, 27.1.

Reference

(1) (a) Humphrey, J. M.; Aggen, J. B.; Chamberlin, A. R. *J. Am. Chem. Soc*. **1996**, 118, 11759-11770.

(b) Park, J.; Tian, G. R.; Kim, D. H. *J. Org. Chem*. **2001**, 66, 3696-3703.

(2) Gemal, A. L.; Luche, J. L.; *J. Am. Chem. Soc.* **1981**, 103, 5454-5459.

(3) (a) Jung, M. E.; D'Amico, D. C.; *J. Am. Chem. Soc.* **1995**, 117, 7379-7388; (b) Organ, M. G.; Bratovanov, S. *Tetrahedron Lett.* **2000**, 41, 6945-6949.

(4) Jasperse, C. P.; Curran, D. P. *J. Am. Chem. Soc*. **1990**, 112, 5601-5609.

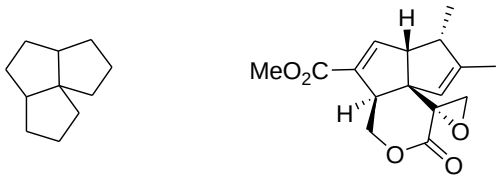
Chapter 3

Total Synthesis of Pentalenolactone F

3-1 : Introduction

A lot of antibiotic agents have been produced by actinomycetes, and some of them were applied to effective medicines. Especially, sesquiterpene antibiotic pentalenolactone (**1**), which was isolated from a variety of Streptomyces species (Figure 1), has broad spectrum activity as antibiotic and antiviral agent, pathogenic and saprophytic fungi, antitumor property, and important selective inhibition of glyceraldehyde-3-phosphate dehydrogene.[1)] Therefore, pentalenolactone (**1)** has great possibility as future medicines.

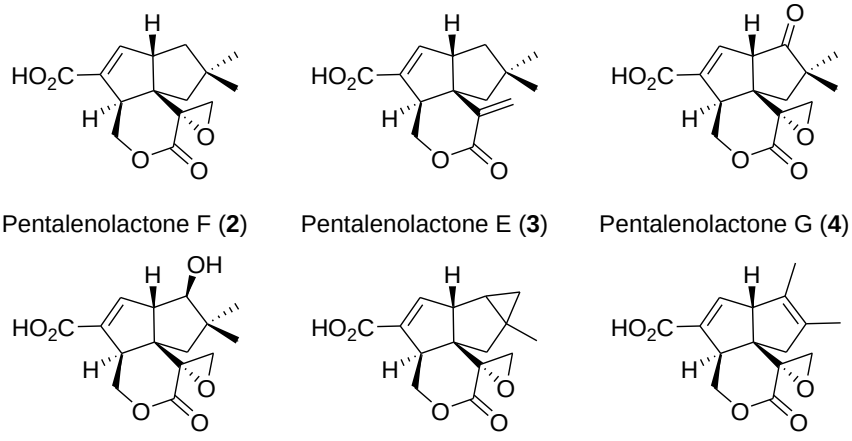
Figure 1



Angular triquinane Pentalenolactone (**1**)

Over the last several years additional representatives of novel metabolite, such as pentalenolactone F (**2**)[2)], E (**3**)[3)], G (**4**)[4)], H (**5**)[5)], P (**6**)[6)], and A (**7**)[7)], have been isolated and devoted considerable efforts toward synthetic study of them (Figure 2). According to biosynthetic researches, they are supposed to be intermediate or shunt metabolite of pentalenolactone (**1**). I have been interested in its remarkable bioactivities and characteristic structural feature, and selected it as a synthetic target. I now report my considerable efforts to accomplish total synthesis of pentalenolactone F (**2**).

Figure 2



Pentalenolactone F (**2**) Pentalenolactone E (**3**) Pentalenolactone G (**4**)

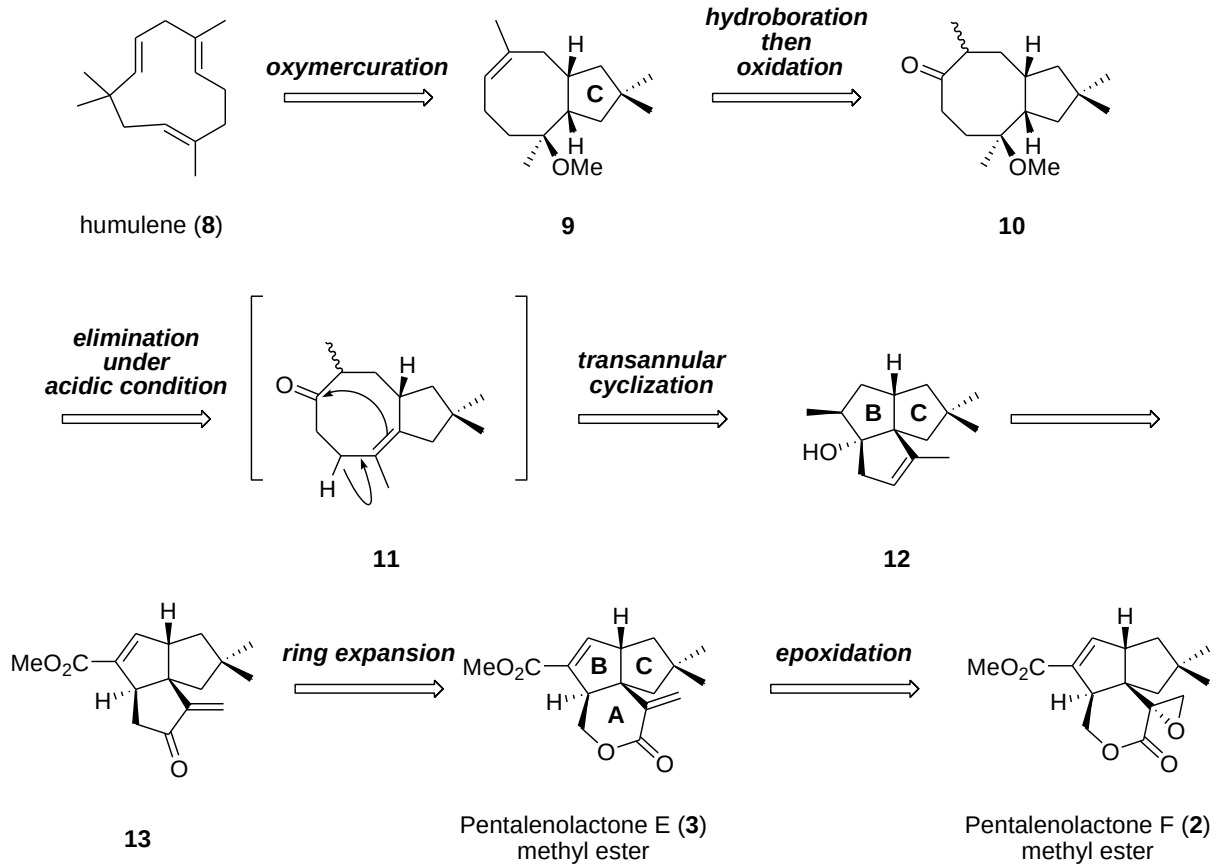
Pentalenolactone H (**5**) Pentalenolactone P (**6**) Pentalenolactone A (**7**)

3-2 : Previous Reports

3-2-1 : Methodology by Ohtsuka's Group[2f)]

In 1983, Ohtuka have reported the first total synthesis of pentalenolactone F (**2**) methyl ester (Scheme 1). They led humulene (**8**), which was used as a starting material, to cyclization precursor **10** composed of a bicyclo[6.3.0] framework by means of oxymercuration and hydroboration-oxidation sequence. Subsequent treatment of **10** with formic acid resulted in elimination followed by transannular cyclization of the intermediate to furnish the angular triquinane framework in **12**. In the next stage, dehydration of **12** followed by isomerization and allylic oxidation with selenium dioxide provided unsaturated ester **13**. Finally, oxidation of the A-ring and then introduction of the epoxide afforded pentalenolactone F (**2**) methyl ester. In this stage, the selectivity of epoxidation selectivity was so far as α- : β- = 73 : 27, and this synthetic method provided a racemic form.

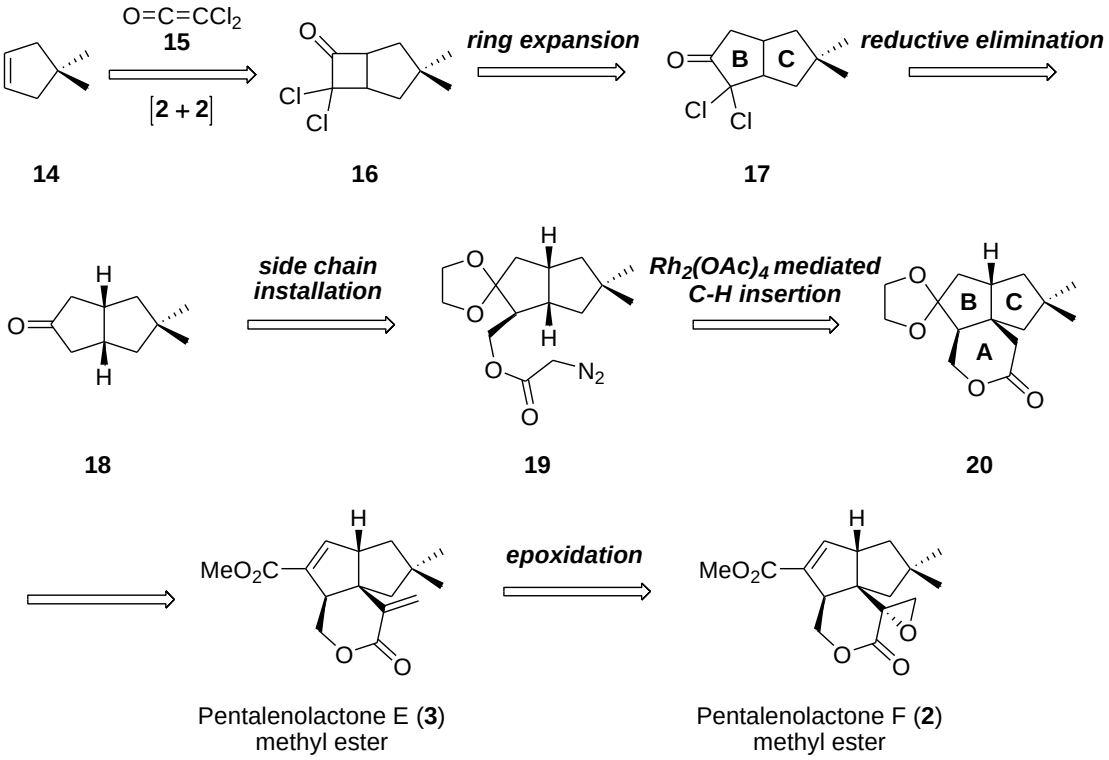
Scheme 1



3-2-2 : Methodology by Cane's Group[2b)]

In 1984, David, E. Cane have reported total synthesis of pentalenolactone F (**2**) methyl ester (Scheme 2). Firstly, they led dimethyl-3,3-dimethylglutarate, which was used as starting material, to α-dichloroketone **16** composed of a bicyclo [2.3.0] framework by means of [2+2]-cycloaddition of acyl carbene **15** to **14**. Subsequently, regioselective ring expansion of **16** by use of diazomethane followed by reduction of chlorine functionalities with zinc provided **18** possessing the bicyclo[3.3.0]octane skeleton. Installation of a diazoacetoxymethyl group for the formation of the A-ring gave **19** which was treated with catalytic $Rh_2(OAc)_4$ resulted in intramolecular C-H insertion of the carbenoid to afford δ-lactone **20**. Conversion of the carbonyl group into the methyl ester moiety was easily achieved via CO_2 insertion of vinyl triflate by use of a palladium catalyst. Subsequently introdution of *exo*-methylene at the α-posion of the lactone afforded the methyl ester derivative of **3**. Stereoselective introduction of α-epoxide was performed via an ingenious stepwise route: 1) reduction of lactone, 2) resulting allyl hemiacetal employing the Sharpless method in the presence of a vanadium catalyst, 3) oxidation of the hemiacetal to the lactone.[8)] The method accomplished with high α-selectivity, however, it required a multi- step conversion. In addition to that, this synthetic procedure provided racemic substance.

Scheme 2

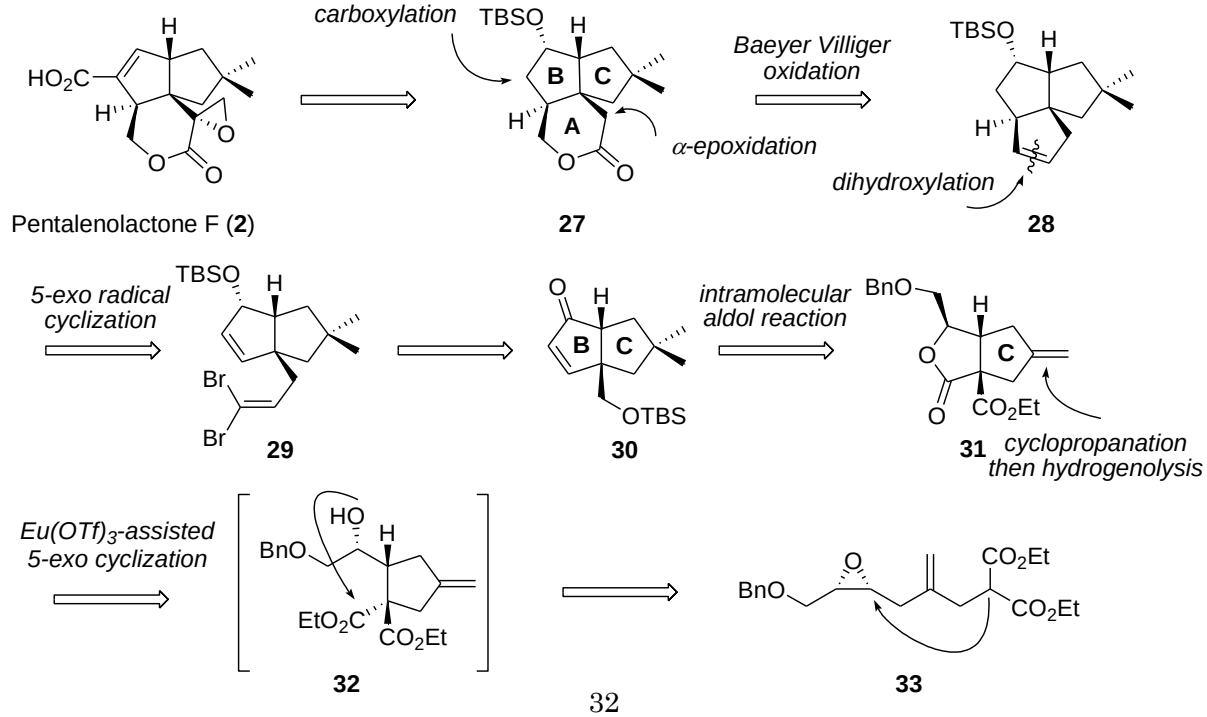


3-3 : Synthetic Strategy

As described in the champer 3-3, there are two problems in the total synthesis of pentalenolactone F (**2**). One of them is unresolved synthetic procedure for construction of **2** as an optical active form. In the past, several groups have already reported the synthesis of **2**. However, they were racemic routes. The other problem is the stereoselective introduction of α-epoxide. In the previous synthetic studies reported so far, it has been not reached a satisfactry degree. Therefore, it is necessary to develop the new approach resolving these problems.

Synthetic strategy involving the bicyclic lactone **31** as a key precursor is shown in scheme 4. The design of our synthetic plan relied on the combination of $Eu(OTf)_3$ mediated 5-*exo*-cyclization and regioselective Baeyer Villiger oxidation to construct core framework of natural product. I envisaged that application of the method developed by our laboratory would give bicyclic lactone **31** from **33**. Diquinane **30** would be synthesized through installation of the dimethyl moiety on the C-ring and an intramolecular aldol condensation of lactone derivative in **31**. The angular triquinane skeleton of **28** would be constructed via 5-*exo* radial cyclization of **29**, which would be derived by installation of a dibromoalkenyl moiety on the primary hydroxy group of **30**. Application of dihydroxylation and subsequent Baeyer-Villiger oxidation to **28** would give δ-lactone **27**. The Baeyer-Villiger oxidation is expected to provide **27** with high regioselectivity. Finally, introduction of the α-epoxide and conversion to carbonyl group would complete total synthesis of pentalenolactone F (**2**).

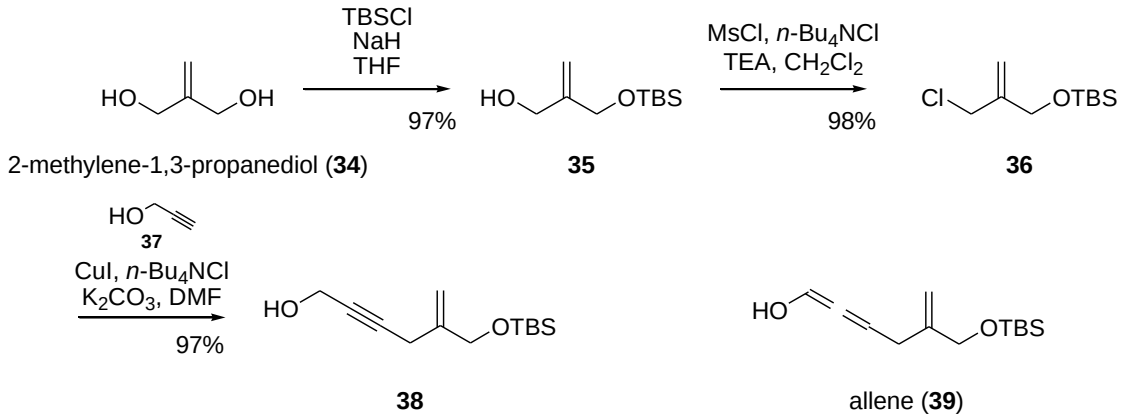
Scheme 4



3-4 : Construction of the Bicyclic Lactone by 5-*exo* Cyclization

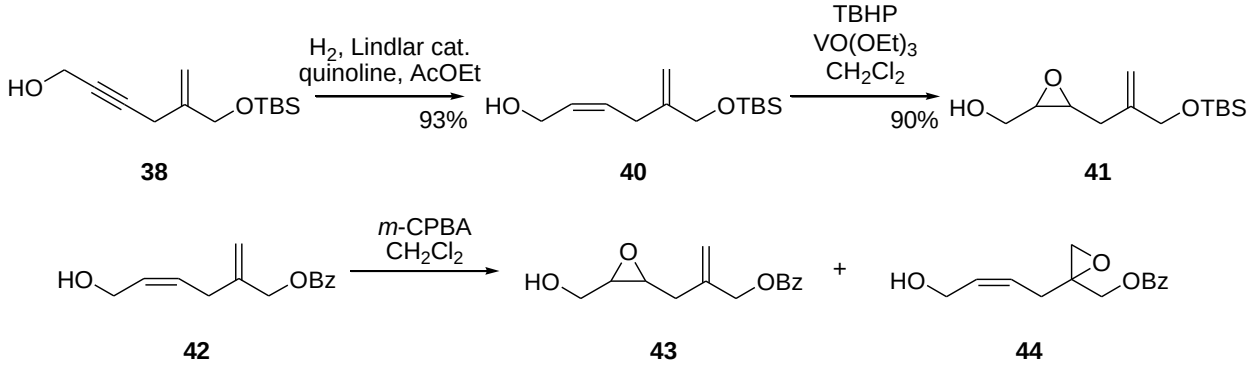
Synthetic study commenced with preparation of bicyclic lactone **31** from commercially available 2-methylene-1,3-propanediol (**34**) (Scheme 5). One of the two hydroxyl group of **34** was protected by sodium hydride and TBSCl to provide **35**. The other one was converted to the corresponding chloride giving **36**. Subsequently, the requisite carbon chain for synthesis of cyclization precursor was extended by coupling with 2-propyn-1-ol (**37**) by use of a cupper catalyst.[9] In this reaction, high purity of the cupper catalyst was essential for obtaining a high yield. When copper iodide with 99.999% purity was used, the coupling product **38** was obtained in 97% yield. On the other hand, the catalyst with 99.5% purity decreased reaction rates and chemical yield accompanied by producing an allenic by-product **39**.

Scheme 5



Next, reioselective epoxidation of allyl alcohol **40**, which was obtained from acetylenic alcohol **38** via hydrogenation in the presence of Lindlar catalyst was examined. Whereas the use of *m*-CPBA was accompanied with epoxidation of the *exo*-methlene, Sharpless method, namely, *tert*-butyl hydroperoxide in the presence of vanadium catalyst[10] has successfully afforded the desired epoxide **41** (Scheme 6).

Scheme 6



Subsequently, preparation of cyclization precursor **33** was examined (Scheme 7). Hydroxyl group of **41** was protected with benzyl bromide under basic conditions. Although it was concerned about Payne rearrangement of **41** leading to **48**, it is fortunately to obtain **45** with no rearrangement products. The TBS group was removed with TBAF in the presence of acetic acid in high yield. In the reaction, neutralization with acetic acid was essential to avoid subsequent cyclization of an alkoxide due to the basic conditions (Figure 3). Additionally, it was revealed that cyclization of **46** was easily proceeded under the acidic conditions such as $CDCl_3$. It was required to pass through an activated alumina for use of NMR measurement. Chlorination of **46** followed by addition of a malonate anion in terms of Tsuji-Trost allylation[11] afforded desired **33** in high yield.

Scheme 7

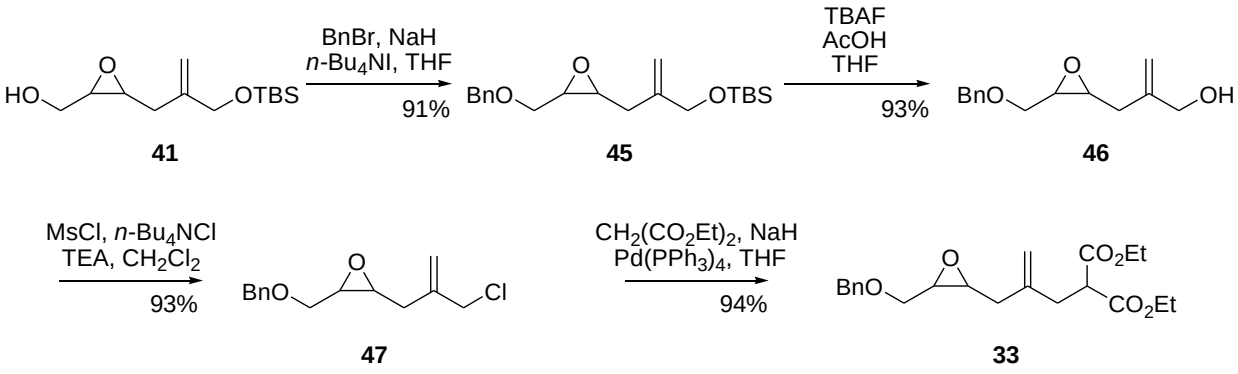
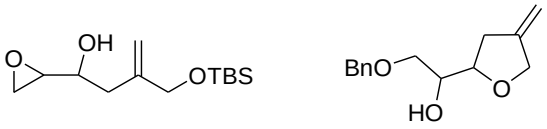


Figure 3

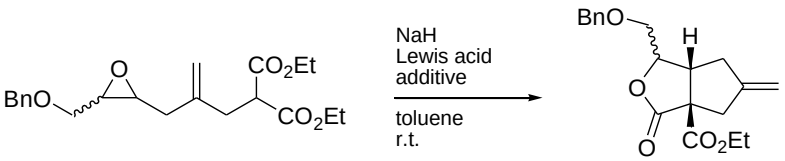


48 **49**

Examinations of 5-exo cyclization mediated by the Lewis acid mediated was described in Table 1. Our laboratory has already reported the reaction of *trans*-epoxide **50** leading to **51**. The reaction using sodium hydride and Europium(Ⅲ) trifluoromethanesulfonate was low yield (entry 1,2), however, addition of 15-crown-5 accelerated the reaction to produce **51** in 81% yield (entry 3). On the other hand, cyclization reaction of *cis*-epoxide **33** proceeded easily without addition of 15-crown-5 to give **31** in high yield (entry 4-6). I considered that difference of the reactivity between **50** and **33** was largely

attributable to each transition state (Figure 4). In the transition state **52** derived from *trans*-epoxide **50**, two C-C bond lie in the same plane. On the other hand, **53** derived from *cis*-epoxide **33** has a C-C bond and a C-H bond lie in the same plane. Therefore, the reactivity can be supposed that *cis*-epoxide is better than *trans*-epoxide because of difference of stability in transition state.

Table 1



50: *trans*-epoxide

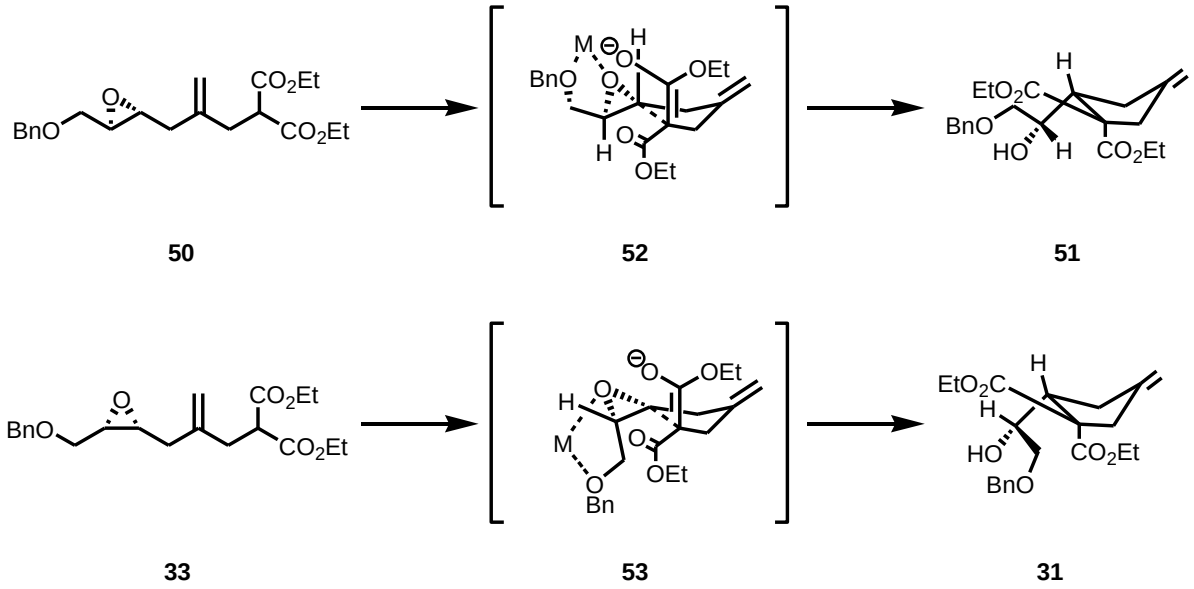
33: *cis*-epoxide

51: α-CH_2OBn

31: β-CH_2OBn

entry	substrate	NaH(eq.)/Lewis acid(eq.)/additive(eq.)	product	yield(%) d.p.	yield(%) rec.s.m.
1	**50**	NaH(2.0)/$Eu(OTf)_3$(0.1)	**51**	19	37
2		NaH(2.0)/$Eu(OTf)_3$(1.0)		32	40
3		NaH(2.0)/$Eu(OTf)_3$(1.0)/15crown-5(2.0)		81	16
4	**33**	NaH(1.5)/$Eu(OTf)_3$(0.1)	**31**	77	0
5		NaH(1.5)/$Eu(OTf)_3$(0.5)		82	9
6		NaH(1.5)/$Eu(OTf)_3$(1.0)		89	0

Figure 4



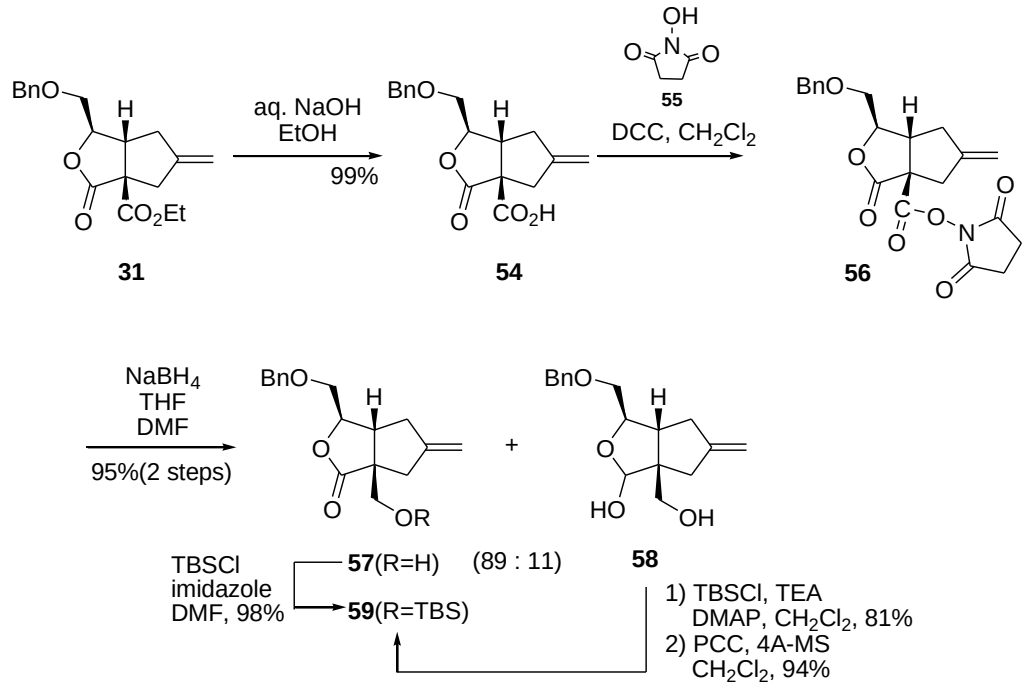
50 **52** **51**

33 **53** **31**

3-5 : Transformation of Bicyclic Lactone into Diquinane Framework

I next focused on the construction of the diquinane framework and installation of a dimethyl moiety. Chemoselective reduction of an ethylester in **31** was carried out (Scheme 8). Hydrolysis of **31** in basic condition proceeded smoothly to produce **54** in quantitative yield. Direct reduction of the carboxyl group in **54** by use of borane dimethyl sulfide complex or thionyl chloride gave a mixture of several reduction products. This transformation was achieved reduction of active ester **56**, which was obtained with dicyclohexylcarbodiimide (DCC) and N-hydroxysuccinimide (**51**),[12] with sodium borohidride in a combination of THF and DMF. The resulting hydroxy group was protected with TBSCl to give **59** in high yield. Hemiacetal **58**, which was obtained in reduction of **56** as a small quantity, could be also converted to **59** in short process: selective protection of primary alcohol with TBSCl followed by oxidation with PCC.

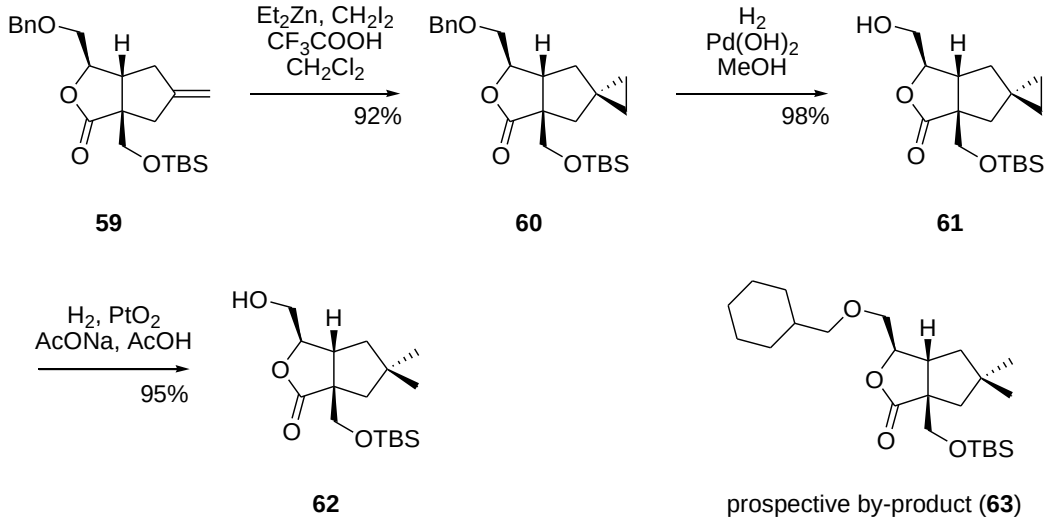
Scheme 8



Subsequently, conversion from *exo*-methylene of **59** to dimethyl group was examined (Scheme 9). As a general and effective method for preparation of dimethyl moiety, a sequential protocol: cyclopropanation of *exo*-methlene followed by C-C bond cleavage with platinum catalyst was applied. Cyclopropanation employing improved Simmons-Smith method in the presence of trifluoroacetic acid developed by Shi and co-workers[13] gave 60 in high yield. In this reaction, it was observed low reactivity and yield under the ordinary conditions. Subsequently, removal of the benzyl ether followed by

cyclopropane cleavage with platinum (IV) oxide[14] afforded **62**. During the conversion from **60** to **62**, a stepwise approach is essential. When the conditions of H_2/PtO_2 was applied on **60**, aromatic ring would be reduced to give undesired **63**.

Scheme 9

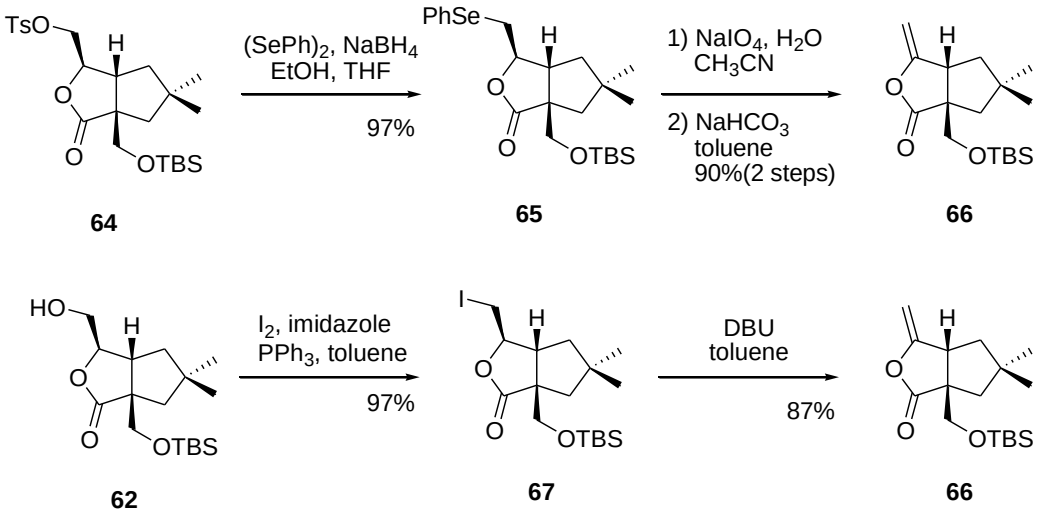


59 **60** **61**

62 prospective by-product (**63**)

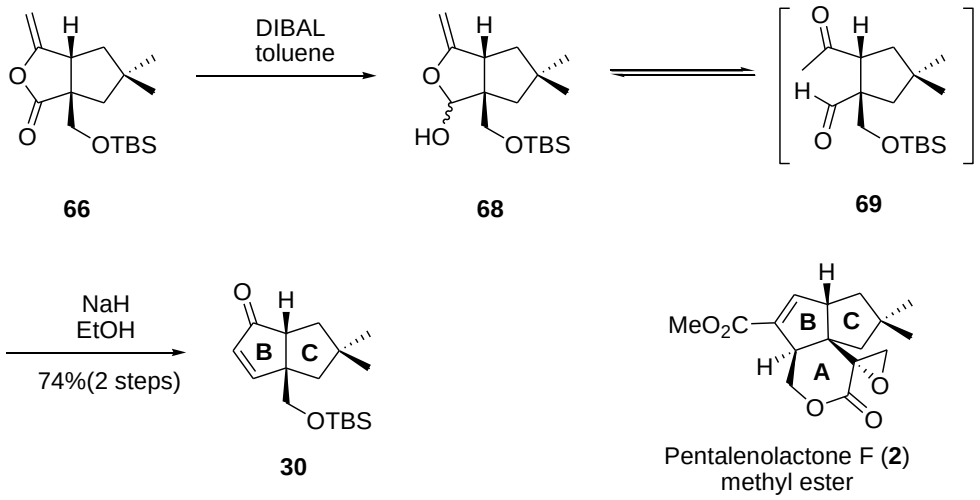
In the next stage, I prepared vinyl ether **66** (Scheme 10). In order to obtain **66** from **62**, it is a useful method to carry out elimination of a leaving group. In the use of lactone **62**, however, it was supposed that lactone opening with a base followed by formation of epoxide would occur in succession. Therefore, *syn*-elimination using selenoxide was applied. After addition of a selenyl anion to relative compound **64**, oxidation with sodium periodate and consecutive *syn*-elimination afforded **66** in high yield. On the other hand, iodination of primary alcohol of **62** and then elimination in the presence of DBU at 110℃ was tentatively carried out. As a result, desired **66** was obtained without any by-products. This experimental fact in the reaction indicated that lactone opening did not proceed. In addition, **66** was guessed to be unstable. Therefore, florisil was used instead of silica gel for purification of **66**.

Scheme 10



Finally, construction of the BC-ring was examined by an intramolecular aldol condensation (Scheme 11). Diisobutylaluminum hydride (DIBAL) reduction of **66** provided **68** with ease. By reason that the resultant **68**, was chemically equivalent to keto-aldehyde **69**, subsequent treatment with a catalytic amount of sodium ethoxide permitted to trigger intramolecular aldol condensation to give diquinane **30** in good yield. In this reaction, no isomerization of the methyl carbonyl substituent was observed.

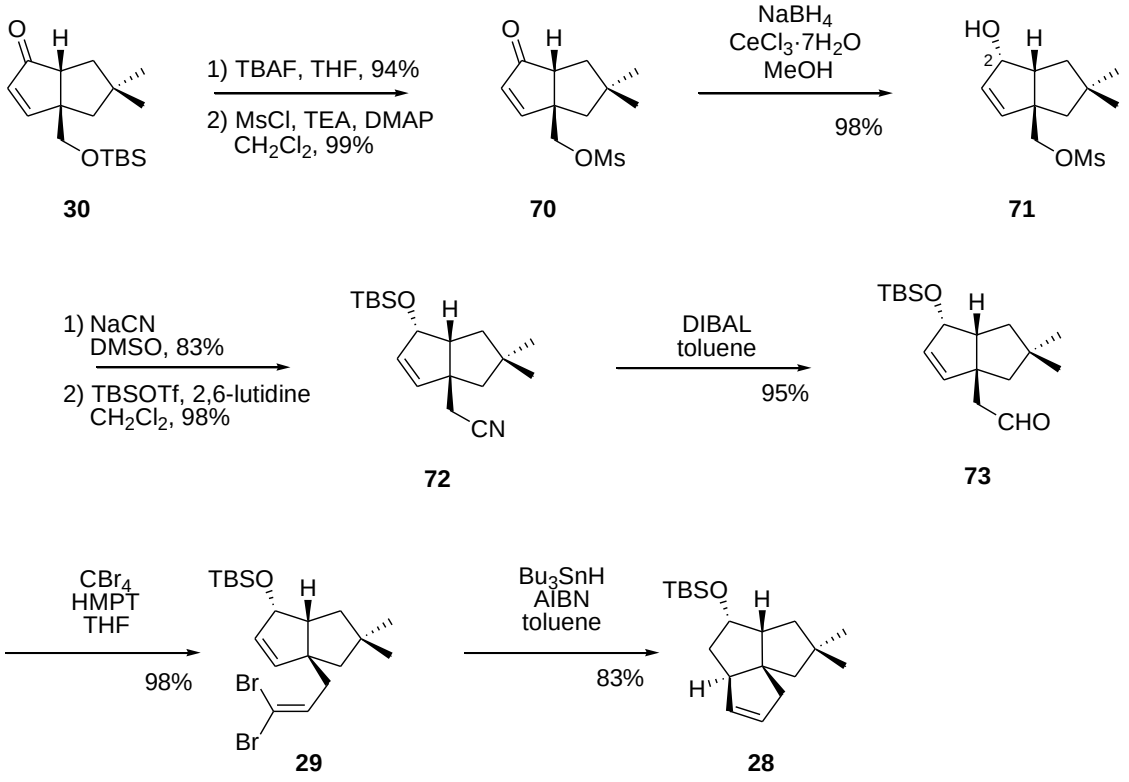
Scheme 11



3-6 : Construction of the Angular Triquinane Framework

With the requisite diquinane **30** in hand, construction of the angular triquinane framework was examined by 5-*exo*-radical cyclization (Scheme 12). Removal of the TBS group with TBAF followed by mesylation of the resulting hydroxy group afforded **70**, which was subjected to Luche reduction[15] provided desired **71** as a single isomer. Structural determination at the C_2 position was described in figure **5**. Addition reaction to **71** with sodium cyanide to elongate the C1 unit and subsequent protection of secondary alcohol with TBSOTf gave desired **72**. After that, DIBAL reduction of **72** to provide aldehyde **73**, followed by dibromoolefination with tetrabromomethane and hexamethyl phosphorous triamide (HMPT)[16] gave **29**. In this reaction, it was appeared that sequence of reagents added to the reaction was very important. To a mixture of active species prepared with CBr_4/HMPT, aldehyde **73** was added to afford **29** in high yield, otherwise removal of TBS group occurred as side reaction. Finally, Treatment of **29** with tributyltin hydride and AIBN resulted in 5-*exo* radical cyclization[17] to furnish **28** composed of angular triquinane framework in 83% yield.

Scheme 12



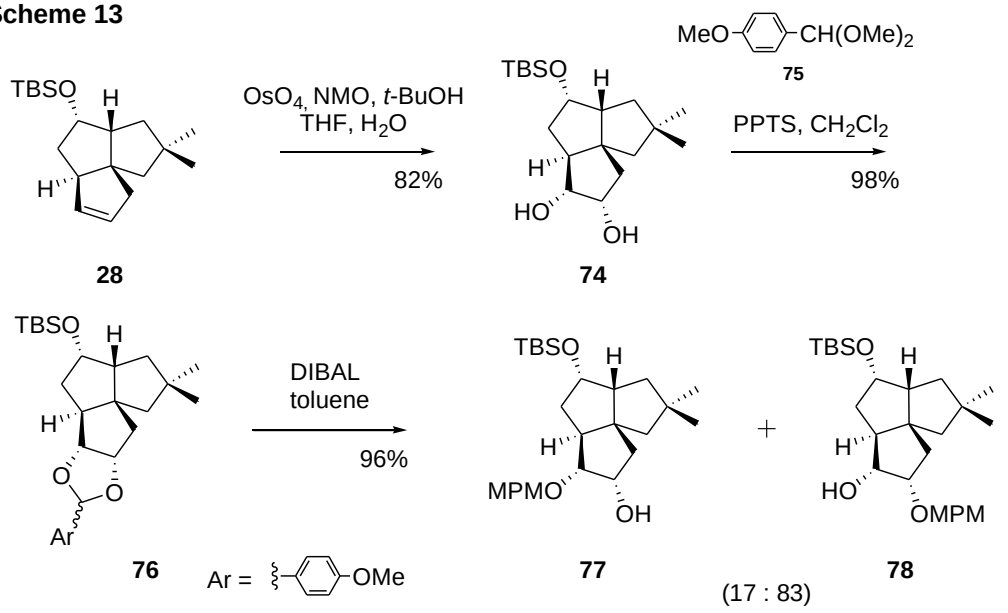
30 **70** **71** **72** **73** **29** **28**

3-7: Application of Baeyer-Villiger Oxidation to Construct *δ*-Lactone Ring

3-7-1 : Dihydroxylation and Selective Protection

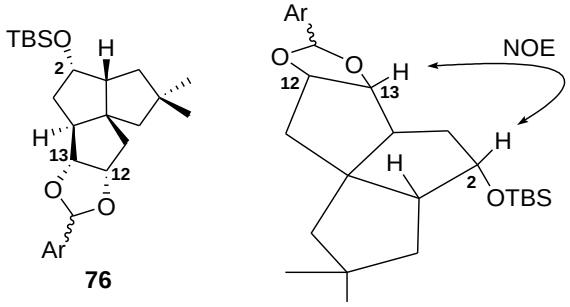
I next focused on the construction of A-ring composed of δ-lactone from angular triquinane framework, and envisaged that it was possible to obtain desired 6-membered ring by Baeyer-Villiger oxidation procedure. Firstly, treatment of **28** with osumium tetraoxide and NMO afforded α-diol **74** as a single isomer (Scheme 13). This stereoselectivity stemmed largely from steric hindrance of β-face because of fused ring and sensitivity of this reaction condition. Subsequently diol **74** was protected as anisylideneacetal with **75**, and then reductive cleavage of **76** with DIBAL provided **77** and **78** at a ratio of 17 : 83 in quantitative yield. Both of them were converted to **27** respectively by similar conditions.

Scheme 13



At this stage, the stereochemistry at $C_{2,12,13}$ generated by Luche reduction and dihydroxylation was verified by NOE experiments using **76** (Figure 5). In the result, there were correlation between C_2-H and C_{13}-H. Therefore, absolute configuration was determined as **76** described in Figure 5.

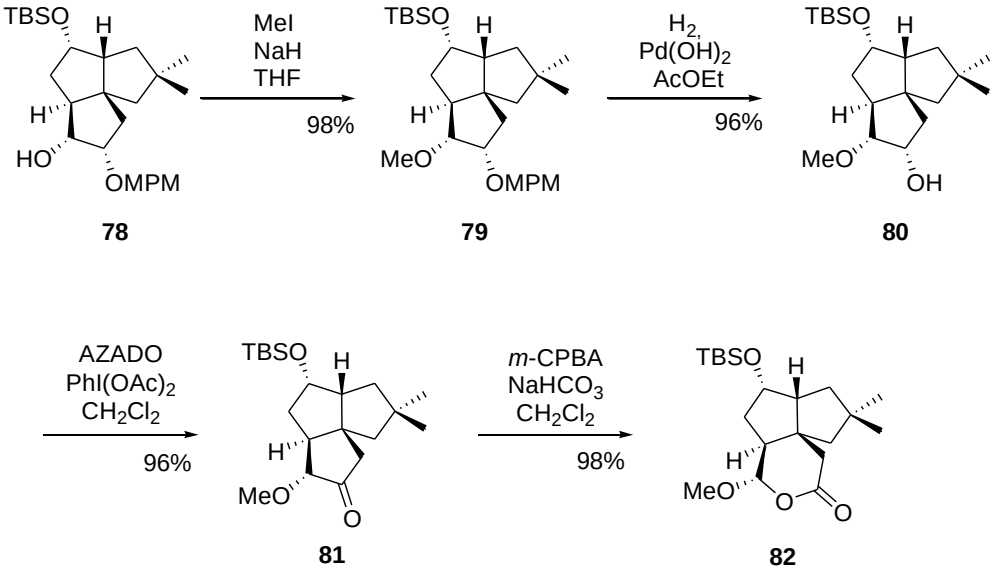
Figure 5



3-7-2 : Baeyer-Villiger Oxidation for Construction of δ-Lactone Framework

Transformation of the 5-membered ring into δ-lactone framework was examined by Baeyer-Villiger oxidation procedure (Scheme 14). In the first, O-alkylation of **78** with iodomethane and sodium hydride followed by hydrogenolysis with $Pd(OH)_2$ gave **80** in high yield. After that, the resulting secondary alcohol was converted to α-alkoxyketone **81** by oxidation with AZADO[18] in quantitative yield. In the oxidation step, PDC oxidation was firstly attempted, however, filtration invited yield loss. Therefore, AZADO oxidation which has easy aftertreatment was adopted. Subsequently, construction of δ-lactone ring was accomplished in the next step. Baeyer-Villiger oxidation of **81** using *m*-CPBA and solid sodium hydrogen carbonate[19] afforded **82** in 98% yield. In addition, oxidation step proceeded with preservation of stereochemistry and without preparation of **84** (Figure 6). This method resulted in high regioselectivity due to a mesomeric effect from oxygen atom substituted at the α-position.

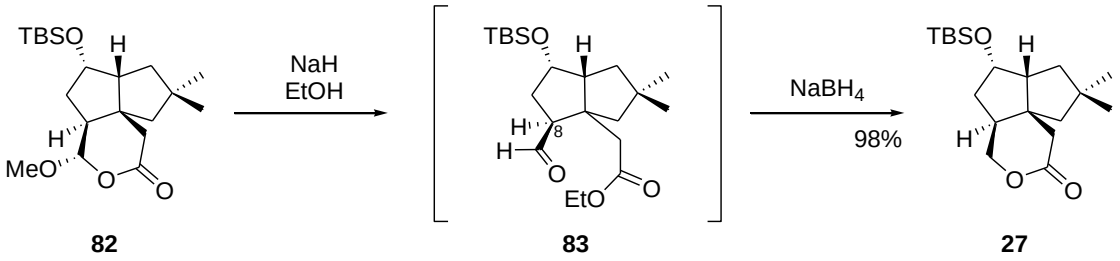
Scheme 14



Next, I attempted to remove the acetal moiety of **82** (Scheme 15). However ring opening did not proceed with sodium borohydride in ethanol conditions. Therefore, sodium hydride was added to accelerate ring-opening. As a result, reduction of the acetal moiety was achieved via aldehyde **83** to provide **27**. This experimental fact indicated that sodium ethoxide accelerate ring-opening to provide **83**,

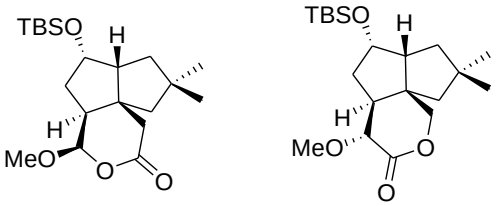
and subsequent reduction of aldehyde followed by intramolecular formation of δ-lactone framework afforded **27**. And although it was concerned about epimerization at C_8 because of addition of sodium hydride, anticipated **85** was not obtained (Figure 6).

Scheme 15



82 **83** **27**

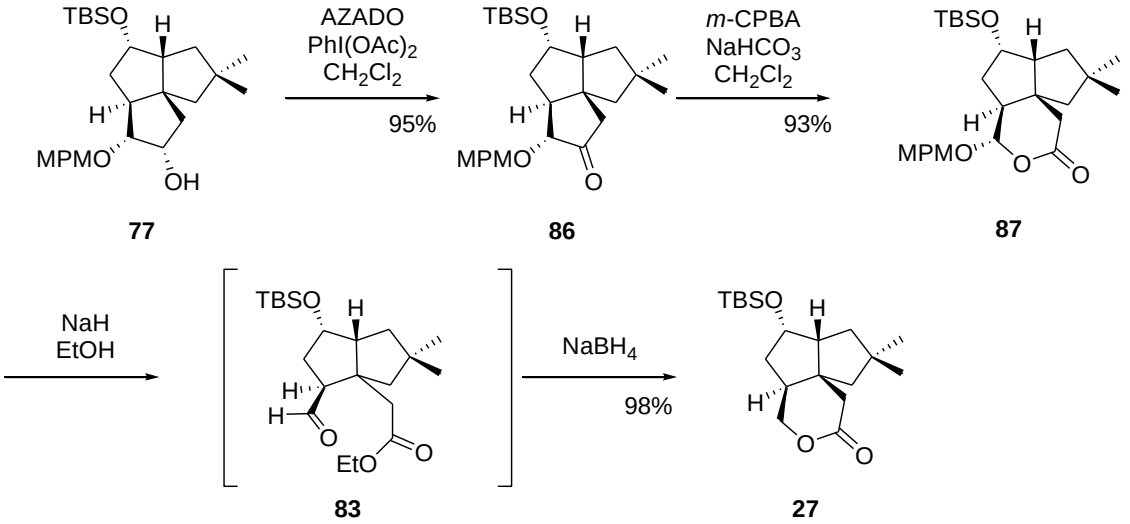
Figure 6



84 **85**

A similar procedure was applied for **77** (Scheme 16), which means that oxidation with AZADO followed by Baeyer-Villiger reaction and subsequent reduction with sodium borohydride and sodium hydride were carried out. As a result, desired **27** was obtained almost exclusively.

Scheme 16



77 **86** **87**

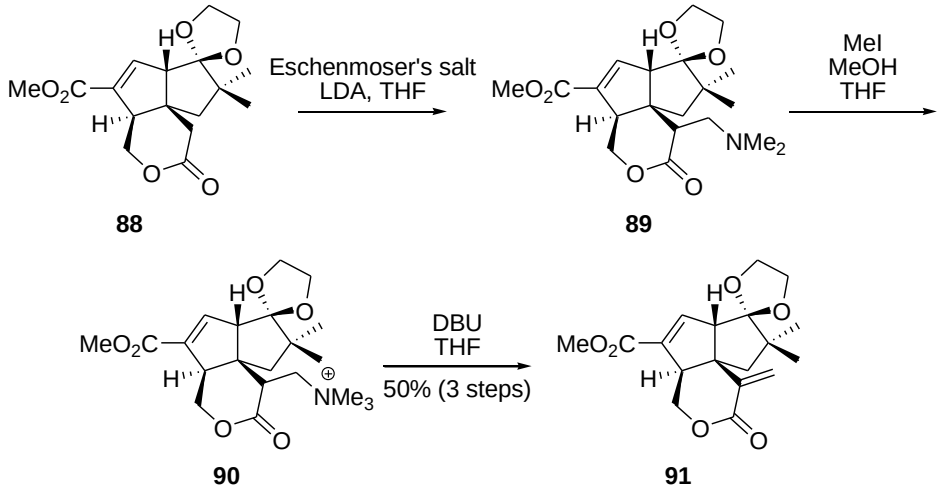
83 **27**

3-8 : New Approach to Construct *α*-Epoxide

3-8-1 : Installation of *exo*-Olefine

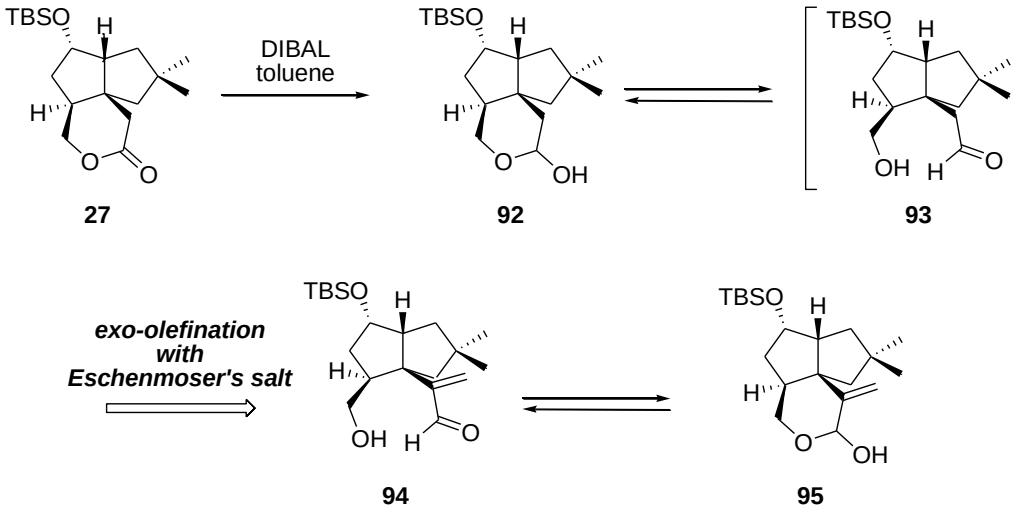
I next focused on the installation of the oxygen atom to construct α-epoxide. In the first, *exo*-olefination to add essential one carbon unit was resolved. It is useful method to utilize Eschenmoser's salt[20] for installation of *exo*-olefine at carbonyl α-position. In the synthetic report by Pirrung and co-workers[4b], this reagent was used to achieve the assignment (Scheme 17). However, this procedure gave unsatisfied yields for installation of *exo*-olefine.

Scheme 17



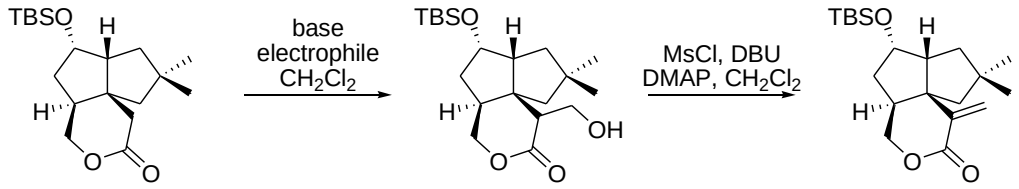
On the other hand, by many synthetic researchers who accomplished total synthesis of Pentalenolactones it was indicated that great steric hindrance existed around the reaction position due to hindered neopentyl carbon and fused framework[4b,6]. Therefore, I considered that *exo*-olefination with lactol **92** which obtained by DIBAL reduction of **27** would be effective (Scheme 18). Because lactol **92** was equivalent to hydroxy aldehyde **93** which was guessed to have low steric hindrance, I thought that *exo*-olefination of **93** followed by re-formation of 6-membered ring to give **95** would afford sufficient result. However, desired **95** was not obtained. Secondary, TBS protection of primary alcohol of **93** to provide aldehyde followed by olefination was attempted. In the result, TBS protected compound from **92** was observed. It is necessary to open the 6-membered ring for olefination via lactol **92**, but there were few possibilities to gain **93** because of stability of **92**.

Scheme 18



I gave up the olefination via lactol **92** due to the difficulty of ring opening and changed my mindset. Pirrung and co-workers used Eschenmoser's salt as electrophile to install *exo*-olefine moiety[4b]. However, the yield of olefination was unsatisfied because of highly steric hindrance around reaction position. Therefore, I attempted new procedure to install *exo*-olefine using formaldehyde which was the least electrophile for addition of one carbon unit (Table 2). In the first, commercially available *p*-formaldehyde was added to a mixture of **27** and LDA in CH_2Cl_2 at -50℃ for preparation of hydroxymethyl comound **96**. After that, mesylation was carried out to provide **97** (entry 1). However, desired **97** was not obtained. And also the condition at -20℃ or 0℃ afforded similar result (entry 2, 3). Subsequently NaHMDS was applied to this reaction as substitute for LDA, but desired **97** was little obserbed (entry 4, 5). Considering these experimental result, it was supposed that main reason to disturb the reaction progress was size of electrophile. Therefore, monomeric formaldehyde according to a method developed by the Paquette group[6,21] which is smaller electrophile reagent than *p*-formaldehyde was applied to this reaction. As a consequence, desired **97** was produced in moderate yield (entry 6-8). In this reaction, the temperature was considered to be very important. High temperature caused ring opening of lactone, and low temperature caused not preparation of anion. By the result of investigation, after anion preparation and addition of monomeric formaldehyde at -60℃, warming to -10℃ followed by quench gave **97** in 63% yield and **27** was recovered in 32% yield (entry 7). Although, olefination succeeded, there were several problems about monomeric formaldehyde. One of them was instability of

this reagent. After adjustment, it was necessary to use quickly. Otherwise, white solid was produced and concentration of this solution would change. In addition to that, the concentration was different of each adjustment. Therefore, excessive amounts of monomeric formaldehyde were needed.



27 **96** **97**

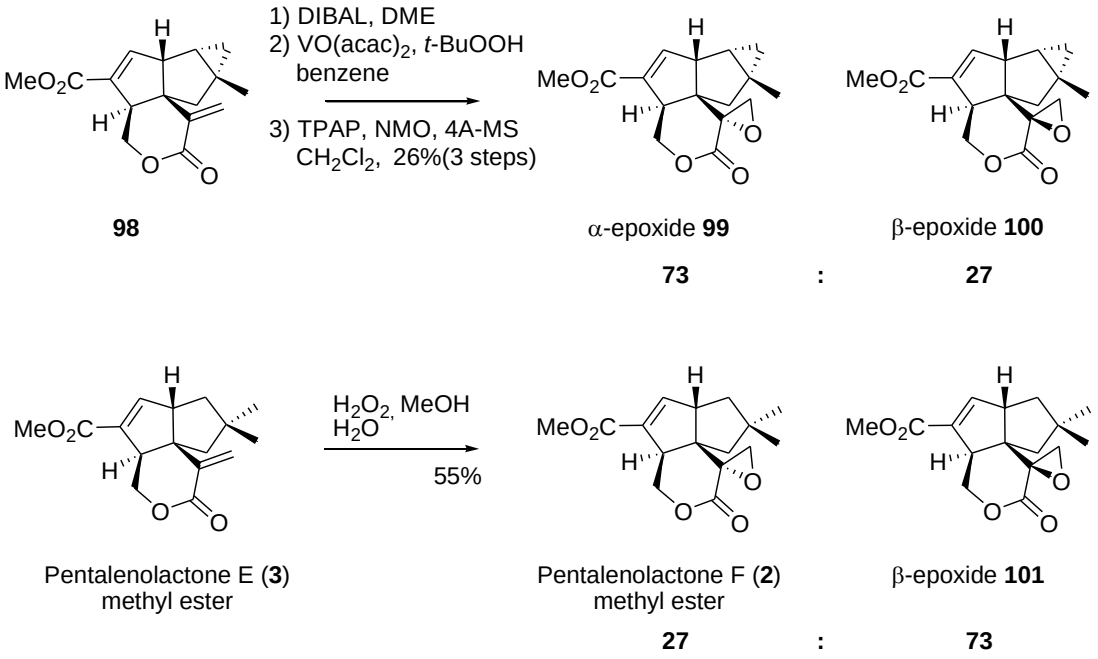
Table 2

entry	base	electrophile	temperature(°C)	yields(%) d.p.(**97**)	yields(%) rec.s.m.(**27**)
1	LDA	p-formaldehyde	-50	0	99
2	LDA	p-formaldehyde	-20	0	95
3	LDA	p-formaldehyde	0	0	87
4	NaHMDS	p-formaldehyde	-10	0	97
5	NaHMDS	p-formaldehyde	0	6	82
6	NaHMDS	monomeric formaldehyde	-78	42	23
7	NaHMDS	monomeric formaldehyde	-60	63	32
8	NaHMDS	monomeric formaldehyde	-50	33	43

3-8-2 : *α*-Selective Dihydroxylation

Before now, several procedures to install epoxide have been reported (Scheme 19). Among them, Paquette[22] and co-workers reported epoxidation with allyl alcohol. After DIBAL reduction of **98** to give lactol, epoxidation by Sharpless method and subsequent TPAP oxidation afforded **99**. On the other hand, Ohtsuka[2f] and co-workers reported epoxidation with hydrogen peroxide to provide Pentalenolactone F (**2**) methyl ester. However, both procedures were low yield and selectivity, respectively. Therefore, I explored new epoxidation method to afford desired product with high yield and selectivity.

Scheme 19



I anticipated that formation of epoxide via dihydroxylation was the best procedure for high selectivity. Because general dihydroxylation method with osumium tetraoxide was sensitive to steric hindrance, it was supposed that this procedure would afford high selectivity. After that, mesylation of primary alcohol followed by treatment with base would provide α-epoxide. By reference to this thinking, oxidation of double bond was attempted (Scheme 20). In the result, dihydroxylation of double bond with osumium tetraoxide and NMO was accomplished in high yield and selectivity. In association with this reaction, conformation of **97** was verified by NOESY experiments. It was supposed that A-ring of

97 was chair-conformation due to correlation between C_{14}-H and $C_{3,6}$-H. And it was supposed that this stereoselectivity stemmed largely from steric hindrance of β-face.

Scheme 20

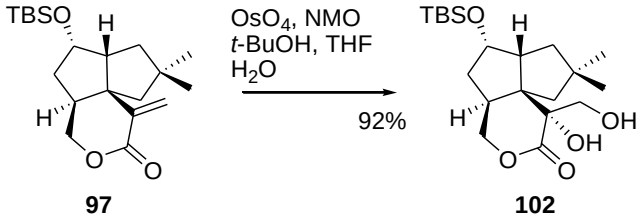
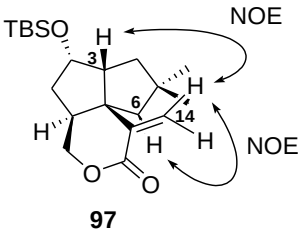
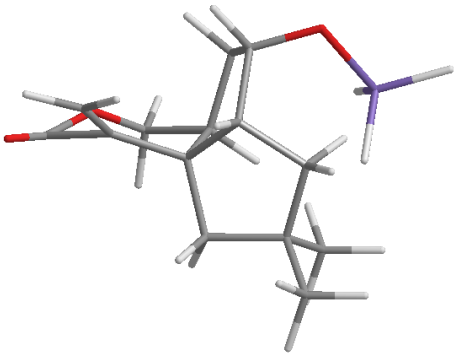


Figure 6





After protection of **102** with dimethoxypropane and CSA to afford **103**, removal of TBS group and subsequent oxidation of secondary alcohol with PDC[23] provided **104** in good yield (Scheme 21). At this stage, the stereochemistry generated by dihydroxylation with osumium tetraoxide was verified by NOE experiments using **104** (Figure 7). In the result, there were correlation between C_3-H and C_{14}-H. Therefore, absolute configuration of **104** was determined and it was appeared that oxidation of double bond of **97** proceeded from α-face.

Scheme 21

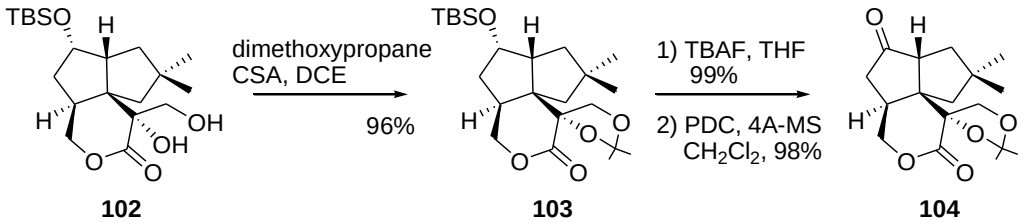
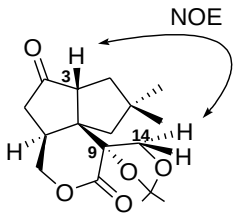
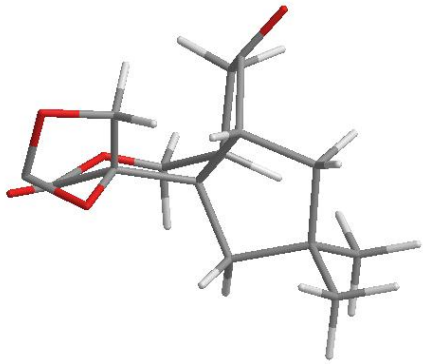


Figure 7



104



In association with dihydroxylation of **97**, I made an interesting discovery. More specifically, oxidation of relative **105** with osumium tetraoxide gave undesired **106** selectively (Scheme 22). By the result of NOESY experiments described in Figure 8, it was supposed that A-ring of **105** was boat conformation unlike in the case of **97**. And I guessed that these differences caused different reactivity between **97** and **105**.

Scheme 22

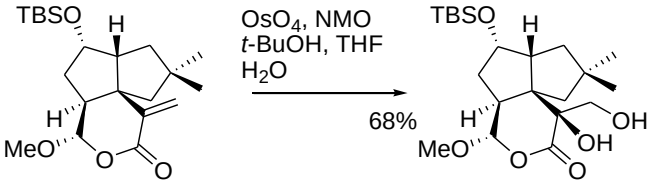
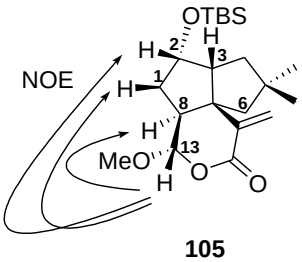
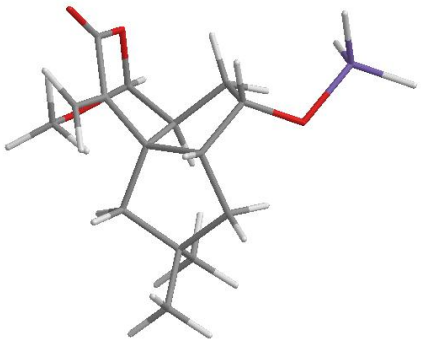


Figure 8



105

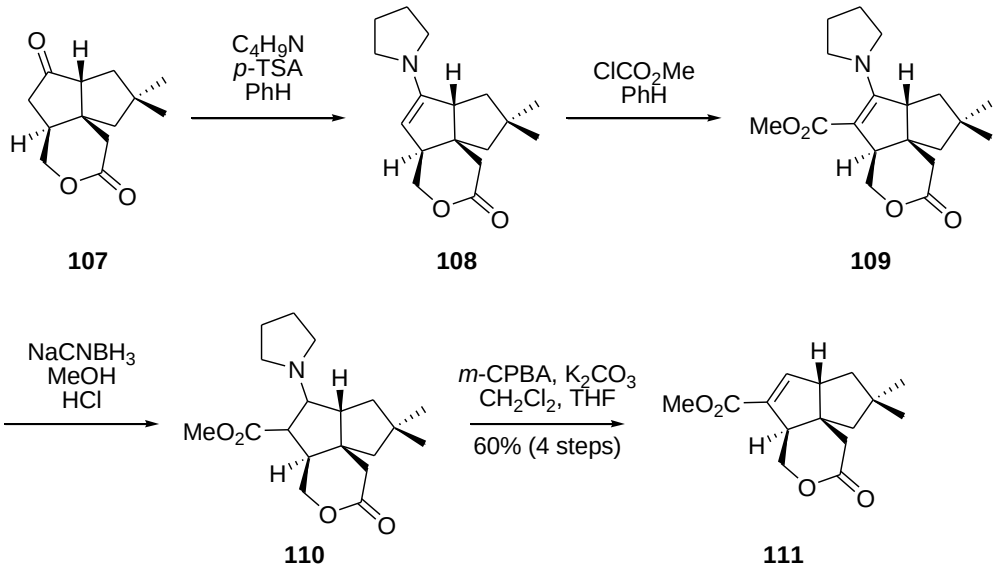


3-9 : Total Synthesis of Pentalenolactone F Methyl Ester

3-9-1 : Installation of One Carbon Atom

Finally, the required unsaturated ester and α-epoxide were prepared. In 1987, Marino and co-workers accomplished installation of unsaturated ester by original method[3b] (Scheme 23). More specifically, conversion of **107** to pyrrolidine enamine **108** followed by carbomethoxylation gave **109**. After conjugate reduction with sodium cyanoborohydride to provide **110**, elimination of the pyrrolidine via its N-oxide in base afforded **111** in 60% yield (4 steps). In reference to this procedure, I attempted installation of carbomethoxy group with **104**. However, desired product was not obtained. Therefore, I decided to explore new method for installation of unsaturated ester.

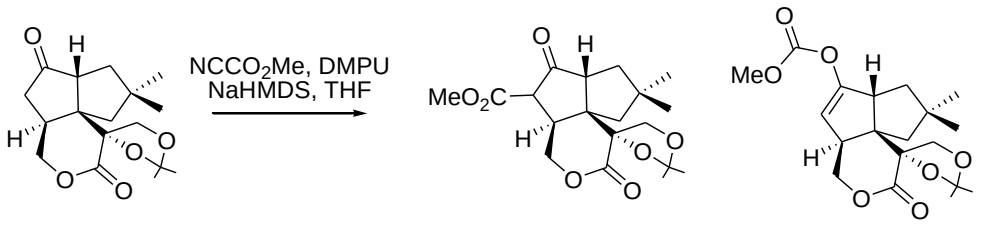
Scheme 23



107 **108** **109** **110** **111**

Initial attempt was carried out by direct installation of methylester with methyl cyanoformate (Scheme 24). However, this reaction of **104** proceeded smoothly to produce not desired C-alkylated **112** but undesired O alkylated **113**.

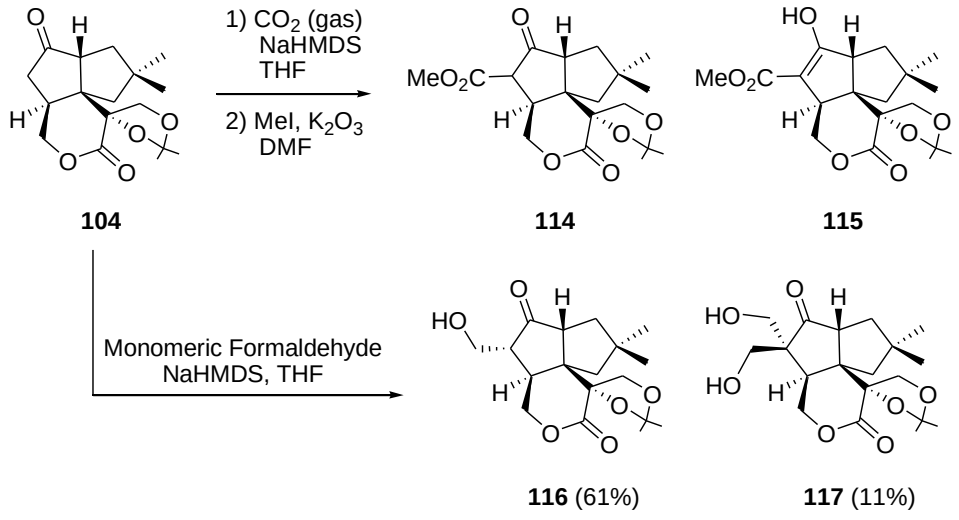
Scheme 24



104 **112** **113**

Because direct esterification of **104** was difficult, carboxylation and subsequent methylation was attempted (Scheme 25). Carboxylation of **104** with CO_2 gas followed by methylation with iodomethane and potassium carbonate afforded not **114** but **115**. In order to lead **115** to natural product, it was necessary to remove the hydroxy group. Therefore, conversion of resultant alcohol to the corresponding triflate and subsequent treatment with Pd catalyst and tributyltin hydride was planned. But hydrolysis was provoked by the use of sodium hydride and comins reagent. Because of failure of direct deoxygenization, reduction of double bond followed by elimination was attempted. Although the condition to reduce double bond, ①Pd-C/H_2/MeOH, ②PtO_2/H_2/EtOH, ③$NaBH_4$/$NiCl_2$/MeOH, were carried out, reduced product was not observed. It was a real pity that the procedure for direct carbonylation was unsuccessful, however, alternative new method was explored. Owing to severe steric hindrance around reaction position, some deirect carbonylation procedure were all unsuccessful. Therefore, the least small reagent which was monomeric formaldehyde[21] to add one carbon atom was applied. In the result, treatment of **104** with the reagent gave desired **116** in 61% yield. In this regard, however it was necessary to observe carefully because warming in reaction mixture permitted to produce more **117**. And luckily, undesired enone by elimination was not observed. In my synthetic route, I needed a method using monomeric formaldehyde for modification of A-ring, or else I couldn't complete it.

Scheme 25



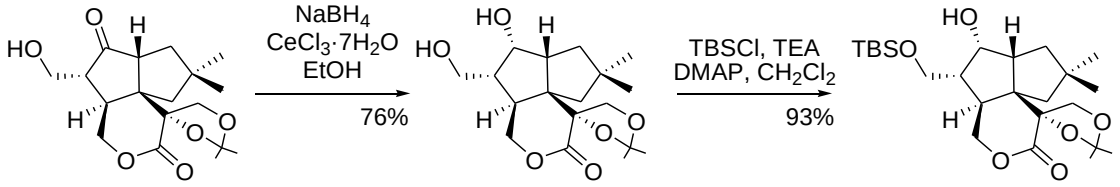
104 **114** **115**

116 (61%) **117** (11%)

3-9-2 : Modification of A-Ring and Construction of Epoxide

Subsequently, oxidation of **116** with Jones reagent[24] or $RuCl_3$ was carried out. However, they resulted in decomposition. Because it was hard to achieve direct oxidation of **116**, an alternative stepwise procedure was explored. Luche reduction of **116** to give corresponding **118** followed by protection of primary alcohol with TBSCl afforded **119** in good yield (Scheme 26). In these steps, the sequence of reactions was very important to prevent elimination side reaction to give enone.

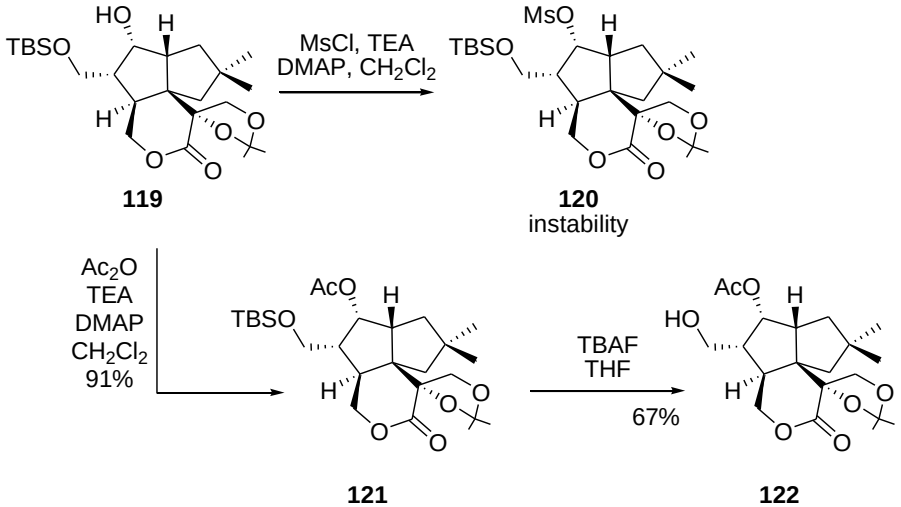
Scheme 26



116 **118** **119**

Mesylation of **119** resulted in decomposition and desired **120** was not obtained due to unexplained instability of **120** (Scheme 27). Because of that reason, protection with acetic anhydride was selected to give **121** in high yield. Subsequent TBAF treatment afforded **122**, which was oxidized in the following steps.

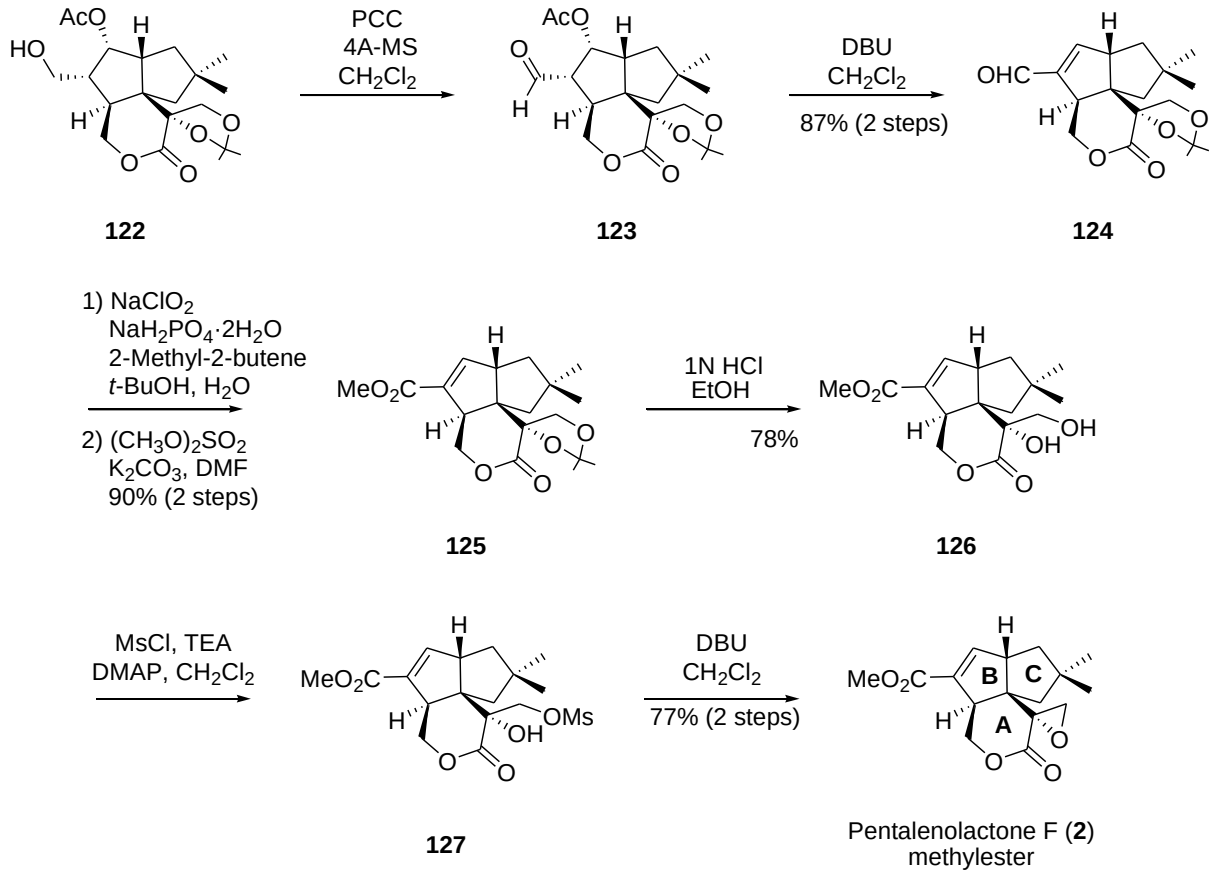
Scheme 27



119 **120** instability **121** **122**

Finally, conversion of **122** into unsaturated ester and construction of epoxide were achieved (Scheme 28). After PCC oxidation[25] of primary alcohol to give **123** followed by treatment with DBU to produce **124**, Pinnick oxidation[26] and subsequent esterification afforded **125** in high yield. Having successfully introduced unsaturated ester, I turned my attention to construct α-epoxide. Removal of acetonide in acidic condition provided **126**, which was mesylated to give **127**. Lastly, the treatment of **127** with DBU without purification accomplished total synthesis of pentalenolactone F (**2**) methyl ester and the ^{1}H and ^{13}C NMR spectra were identical to those already reported.

Scheme 28



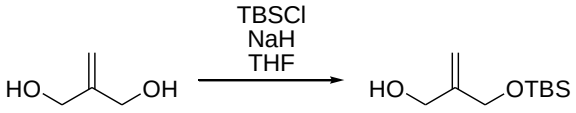
Experimental Section

General

IR spectra were recorded on a JASCO FT/IR-4200 spectrometer. Oily products were measured directly, solid products were diluted with chloroform and then measured. ^{1}H and ^{13}C NMR spectra were obtained for solutions in dueteriochloroform with VARIAN 400MHz and 700MHz spectrometer with residual solvent as the internal standard. Mass spectral data were run on JEOL GC-mate. Optical rotation was measured on a HORIBA SEPA-200 spectrometer. Thin layer chromatography (TLC) was carried out on MERCK Silica gel 60 F_{254} plates employing *n*-hexane/ethyl acetate as the mobile phase. KANTO Silica gel 60 N 40-50 μm was employed for flash column chromatography. THF and Et_2O were distilled from sodium/benzophenone ketyl. Benzene, CH_2Cl_2, toluene, CH_3CN, 2,6-lutidine, and TEA were distilled from CaH_2. Commercialized MeOH, EtOH, DMSO and DMF were used as reaction solvent. Simple distillation was carried out about ethyl acetate and *n*-hexane.

3-4 : Experimental Section

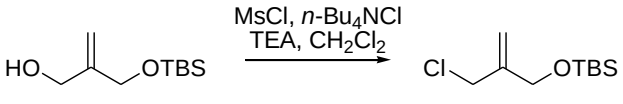
TBS Ether 35



2-methylene-1,3-propanediol (**34**) **35**

To a stirred solution of 2-Methylene-1,3-propanediol **34** (2.01 g, 22.81 mmol) in anhydrous THF (46 ml), NaH (1.19 g, 27.37 mmol) was added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 30 min, TBSCl (4.26 g, 27.37 mmol) was added to the reaction mixture at 0 ℃ and then mixture was warmed to room temperature. After being stirred for 2 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes =1:15→1:4) to give TBS ether **35** (4.50 g, 22.24 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3356, 3094, 2955, 2929, 2885, 2857, 2774, 2739, 2710, 1658, 1472, 1255, 1083, 836, 777 cm^{-1}. ^{1}H NMR (700 MHz, $CDCl_3$): δ = 5.11-5.09 (m, 1H), 5.09-5.07 (m, 1H), 4.25 (s, 2H), 4.17 (s, 2H), 0.91 (s, 9H), 0.08 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 147.4, 111.1, 65.1, 64.7, 25.9, 18.3, 5.4. HRMS: calcd for $C_{10}H_{22}O_2Si$, 202.1389; found 202.1393.

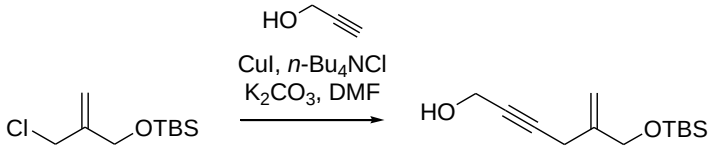
Allyl Chloride 36



35 **36**

To a stirred solution of TBS ether **35** (1.37 g, 6.781 mmol) in anhydrous CH_2Cl_2 (23 ml), TEA (2.8 ml, 20.34 mmol), *n*-Bu_4NCl (3.76 g, 13.56 mmol) and MsCl (0.8 ml, 10.17 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature and stirred for 2 h. Although TLC analysis showed incomplete disappearance of **35**, additional MsCl (0.8 ml, 10.17 mmol) was added. After being stirred for 1 h, the reaction was quenched by addition of aq.$NaHCO_3$ and diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:15) to give allyl chloride **36** (1.47 g, 6.658 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3442, 3100, 3084, 2955, 2930, 2885, 2857, 2803, 1653, 1462, 1257, 1089, 846, 777 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.29-5.27 (m, 1H), 5.22-5.20 (m, 1H), 4.24 (s, 2H), 4.10 (s, 2H), 0.92 (s, 9H), 0.09 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 144.5, 114.4, 63.4, 45.0, 25.9, 18.3, 5.4. HRMS: calcd for $C_{10}H_{21}ClOSi$, 220.1050; found 220.1045.

Alkynyl Alcohol 38

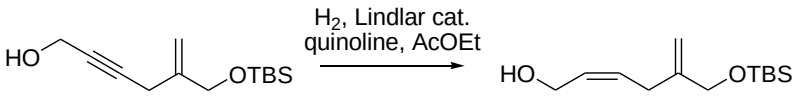


36 **38**

To a stirred solution of allyl chloride **36** (8.58 g, 38.36 mmol) in degassed anhydrous DMF (97 ml), crushed K_2CO_3 (10.70 g, 77.72 mmol), *n*-Bu_4NCl (1.10 g, 3.886 mmol), CuI (99.999% trace metals basis, 740.1 mg, 3.886 mmol) and then 2-propyn-1-ol **37** (7.0 ml, 116.58 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 18 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The heterogeneous mixture was filtered through a celite pad with ethyl acetate and then resultant organic layer was washed with H_2O followed by brine. After separation of two layers, the organic layer was dried over Na_2SO_4 and concentrated. The residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:5) to give alkynyl alcohol **38** (9.00 g, 37.44 mmol) as a slightly yellow oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3352, 3084, 2955, 2929, 2884, 2857, 2739, 2710, 2288, 2224, 1659, 1255, 1085, 837, 777 cm^{-1}. ^1H

NMR (700 MHz, $CDCl_3$): δ = 5.15-5.13 (m, 1H), 5.13-5.11 (m, 1H), 4.29 (dd, J = 2.2, 2.2 Hz, 2H), 4.13 (s, 2H), 3.00 (br-s, 2H), 0.91 (s, 9H), 0.02 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 143.3, 110.9, 83.1, 80.7, 65.5, 51.4, 25.9, 22.8, 18.3, 5.4. HRMS: calcd for $C_{13}H_{24}O_2Si$, 240.1546; found 240.1549.

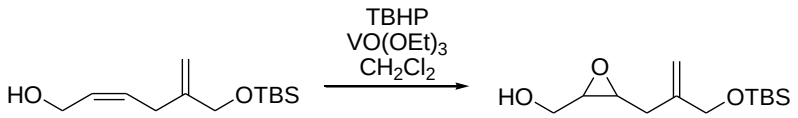
Allyl Alcohol 40



38 **40**

To a stirred solution of alkynyl alcohol **38** (10.20 g, 42.43 mmol) in MeOH (106 ml), quinoline (0.9 ml, 10Wt%) and Lindlar cat. (510.0 mg, 5Wt%) were added at room temperature, and then purged with hydrogen. After being stirred for 3.5 h under a balloon of hydrogen, the heterogeneous mixture was filtered through a celite pad with ethyl acetate and concentrated. The residual oil was diluted with ethyl acetate and then washed with 0.5N HCl, aq.$NaHCO_3$ followed by brine. After drying over Na_2SO_4 and subsequent concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:4) to give allyl alcohol **40** (9.60 g, 39.44 mmol) as a slightly yellow oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3345, 3094, 3077, 3019, 2955, 2929, 2885, 2857, 2738, 2710, 1650, 1462, 1255, 1083, 836 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.80-5.74 (m, 1H), 5.62-5.56 (m, 1H), 5.02 (d, J = 0.8 Hz, 1H), 4.85 (d, J = 0.8 Hz, 1H), 4.19 (d, J = 6.9 Hz, 2H), 4.08 (s, 2H), 2.85 (d, J = 7.7 Hz, 2H), 0.91 (s, 9H), 0.08 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 146.9, 130.2, 129.9, 110.3, 65.9, 58.2, 30.8, 25.9, 18.4, 5.3. HRMS: calcd for $C_{13}H_{26}O_2Si$, 242.1702; found 242.1724.

Epoxide 41

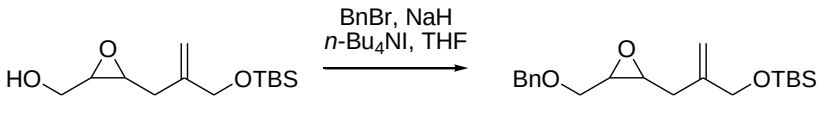


40 **41**

To a stirred solution of allyl alcohol **40** (13.20 g, 54.23 mmol) in anhydrous CH_2Cl_2 (68 ml), TBHP (5.0 Msoln in decane, 14.1 ml, 70.50 mmol) and then $VO(OEt)_3$ (1.0 ml, 5.423 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 4 h, the reaction was quenched by addition of aq.$NaHCO_3$ and diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:2) to give epoxide **41** (12.60 g, 48.76 mmol) as a slightly yellow oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3427, 3094, 3079, 2955, 2930, 2885, 2857, 2774, 2739, 2710, 1740, 1655, 1255, 1085, 836 cm^{-1}. ^1H NMR (400

MHz, $CDCl_3$): δ = 5.12 (br-s, 1H), 5.00 (br-s, 1H), 4.18 (br-d, J = 13.4 Hz, 1H), 4.10 (br-d, J = 13.4Hz, 1H), 3.85-3.70 (m, 2H), 3.21 (ddd, J = 5.8, 5.8, 5.8 Hz, 1H), 3.13 (ddd, J = 7.5, 5.4, 4.1 Hz, 1H), 2.47 (br-dd, J = 15.4, 5.4 Hz, 1H), 2.38 (br-dd, J = 6.6, 6.6 Hz, 1H), 2.28 (br-dd, J = 15.4, 7.5 Hz, 1H), 0.90 (s, 9H), 0.08 (s, 3H), 0.08 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 144.6, 112.3, 66.3, 60.3, 56.2, 55.8, 31.2, 25.8, 18.3, -5.2, -5.4. HRMS: calcd for $C_{13}H_{26}O_3Si$, 258.1651; found 258.1657.

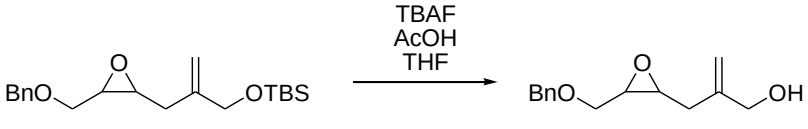
Benzyl Ether 45



41 **45**

To a stirred solution of epoxide **41** (555.9 mg, 2.140 mmol) in anhydrous THF (7 ml), NaH (140.1 mg, 3.210 mmol), BnBr (390 μl, 3.210 mmol) and then n-Bu_4NI (79.2 mg, 0.210 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 1 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/hexanes = 1:12) to give benzyl ether **45** (680.3 mg, 1.952 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3088, 3065, 3030, 2954, 2929, 2884, 2856, 2739, 2710, 1654, 1254, 1101, 836, 777, 698 cm^{-1}. ^{1}H NMR (700 MHz, $CDCl_3$): δ = 7.37-7.27 (m, 5H), 5.14 (br-s, 1H), 4.97 (br-s, 1H), 4.64 (d, J = 11.8 Hz, 1H), 4.54 (d, J = 11.8 Hz, 1H), 4.13 (br-d, J = 14.0 Hz, 1H), 4.08 (br-d, J = 14.0 Hz, 1H), 3.74 (dd, J = 11.2, 4.2 Hz, 1H), 3.56 (dd, J = 11.2, 6.4 Hz, 1H), 3.23 (ddd, J = 6.4, 4.3, 4.2 Hz, 1H), 3.14 (ddd, J = 6.5, 6.5, 4.3 Hz, 1H), 2.26-2.23 (m, 2H), 0.91 (s, 9H), 0.07 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 144.8, 137.8, 128.4, 127.8, 110.8, 73.3, 68.2, 66.0, 55.1, 54.8, 31.4, 25.9, 18.3, 5.4. HRMS: calcd for $C_{20}H_{32}O_3Si$, 348.2121; found 348.2119.

Alcohol 46

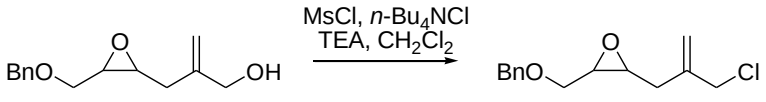


45 **46**

To a stirred solution of benzyl ether **45** (3.20 g, 9.182 mmol) in anhydrous THF (31 ml), AcOH (526 μl, 9.182 mmol) and then TBAF (1.0 Msoln in THF, 13.8 ml, 13.77 mmol) were added at room temperature under nitrogen atmosphere and stirred for 6 h. Although TLC analysis showed incomplete

disappearance of **45**, additional TBAF (1.0 Msoln in THF, 4.6 ml, 4.591 mmol) was added. After being stirred for 2.5 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4 .After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:3→ 1:1) to give alcohol **46** (1.99 g, 8.520 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3424, 3087, 3064, 3030, 2988, 2916, 2862, 2745, 1653, 1606, 1587, 1454, 1077, 741, 699 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.37-7.27 (m, 5H), 5.13 (br-s, 1H), 5.03 (br-s, 1H), 4.64 (d, *J* = 11.9 Hz, 1H), 4.55 (d, *J* = 11.9 Hz, 1H), 4.12 (br-s, 1H), 4.11 (br-s, 1H), 3.70 (dd, *J* = 11.1, 5.1 Hz, 1H), 3.63 (dd, *J* = 11.1, 5.9 Hz, 1H), 3.25 (ddd, *J* = 5.9, 5.1, 4.3 Hz, 1H), 3.13 (ddd, *J* = 6.0, 6.0, 4.3 Hz, 1H), 2.34-2.31 (m, 2H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 145.0, 137.6, 128.5, 127.9, 127.9, 112.5, 73.5, 67.9, 66.0, 55.2, 55.1, 31.8. HRMS: calcd for $C_{14}H_{18}O_3$, 234.1256; found 234.1261.

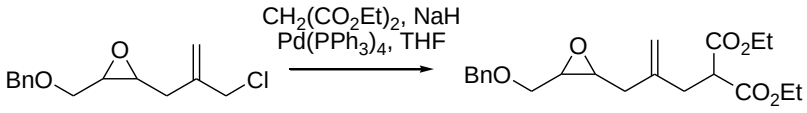
Allyl Chloride 47



46 **47**

To a stirred solution of alcohol **46** (417.5 mg, 1.782 mmol) in anhydrous CH_2Cl_2 (18 ml), TEA (0.7 ml, 5.346 mmol), *n*-Bu_4NCl (990.5 mg, 3.564 mmol) and then MsCl (207 μl, 2.673 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 3 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1: 5) to give allyl chloride **47** (419.9 mg, 1.661 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3086, 3063, 3030, 2988, 2917, 2860, 1645, 1454, 1097, 913, 745, 699 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.34-7.27 (m, 5H), 5.25 (br-s, 1H), 5.14 (br-s, 1H), 4.64 (d, *J* = 11.8 Hz, 1H), 4.55 (d, *J* = 11.8 Hz, 1H), 4.10 (dd, *J* = 11.7, 0.8 Hz, 1H), 4.08 (dd, *J* = 11.7, 0.8 Hz, 1H), 3.72 (dd, *J* = 11.1, 4.7 Hz, 1H), 3.61 (dd, *J* = 11.1, 6.1 Hz, 1H), 3.25 (ddd, *J* = 6.1, 4.7, 4.3 Hz, 1H), 3.15 (ddd, *J* = 7.1, 5.5, 4.3 Hz, 1H), 2.43 (br-dd, *J* = 16.1, 5.5 Hz, 1H), 2.38 (br-dd, *J* = 16.1, 7.1 Hz, 1H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 141.6, 137.7, 128.5, 127.8, 116.6, 73.4, 67.9, 54.9, 54.5, 48.3, 31.7. HRMS: calcd for $C_{14}H_{17}ClO_2$, 252.0917; found 252.0916.

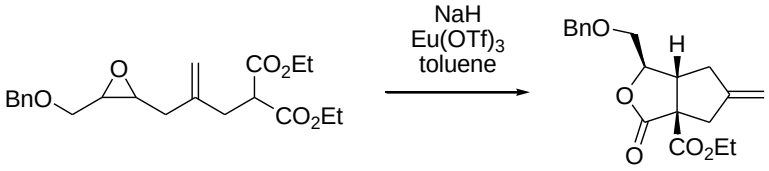
Epoxy Malonate 33



47 **33**

To a stirred solution of allyl chloride **47** (12.20 g, 48.27 mmol) in degassed anhydrous THF (69 ml), PPh_3 (968.9 mg, 3.620 mmol), $Pd(PPh_3)_4$ (1.40 g, 1.207 mmol) and then $NaCH(CO_2Et)_2$ in THF (47.5 ml, 77.23 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 30 min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified three times by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:4→1:3) to give epoxy malonate **33** (17.10 g, 45.43 mmol) as a yellow oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3085, 3064, 3029, 2982, 2937, 2906, 2870, 1748, 1731, 1649, 1236, 1152, 1097, 1034, 699 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.36-7.28 (m, 5H), 4.96 (s, 1H), 4.90 (s, 1H), 4.63 (d, *J* = 11.8Hz, 1H), 4.54 (d, *J* = 11.8 Hz, 1H), 4.23-4.15 (m, 4H), 3.71 (d, *J* = 11.2, 4.4 Hz, 1H), 3.60 (dd, *J* = 7.9, 7.9 Hz, 1H), 3.56 (dd, *J* = 11.2, 6.3 Hz, 1H), 3.23 (ddd, *J* = 6.3, 4.4, 4.4 Hz, 1H), 3.11 (ddd, *J* = 6.5, 5.7, 4.4 Hz, 1H), 2.68 (br-d, *J* = 7.8 Hz, 2H), 2.27-2.24 (m, 2H), 1.26 (dd, *J* = 7.1, 7.1 Hz, 3H), 1.25 (dd, *J* = 7.1, 7.1 Hz, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 168.9, 168.9, 142.0, 137.8, 128.4, 127.8, 113.4, 73.3, 68.1, 61.5, 61.5, 54.9, 54.6, 50.4, 35.2, 34.6, 14.1. HRMS: calcd for $C_{21}H_{28}O_6$, 376.1886; found 376.1878.

Bicyclic Lactone 31



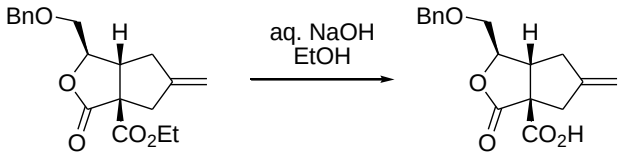
33 **31**

To a stirred solution of dried $Eu(OTf)_3$, epoxy malonate **33** (106.1 mg, 0.2820 mmol) in anhydrous toluene (3 ml) and then NaH (18.5 mg, 0.4230 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 3 h, the reaction was quenched by addition of AcOH (33 μl, 0.5640 mmol) and then Phthalate pH Standard Solution (pH = 4). After aqueous layer was checked to be acidic property with pH paper, the organic layer was diluted with ethyl acetate, washed with brine and then dried with Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/benzene = 1:20→1:5) to give bicyclic lactone **31** (82.7 g, 0.2503 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3080,

3064, 3030, 2983, 2938, 2907, 2864, 2811, 1776, 1735, 1243, 1122, 1051, 740, 699 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.37-7.28 (m, 5H), 4.97 (br-s, 1H), 4.94 (br-s, 1H), 4.59 (d, *J* = 12.1 Hz, 1H), 4.57 (d, *J* = 12.1 Hz, 1H), 4.23 (ddd, *J* = 5.2, 4.9, 4.7 Hz, 1H), 4.18 (dq, *J* = 10.8, 7.4 Hz, 1H), 4.12 (dq, *J* = 10.8, 7.4 Hz, 1H), 3.67 (dd, *J* = 10.6, 5.2 Hz, 1H), 3.64 (dd, *J* = 10.6, 4.7 Hz, 1H), 3.18 (br-d, *J* = 16.3 Hz, 1H), 3.13 (ddd, *J* = 7.2, 4.9, 2.3 Hz, 1H), 2.79 (br-d, *J* = 15.6 Hz, 1H), 2.79-2.73 (m, 1H), 2.27 (br-d, *J* = 15.6 Hz, 1H), 1.21 (dd, *J* = 7.4, 7.4Hz, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 175.0, 169.8, 146.0, 137.5, 128.5, 127.9, 127.7, 109.3, 83.4, 73.6, 70.7, 62.3, 60.9, 40.4, 39.1, 13.9. HRMS: calcd for $C_{19}H_{22}O_5$, 330.1467; found 330.1469.

3-5 : Experimental Section

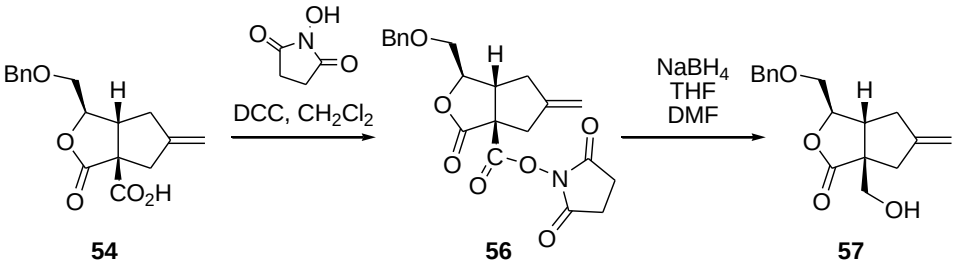
Carboxylic Acid 54



31 **54**

To a stirred solution of bicyclic lactone **31** (3.90 g, 11.80 mmol) in EtOH (24 ml), 3N NaOH aq. (20 ml, 59.00 mmol) was added at room temperature under air atmosphere. After being stirred for 2 h at 50 ℃, the reaction was quenched by addition of 3N HCl aq.(20 ml, 59.00 ml). After being diluted with ethyl acetate, aqueous layer was checked to be acidic property with pH paper and then extracted with ethyl acetate three times in the presence of solid NaCl. The organic layer was dried with Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (150 g, CH_2Cl_2/MeOH = 10: 1→5:1) to give carboxylic acid **54** (3.54 g, 11.71 mmol) as a slightly yellow oil.

Alcohol 57



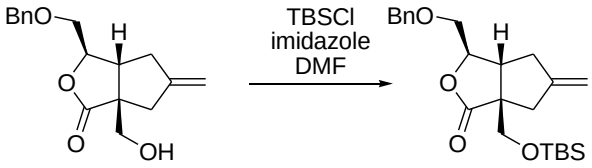
54 **56** **57**

To a stirred solution of carboxylic acid **54** (810.8 mg, 2.682 mmol) in anhydrous CH_2Cl_2 (13 ml), N-hydroxy succinimide **55** (413.7 mg, 3.487 mmol) and then DCC (726.8 mg, 3.487 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 1 h, N-hydroxy succinimide

(63.7 mg, 0.5364 mmol) and then DCC (111.8 mg, 0.5364 mmol) were added because of incomplete esterification. Subsequently, removal of solvent by decompression and then filtration through a celite pad (ethyl acetate/hexane = 2:1) were carried out. After concentration, the residual oil was used in next step.

The crude active ester **56** in anhydrous THF (11 ml) and anhydrous DMF (2 ml), $NaBH_4$ (88.3 mg, 2.146 mmol) was added at 0 ℃ under nitrogen atmosphere. After being stirred for 1 h, the reaction was quenched by addition of AcOH (0.6 ml, 10.73 mmol) and sat.NH_4Cl aq. at 0 ℃. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/benzene = 1: 3→1: 1) to give alcohol **57** (656.5 mg, 1.691 mmol) as a slightly white oil.

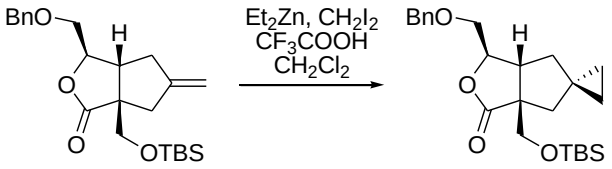
TBS Ether 59



57 **59**

To a stirred solution of alcohol **57** (6.48 g, 22.47 mmol) in anhydrous DMF (45 ml), imidazole (4.59 g, 67.41 mmol) and TBSCl (5.24 g, 33.71 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 1 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with H_2O, brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:10→1:5) to give TBS ether **59** (8.82 g, 21.90 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3066, 3031, 2953, 2929, 2896, 2857, 2804, 2739, 2711, 1773, 1667, 1255, 1147, 1096, 838 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.37-7.28 (m, 5H), 4.91 (br-s, 1H), 4.89 (br-s, 1H), 4.60 (d, *J* = 12.0 Hz, 1H), 4.56 (d, *J* = 12.0 Hz, 1H), 4.14 (dt, *J* = 6.3, 5.2 Hz, 1H), 3.89 (d, *J* = 9.7 Hz, 1H), 3.63 (d, *J* = 5.2 Hz, 2H), 3.50 (d, *J* = 9.7 Hz, 1H), 2.80 (br-dd, *J* = 6.9, 6.3 Hz, 1H), 2.67-2.61 (m, 1H), 2.52 (br-d, *J* = 16.3Hz, 1H), 2.37 (br-d, *J* = 16.3 Hz, 1H), 2.25 (br-d, *J* = 15.4 Hz, 1H), 0.86 (s, 9H), 0.03 (s, 3H), 0.03 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 179.7, 147.4, 137.7, 128.4, 127.8, 127.7, 108.8, 82.8, 73.5, 71.4, 65.2, 57.3, 43.8, 38.8, 38.8, 25.8, 18.2, -5.6. HRMS: calcd for $C_{23}H_{34}O_4Si$, 402.2226; found 402.2229.

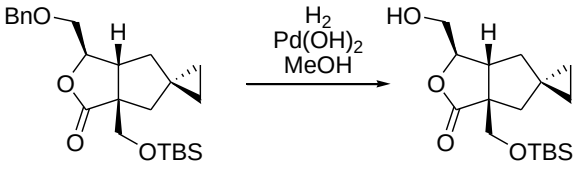
Cyclopropane 60



59 **60**

To a stirred solution of Et_2Zn (1.0 M in Hexanes, 24.7 ml, 24.67 mmol) in anhydrous CH_2Cl_2 (29 ml), CF_3CO_2H (1.9 ml, 24.67 mmol) was added at 0 ℃ under nitrogen atmosphere. After being stirred for 20 min at 0 ℃, CH_2I_2 (2.0 ml, 24.67 mmol) was added at 0 ℃ and stirred for 20 min. To a reaction mixture, TBS ether **59** (0.7 M in CH_2Cl_2, 3.31 g, 8.222 mmol) was added at 0 ℃, and then was warmed to room temperature. After being stirred for 10.5 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with aq.$NaHCO_3$, H_2O followed by brine, and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:6) to give cyclopropane **60** (3.14 g, 7.537 mmol) as a slightly yellow oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3067, 3030, 2994, 2951, 2929, 2896, 2884, 2857, 2803, 2739, 2711, 1769, 1252, 1126, 1095, 838 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.36-7.27 (m, 5H), 4.60 (d, J = 12.0 Hz, 1H), 4.55 (d, J = 12.0 Hz, 1H), 4.37 (ddd, J = 6.2, 4.8, 4.8 Hz, 1H), 3.89 (d, J = 9.6 Hz, 1H), 3.64 (dd, J = 10.3, 6.2 Hz, 1H), 3.61 (dd, J = 10.3, 4.8 Hz, 1H), 3.49 (d, J = 9.6 Hz, 1H), 2.72 (ddd, J = 7.9, 4.8, 0.9 Hz, 1H), 2.23 (dd, J = 13.1, 7.9 Hz, 1H), 1.90 (d, J = 13.1 Hz, 1H), 1.54 (dd, J = 13.1, 0.9 Hz, 1H), 1.25 (br-d, J = 13.1 Hz, 1H), 0.87 (s, 9H), 0.50-0.44 (m, 4H), 0.03 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 180.8, 137.8, 128.4, 127.8, 127.7, 84.0, 73.6, 72.3, 65.8, 59.0, 45.0, 42.0, 41.8, 25.9, 22.0, 18.3, 13.8, 5.6, -5.5. HRMS: calcd for $C_{24}H_{36}O_4Si$, 416.2383; found 416.2380.

Alcohol 61

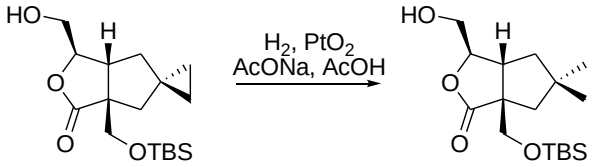


60 **61**

To a stirred solution of cyclopropane **60** (5.80 g, 13.92 mmol) in MeOH (35 ml), $Pd(OH)_2$-C (580.0 mg, 10Wt%) was added at room temperature, and then purged with hydrogen. After being stirred for 5 h under a balloon of hydrogen, the heterogeneous mixture was filtered through a celite pad with ethyl acetate and concentrated. Subsequently, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:2) to give alcohol **61** (4.44 g, 13.60 mmol) as a colorless

oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3422, 2952, 2930, 2897, 2884, 2857, 1769, 1253, 1094, 1030, 839, 778 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.33 (ddd, *J* = 6.4, 5.0, 3.3 Hz, 1H), 3.93 (d, *J* = 9.6 Hz, 1H), 3.80 (ddd, *J* = 12.2, 7.7, 3.3 Hz, 1H), 3.74 (ddd, *J* = 12.2, 6.4, 5.1 Hz, 1H), 3.53 (d, *J* = 9.6Hz, 1H), 2.76 (ddd, *J* = 7.9, 5.0, 1.1 Hz, 1H), 2.26 (dd, *J* = 13.1, 7.9 Hz, 1H), 2.14-2.09 (m, 1H), 1.84 (d, *J* = 13.2 Hz, 1H), 1.59-1.55 (m, 1H), 1.27 (br-d, *J* = 13.2 Hz, 1H), 0.89 (s, 9H), 0.52-0.46 (m, 4H), 0.08 (s, 3H), 0.07 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 180.6, 85.7, 66.5, 64.9, 59.3, 43.7, 42.1, 41.5, 25.9, 22.0, 18.4, 13.8, 5.6, -5.6, -5.6. HRMS: calcd for $C_{17}H_{30}O_4Si$, 326.1913; found 326.1912.

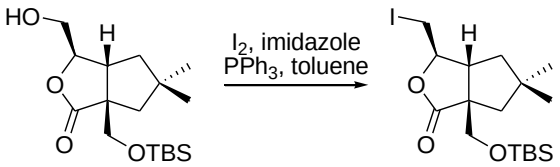
Dimethyl Compound 62



61 **62**

To a stirred solution of alcohol **61** (5.48 g, 16.78 mmol) in AcOH (56 ml), CH_3CO_2Na (2.09 g, 25.17 mmol) and PtO_2 (381.0 mg, 1.678 mmol) were added at room temperature and then purged with hydrogen. After being stirred for 18 h under a balloon of hydrogen, the heterogeneous mixture was filtered through a celite pad with ethyl acetate and then washed with H_2O, aq.$NaHCO_3$ followed by brine. Subsequently, the organic layer was dried with Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:1) to give dimethyl compound **62** (5.21 g, 15.86 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3443, 2953, 2931, 2901, 2884, 1768, 1256, 1113, 1093, 838, 778 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.32 (ddd, *J* = 5.7, 4.0, 3.7 Hz, 1H), 3.91 (d, *J* = 9.5 Hz, 1H), 3.81-3.74 (m, 2H), 3.51 (d, *J* = 9.5 Hz, 1H), 2.71 (ddd, *J* = 9.1, 3.7, 3.7 Hz, 1H), 2.24 (br-dd, *J* = 5.6, 5.6 Hz, 1H), 1.93 (dd, *J* = 13.4, 9.1 Hz, 1H), 1.87 (d, *J* = 13.4 Hz, 1H), 1.60 (br-dd, *J* = 13.4, 3.7 Hz, 1H), 1.43 (d, *J* = 13.4 Hz, 1H), 1.05 (s, 3H), 1.04 (s, 3H), 0.89 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 181.3, 86.0, 68.0, 65.0, 59.4, 48.2, 47.7, 43.7, 40.5, 29.5, 27.7, 25.9, 18.5, -5.5, -5.7. HRMS: calcd for $C_{17}H_{32}O_4Si$, 328.2070; found 328.2064.

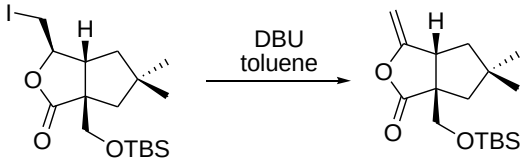
Iodide 67



62 **67**

To a stirred solution of dimethyl compound **62** (5.21 g, 15.86 mmol) in anhydrous toluene (53 ml), imidazole (4.32 g, 63.44 mmol), PPh_3 (8.49 g, 31.72 mmol) and then I_2 (6.05 g, 23.79 mmol) were added at 0 ℃ under nitrogen atmosphere. Subsequently, the mixture was warmed to 70 ℃. After being stirred for 30 min, the reaction was quenched by addition of aq.Na_2SO_3 at 0 ℃ and then filtered through a silica pad with ethyl acetate. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:25→1:10) to give iodide **67** (6.75 g, 15.40 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 2953, 2932, 2901, 2883, 2857, 1775, 1098, 1078, 838, 778 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.36 (ddd, *J* = 9.7, 5.1, 2.8 Hz, 1H), 3.92 (d, *J* = 9.5 Hz, 1H), 3.47 (d, *J* = 9.5 Hz, 1H), 3.39 (dd, *J* = 9.4, 5.1 Hz, 1H), 3.35 (dd, *J* = 9.7, 9.4 Hz, 1H), 2.78 (ddd, *J* = 9.2, 5.3, 2.8 Hz, 1H), 2.01 (dd, *J* = 13.3, 9.2 Hz, 1H), 1.86 (d, *J* = 13.5 Hz, 1H), 1.59 (dd, *J* = 13.3, 5.3 Hz, 1H), 1.42 (d, *J* = 13.5 Hz, 1H), 1.03 (s, 3H), 1.03 (s, 3H), 0.89 (s, 9H), 0.08 (s, 3H), 0.06 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 181.4, 84.5, 67.8, 59.9, 49.0, 48.3, 47.7, 40.4, 29.0, 27.9, 25.9, 18.5, 7.4, -5.5. HRMS: calcd for $C_{17}H_{31}O_3SiI$, 438.1088; found 438.1074.

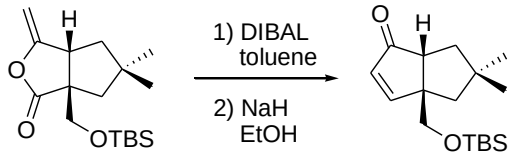
Vinyl Ether 66



67 **66**

To a stirred solution of iodide **67** (123.8 mg, 0.2824 mmol) in anhydrous toluene (3 ml), DBU (130 μl, 0.8472 mmol) was added at room temperature under nitrogen atmosphere and then warmed to 110 ℃. After being stirred for 13 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on florisil (150 g, ethyl acetate/hexanes = 1:25) to give vinyl ether **66** (76.2 mg, 0.2454 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3120, 2955, 2931, 2899, 2858, 2737, 2709, 1800, 1687, 1667, 1464, 1257, 1114, 838, 777 cm^{-1}. ^1HNMR (700 MHz, $CDCl_3$): δ = 4.65 (dd, *J* = 2.3, 1.9 Hz, 1H), 4.24 (dd, *J* = 2.3, 1.6 Hz, 1H), 3.90 (d, *J* = 9.5 Hz, 1H), 3.49 (d, *J* = 9.5 Hz, 1H), 3.41 (dddd, *J* = 9.1, 5.3, 1.9, 1.6 Hz, 1H), 1.96 (dd, *J* = 13.0, 9.1 Hz, 1H), 1.88 (d, *J* = 13.6 Hz, 1H), 1.67 (dd, *J* = 13.0, 5.3 Hz, 1H), 1.46 (d, *J* = 13.6 Hz, 1H), 1.02 (s, 3H), 1.01 (s, 3H), 0.89 (s, 9H), 0.03 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 180.0, 160.6, 87.1, 67.1, 59.4, 48.8, 46.4, 46.1, 40.9, 29.1, 28.0, 25.6, 18.0, -5.7. HRMS: calcd for $C_{17}H_{30}O_3Si$, 310.1964; found 310.1951.

Enone 30



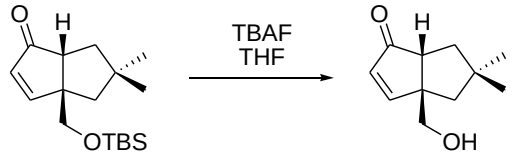
66 **30**

Firstly, azeotropic dehydration of vinyl ether **66** (947.6 mg, 3.052 mmol) with anhydrous toluene was carried out. To a stirred solution of **66** in anhydrous toluene (15 ml), DIBAL (3.1 ml, 3.113 mmol) was added at -78 ℃ under nitrogen atmosphere. After being stirred for 40 min, the reaction was quenched by addition of aq.Rochell's salt and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was used in the next step.

Azeotropic dehydration of residual oil with anhydrous toluene was carried out. In the next place, the oil was diluted with anhydrous EtOH (15 ml), and subsequently NaH (13.3 mg, 0.3052 mmol) was added to a reaction mixture at 0 ℃. After being stirred for 7.5 h at room temperature, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/hexanes = 1:15→1:10) to give enone **30** (667.8 g, 2.267 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3074, 3033, 2953, 2929, 2897, 2857, 2736, 2710, 1709, 1586, 1470, 1256, 1093, 839, 777 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.49 (d, J = 5.7 Hz, 1H), 6.04 (d, J = 5.7 Hz, 1H), 3.62 (d, J = 9.6 Hz, 1H), 3.57 (d, J = 9.6 Hz, 1H), 2.58 (dd, J = 10.0, 4.4 Hz, 1H), 1.82 (dd, J = 13.1, 10.0 Hz, 1H), 1.71 (dd, J = 13.1, 4.4 Hz, 1H), 1.59 (d, J = 13.4 Hz, 1H), 1.52 (d, J = 13.4 Hz, 1H), 1.03 (s, 3H), 0.90 (s, 3H), 0.86 (s, 9H), 0.03 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 213.3, 169.6, 132.3, 68.3, 60.7, 53.9, 45.2, 43.3, 42.3, 30.6, 29.3, 25.8, 18.2, -5.5. HRMS: calcd for $C_{17}H_{30}O_2Si$, 294.2015; found 294.2019.

3-6 : Experimental Section

Alcohol 128

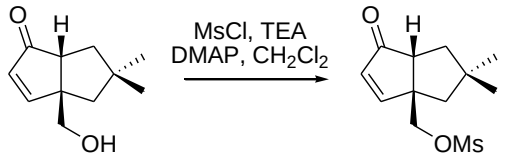


30 **128**

To a stirred solution of enone **30** (2.84 g, 9.643 mmol) in THF (48 ml), TBAF (1.0 M in THF, 11.6 ml, 11.57 mmol) was added at room temperature under nitrogen atmosphere. After being stirred for 30

min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 1:2→2:1→4:1) to give alcohol **128** (1.63 g, 9.043 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3417, 3079, 3037, 2952, 2930, 2863, 2731, 2720, 1704, 1695, 1584, 1367, 1061, 817, 798 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.55 (d, *J* = 5.6 Hz, 1H), 6.10 (br-d, *J* = 5.6 Hz, 1H), 3.74 (dd, *J* = 10.5, 3.0 Hz, 1H), 3.64 (dd, *J* = 10.5, 6.0 Hz, 1H), 2.63 (dd, *J* = 10.0, 4.4 Hz, 1H), 1.85 (dd, *J* = 13.2, 10.1 Hz, 1H), 1.74 (br-d, *J* = 13.2 Hz, 1H), 1.64-1.59 (m, 1H), 1.59 (d, *J* = 13.5 Hz, 1H), 1.55 (d, *J* = 13.5 Hz, 1H), 1.03 (s, 3H), 0.91 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 212.7, 168.7, 133.1, 68.2, 60.5, 53.6, 45.5, 43.2, 42.2, 30.5, 29.2. HRMS: calcd for $C_{11}H_{16}O_2$, 180.1150; found 180.1149.

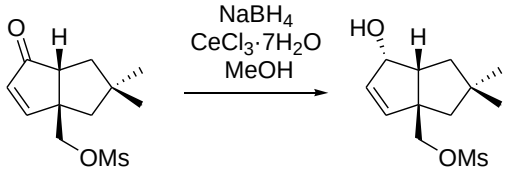
Mesylate 70



128 **70**

To a stirred solution of alcohol **128** (44.3 mg, 0.2458 mmol) in CH_2Cl_2 (3 ml), TEA (137 μl, 0.9832 mmol), MsCl (38 μl, 0.4916 mmol) and then DMAP (3.0 mg, 0.02458 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 1 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:1) to give mesylate **70** (63.2 mg, 0.2446 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3024, 2954, 2937, 2906, 2866, 1713, 1588, 1357, 1176, 978, 957, 845 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.52 (d, *J* = 5.6Hz, 1H), 6.13 (d, *J* = 5.6Hz, 1H), 4.29 (d, *J* = 9.7 Hz, 1H), 4.19 (d, *J* = 9.7 Hz, 1H), 3.01 (s, 3H), 2.65 (dd, *J* = 10.0, 4.2 Hz, 1H), 1.89 (dd, *J* = 13.3, 10.0 Hz, 1H), 1.79 (dd, *J* = 13.3, 4.2 Hz, 1H), 1.67 (d, *J* = 13.7 Hz, 1H), 1.61 (d, *J* = 13.7 Hz, 1H), 1.06 (s, 3H), 0.92 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 211.0, 166.1, 133.7, 72.6, 57.8, 53.6, 45.6, 43.2, 42.4, 37.6, 30.4, 29.0. HRMS: calcd for $C_{12}H_{18}O_4S$, 258.0926; found 258.0926.

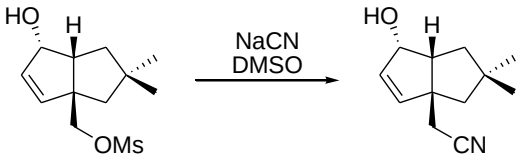
Allyl Aocohol 71



70 **71**

To a stirred solution of mesylate **70** (1.61 g, 6.232 mmol) in MeOH (31 ml), $CeCl_3 \cdot 7H_2O$ (2.79 g, 7.478 mmol) and then $NaBH_4$ (307.5 mg, 7.478 mmol) were added at 0 ℃ under nitrogen atmosphere. After being stirred for 40 min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/hexanes = 2:1) to give allyl alcohol **71** (1.59 g, 6.107 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3531, 3387, 3051, 3029, 2952, 2864, 1352, 1174, 974, 952, 844, 529 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.68 (dd, *J* = 5.5, 1.6 Hz, 1H), 5.63 (dd, *J* = 5.5, 2.0 Hz, 1H), 4.97 (dddd, *J* = 7.4, 7.4, 1.6, 1.6 Hz, 1H), 4.12 (d, *J* = 9.4 Hz, 1H), 4.09 (d, *J* = 9.4 Hz, 1H), 2.98 (s, 3H), 2.89 (ddd, *J* = 11.0, 7.4, 7.4 Hz, 1H), 1.62 (dd, *J* = 12.3, 11.0 Hz, 1H), 1.59 (dd, *J* = 13.5, 1.7 Hz, 1H), 1.54-1.46 (m, 3H), 1.07 (s, 3H), 1.03 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 136.6, 134.1, 77.3, 74.9, 61.3, 50.2, 49.1, 41.1, 41.0, 37.4, 29.7, 28.7. HRMS: calcd for $C_{12}H_{20}O_4S$, 260.1082; found 260.1080.

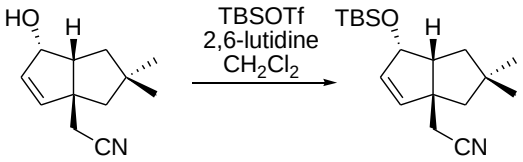
Nitrile 129



71 **129**

To a stirred solution of allyl alcohol **71** (1.59 g, 6.107 mmol) in anhydrous DMSO (31 ml), NaCN (925.7 mg, 18.32 mmol) was added at room temperature under nitrogen atmosphere. The mixture was warmed to 120 ℃. After being stirred for 2 h, the reaction was quenched by addition of H_2O and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (150 g, ethyl acetate/hexanes = 2:3) to give nitrile **129** (965.4 mg, 5.047 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 3317, 3260, 3061, 3019, 2955, 2931, 2895, 2865, 2249, 1215, 1090, 1046, 756 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.71 (d, *J* = 6.5 Hz, 1H), 5.71 (d, *J* = 6.5 Hz, 1H), 5.10 (dd, *J* = 7.6, 7.4 Hz, 1H), 2.85 (ddd, *J* = 10.5, 7.6, 7.6 Hz, 1H), 2.52 (d, *J* = 16.6 Hz, 1H), 2.47 (d, *J* = 16.6 Hz, 1H), 1.68 (d, *J* = 13.4 Hz, 1H), 1.65 (dd, *J* = 12.7, 10.5 Hz, 1H), 1.59 (dd, *J* = 13.4, 1.8 Hz, 1H), 1.56 (ddd, *J* = 12.7, 7.6, 1.8 Hz, 1H), 1.53 (br-d, *J* = 7.4 Hz, 1H), 1.07 (s, 3H), 1.06 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 137.9, 133.7, 118.4, 77.1, 59.1, 52.5, 52.3, 41.4, 41.3, 29.6, 29.5, 28.9. HRMS: calcd for $C_{12}H_{17}NO$, 191.1310; found 191.1314.

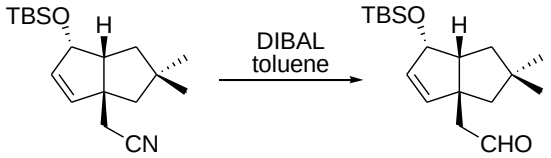
TBS Ether 72



129 **72**

To a stirred solution of nitrile **129** (965.4 mg, 5.047 mmol) in CH_2Cl_2 (25 ml), 2,6-lutidine (1.4 ml, 12.11 mmol) and then TBSOTf (1.4 ml, 6.056 mmol) were added at 0 ℃ under nitrogen atmosphere. After being stirred for 40 min, the reaction was quenched by addition of ap.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/hexanes = 1:20) to give TBS ether **72** (1.51 g, 4.942 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3058, 3044, 2954, 2929, 2896, 2858, 2248, 1471, 1367, 1131, 1102, 860, 837 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.63 (dd, *J* = 5.5, 1.8 Hz, 1H), 5.60 (dd, *J* = 5.5, 1.5 Hz, 1H), 5.03 (ddd, *J* = 7.7, 1.8, 1.5 Hz, 1H), 2.74 (ddd, *J* = 10.1, 7.7, 7.7 Hz, 1H), 2.50 (d, *J* = 16.6 Hz, 1H), 2.45 (d, *J* = 16.6 Hz, 1H), 1.78 (dd, *J* = 13.2, 10.1 Hz, 1H), 1.65 (d, *J* = 13.4 Hz, 1H), 1.56 (dd, *J* = 13.4, 1.7 Hz, 1H), 1.44 (ddd, *J* = 13.2, 7.7, 1.7 Hz, 1H), 1.04 (s, 3H), 1.04 (s, 3H), 0.90 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 136.6, 134.5, 118.6, 77.0, 58.7, 53.1, 52.6, 41.9, 40.9, 29.7, 29.5, 29.2, 25.9, 18.2, -4.8, -4.9. HRMS: calcd for $C_{18}H_{31}NOSi$, 305.2175; found 305.2179.

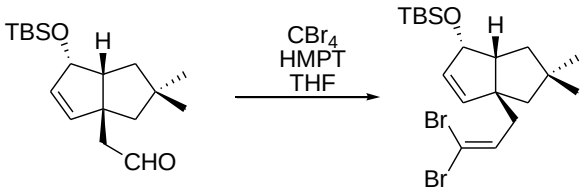
Aldehyde 73



72 **73**

To a stirred solution of TBS ether **72** (1.29 g, 4.222 mmol) in anhydrous toluene (42 ml), DIBAL (1.0 M in toluene, 6.2 ml, 6.333 mmol) was added at -78 ℃ under nitrogen atmosphere. After being stirred for 30 min, the reaction mixture was warmed to -20 ℃ and then quenched by addition of aq.Rochell's salt. The heterogeneous mixture was diluted with ethyl acetate and then washed with brine. Subsequently, the organic layer was dried over Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/hexanes = 1:20) to give aldehyde **73** (1.23 g, 3.987 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3057, 3039, 2953, 2929, 2895, 2857, 2726, 1724, 1365, 1255, 1106, 860, 836, 775 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 9.64 (dd, *J* = 2.6, 2.6 Hz, 1H), 5.74 (ddd, *J* = 5.5, 1.9 Hz, 1H), 5.47 (dd, *J* = 5.5, 1.5 Hz, 1H), 4.88 (ddd, *J* = 7.4, 1.9, 1.5 Hz, 1H), 2.73 (ddd, *J* = 10.3, 7.6, 7.4 Hz, 1H), 2.65 (dd, *J* = 15.2, 2.6 Hz, 1H), 2.51 (dd, *J* = 15.2, 2.6 Hz, 1H), 1.74 (dd, *J* = 13.1, 10.3 Hz, 1H), 1.64 (d, *J* = 13.2 Hz, 1H), 1.57 (dd, *J* = 13.1, 1.7 Hz, 1H), 1.39 (ddd, *J* = 13.1, 7.6, 1.7 Hz, 1H), 1.03 (s, 3H), 1.01 (s, 3H), 0.89 (s, 9H), 0.07 (s, 3H), 0.06 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 202.5, 138.3, 132.6, 77.3, 57.8, 55.2, 53.6, 53.1, 41.5, 40.8, 29.6, 29.3, 25.9, 18.3, -4.8. HRMS: calcd for $C_{18}H_{32}O_2Si$, 308.2172; found 308.2167.

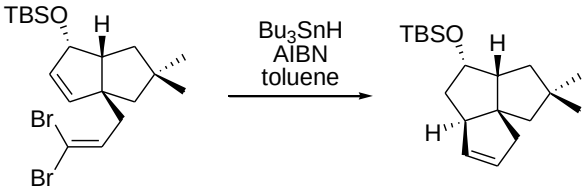
Dibromo Olefin 29



73 **29**

To a stirred solution of CBr_4 (1.73 g, 5.116 mmol) and HMPT (1.9 ml, 10.23 mmol) in THF (17 ml), aldehyde **73** (0.3 M in THF, 789.3 mg, 2.558 mmol) was added at 0 ℃ under nitrogen atmosphere. After being stirred for 15 min, the reaction was quenched by addition of H_2O and then diluted with ethyl acetate. The organic layer was washed with ap.$NaHCO_3$, H_2O and then brine. Subsequently, this layer was dried over Na_2SO_4 and then concentrated. The residual oil was purified by column chromatography on silica gel (80 g, ethyl acetate/hexanes = 1:40) to give dibromo olefine **29** (1.17 g, 2.520 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3055, 3036, 2952, 2928, 2896, 2857, 1714, 1618, 1365, 1251, 1101, 861, 836, 778 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 6.26 (dd, *J* = 8.2, 6.9 Hz, 1H), 5.55 (dd, *J* = 5.5, 1.9 Hz, 1H), 5.46 (dd, *J* = 5.5, 1.5 Hz, 1H), 4.85 (ddd, *J* = 7.5, 1.9, 1.5 Hz, 1H), 2.64 (ddd, *J* = 10.7, 7.5, 7.5 Hz, 1H), 2.30 (dd, *J* = 14.4, 8.2 Hz, 1H), 2.25 (dd, *J* = 14.4, 6.9 Hz, 1H), 1.68 (dd, *J* = 12.9, 10.7 Hz, 1H), 1.52 (d, *J* = 13.2 Hz, 1H), 1.49 (dd, *J* = 13.2, 1.3 Hz, 1H), 1.36 (ddd, *J* = 12.9, 7.5, 1.3 Hz, 1H), 1.03 (s, 3H), 1.02 (s, 3H), 0.90 (s, 9H), 0.09 (s, 3H), 0.07 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 138.7, 136.6, 132.5, 89.5, 77.5, 60.4, 52.7, 52.6, 44.3, 41.9, 40.7, 29.8, 29.1, 26.0, 18.4, -4.8. HRMS: calcd for $C_{19}H_{32}Br_2OSi$, 462.0590; found 462.0590.

Tricyclic Compound 28



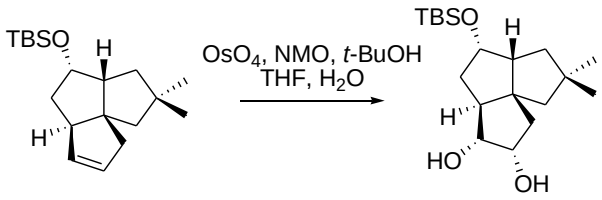
29 **28**

To a stirred solution of dibromo olefine **29** (656.7 mg, 1.414 mmol) in anhydrous toluene (14 ml), Bu_3SnH (1.6 ml, 5.656 mmol) and AIBN (23.2 mg, 0.1414 mmol) were added and then warmed to 100 ℃. After being stirred for 1 h, the reaction mixture was concentrated. The residual oil was purified by column chromatography on silica gel (40 g, ethyl acetate/hexanes/TEA = 1:20:1) to give tricyclic compound **28** (357.9 mg, 1.167 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3046, 2951, 2934, 2885, 2857, 1470, 1364, 1254, 1101, 858, 835, 774 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.55 (dddd, *J* = 5.7, 2.4, 2.4, 2.4 Hz, 1H), 5.40 (dddd, *J* = 5.7, 2.2, 2.2, 2.2 Hz, 1H), 4.14 (ddd, *J* = 10.5, 7.9,

6.6 Hz, 1H), 2.64-2.58 (m, 1H), 2.56 (dddd, *J* = 16.9, 2.4, 2.3, 2.2 Hz, 1H), 2.52 (dddd, *J* = 16.9, 2.4, 2.4, 2.2 Hz, 1H), 2.27 (ddd, *J* = 10.8, 7.9, 7.9 Hz, 1H), 1.79 (ddd, *J* = 12.1, 10.5, 6.0 Hz, 1H), 1.72 (dd, *J* = 12.1, 6.6 Hz, 1H), 1.65 (s, 2H), 1.49 (dd, *J* = 12.9, 10.8 Hz, 1H), 1.37 (dd, *J* = 12.9, 7.9 Hz, 1H), 1.05 (s, 3H), 0.98 (s, 3H), 0.86 (s, 9H), 0.01 (s, 3H), 0.00 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 134.1, 129.6, 73.9, 58.5, 57.7, 57.2, 56.0, 51.6, 42.7, 40.6, 36.1, 29.2, 27.4, 25.9, 18.2, -4.8. HRMS: calcd for $C_{19}H_{34}OSi$, 306.2379; found 306.2384.

3-7 : Experimental Section

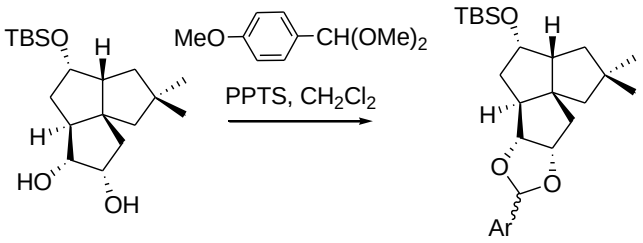
Diol 74



28 **74**

To a stirred solution of tricyclic compound **28** (540.6 mg, 1.763 mmol) in anhydrous THF (3 ml) and *t*-BuOH (10 ml), H_2O (1 ml), NMO (309.9 mg, 2.645 mmol) and then OsO_4 (44.8 mg, 0.1763 mmol) were added at room temperature under air atmosphere. After being stirred for 50 min, the reaction was quenched by addition of $NaHSO_3$ (550.4 mg, 5.289 mmol) and then diluted with ethyl acetate and H_2O. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (40 g, ethyl acetate/hexanes = 1:2→2:1) to give diol **74** (494.5 mg, 1.452 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 3334, 3017, 2949, 2931, 2904, 2858, 1463, 1363, 1105, 837, 765 cm^{-1}. ^{1}H NMR (700 MHz, $CDCl_3$): δ = 4.15 (ddd, *J* = 9.6, 7.8, 6.7 Hz, 1H), 4.02 (dddd, *J* = 5.0, 5.0, 5.0, 5.0 Hz, 1H), 3.63 (ddd, *J* = 5.1, 5.1, 5.0 Hz, 1H), 2.24 (ddd, *J* = 10.6, 8.0, 7.8 Hz, 1H), 2.02-1.87 (m, 6H), 1.77-1.72 (m, 2H), 1.60 (d, *J* = 13.0 Hz, 1H), 1.47 (dd, *J* = 13.1, 10.6 Hz, 1H), 1.34 (ddd, *J* = 13.1, 8.0, 2.4 Hz, 1H), 1.03 (s, 3H), 0.96 (s, 3H), 0.87 (s, 9H), 0.03 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 79.0, 74.8, 73.8, 59.1, 57.3, 55.8, 55.2, 48.0, 41.7, 41.0, 36.3, 29.2, 27.6, 25.9, 18.2, -4.7, -4.8. HRMS: calcd for $C_{19}H_{36}O_3Si$, 340.2434; found 340.2439.

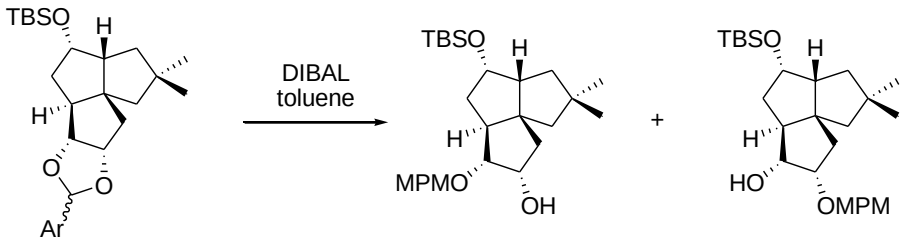
Anisylidene Acetal 76



74 **76**

To a stirred solution of diol **74** (494.5 mg, 1.452 mmol) in anhydrous CH_2Cl_2 (15 ml), *p*-Anisaldehyde dimethylacetal (400 μl, 2,178 mmol) and then PPTS in CH_2Cl_2 (2.5 ml, 0.1452 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 50 min, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (40 g, benzene) to anisylidene acetal **76** (652.9 mg, 1.423 mmol) as a colorless oil. Analytical data: (about major product) IR (KBr): $\tilde{\nu}$ = 3070, 2999, 2952, 2930, 2903, 2857, 2803, 2767, 1616, 1518, 1250, 1078, 822, 775 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.46-7.43 (m, 2H), 6.93-6.90 (m, 2H), 5.66 (s, 1H), 4.65 (ddd, *J* = 6.1, 6.1, 3.4 Hz, 1H), 4.32 (d, *J* = 6.1 Hz, 1H), 4.13 (ddd, *J* = 5.4, 5.2, 5.2 Hz, 1H), 3.81 (s, 3H), 2.50 (dd, *J* = 7.6, 7.0 Hz, 1H), 2.38-2.33 (m, 1H), 2.23 (dd, *J* = 14.3, 3.4 Hz, 1H), 2.02 (dd, *J* = 14.3, 6.2 Hz, 1H), 1.93 (ddd, *J* = 12.6, 7.0, 5.4 Hz, 1H), 1.82 (dd, *J* = 12.8, 2.1 Hz, 1H), 1.67 (d, *J* = 12.8 Hz, 1H), 1.65-1.58 (m, 1H), 1.60 (dd, *J* = 12.7, 8.1 Hz, 1H), 1.29 (ddd, *J* = 12.7, 8.3, 2.1 Hz, 1H), 1.05 (s, 3H), 1.00 (s, 3H), 0.89 (s, 9H), 0.04 (s, 3H), 0.03 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 160.5, 129.0, 128.3, 113.8, 104.7, 87.2, 83.9, 73.7, 61.0, 57.9, 56.0, 55.3, 55.2, 48.1, 42.9, 40.7, 40.3, 29.6, 28.1, 25.9, 18.2, -4.7, -5.0. HRMS: calcd for $C_{27}H_{42}O_4Si$, 458.2852; found 458.2863. (about minor product) IR (KBr): $\tilde{\nu}$ = 3068, 2951, 2930, 2857, 2768, 2737, 2709, 1614, 1515, 1249, 835, 775 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.40-7.35 (m, 2H), 6.90-6.88 (m, 2H), 6.02 (s, 1H), 4.73 (ddd, *J* = 6.5, 5.6, 5.0 Hz, 1H), 4.28 (dd, *J* = 5.6, 1.8 Hz, 1H), 4.08 (ddd, *J* = 7.1, 6.9, 5.2 Hz, 1H), 3.80 (s, 3H), 2.35-2.30 (m, 1H), 2.30 (ddd, *J* = 10.1, 8.3, 6.9 Hz, 1H), 2.15 (dd, *J* = 14.2, 5.0 Hz, 1H), 2.09 (dd, *J* = 14.2, 6.5 Hz, 1H), 1,95 (ddd, *J* = 12.7, 7.1, 7.1 Hz, 1H), 1.79 (dd, *J* = 12.7, 2.2 Hz, 1H), 1.68-1.63 (m, 1H), 1.65 (d, *J* = 12.7 Hz, 1H), 1.62 (dd, *J* = 12.9, 10.1 Hz, 1H), 1.33 (ddd, *J* = 12.9, 8.3, 2.2 Hz, 1H), 1.05 (s, 3H), 1.01 (s, 3H), 0.88 (s, 9H), 0.04 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 160.1, 130.8, 127.6, 113.7, 102.7, 86.9, 83.3, 73.7, 59.7, 57.2, 56.2, 55.3, 54.7, 47.0, 42.1, 41.2, 39.7, 29.5, 28.1, 25.9, 18.2, -4.7, -4.9. HRMS: calcd for $C_{27}H_{42}O_4Si$, 458.2852; found 458.2863.

MPM Ether 77 and 78

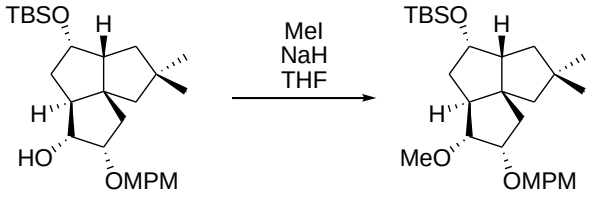


76 **77** **78**

Firstly, azeotropic dehydration of anisylidene acetal **76** (652.9 mg, 1.423 mmol) with anhydrous toluene was carried out. To a stirred solution of **76** in anhydrous toluene (14 ml), DIBAL (1.0 M in toluene, 2.8 ml, 2.846 mmol) was added at -78 ℃ under nitrogen atmosphere and subsequently the reaction mixture was stirred for 50 min. TLC analysis showed incomplete disappearance of **76** and additional DIBAL (1.0 M in toluene, 1.4 ml, 1.423 mmol) was added to reaction mixture at -78 ℃. After being stirred for 30 min, the reaction was quenched by addition of aq.Rochell's salt at -20 ℃ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified three times by column chromatography on silica gel (40 g, ethyl acetate/hexanes = 1:5) to give MPM ether **77** (105.1 mg, 0.2281 mmol) and **78** (524.1 mg, 1.138 mmol) as a colorless oil. Analytical data: (about major product **78**) IR (KBr): $\tilde{\nu}$ = 3552, 3016, 2952, 2931, 2858, 1613, 1513, 1250, 1215, 835, 758 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.26 (d, *J* = 8.6 Hz, 2H), 6.89 (d, *J* = 8.6 Hz, 2H), 4.54 (d, *J* = 11.2 Hz, 1H), 4.41 (d, *J* = 11.2 Hz, 1H), 4.08 (ddd, *J* = 9.8, 7.8, 5.9 Hz, 1H), 3.81 (s, 3H), 3.75 (ddd, *J* = 6.7, 5.2, 4.7 Hz, 1H), 3.62 (ddd, *J* = 5.3, 4.7, 4.7 Hz, 1H), 2.41 (d, *J* = 5.3 Hz, 1H), 2.19 (ddd, *J* = 10.4, 7.8, 7.8 Hz, 1H), 2.01 (dd, *J* = 13.4, 6.7 Hz, 1H), 2.01-1.98 (m, 1H), 1.87 (ddd, *J* = 12.9, 9.3, 8.3 Hz, 1H), 1.84 (dd, *J* = 13.4, 5.2 Hz, 1H), 1.71 (ddd, *J* = 12.9, 5.9, 2.4 Hz, 1H), 1.68 (dd, *J* = 13.0, 2.1 Hz, 1H), 1.62 (d, *J* = 13.0 Hz, 1H), 1.48 (dd, *J* = 13.0, 10.4 Hz, 1H), 1.34 (ddd, *J* = 13.0, 7.8, 2.1 Hz, 1H), 1.03 (s, 3H), 0.96 (s, 3H), 0.87 (s, 9H), 0.02 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 159.3, 130.1, 129.3, 113.9, 81.2, 77.5, 74.0, 70.9, 58.8, 57.4, 55.7, 55.4, 55.3, 44.6, 41.7, 41.0, 36.7, 29.3, 28.0, 25.9, 18.2, -4.7, -4.8. HRMS: calcd for $C_{27}H_{44}O_4Si$, 460.3009; found 460.3009. (about minor product **77**) IR (KBr): $\tilde{\nu}$ = 3551, 3018, 2953, 2933, 2858, 1513, 1215, 757 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.27 (d, *J* = 8.7 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 4.50 (d, *J* = 11.5 Hz, 1H), 4.48 (d, *J* = 11.5 Hz, 1H), 4.09 (ddd, *J* = 10.3, 7.7, 6.2 Hz, 1H), 4.06 (dddd, *J* = 4.9, 4.4, 4.3, 4.1 Hz, 1H), 3.81 (s, 3H), 3.35 (dd, *J* = 6.5, 4.1 Hz, 1H), 2.37 (d, *J* = 4.3 Hz, 1H), 2.21 (ddd, *J* = 11.1, 7.9, 7.7 Hz, 1H), 2.06 (dd, *J* = 8.2, 6.5 Hz, 1H), 1.96 (dd, *J* = 13.7, 4.4 Hz, 1H), 1.86 (ddd, *J* = 12.8, 10.3, 8.2 Hz, 1H), 1.78 (dd, *J* = 13.7, 4.9 Hz, 1H), 1.77 (dd, *J* = 13.1, 2.4 Hz, 1H), 1.64 (ddd, *J* = 12.8, 6.2, 1.2 Hz, 1H), 1.55 (d, *J* = 13.1Hz, 1H), 1.42 (dd, *J* = 12.9, 11.1 Hz, 1H), 1.31 (ddd, *J* = 12.9, 7.9, 2.4 Hz, 1H), 1.02 (s, 3H), 0.94 (s, 3H), 0.86 (s, 9H), 0.00 (s, 3H), -0.01 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 159.3, 130.1, 129.4, 113.9, 85.6, 73.7, 72.7, 71.2, 59.5, 57.2,

55.5, 55.3, 52.4, 48.1, 41.6, 40.9, 36.0, 29.2, 27.4, 25.9, 18.2, -4.8, -4.9. HRMS: calcd for $C_{27}H_{44}O_4Si$, 460.3009; found 460.3009.

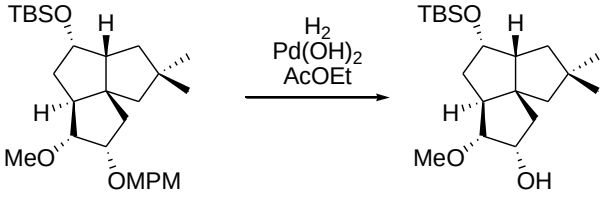
Methyl Ether 79



78 **79**

To a stirred solution of MPM ether **78** (415.2 mg, 0.9012 mmol) in anhydrous THF (9 ml), NaH (58.9 mg, 1.352 mmol) and then MeI (86 μl, 1.352 mmol) were added at 0 ℃ under nitrogen atmosphere, and subsequently warmed to room temperature. After being stirred for 4 h, TLC analysis showed incomplete disappearance of **78** and additional NaH (39.3 mg, 0.9012 mmol) and then MeI (57 μl, 0.9012 mmol) were added. After being stirred for 40 min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1:6) to give methyl ether **79** (419.1 mg, 0.8828 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3102, 3064, 3032, 2950, 2934, 2857, 2737, 2709, 2241, 1613, 1513, 1248, 1105, 835 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 7.29 (d, J = 8.7 Hz, 2H), 6.87 (d, J = 8.7 Hz, 2H), 4.56 (d, J = 11.9 Hz, 1H), 4.46 (d, J = 11.9 Hz, 1H), 4.12 (ddd, J = 9.5, 6.7, 6.7 Hz, 1H), 3.80 (s, 3H), 3.79 (ddd, J = 5.3, 4.5, 4.0 Hz, 1H), 3.32 (s, 3H), 3.15 (dd, J = 6.3, 4.0 Hz, 1H), 2.20 (ddd, J = 10.8, 8.0, 6.7 Hz, 1H), 2.11 (br-dd, J = 8.4, 6.3 Hz, 1H), 2.05 (dd, J = 13.5, 5.3 Hz, 1H), 1.88 (ddd, J = 12.9, 9.7, 8.4 Hz, 1H), 1.73-1.65 (m, 3H), 1.60 (d, J = 13.0 Hz, 1H), 1.45 (dd, J = 13.0, 10.8 Hz, 1H), 1.32 (dd, J = 13.0, 8.0, 2.2 Hz, 1H), 1.02 (s, 3H), 0.95 (s, 3H), 0.86 (s, 9H), 0.02 (s, 3H), 0.01 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 159.1, 130.7, 129.4, 113.6, 87.2, 78.1, 73.9, 70.3, 59.2, 57.3, 57.3, 55.2, 55.2, 52.5, 44.4, 41.6, 40.9, 36.5, 29.3, 27.8, 25.9, 18.2, -4.8. HRMS: calcd for $C_{28}H_{46}O_4Si$, 474.3165; found 474.3157.

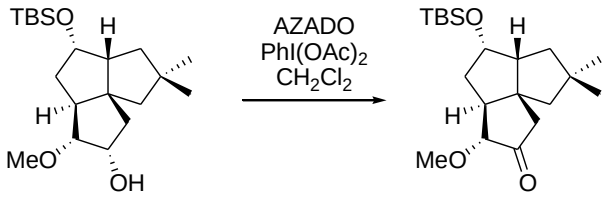
Alcohol 80



79 **80**

To a stirred solution of methyl ether **79** (515.6 mg, 1.086 mmol) in ethyl acetate (11 ml), $Pd(OH)_2$-C (25.8 mg, 5Wt%) was added and then purged with hydrogen. After being stirred for 4 h under a balloon of hydrogen, the heterogeneous mixture was filtered through a celite pad with ethyl acetate. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:3) to give alcohol **80** (370.3 mg, 1.044 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3557, 3470, 2950, 2934, 2857, 2828, 1463, 1253, 1130, 1105, 835, 775 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.18 (ddd, *J* = 9.0, 7.4, 7.4 Hz, 1H), 4.08 (dddd, *J* = 4.5, 4.5, 4.5, 4.5 Hz, 1H), 3.38 (s, 3H), 3.17 (br-dd, *J* = 6.8, 4.5 Hz, 1H), 2.32 (d, *J* = 4.5Hz, 1H), 2.24 (br-ddd, *J* = 10.3, 7.7, 7.4 Hz, 1H), 2.00 (dd, *J* = 6.8, 6.8 Hz, 1H), 1.96-1.88 (m, 2H), 1.81 (dd, *J* = 13.6, 4.5 Hz, 1H), 1.76 (d, *J* = 13.0 Hz, 1H), 1.71 (dd, *J* = 12.8, 7.4 Hz, 1H), 1.56 (d, *J* = 13.0 Hz, 1H), 1.44 (dd, *J* = 12.5, 10.3 Hz, 1H), 1.33 (br-dd, *J* = 12.5, 7.7 Hz, 1H), 1.02 (s, 3H), 0.95 (s, 3H), 0.88 (s, 9H), 0.04 (s, 3H), 0.03 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 88.5, 73.8, 72.6, 59.3, 57.4, 57.0, 55.7, 52.2, 48.0, 41.7, 40.9, 36.5, 29.2, 27.5, 25.9, 18.2, -4.8, -4.8. HRMS: calcd for $C_{20}H_{38}O_3Si$, 354.2590; found 354.2584.

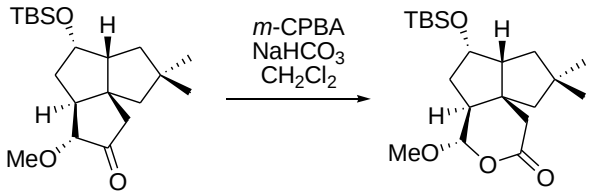
Ketone 81



80 **81**

To a stirred solution of alcohol **80** (470.0 mg, 1.325 mmol) in anhydrous CH_2Cl_2 (13 ml), AZADO (20.2 mg, 0.1325 mmol) and then $PhI(OAc)_2$ (653.2 mg, 1.988 mmol) were added at 0 ℃ under nitrogen atmosphere, and subsequently warmed to room temperature. After being stirred for 11.5 h, the reaction mixture was diluted with ethyl acetate and then quenched by addition of aq.Na_2SO_3. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:8) to give ketone **81** (448.1 mg, 1.271 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3472, 3351, 3174, 2952, 2931, 2857, 2826, 2737, 2709, 1749, 1464, 1253, 1106, 836, 775 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.27 (ddd, *J* = 7.6, 7.6, 4.9 Hz, 1H), 3.48 (s, 3H), 3.35 (br-d, *J* = 6.6 Hz, 1H), 2.55 (d, *J* = 18.9 Hz, 1H), 2.48 (d, *J* = 18.9 Hz, 1H), 2.37 (ddd, *J* = 8.4, 8.3, 7.6 Hz, 1H), 2.17 (br-ddd, *J* = 7.1, 6.6, 4.9 Hz, 1H), 2.01 (ddd, *J* = 13.0, 7.6, 7.1 Hz, 1H), 1.78 (ddd, *J* = 13.0, 4.9, 4.9 Hz, 1H), 1.66-1.59 (m, 3H), 1.41 (ddd, *J* = 13.1, 8.4, 2.2 Hz, 1H), 1.06 (s, 3H), 0.95 (s, 3H), 0.89 (s, 9H), 0.05 (s, 3H), 0.04 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 216.0, 86.2, 73.2, 59.0, 58.2, 58.0, 52.7, 52.3, 50.8, 42.0, 41.6, 38.2, 29.0, 27.5, 25.8, 18.1, -4.8, -4.9. HRMS: calcd for $C_{20}H_{36}O_3Si$, 352.2434; found 352.2432.

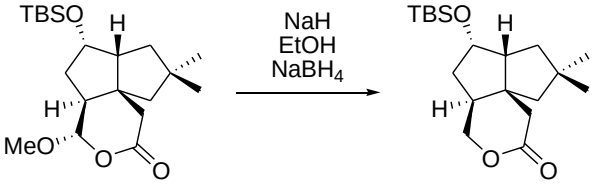
Methyl Acetal 82



81 **82**

To a stirred solution of ketone **81** (448.1 mg, 1.271 mmol) in anhydrous CH_2Cl_2 (13 ml), crushed $NaHCO_3$ (320.3 mg, 3.813 mmol) and then *m*-CPBA (506.3 mg, 1.907 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 30 min, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration and then short column chromatography, the residual oil was purified by column chromatography on silica gel (40 g, ethyl acetate/hexanes = 1:6) to give methyl acetal **82** (457.9 mg, 1.242 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 2953, 2931, 2857, 2253, 1754, 1464, 1250, 1111, 837 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.91 (d, *J* = 3.0 Hz, 1H), 4.20 (ddd, *J* = 8.7, 6.5, 6.5 Hz, 1H), 3.47 (s, 3H), 2.79 (d, *J* = 14.8 Hz, 1H), 2.52 (d, *J* = 14.8 Hz, 1H), 2.37 (br-ddd, *J* = 9.9, 8.1, 6.5 Hz, 1H), 2.09 (ddd, *J* = 9.0, 3.1, 3.0 Hz, 1H), 2.05 (ddd, *J* = 13.0, 9.0, 9.0 Hz, 1H), 1.77 (ddd, *J* = 13.0, 6.5, 3.1 Hz, 1H), 1.69 (dd, *J* = 13.4, 1.9 Hz, 1H), 1.62 (d, *J* = 13.4 Hz, 1H), 1.61 (dd, *J* = 13.3, 9.9 Hz, 1H), 1.48 (ddd, *J* = 13.3, 8.1, 1.9 Hz, 1H), 1.06 (s, 3H), 1.02 (s, 3H), 0.87 (s, 9H), 0.03 (s, 3H), 0.02 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 171.6, 106.7, 72.6, 58.4, 56.7, 56.3, 50.1, 48.7, 43.0, 41.8, 40.7, 37.0, 30.1, 29.0, 25.8, 18.1, -4.8, -4.8. HRMS: calcd for $C_{20}H_{36}O_4Si$, 368.2383; found 368.2377.

Lactone 27

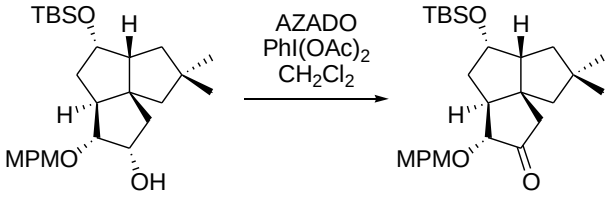


82 **27**

To a stirred solution of methyl acetal **82** (213.6 mg, 0.5795 mmol) in anhydrous EtOH (6 ml), $NaBH_4$ (71.5 mg, 1.739 mmol) and then NaH (38.0 mg, 0.8693 mmol) were added at 0 ℃ under nitrogen atmosphere. After being stirred for 50 min, the reaction was quenched by addition of Phthalate pH Standard Solution (pH = 4) and then diluted with ethyl acetate. Subsequently, aqueous layer was checked to be acidic property with pH paper and then the organic layer was washed with brine and dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1:5) to give lactone **27** (192.7 mg, 0.5692 mmol) as a white solid.

Analytical data: IR (KBr): $\tilde{\nu}$ = 2954, 2930, 2857, 2253, 1748, 1464, 1385, 1258, 1107, 909, 836, 777, 734 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.30 (ddd, *J* = 8.9, 7.6, 7.0 Hz, 1H), 4.18 (dd, *J* = 11.5, 5.0 Hz, 1H), 3.93 (dd, *J* = 11.5, 7.7 Hz, 1H), 2.58 (d, *J* = 14.5 Hz, 1H), 2.52 (d, *J* = 14.5 Hz, 1H), 2.42 (ddd, *J* = 10.8, 7.8, 7.6 Hz, 1H), 2.10-2.02 (m, 2H), 1.74 (dd, *J* = 13.4, 2.0 Hz, 1H), 1.66 (dd, *J* = 11.2, 7.0 Hz, 1H), 1.58 (dd, *J* = 13.1, 10.8 Hz, 1H), 1.51 (d, *J* = 13.4 Hz, 1H), 1.46 (ddd, *J* = 13.1, 7.8, 2.0 Hz, 1H), 1.07 (s, 3H), 1.02 (s, 3H), 0.87 (s, 9H), 0.03 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 173.0, 72.8, 70.5, 57.9, 57.0, 50.7, 44.4, 42.9, 41.8, 40.8, 36.1, 29.9, 28.3, 25.8, 18.1, -4.8. HRMS: calcd for $C_{19}H_{34}O_3Si$, 338.2277; found 338.2279.

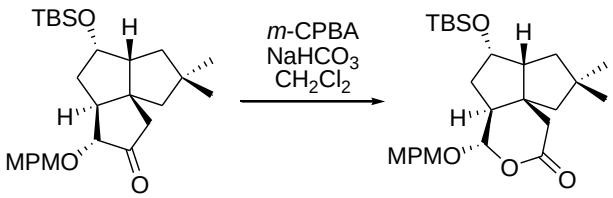
Ketone 86



77 **86**

To a stirred solution of alcohol **77** (158.4 mg, 0.3438 mmol) in anhydrous CH_2Cl_2 (3 ml), AZADO (5.2 mg, 0.03438 mmol) and then $PhI(OAc)_2$ (169.5 mg, 0.5157 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 17 h, the reaction was diluted with ethyl acetate and then quenched by addition of aq.Na_2SO_3. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:9) to give ketone **86** (149.9 mg, 0.3268 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 3001, 2954, 2932, 2857, 2252, 1746, 1513, 1250, 1108, 909, 733 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.28 (d, *J* = 8.6 Hz, 2H), 6.88 (d, *J* = 8.6 Hz, 2H), 4.77 (d, *J* = 11.7 Hz, 1H), 4.57 (d, *J* = 11.7 Hz, 1H), 4.13 (ddd, *J* = 8.8, 8.1, 5.5 Hz, 1H), 3.80 (s, 3H), 3.51 (d, *J* = 7.5 Hz, 1H), 2.52 (s, 2H), 2.32 (br-ddd, *J* = 8.4, 8.3, 8.1 Hz, 1H), 2.15 (ddd, *J* = 7.5, 7.2, 3.3 Hz, 1H), 1.90 (ddd, *J* = 12.9, 8.8, 7.2 Hz, 1H), 1.68 (ddd, *J* = 12.9, 5.5, 3.3 Hz, 1H), 1.66-1.55 (m, 3H), 1.39 (ddd, *J* = 12.9, 8.4, 2.2 Hz, 1H), 1.05 (s, 3H), 0.94 (s, 3H), 0.85 (s, 9H), -0.03 (s, 3H), -0.04 (s, 3H). ^{13}C NMR (400 MHz, $CDCl_3$): δ = 216.7, 159.3, 129.7, 129.6, 113.8, 82.5, 73.0, 71.4, 59.2, 57.7, 55.2, 52.7, 51.6, 50.5, 41.9, 41.6, 37.0, 28.8, 27.3, 25.8, 18.1, -4.8, -5.0. HRMS: calcd for $C_{27}H_{42}O_4Si$, 458.2852; found 458.2863.

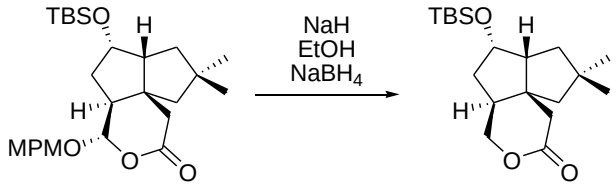
MPM Acetal 87



86 **87**

To a stirred solution of ketone **86** (149.9 mg, 0.3268 mmol) in anhydrous CH_2Cl_2 (3 ml), crushed $NaHCO_3$ (82.4 mg, 0.9804 mmol) and then *m*-CPBA (130.1 mg, 0.4902 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 30 min, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by short column chromatography on silica gel (ethyl acetate/TEA = 1:0.01). After concentration, the residual oil was purified by chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:5) to give MPM acetal **87** (143.7 mg, 0.3027 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3066, 3035, 2953, 2931, 2857, 2253, 1748, 1613, 1514, 1250, 1109, 909, 734 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ 7.25 (d, *J* = 8.6 Hz, 2H), 6.89 (d, *J* = 8.6 Hz, 2H), 5.03 (d, *J* = 3.8 Hz, 1H), 4.76 (d, *J* = 11.6 Hz, 1H), 4.53 (d, *J* = 11.6 Hz, 1H), 4.13 (ddd, *J* = 9.2, 6.6, 6.0 Hz, 1H), 3.81 (s, 3H), 2.81 (d, *J* = 14.7 Hz, 1H), 2.49 (d, *J* = 14.7 Hz, 1H), 2.35 (ddd, *J* = 9.8, 8.0, 6.6 Hz, 1H), 2.08 (ddd, *J* = 9.2, 3.8, 3.2 Hz, 1H), 2.00 (ddd, *J* = 13.2, 9.2, 9.2 Hz, 1H), 1.73 (ddd, *J* = 13.2, 6.0, 3.2 Hz, 1H), 1.70 (dd, *J* = 13.4, 1.8 Hz, 1H), 1.61-1.55 (m, 2H), 1.46 (ddd, *J* = 13.3, 8.0, 1.8 Hz, 1H), 1.05 (s, 3H), 1.00 (s, 3H), 0.85 (s, 9H), 0.00 (s, 3H), -0.01 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 171.7, 159.5, 129.8, 128.4, 113.7, 103.5, 72.4, 70.2, 58.3, 56.3, 55.3, 49.9, 48.8, 43.2, 41.8, 40.7, 36.6, 30.0, 28.8, 25.8, 18.1, -4.8. HRMS: calcd for $C_{27}H_{42}O_5Si$, 474.2802; found 474.2804.

Lactone 27

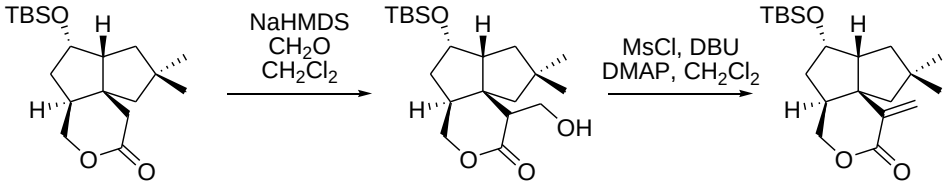


87 **27**

To a stirred solution of MPM acetal **87** (33.1 mg, 0.06973 mmol) in anhydrous EtOH (1 ml), $NaBH_4$ (8.6 mg, 0.2092 mmol) and then NaH (4.5 mg, 0.1046 mmol) were added at 0 ℃ under nitrogen atmosphere. After being stirred for 50 min, the reaction was quenched by addition of Phthalate pH Standard Solution (pH = 4) and then diluted with ethyl acetate. Subsequently, aqueous layer was checked to be acidic property with pH paper and then the organic layer was washed with brine and dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:5) to give lactone **27** (23.0 mg, 0.06793 mmol) as a white solid.

3-8 : Experimental Section

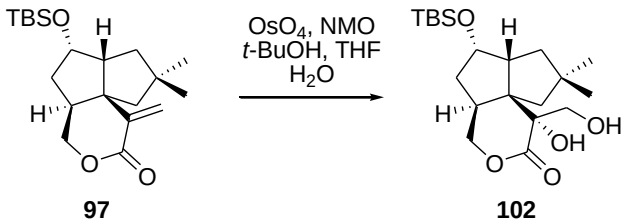
***exo*-Methylene 97**



27 **96** **97**

Firstly, azeotropic dehydration of lactone **27** (74.2 mg, 0.2192 mmol) with anhydrous toluene was carried out. To a stirred solution of **27** in THF (2 ml), NaHMDS (0.6 M in toluene, 550 μl, 0.3288 mmol) was added at -60 ℃ under nitrogen atmosphere and then stirred for 2 h. Subsequently, Monomeric Formaldehyde (0.2 M in THF, 5.5 ml, 1.096 mmol) was added to reaction mixture at -60 ℃. After being stirred for 30 min, the reaction mixture was warmed to -10 ℃ and then quenched by addition of Phthalate pH Standard Solution (pH = 4). After being diluted with ethyl acetate, aqueous layer was checked to be acidic property with pH paper and then the organic layer was washed with brine and dried over Na_2SO_4. The residual oil which was obtained by concentration was dissolved in CH_2Cl_2 (2 ml) and then treated with DBU (102 μl, 0.6576 mmol), MsCl (25 μl, 0.3288 mmol) and then DMAP (2.7 mg, 0.02192 mmol) at room temperature under nitrogen atmosphere. After being stirred for 2 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:7) to give *exo*-methylene **97** (48.4 mg, 0.1381 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3019, 2954, 2930, 2893, 2857, 1733, 1634, 1614, 1470, 1253, 1214, 1132, 836, 759 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.97 (s, 1H), 5.58 (s, 1H), 4.31 (ddd, *J* = 9.1, 7.5, 7.0 Hz, 1H), 4.14 (dd, *J* = 11.4, 4.7 Hz, 1H), 3.87 (dd, *J* = 11.4, 6.0 Hz, 1H), 2.69 (ddd, *J* = 10.7, 7.5, 7.5 Hz, 1H), 2.26-2.21 (m, 1H), 2.08 (ddd, *J* = 13.3, 9.2, 9.1 Hz, 1H), 1.98 (dd, *J* = 13.7, 1.9 Hz, 1H), 1.75 (ddd, *J* = 13.3, 7.0, 3.3 Hz, 1H), 1.69 (dd, *J* = 13.2, 10.7 Hz, 1H), 1.63 (d, *J* = 13.7 Hz, 1H), 1.53 (ddd, *J* = 13.2, 7.5, 1.9 Hz, 1H), 1.10 (s, 3H), 1.00 (s, 3H), 0.87 (s, 9H), 0.02 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 170.0, 145.1, 120.6, 72.8, 69.8, 56.2, 56.2, 55.8, 45.2, 42.1, 40.7, 36.6, 30.3, 28.8, 25.8, 18.1, -4.8. HRMS: calcd for $C_{20}H_{34}O_3Si$, 350.2277; found 350.2278.

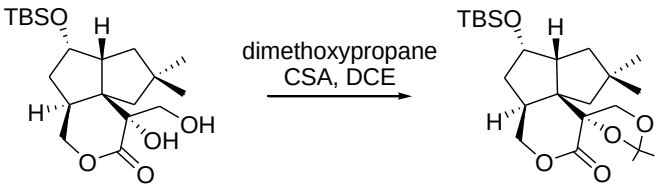
Diol 102



97 **102**

To a stirred solution of *exo*-methylene **97** (34.4 mg, 0.09813 mmol) in anhydrous THF (0.3 ml) and *t*-BuOH (1 ml), H_2O (0.1 ml), NMO (34.5 mg, 0.2944 mmol) and then OsO_4 (2.5 mg, 9.813 μmol) were added at room temperature under air atmosphere. After being stirred for 4.5 h, the reaction was quenched by addition of $NaHSO_3$ (209.7 mg, 1.178 mmol) and then diluted with ethyl acetate followed by H_2O. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:3) to give diol **102** (34.6 mg, 0.08997 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 3505, 3152, 2955, 2931, 2884, 2858, 2253, 1722, 1471, 1257, 1113, 1018, 908, 733 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.97 (dd, *J* = 10.9, 3.9 Hz, 1H), 4.18-4.12 (m, 1H), 4.14 (dd, *J* = 11.5, 4.8 Hz, 1H), 4.07 (dd, *J* = 10.9, 3.3 Hz, 1H), 3.89 (s, 1H), 3.49 (dd, *J* = 11.5, 10.3 Hz, 1H), 2.59 (dd, *J* = 10.3, 4.8 Hz, 1H), 2.45 (ddd, *J* = 11.2, 7.0, 7.0 Hz, 1H), 2.33 (dddd, *J* = 11.0, 3.9, 3.3, 2.8 Hz, 1H), 2.20 (ddd, *J* = 13.5, 11.0, 11.0 Hz, 1H), 2.14 (dd, *J* = 14.9, 1.2 Hz, 1H), 1.81 (ddd, *J* = 13.5, 7.9, 2.8 Hz, 1H), 1.69 (dd, *J* = 13.4, 11.2 Hz, 1H), 1.65 (d, *J* = 14.9 Hz, 1H), 1.56-1.50 (m, 1H), 1.13 (s, 3H), 1.00 (s, 3H), 0.85 (s, 9H), 0.01 (s, 6H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 174.4, 75.8, 73.2, 71.4, 63.5, 58.4, 51.8, 51.4, 45.3, 42.6, 38.1, 37.0, 31.5, 30.2, 25.8, 18.0, -4.8, -4.9. HRMS: calcd for $C_{20}H_{36}O_5Si$, 384.2332; found 384.2339.

Acetonide 103

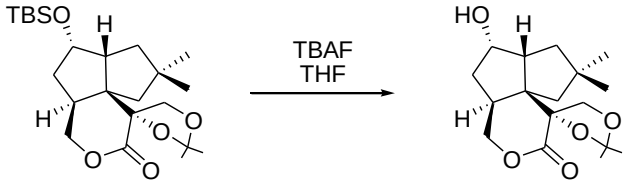


102 **103**

To a stirred solution of diol **102** (77.1 mg, 0.2005 mmol) in DCE (2 ml), dimethoxy propane (246 μl, 2.005 mmol) and then CSA (4.7 mg, 0.02005 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 1 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:5) to give acetonide **103** (81.9 mg, 0.1929 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 2986, 2953, 2932, 2886, 2858, 2254, 1742, 1471, 1384, 1250, 1113, 909, 733 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.84 (dd, *J* = 10.9, 3.2 Hz, 1H), 4.64 (d, *J* = 8.8 Hz, 1H), 4.20 (ddd, *J* = 9.6, 7.3, 7.3 Hz, 1H), 3.93 (dd, *J* = 11.0, 3.2 Hz, 1H), 3.82 (d, *J* = 8.8 Hz, 1H), 2.33-2.25 (m, 2H), 2.21 (ddd, *J* = 13.3, 10.3, 9.6 Hz, 1H), 2.11 (d, *J* = 14.7 Hz, 1H), 1.82 (ddd, *J* = 13.3, 7.3, 2.2 Hz, 1H), 1.79 (dd, *J* = 13.8, 10.0 Hz, 1H), 1.71 (d, *J* = 14.7 Hz, 1H), 1.56 (dd, *J* = 13.8, 8.4 Hz, 1H), 1.43 (s, 3H), 1.36 (s, 3H), 1.14 (s, 3H), 1.05 (s, 3H), 0.85 (s, 9H), 0.01 (s, 3H), 0.01 (s, 3H). ^{13}C NMR (700 MHz,

$CDCl_3$): δ = 172.1, 111.2, 84.4, 73.3, 70.9, 67.5, 59.0, 53.7, 52.9, 45.5, 42.6, 38.3, 38.0, 31.4, 30.8, 26.5, 26.2, 25.8, 18.0, -4.8, -4.9. HRMS: calcd for $C_{23}H_{40}O_5Si$, 424.2645; found 424.2663.

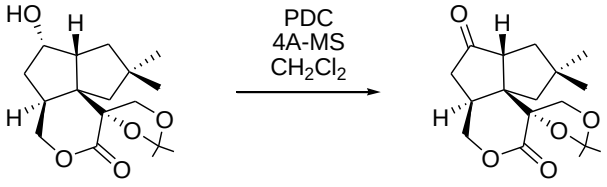
Alcohol 130



103 **130**

To a stirred solution of acetonide **103** (10.8 mg, 0.02453 mmol) in THF (1 ml), TBAF (1.0 M in THF, 74 μl, 0.07539 mmol) was added at room temperature under nitrogen atmosphere. After being stirred for 6.5 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with brine. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g, ethyl acetate/hexanes = 1:1) to give alcohol **130** (7.5 mg, 0.02416 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 3446, 2990, 2955, 2869, 2253, 1738, 1472, 1375, 1071, 908, 732, 649 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.86 (br-d, J = 11.1 Hz, 1H), 4.63 (br-d, J = 8.8 Hz, 1H), 4.31 (br-ddd, J = 10.5, 8.3, 8.3 Hz, 1H), 3.96 (dd, J = 11.1, 3.2 Hz, 1H), 3.83 (d, J = 8.8 Hz, 1H), 2.41-2.31 (m, 2H), 2.24 (ddd, J = 13.7, 10.5, 10.5 Hz, 1H), 2.13 (d, J = 14.8 Hz, 1H), 1.93 (br-dd, J = 13.7, 8.3 Hz, 1H), 1.77-1.71 (m, 2H), 1.64 (dd, J = 13.5, 8.1 Hz, 1H), 1.43 (s, 3H), 1.35 (s, 3H), 1.16 (s, 3H), 1.06 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 172.3, 111.3, 84.2, 73.0, 70.8, 67.4, 59.5, 53.1, 52.7, 45.8, 42.3, 38.5, 37.0, 31.4, 30.6, 26.5, 26.2. HRMS: calcd for $C_{17}H_{26}O_5$, 310.1780; found310.1779.

Ketone 104



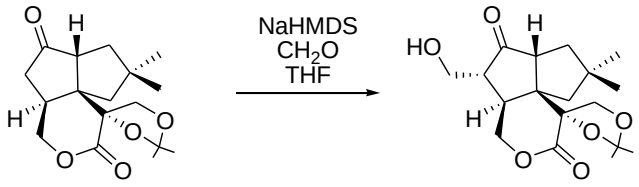
130 **104**

To a stirred solution of alcohol **130** (31.3 mg, 0.1008 mmol) in CH_2Cl_2 (1 ml) crushed 4A-MS (50.4 mg) and then PDC (77.4 mg, 0.2016 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 1.5 h, the reaction was quenched by addition of 2-propanol (77 μl, 1.008 mmol). The heterogeneous mixture was filtered through a silica gel (10 g, ethyl acetate/hexanes = 2:1). After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:1) to give ketone **104** (30.4 mg, 0.09858 mmol) as a colorless oil. Analytical

data: IR (KBr): $\tilde{\nu}$ = 2989, 2958, 2937, 2869, 2360, 2337, 2254, 1743, 1770, 1469, 1382, 1274, 1066, 732 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.05 (br-d, *J* = 7.9 Hz, 1H), 4.65 (br-s, 1H), 4.05 (br-d, *J* = 9.5 Hz, 1H), 3.78 (d, *J* = 8.9 Hz, 1H), 2.73 (dd, *J* = 18.0, 9.1 Hz, 1H), 2.70-2.65 (m, 1H), 2.58 (dd, *J* = 18.0, 8.9 Hz, 1H), 2.10-2.05 (m, 2H), 1.70-1.63 (m, 2H), 1.48 (s, 3H), 1.38 (s, 3H), 1.10 (s, 3H), 0.82 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 217.3, 171.6, 111.8, 84.2, 68.6, 67.2, 56.9, 56.4, 52.0, 45.7, 42.2, 42.0, 40.1, 29.5, 28.0, 26.3, 25.2. HRMS: calcd for $C_{17}H_{24}O_5$, 308.1624; found308.1632.

3-9 : Experimental Section

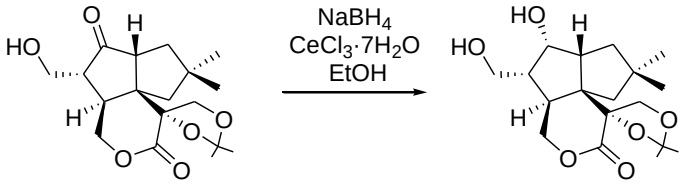
Hydroxy Methyl Compound 116



104 **116**

Firstly, azeotropic dehydration of ketone **104** (28.7 mg, 0.09307 mmol) with anhydrous toluene was carried out. To a stirred solution of ketone **104** in THF (1 ml), NaHMDS (0.6 M in toluene, 465 μl, 0.2792 mmol) was added at -78 ℃ under nitrogen atmosphere and then stirred for 30 min. Subsequently, Monomeric Formaldehyde (0.2 M in THF, 465 μl, 0.09307 mmol) was added to reaction mixture at -55 ℃ and then stirred for 30 min. TLC analysis showed incomplete disappearance of **104** and additional Monomeric Formaldehyde (0.2 M in THF, 465 μl, 0.09307 mmol) was added at -55 ℃. After being stirred for 10 min, the reaction mixture was warmed to -15 ℃ and quenched by addition of Phthalate pH Standard Solution (pH = 4) and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 2:1→3:1) to give hydroxy methyl compound **116** (19.1 mg, 0.05648 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3495, 3019, 2992, 2958, 2935, 2870, 1739, 1215, 756 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.11 (dd, *J* = 11.5, 3.6 Hz, 1H), 4.65 (d, *J* = 9.0 Hz, 1H), 4.15 (dd, *J* = 11.5, 3.5 Hz, 1H), 3.93 (dd, *J* = 11.6, 4.6 Hz, 1H), 3.82 (dd, *J* = 11.6, 5.1 Hz, 1H), 3.79 (d, *J* = 9.0 Hz, 1H), 2.77-2.72 (m, 1H), 2.51 (ddd, *J* = 11.4, 3.6, 3.5 Hz, 1H), 2.46 (d, *J* = 9.6 Hz, 1H), 2.14 (d, *J* = 13.2 Hz, 1H), 2.06 (d, *J* = 14.1 Hz, 1H), 1.67-1.61 (m, 1H), 1.48 (s, 3H), 1.39 (s, 3H), 1.10 (s, 3H), 0.79 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 217.0, 171.7, 111.9, 84.4, 67.4, 67.1, 59.9, 55.9, 55.0, 53.1, 51.5, 44.8, 44.5, 39.6, 29.6, 28.0, 26.4, 25.4. HRMS: calcd for $C_{18}H_{26}O_6$, 338.1729; found 338.1724.

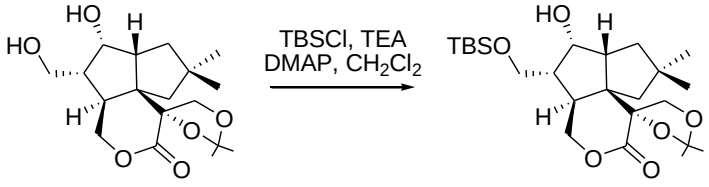
Diol 118



116 **118**

To a stirred solution of hydroxy methyl compound **116** (9.8 mg, 0.02898 mmol) in EtOH (1 ml), $CeCl_3 \cdot 7H_2O$ (0.3 M in EtOH, 40 μl, 0.01159 mmol) and then $NaBH_4$ (0.3 M in EtOH, 41 μl, 0.01159 mmol) were added at -60 ℃ under nitrogen atmosphere. After being stirred for 20 min, the reaction was quenched by addition of acetone (9 μl, 0.1159 mmol) and aq.NH_4Cl. The heterogeneous mixture was diluted with ethyl acetate. Subsequently, the organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g, ethyl acetate) to give diol **118** (7.5 mg, 0.02203 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 3437, 3019, 2955, 2931, 2837, 2402, 2359, 2335, 1739, 1215, 756 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.83 (dd, *J* = 11.5, 4.2 Hz, 1H), 4.50 (d, *J* = 8.9 Hz, 1H), 4.35 (dd, *J* = 6.3, 6.3 Hz, 1H), 3.98 (dd, *J* = 11.5, 4.9 Hz, 1H), 3.90 (dd, *J* = 11.4, 3.8 Hz, 1H), 3.84 (d, *J* = 8.9 Hz, 1H), 3.82 (dd, *J* = 11.4, 6.1 Hz, 1H), 2.57 (ddd, *J* = 10.7, 4.9, 4.2 Hz, 1H), 2.46 (ddd, *J* = 9.7, 6.3, 4.7 Hz, 1H), 2.18 (dddd, *J* = 10.7, 6.3, 6.1, 3.8 Hz, 1H), 2.15 (d, *J* = 14.7 Hz, 1H), 1.82 (dd, *J* = 14.0, 4.7 Hz, 1H), 1.68 (dd, *J* = 14.0, 9.7 Hz, 1H), 1.66 (d, *J* = 14.7 Hz, 1H), 1.48 (s, 3H), 1.40 (s, 3H), 1.18 (s, 3H), 1.12 (s, 3H). ^{13}C NMR (700MHz, $CDCl_3$): δ = 172.8, 111.4, 84.9, 67.6, 67.2, 61.6, 61.6, 53.9, 52.2, 49.0, 48.8, 42.2, 40.2, 31.9, 31.0, 26.4, 25.9. HRMS: calcd for $C_{18}H_{28}O_6$, 340.1886; found 340.1888.

TBS Ether 119

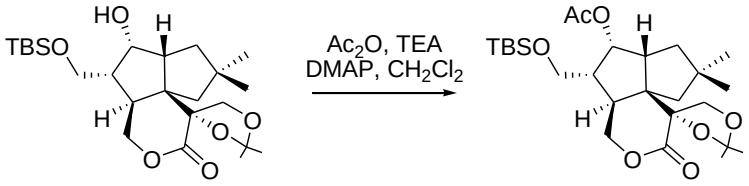


118 **119**

To a stirred solution of diol **118** (5.6 mg, 0.01645 mmol) in CH_2Cl_2 (1 ml), TEA (23 μl, 0.1645 mmol), TBSCl (12.8 mg, 0.08225 mmol) and then a small amount of DMAP were added at room temperature under nitrogen atmosphere. After being stirred for 9.5 h, TLC analysis showed imcomplete disappearance of **118** and additional TEA (23 μl, 0.1645 mmol) and then TBSCl (12.8 mg, 0.08225 mmol) were added. After being stirred for 9.5 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g,

ethyl acetate/hexanes = 1:4) to give TBS ether **119** (7.0 mg, 0.01540 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3478, 3018, 2992, 2953, 2931, 2884, 2860, 1744, 1257, 1215, 1071, 837, 757, 667 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 4.80 (dd, *J* = 11.5, 4.5 Hz, 1H), 4.48 (d, *J* = 8.9 Hz, 1H), 4.26 (br-dd, *J* = 5.5, 5.3 Hz, 1H), 3.91 (dd, *J* = 11.5, 5.2 Hz, 1H), 3.89 (dd, *J* = 10.6, 5.3 Hz, 1H), 3.87 (d, *J* = 8.9 Hz, 1H), 3.81 (dd, *J* = 10.6, 5.3 Hz, 1H), 3.09 (br-s, 1H), 2.48 (ddd, *J* = 10.6, 5.2, 4.5 Hz, 1H), 2.45 (ddd, *J* = 9.5, 5.3, 4.6 Hz, 1H), 2.18 (d, *J* = 14.6 Hz, 1H), 2.12 (dddd, *J* = 10.6, 5.5, 5.3, 5.3 Hz, 1H), 1.93 (dd, *J* = 13.7, 4.6 Hz, 1H), 1.63 (d, *J* = 14.6 Hz, 1H), 1.62 (dd, *J* = 13.7, 9.5 Hz, 1H), 1.48 (s, 3H), 1.41 (s, 3H), 1.19 (s, 3H), 1.11 (s, 3H), 0.89 (s, 9H), 0.09 (s, 3H), 0.07 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 172.8, 111.3, 85.0, 75.8, 67.6, 67.2, 62.1, 61.6, 54.1, 52.8, 49.5, 49.3, 41.8, 40.4, 31.9, 31.2, 26.4, 25.8, 25.8, 18.1, -5.6, -5.7. HRMS: calcd for $C_{24}H_{42}O_6Si$, 454.2751; found 454.2746.

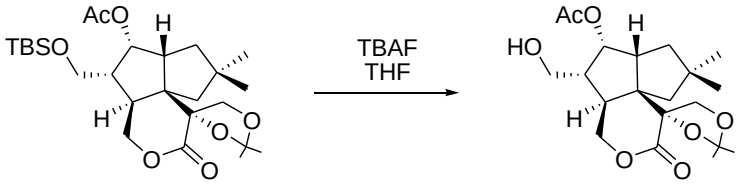
Acetate 121



119 **121**

To a stirred solution of TBS ether **119** (17.6 mg, 0.03871 mmol) in CH_2Cl_2 (1 ml), TEA (32 μl, 0.2323 mmol), Ac_2O (11 μl, 0.1161 mmol) and then a small amount of DMAP were added at room temperature under nitrogen atmosphere. After being stirred for 3 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:3) to give acetate **121** (17.5 mg, 0.03523 mmol) as a white solid. Analytical data: IR (KBr): $\tilde{\nu}$ = 2992, 2955, 2931, 2860, 2254, 1739, 1383, 1244, 1093, 909, 733 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 5.36 (dd, *J* = 7.0, 7.0 Hz, 1H), 4.71 (dd, *J* = 12.0, 6.2 Hz, 1H), 4.34 (d, *J* = 9.0 Hz, 1H), 3.91 (d, *J* = 9.0 Hz, 1H), 3.89 (dd, *J* = 12.0, 6.4 Hz, 1H), 3.72 (dd, *J* = 9.9, 5.6 Hz, 1H), 3.54 (dd, *J* = 9.9, 8.5 Hz, 1H), 2.78 (ddd, *J* = 9.0, 6.4, 6.2 Hz, 1H), 2.52 (ddd, *J* = 9.7, 7.0, 6.8 Hz, 1H), 2.34-2.22 (m, 1H), 2.12 (d, *J* = 14.1 Hz, 1H), 2.07 (s, 3H), 1.63 (d, *J* = 14.1 Hz, 1H), 1.62-1.53 (m, 2H), 1.49 (s, 3H), 1.44 (s, 3H), 1.14 (s, 3H), 1.07 (s, 3H), 0.87 (s, 9H), 0.04 (s, 3H), 0.03 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 172.6, 170.1, 111.1, 84.7, 76.5, 69.0, 67.5, 62.8, 61.7, 53.1, 51.9, 51.3, 50.5, 43.0, 40.5, 31.2, 31.1, 26.4, 25.8, 25.4, 21.0, 18.2, -5.5. HRMS: calcd for $C_{26}H_{44}O_7Si$, 496.2856; found 496.2856.

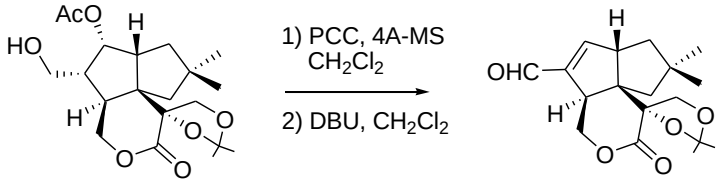
Alcohol 122



121 **122**

To a stirred solution of acetate **121** (5.8 mg, 0.01168 mmol) in THF (1 ml), AcOH (0.9 M in THF, 21 μl, 0.01752 mmol) and then TBAF (1.0 M in THF, 35 μl, 0.03504 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 4 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g, ethyl acetate/hexanes = 3:1) to give alcohol **122** (3.0 mg, 0.007844 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.33 (dd, J = 5.9, 5.9 Hz, 1H), 4.72 (dd, J = 11.8, 5.1 Hz, 1H), 4.40 (d, J = 9.0 Hz, 1H), 3.93 (d, J = 9.0 Hz, 1H), 3.92 (dd, J = 11.8, 6.5 Hz, 1H), 3.55 (d, J = 6.2 Hz, 2H), 2.75 (ddd, J = 9.3, 6.5, 5.1 Hz, 1H), 2.45-2.20 (m, 2H), 2.15 (s, 3H), 1.73-1.60 (m, 4H), 1.50 (s, 3H), 1.44 (s, 3H), 1.18 (s, 3H), 1.12 (s, 3H).

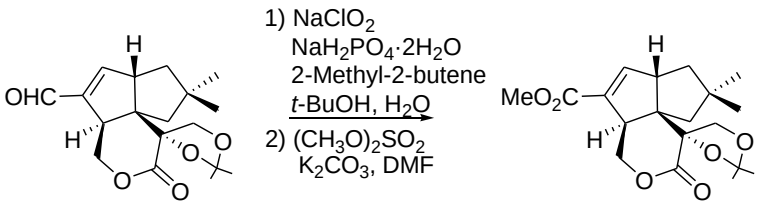
Aldehyde 124



122 **124**

To a stirred solution of alcohol **122** (8.5 mg, 0.02223 mmol) in CH_2Cl_2 (1 ml), 4A-MS (11.1 mg) and then PCC (14.7 mg, 0.06669 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for1 h, the reaction was quenched with 2-propannol (26 μl, 0.3335 mmol). The heterogeneous mixture was filtered through a silica gel (10 g, ethyl acetate/hexanes = 2:1) and then concentrated. This oil was dissolved in CH_2Cl_2 (1 ml) and then treated with DBU (10 μl, 0.06669 mmol) at room temperature under nitrogen atmosphere. After being stirred for 30 min, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g, ethyl acetate/hexanes = 1:3) to give unsaturated aldehyde **124** (6.2 mg, 0.01935 mmol) as a colorless oil. Analytical data: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.30 (s, 1H), 6.79 (br-s, 1H), 5.04 (dd, J = 11.4, 3.1 Hz, 1H), 4.90 (d, J = 8.1 Hz, 1H), 4.60 (d, J = 11.4 Hz, 1H), 3.77 (d, J = 8.1 Hz, 1H), 3.32 (br-s, 1H), 2.92 (br-s, 1H), 2.02 (d, J = 15.4 Hz, 1H), 1.85-1.55 (m, 3H), 1.48 (s, 3H), 1.34 (s, 3H), 1.10 (s, 3H), 0.96 (s, 3H).

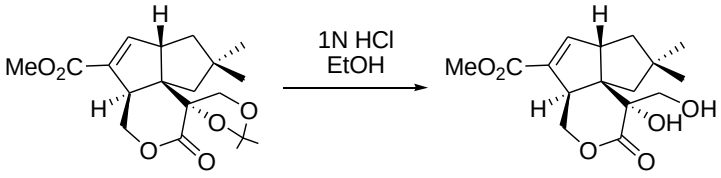
Methyl Ester 125



124 **125**

To a stirred solution of unsaturated aldehyde **124** (6.2 mg, 0.01935 mmol) in *t*-BuOH (600 μl), 2-methyl-2-butene (31 μl, 0.2903 mmol), H_2O (200 μl), $NaH_2PO_4 \cdot 2H_2O$ (9.1 mg, 0.05805 mmol) and then $NaClO_2$ (6.6 mg, 0.05805 mmol) were added at room temperature under air atmosphere. After being stirred for 2 h, DMF (600 μl), crushed K_2CO_3 (13.4 mg, 0.09675 mmol) and then $(CH_3O)_2SO_2$ (10 μl, 0.09675 mmol) were added at room temperature. The reaction mixture was stirred for 11.5 h, afterwards, it was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with H_2O, brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g, ethyl acetate/hexanes = 1:3) to give methyl ester **125** (6.1 mg, 0.01813 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3020, 2992, 2954, 2934, 2870, 1740, 1711, 1215, 756, 668 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 6.71 (br-s, 1H), 5.02 (br-d, J = 9.7 Hz, 1H), 4.88 (br-d, J = 7.3 Hz, 1H), 4.63 (br-d, J = 9.7 Hz, 1H), 3.76-3.74 (m, 1H), 3.75 (s, 3H), 3.27 (br-s, 1H), 2.81 (br-s, 1H), 2.01 (br-d, J = 14.0 Hz, 1H), 1.78 (br-d, J = 14.0 Hz, 1H), 1.70-1.53 (m, 2H), 1.48 (s, 3H), 1.34 (s, 3H), 1.08 (s, 3H), 1.00 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 171.3, 164.1, 149.8, 133.3, 111.6, 84.1, 67.4, 67.2, 58.9, 54.9, 54.7, 51.7, 51.0, 44.5, 40.2, 31.4, 29.0, 26.4, 25.2. HRMS: calcd for $C_{19}H_{26}O_6$, 350.1729; found 350.1732.

Diol 126

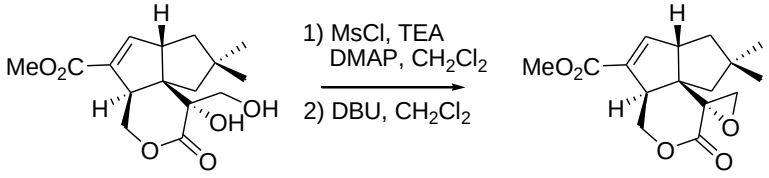


125 **126**

To a stirred solution of methyl ester **125** (8.0 mg, 0.02283 mmol) in EtOH (590 μl), 1N HCl (460 μl) was added and then warmed to 50 ℃. After being stirred for 22 h, the reaction was diluted with ethyl acetate and then quenched with mixture of aq.$NaHCO_3$ and brine. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:1) to give diol **126** (4.9 mg, 0.01579 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3515, 3506, 3498, 3019, 2955, 1720, 1714, 1215, 757, 669 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 6.73 (dd, J = 2.2, 2.2 Hz, 1H), 5.15 (dd, J =

11.3, 4.8Hz, 1H), 4.59 (dd, *J* = 11.3, 1.4Hz, 1H), 4.15 (d, *J* = 11.5 Hz, 1H), 3.91 (br-s, 1H), 3.76 (s, 3H), 3.51 (d, *J* = 11.5 Hz, 1H), 3.33-3.30 (m, 1H), 3.10-3.06 (m, 1H), 2.18 (d, *J* = 14.9 Hz, 1H), 1.71 (d, *J* = 14.9 Hz, 1H), 1.63 (d, *J* = 13.6 Hz, 1H), 1.56 (dd, *J* = 13.6, 9.7 Hz, 1H), 1.07 (s, 3H), 1.00 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 173.2, 164.2, 149.8, 133.1, 76.9, 68.3, 62.9, 58.3, 54.5, 53.7, 51.7, 50.9, 44.6, 39.9, 31.1, 30.2. HRMS: calcd for $C_{16}H_{22}O_6$, 310.1416; found 310.1425.

Pentalenolactone F (2) Methyl Ester



126

Pentalenolactone F (**2**) methyl ester

To a stirred solution of diol **126** (4.7 mg, 0.01514 mmol) in CH_2Cl_2 (1 ml), TEA (13 μl, 0.09084 mmol), MsCl (4 μl, 0.04542 mmol) and then a small amount of DMAP were added at room temperature under nitrogen atmosphere. After being stirred for 50 min, the reaction was quenched with aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was diluted with CH_2Cl_2 (1 ml) and then treated with DBU (7 μl, 0.04542 mmol). Although the reaction mixture was stirred for 1 h, TLC analysis showed incomplete disappearance of **127** and additional DBU (7 μl, 0.04542 mmol) was added. After being stirred for 4 h, the reaction was quenched with H_2O and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (5 g, ethyl acetate/hexanes = 1:2) to give Pentalenolactone F (**2**) methyl ester (3.4 mg, 0.01163 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3019, 2956, 2931, 2860, 1765, 1712, 1439, 1260, 1215, 756, 669 cm^{-1}. ^{1}H NMR (700 MHz, $CDCl_3$): δ = 6.86 (dd, *J* = 2.6, 2.6 Hz, 1H), 4.88 (dd, *J* = 11.7, 6.1 Hz, 1H), 4.19 (dd, *J* = 11.7, 9.0 Hz, 1H), 3.76 (s, 3H), 3.59-3.55 (m, 1H), 3.06 (d, *J* = 4.8 Hz, 1H), 3.00-2.96 (m, 1H), 2.95 (d, *J* = 4.8 Hz, 1H), 1.89 (d, *J* = 13.7 Hz, 1H), 1.74 (dd, *J* = 13.0, 9.6 Hz, 1H), 1.71 (d, *J* = 13.7 Hz, 1H), 1.44 (dd, *J* = 13.0, 5.4 Hz, 1H), 1.05 (s, 3H), 1.04 (s, 3H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 170.2, 164.2, 149.7, 132.6, 67.9, 58.4, 55.2, 55.0, 51.9, 51.8, 51.6, 49.5, 45.7, 40.9, 29.5, 29.1. HRMS: calcd for $C_{16}H_{20}O_5$, 292.1311; found 292.1308.

Reference

(1) (a) Koe, B. K.; Sobin, B. A.; Celmer, W. D. *Antibiot. Annu*. **1957**, 672; (b) Takeuchi, S.; Ogawa, Y.; Yonehara, H. *Tetrahedron Lett.* **1969**, 32, 2737; (c) Martin, D.; Slomp, G.; Mizsak, S.; Chidester, C. *Tetrahedron Lett*. **1970**, 56, 4901; (d) Duchamp, D. J.; Chidester, C. G. *Acta Crystallogr., Sect. B*. **1972**, B28, 173; (e) Hartmann, S.; Neff, J.; Heer, U.; Mieke, D. *FEBS Lett*. **1978**, 93, 339.

(2) (a) Cane, D. E.; Sohng, J. K.; Williard, P. G. *J. Org. Chem*. **1992**, 57, 844-851; (b) Tillman, A. M.; Cane, D. E. *J. Antibiot.* **1983**, 36, 170; (c) Seto, H.; Noguchi, H.; Sankawa, U.; Yoichi, I. *J. Antibiot*, **1984**, 37, 816-817; (d) Cane D. E.; Thomas, P. J. *J. Am. Chem. Soc*, **1984**, 106, 5295-5303; (e) Williard, P. G.; Sohng, J. K.; Cane, D. E. *J. Antibiot*, **1988**, 41, 130-133; (f) Ohtsuka, T.; Shirahama, H.; Matsumoto, T. *Tetrahedron Lett*. **1983**, 24, 3851-3854.

(3) (a) Cane, D.E.; Rossi, T. *Tetrahedron Lett*. **1979**, 20, 2973; (b) Marino, J. P.; Silvenia, C.; Comasseto, J.; Petragnani, N. *J. Org. Chem*. **1987**, 52, 4139-4140.

(4) (a) Seto, H.; Sasaki, T.; Yonehara, H.; Uzawa, J. *Tetrahedron Lett*. **1978,** 19, 923; (b) Pirrung, M. C.; Thomson, S. A. *J. Org. Chem.* **1988**, 53, 227-230.

(5) Seto, H.; Sasaki, T.; Umezawa, J.; Takeuchi, S.; Yonehara, H. *Tetrahedron Lett*, **1978**, 19, 4411.

(6) Kang, H. J.; Ra, C. S.; Paquette, L. A. *J. Am. Chem. Soc*. **1991**, 113, 9384-9385.

(7) Liu, Q.; Yue, G.; Wu, N.; Lin, G.; Li, Y.; Quan, J.; Li, Q.; Wang, G.; Yang, Z. *Angew. Chem*. **2012**, 124, 12238-12242.

(8) Danishefsky, S.; Hirama, M.; Gombatz, K.; Harayama, T.; Berman, E.; Schuda, P. F. *J. Am. Chem. Soc*. **1979**, 101, 7020.

(9) (a) Yadav, J. S.; Somaiah, R.; Ravindar, K.; Chandraiah, L.; *Tetrahedron Lett*. **2008**, 49, 2848-2850. (b) Han, L.; Razdan, R. K. *Tetrahedron Lett.* **1998,** 39, 771-774.

(10) (a) Sharpless, K. B.; Michaelson, R. C. *J. Am. Chem. Soc*. **1973**, 95, 6136-6137. (b) Michaelson, R. C.; Palermo, R. E.; Sharpless, K. B. *J. Am. Chem. Soc.* **1977**, 99, 1990-1992. (c) Lempers, H. E. B.; Garcia, A. R. I.; Sheldon, R. A. *J. Org. Chem.* **1998**, 63, 1408-1413.

(11) Trost, B. M.; Terry, J. F. *J. Am. Chem. Soc*. **1973**, 95, 292-294.

(12) (a) Humphrey, J. M.; Aggen, J. B.; Chamberlin, A. R. *J. Am. Chem. Soc*. **1996**, 118, 11759-11770. (b) Park, J.; Tian, G. R.; Kim, D. H. *J. Org. Chem*. **2001**, 66, 3696-3703.

(13) (a) Yang, Z.; Lorenz, J. C.; Shi, Y. *Tetrahedron Lett*. **1998**, 39, 8621-8624. (b) Charette, A. B.; Beauchemin, A.; Francoeur, S. *J. Am. Chem. Soc*. **2001**, 123, 8139-8140.

(14) Yasuyuki, K.; Junko, F.; Yusuke, O.; Hiromichi, F. *J. Org. Chem*. **2003**, 68, 5917-5924.

(15) Gemal, A. L.; Luche, J. L.; *J. Am. Chem. Soc.* **1981**, 103, 5454-5459.

(16) (a) Corey, E. J.; Fuchs, P. L. *Tetrahedron Lett*. **1972**, 3769-3772; (b) Jung, M. E.; D'Amico, D. C.; *J. Am. Chem. Soc*. **1995**, 117, 7379-7388; (c) Organ, M. G.; Bratovanov, S. *Tetrahedron Lett*. **2000**, 41, 6945-6949; (d) Matsumura, R.; Suzuki, T.; Hagiwara, H.; Hoshi, T.; Ando, M. *Tetrahedron Lett*. **2001**, 42, 1543-1546; (e) Saitoh, T.; Suzuki, T.; Sugimoto, M, Hagiwara, H.; Hoshi, T. *Tetrahedron Lett*. **2003**, 44, 3175-3178; (f) Uemura, T.; Suzuki, T.; Onodera, N.; Hagiwara, H.; Hoshi, T. *Tetrahedron Lett*. **2007**, 48, 715-719; (g) Sugimoto, M.; Suzuki, T.; Hagiwara, H.; Hoshi, T. *Tetrahedron Lett*. **2007**, 48, 1109-1112.

(17) Jasperse, C. P.; Curran, D. P. *J. Am. Chem. Soc*. **1990**, 112, 5601-5609.

(18) (a) Shibuya, M.; Tomizawa, M.; Suzuki, I.; Iwabuchi, Y. *J. Am. Chem. Soc*. **2006**, 128, 8412-8413; (b) Kumazaki, H.; Nakajima, R.; Bassho, Y.; Yokoshima, S.; Fukuyama, T. *Synlett*. **2015**, 26, 2131-2134; (c) Hayakawa, I.; Niida, K.; Kigoshi, H. *Chem. Commun*. **2015**, 51, 11568-11571.

(19) (a) Baeyer, A.; Villiger, V. *Ber. Dtsch. Chem. Ges*. **1899**, 32, 3625-3633; (b) Matsutani, H.; Ichikawa, S.; Hiyama, T. *J. Am. Chem. Soc*. **1997**, 119, 4541.

(20) Schreiber, J.; Maag, H.; Hashimoto, N.; Escenmoser, A. *Angew. Chem. Int. Ed*. **1971**, 10, 330-331.

(21) Schlosser, M.; Jenny, T.; Guggisberg, Y. *Synlett*. **1990**, 704.

(22) Kang, H. J.; Ra, C. S.; Paquette, L. A. *J. Am. Chem. Soc*. **1992**, 114, 7387.

(23) Corey, E. J.; Schmidt, G. *Tetrahedron Lett*. **1979**, 20, 399-402.

(24) Bowden, K.; Heillbron, I. M.; Jones, E. R. H.; Weedon, B. C. L. *J. Chem. Soc*. **1946**, 39-45.

(25) Corey, E. J.; William Suggs, J. *Tetrahedron Lett*. **1975**, 16, 2647-2650.

(26) Bal, B. S.; Childers Jr, W. E.; Pinnick, H. W. *Tetrahedron*. **1981**, 37, 2091-2096.

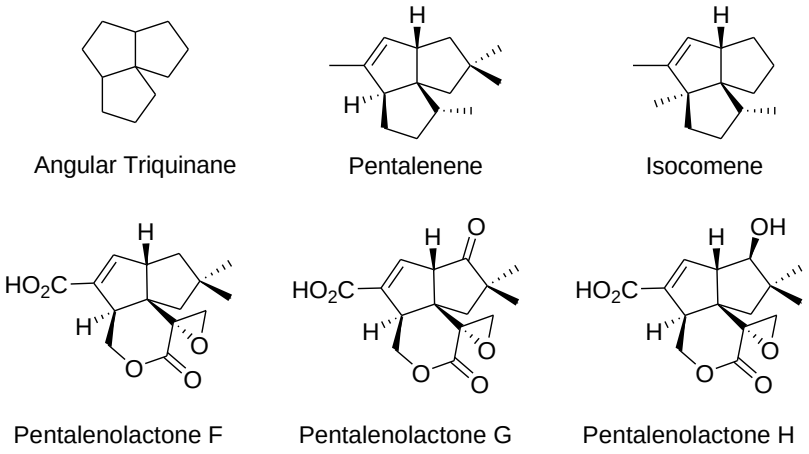
Chapter 4

Application
to
Optically Active Compound

4-1 : Introduction

Among triquinane group, the angular type which has unique structure composed of three cyclopentane rings around one carbon is abundant in nature. For example, pentalenene, isocomene, pentalenolactones have a common angular triquinane framework (Figure 1). And many scientists have considered this type as attractive ring structure consisting of significant interests and promising bioactivity. Therefore, a lot of investigations have been done by many scientists. In the result, various synthetic methods have been explored until now. However, there are few procedures to construct angular triquinane framework as optical active material. In association with this problem, our laboratory has accomplished total synthesis of pentalenolactone F in the past several years (Chapter 1~3). And I considered that application of Sharpless asymmetric epoxidation method[1)] would resolve that problem.

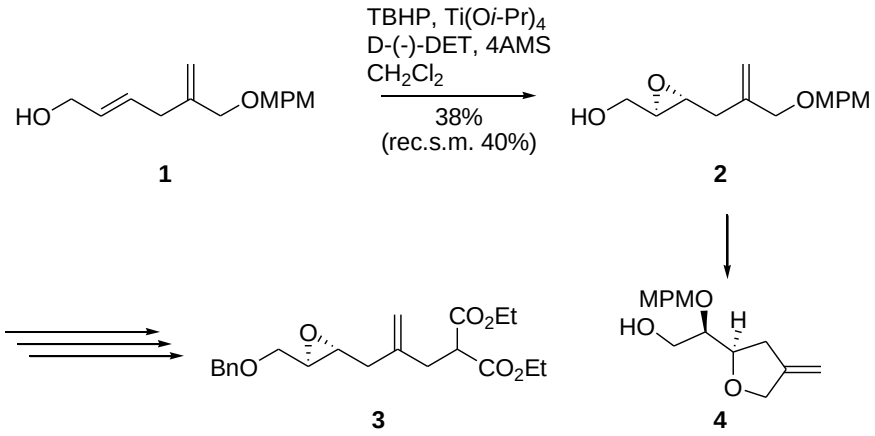
Figure 1



4-2 : Synthetic Study as the Optically Active Form

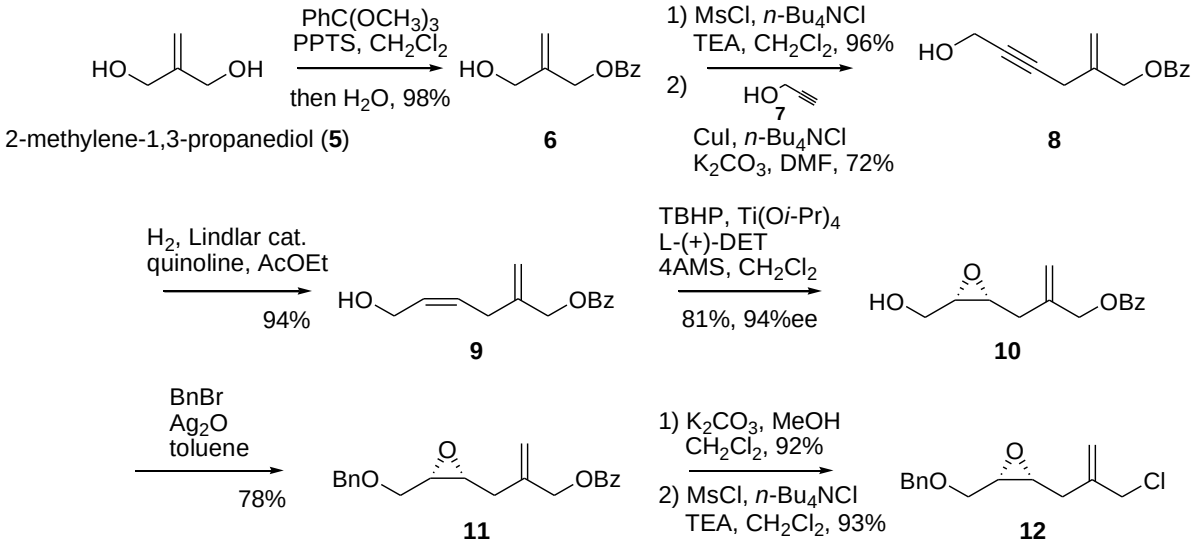
In our laboratory, Sharpless asymmetric epoxidation of **1** was attempted (Scheme 1). As a result, five-membered ether **4** was accompanied as a side product arising from nucleophilic attack of an oxygen atom of MPM ether to the epoxide. Because of this side-reaction, this epoxidation step was low yield. In order to resolve this problem, I planned to replace MPM to Bz group. The electron-withdrawing Bz group would decrease electron density of oxygen atom and expect to prevent the formation of five-membered ether. The asymmetric epoxide formation would make it possible to construct the angular triquinane framework as an optically active form.

Scheme 1



In reference to the synthetic procedure of pentalenolactone F (Chapter 3), application of Sharpless asymmetric epoxidation was examined (Scheme 2). One of the two hydroxyl group of **5** was protected with Bz group to give **6** in high yield. And another one was converted to chlorine, and subsequently essential carbon chain for synthesis of cyclization precursor was extended by coupling with 2-propyn-1-ol (**7**)[2)] to give **8**. Hydrogenation of **8** with Lindlar catalyst provided *cis*-allyl alcohol **9** and then regio and stereoselective epoxidation of **9** was achieved under Sharpless asymmetric conditions to give **10** in high chemical and optical yields. After protection of **10** with BnBr and Ag_2O, removal of Bz group followed by chlorination afforded common intermediate **12**. Synthetic sample **12** exhibited identical spectroscopic data (^{1}H NMR, ^{13}C NMR) with those of the allyl chloride obtained in Chapter 3.

Scheme 2



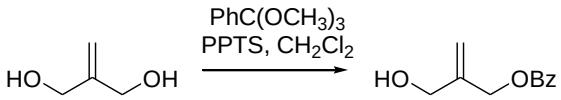
Experimental Section

General

IR spectra were recorded on a JASCO FT/IR-4200 spectrometer. Oily products were measured directly, solid products were diluted with chloroform and then measured. ^{1}H and ^{13}C NMR spectra were obtained for solutions in dueteriochloroform with VARIAN 400MHz and 700MHz spectrometer with residual solvent as the internal standard. Mass spectral data were run on JEOL GC-mate. Optical rotation was measured on a HORIBA SEPA-200 spectrometer. Thin layer chromatography (TLC) was carried out on MERCK Silica gel 60 F_{254} plates employing *n*-hexane/ethyl acetate as the mobile phase. KANTO Silica gel 60 N 40-50 μm was employed for flash column chromatography. THF and Et_2O were distilled from sodium/benzophenone ketyl. Benzene, CH_2Cl_2, toluene, CH_3CN, 2,6-lutidine, and TEA were distilled from CaH_2. Commercialized MeOH, EtOH, DMSO and DMF were used as reaction solvent. Simple distillation was carried out about ethyl acetate and *n*-hexane.

4-2 : Experimental Section

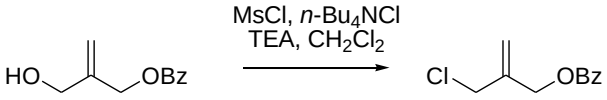
Benzoate 6



2-methylene-1,3-propanediol (**5**) **6**

To a stirred solution of 2-Methylene-1,3-propanediol **5** (311.2 mg, 3.532 mmol) in CH_2Cl_2 (9 ml), $PhC(OCH_3)_3$ (1.9 ml, 10.60 mmol), and then PPTS (1.2 M in CH_2Cl_2, 2.9 ml, 0.3532 mmol) were added at room temperature under nitrogen atmosphere and subsequently stirred for 2 h. TLC analysis showed complete disappearance of **5** and then H_2O was added. After being stirred for 1 h, Na_2SO_4 was added to reaction mixture to remove H_2O and then concentrated. The residual oil was purified by column chromatography on silica gel (40 g, ethyl acetate/hexanes = 1:2) to give benzoate **6** (659.1 mg, 3.431 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3423, 3090, 3064, 3034, 2991, 2933, 2875, 1720, 1660, 1601, 1452, 1271, 1114, 1025, 711 cm^{-1}. ^{1}H NMR (700 MHz, $CDCl_3$): δ = 8.06 (br-d, J = 7.4 Hz, 2H), 7.58 (br-dd, J = 7.4, 7.4 Hz, 1H), 7.46 (br-dd, J = 7.4, 7.4 Hz, 2H), 5.31 (s, 1H), 5.29 (s, 1H), 4.91 (s, 2H), 4.24 (s, 2H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 166.5, 143.4, 133.2, 129.9, 129.7, 128.4, 114.5, 65.1, 63.8. HRMS: calcd for $C_{11}H_{12}O_3$, 192.0787; found 192.0785.

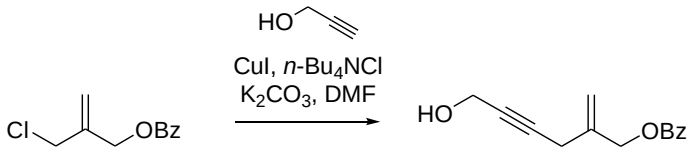
Allyl Chloride 13



6 **13**

To a stirred solution of benzoate **6** (659.1 mg, 3.431 mmol) in CH_2Cl_2 (17 ml), TEA (1.4 ml, 10.29 mmol), *n*-Bu_4NCl (1.91 g, 6.862 mmol) and then MsCl (0.4 ml, 5.147 mmol) were added at 0 ℃ under nitrogen atmosphere. The mixture was warmed to room temperature. After being stirred for 2 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (40 g, ethyl acetate/hexanes = 1:15) to give allyl chloride **13** (685.7 mg, 3.255 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3089, 3063, 3033, 2997, 2957, 2881, 1724, 1451, 1271, 1111, 1026, 934, 710 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 8.07 (d, *J* = 7.4 Hz, 1H), 7.58 (dd, *J* = 7.4, 7.4 Hz, 1H), 7.46 (dd, *J* = 7.4, 7.4 Hz, 2H), 5.41 (s, 1H), 5.38 (s, 1H), 4.95 (s, 2H), 4.19 (s, 2H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 166.0, 139.9, 133.2, 129.8, 129.6, 128.4, 118.1, 64.6, 45.1. HRMS: calcd for $C_{11}H_{11}ClO_2$, 210.0448; found 210.0447.

Alkynyl Alcohol 8

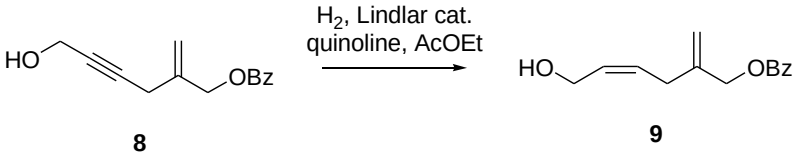


13 **8**

To a stirred solution of allyl chloride **13** (282.8 mg, 1.342 mmol) in degassed DMF (13 ml), crushed K_2CO_3 (278.2 mg, 2.013 mmol), *n*-Bu_4NCl (37.3 mg, 0.1342 mmol), CuI (26.9 mg, 0.1342 mmol) and then 2-propyn-1-ol (242 μl, 4.026 mmol) at room temperature under nitrogen atmosphere. The mixture was stirred for 3 h at 50 ℃. TLC analysis showed incomplete disappearance of **13** and additional K_2CO_3 (278.2 mg, 2.013 mmol) was added three times, and stirred for 3.5 h in total. The reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The heterogeneous mixture was filtered through a celite pad with ethyl acetate. The organic layer was washed with H_2O, brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1:3) to give alkynyl alcohol **8** (205.6 mg, 0.8929 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3415, 3301, 3090, 3068, 3034, 2991, 2932, 2874, 2291, 2223, 1720, 1452, 1274, 1113, 1025 712 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 8.06 (br-d, *J* = 7.6 Hz, 2H), 7.58 (br-dd, *J* = 7.6, 7.6, Hz, 1H), 7.46 (br-dd, *J* = 7.6, 7.6 Hz, 2H), 5.34 (s, 1H), 5.28 (s, 1H), 4.86 (s, 2H), 4.27 (s, 2H), 3.13 (s, 2H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 166.2,

138.7, 133.1, 129.9, 129.6, 128.4, 115.1, 82.1, 81.3, 66.6, 51.3, 23.6. HRMS: calcd for $C_{14}H_{14}O_3$, 230.0943; found 230.0948.

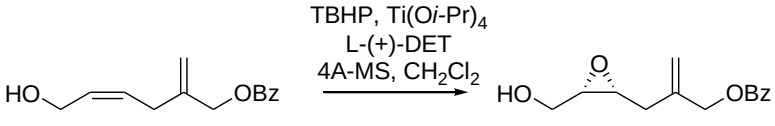
Allyl Alcohol 9



8 **9**

To a stirred solution of alkynyl alcohol **8** (357.9 mg, 1.554 mmol) in ethyl acetate (16 ml), quinolone (33 μl, 10Wt%) and Lindlar cat. (17.9 mg, 5Wt%) were added and then purged with hydrogen. After being stirred for 1 h under a balloon of hydrogen, TLC analysis showed incomplete disappearance of **8** and additional Lindlar cat. (17.9 mg, 5Wt%) six times, and stirred for 17 h in total. The heterogeneous mixture was filtered through a celite pad with ethyl acetate and concentrated. After being diluted with ethyl acetate, the organic layer was extracted and washed with 0.5N HCl, aq.$NaHCO_3$ and then brine. Then organic layer was dried over Na_2SO_4 and concentrated. The residual oil was purified by column chromatography on silica gel (25 g, ethyl acetate/hexanes = 1:5) to give allyl alcohol **9** (340 mg, 1.464 mmol) as a yellow oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3403, 3089, 3070, 3019, 2929, 2877, 1720, 1654, 1601, 1452, 1315, 1274, 1113, 1026, 711 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 8.08-8.05 (m, 2H), 7.59-7.56 (m, 1H), 7.48-7.44 (m, 2H), 5.77 (dtt, J = 10.9, 6.8, 1.4 Hz, 1H), 5.62 (dtt, J = 10.9, 7.7, 1.3 Hz, 1H), 5.18 (d, J = 0.9 Hz, 1H), 5.06 (d, J = 0.9 Hz, 1H), 4.80 (s, 2H), 4.20 (dd, J = 6.8, 1.3 Hz, 2H), 2.94 (br-d, J = 7.7 Hz, 2H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 166.3, 142.3, 133.1, 130.8, 130.0, 129.6, 128.7, 128.4, 114.0, 67.0, 58.3, 31.4. HRMS: calcd for $C_{14}H_{16}O_3$, 232.1100; found 232.1099.

Epoxide 10

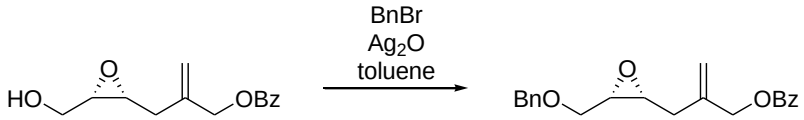


9 **10**

To a stirred solution of L-(+)-DET (351 μl, 2.050 mmol) and crushed 4A-MS (512.5 mg) in CH_2Cl_2 (15 ml), Ti(O*i*-Pr)$_4$ (515 μl, 1.757 mmol) was added at -20 ℃ under nitrogen atmosphere. After being stirred for 20 min, TBHP (2.6 M in isooctane, 1.1 ml, 2.928 mmol) was added to a mixture at -20 ℃ and then stirred for 20 min. allyl alcohol **9** (0.25 M in CH_2Cl_2, 6.0 ml, 1.464 mmol) was added to a mixture and stirred for 27 h. After that, the reaction was quenched by addition of aq.Rochell's salt

and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography two times on silica gel (25 g, ethyl acetate/hexanes = 1:1) to give epoxide **10** (295.7 mg, 1.191 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3428, 3089, 3065, 2986, 2931, 2884, 1721, 1655, 1601, 1452, 1315, 1274, 1113, 1026, 712 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.08-8.04 (m, 2H), 7.61-7.55 (m, 1H), 7.48-7.40 (m, 2H), 5.29 (d, *J* = 0.8 Hz, 1H), 5.19 (d, *J* = 0.8 Hz, 1H), 4.83 (br-s, 2H), 3.87 (br-dd, *J* = 12.2, 3.9 Hz, 1H), 3.75 (dd, *J* = 12.2, 6.1 Hz, 1H), 3.28-3.20 (m, 2H), 2.52 (br-dd, *J* = 15.9, 6.6 Hz, 1H), 2.40 (br-dd, *J* = 15.9, 5.3Hz, 1H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 166.2, 140.3, 133.2, 129.9, 129.6, 128.5, 115.1, 67.3, 60.5, 56.3, 55.4, 31.9. HRMS: calcd for $C_{14}H_{16}O_4$, 248.1049; found 248.1055. $[\alpha]_D^{24}$-26.0 (c = 0.05, $CHCl_3$).

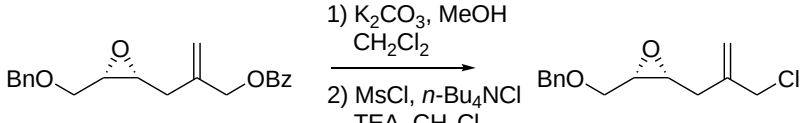
Benzyl Ether 11



10 **11**

To a stirred solution of epoxide **10** (28.3 mg, 0.1140 mmol) in toluene (1 ml), Ag_2O (63.4 mg, 0.2736 mmol) and then BnBr (27 μl, 0.2280 mmol) were added at room temperature under nitrogen and blocked out light atmosphere. The mixture was stirred for 3 h. TLC analysis showed incomplete disappearance of **10** and additional Ag_2O (15.9 mg, 0.06840 mmol) and BnBr (7 μl, 0.05700 mmol) were added and stirred for 1 h. The heterogeneous mixture was filtered through a celite pad with ethyl acetate and concentrated. The residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:4) to give benzyl ether **11** (28.7 mg, 0.08467 mmol) as a colorless oil. Analytical data: IR (KBr): $\tilde{\nu}$ = 3087, 3063, 3031, 2988, 2925, 2861, 1720, 1655, 1452, 1271, 1110, 712, 700 cm^{-1}. ^1H NMR (700 MHz, $CDCl_3$): δ = 8.07-8.04 (m, 2H), 7.59-7.56 (m, 1H), 7.47-7.43 (m, 2H), 7.35-7.32 (m, 4H), 7.30-7.27 (m, 1H), 5.27 (d, *J* = 0.8 Hz, 1H), 5.18 (d, *J* = 0.8 Hz, 1H), 4.80 (br-s, 2H), 4.61 (d, *J* = 11.8 Hz, 1H), 4.52 (d, *J* = 11.8 Hz, 1H), 3.72 (dd, *J* = 11.1, 4.5 Hz, 1H), 3.59 (dd, *J* = 11.1, 6.2 Hz, 1H), 3.26 (ddd, *J* = 6.2, 4.5, 4.3 Hz, 1H), 3.21 (td, *J* = 6.2, 4.3 Hz, 1H), 2.38 (br-d, *J* = 6.2 Hz, 2H). ^{13}C NMR (700 MHz, $CDCl_3$): δ = 166.1, 140.2, 137.7, 133.1, 130.0, 129.6, 128.4, 128.4, 127.8, 127.8, 114.9, 73.4, 68.0, 67.3, 55.0, 54.5, 32.0. HRMS: calcd for $C_{21}H_{22}O_3$, 322.1569; found 322.1571. $[\alpha]_D^{23}$+8.0 (c = 0.33, $CHCl_3$).

Allyl Chloride 12



11 **12**

To a stirred solution of benzyl ether **11** (23.7 mg, 0.07004 mmol) in CH_2Cl_2 and MeOH (1 ml, 5:1), crushed K_2CO_3 (48.4 mg, 0.3502 mmol) was added at room temperature under nitrogen atmosphere. After being stirred for 7 h, the reaction was quenched by addition of aq.NH_4Cl and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:1) to give alcohol **14**.

To a stirred solution of alcohol **14** in CH_2Cl_2 (1 ml), TEA (39 μl, 0.2800 mmol), *n*-Bu_4NCl (39.7 mg, 0.1400 mmol) and then MsCl (11 μl, 0.1400 mmol) were added at room temperature under nitrogen atmosphere. After being stirred for 3 h, the reaction was quenched by addition of aq.$NaHCO_3$ and then diluted with ethyl acetate. The organic layer was washed with brine and then dried over Na_2SO_4. After concentration, the residual oil was purified by column chromatography on silica gel (15 g, ethyl acetate/hexanes = 1:5) to give allyl chloride **12** (13.5 mg, 0.05341 mmol) as a colorless oil. Analytical data: $[\alpha]_D^{25}$+20.3(c = 0.45, $CHCl_3$).

Reference

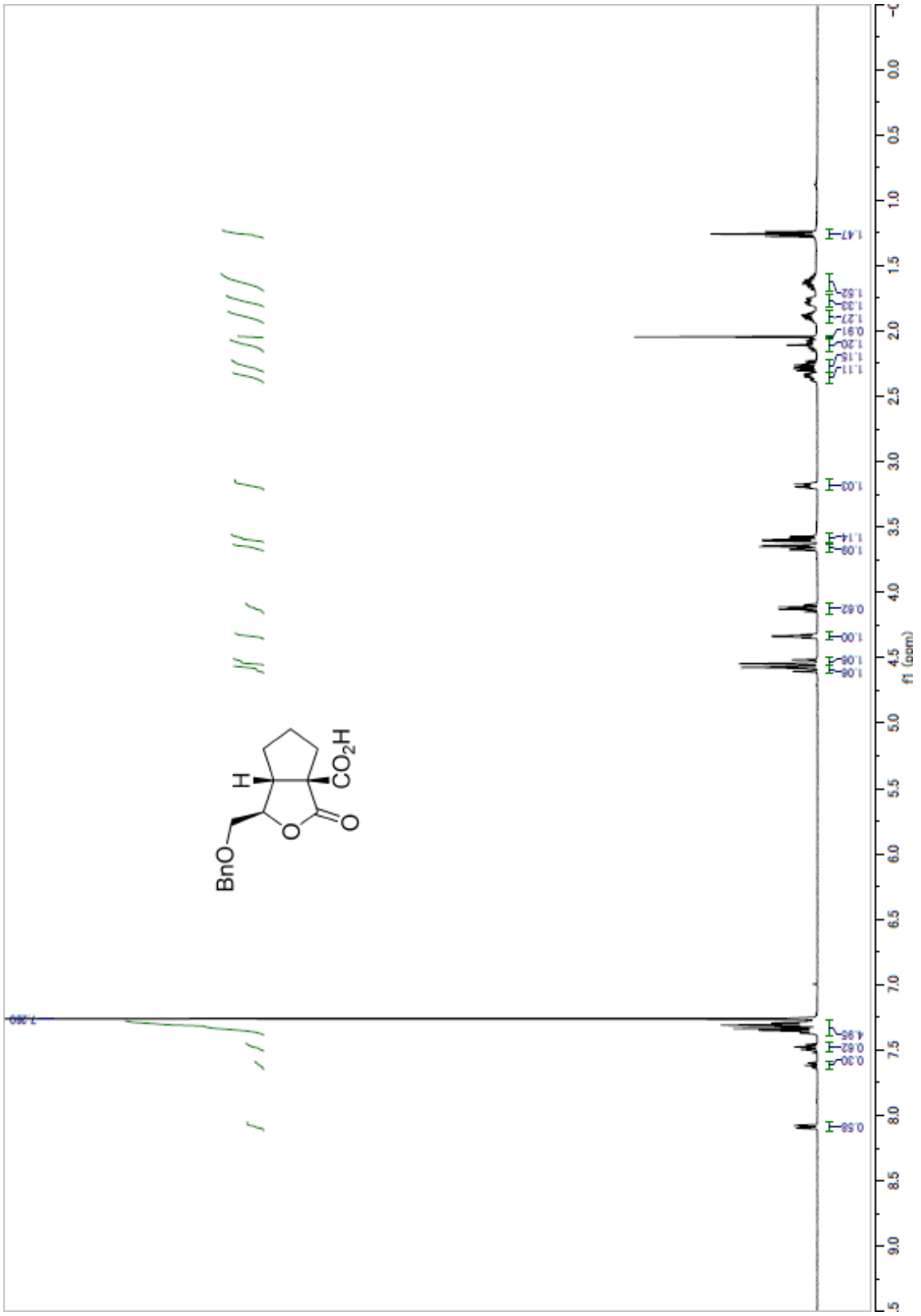
(1) (a) Katsuki, T.; Sharpless, K. B. *J. Am. Chem. Soc.* **1980**, 102, 5976-5978; (b) Saitoh, T.; Suzuki, T.; Sugimoto, M.; Hagiwara, H.; Hoshi, T. *Tetrahedron Lett*. **2003**, 44, 3175-3178.

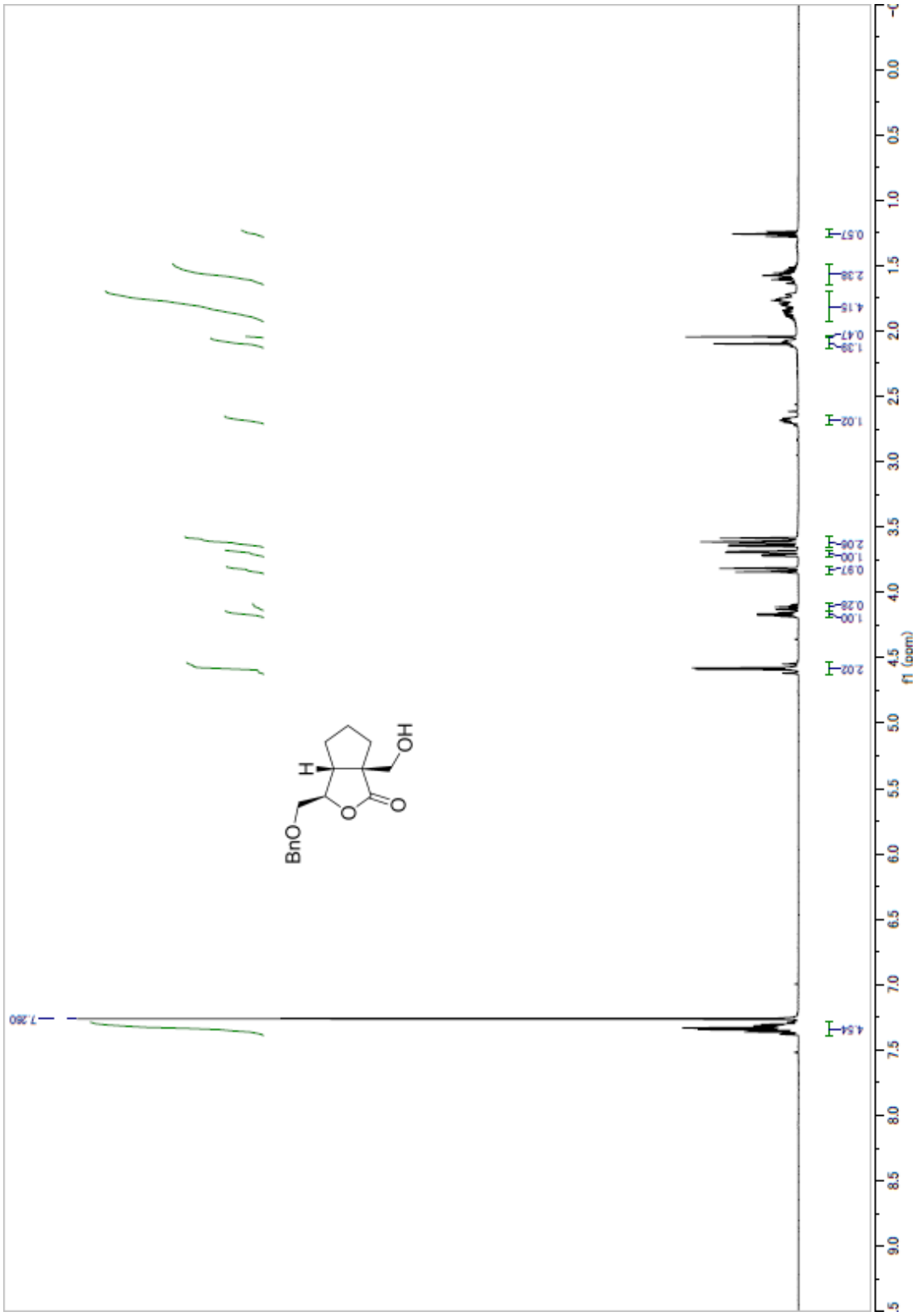
(2) (a) Yadav, J. S.; Somaiah, R.; Ravindar, K.; Chandraiah, L.; *Tetrahedron Lett*. **2008**, 49, 2848-2850. (b) Han, L.; Razdan, R. K. *Tetrahedron Lett.* **1998,** 39, 771-774.

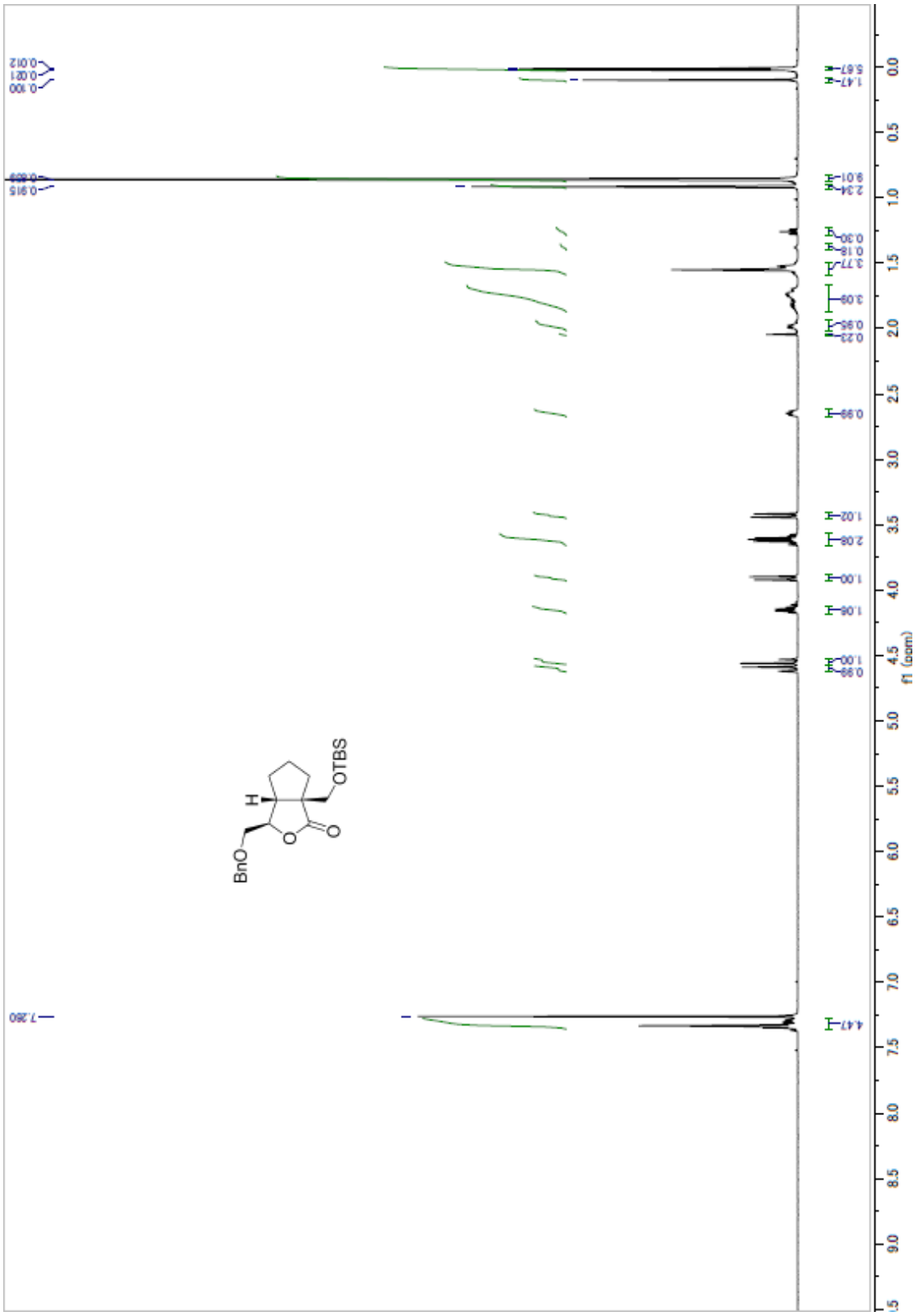
Acknowledgment

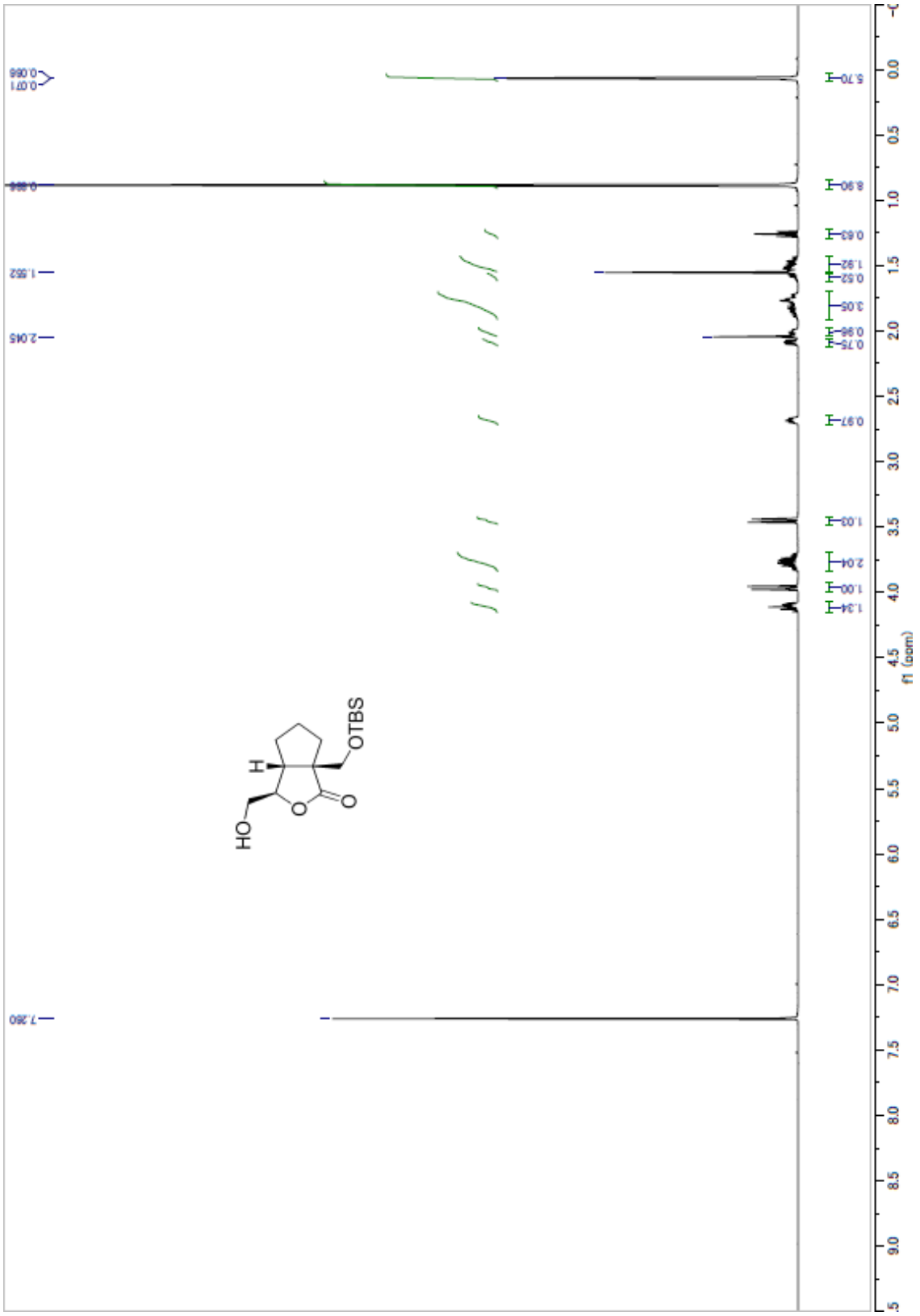
I would like to express my sincere thanks to Professor Toshio Suzuki for his invaluable advice, guidance and engineering discussion throughout the course of this research and the preparation of this manuscript. I would also like to thank Professor Hisahiro Hagiwara for his many helpful discussions and suggestions and continuing encouragement during this work, and the preparation of this manuscript.

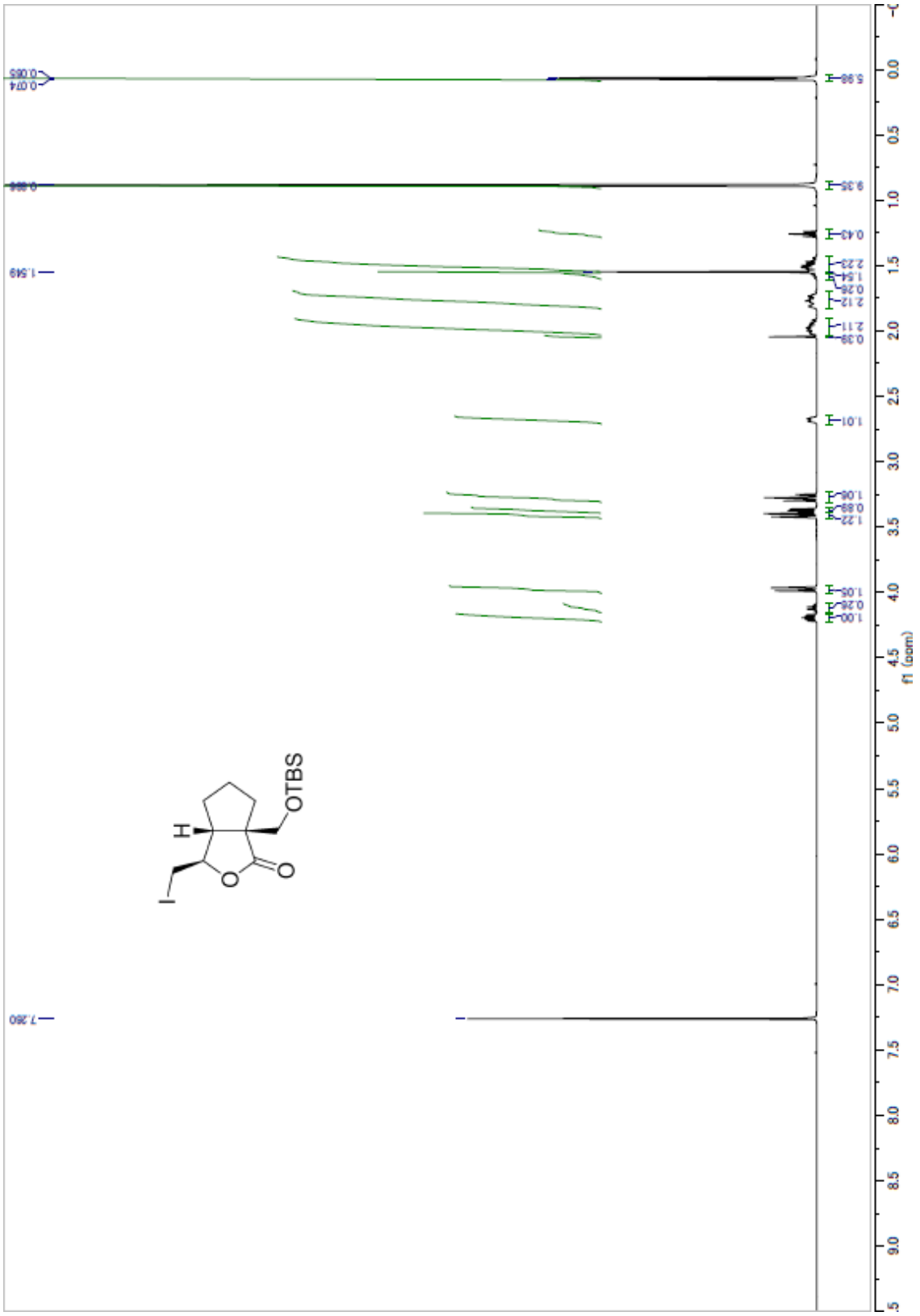
Spectral Data

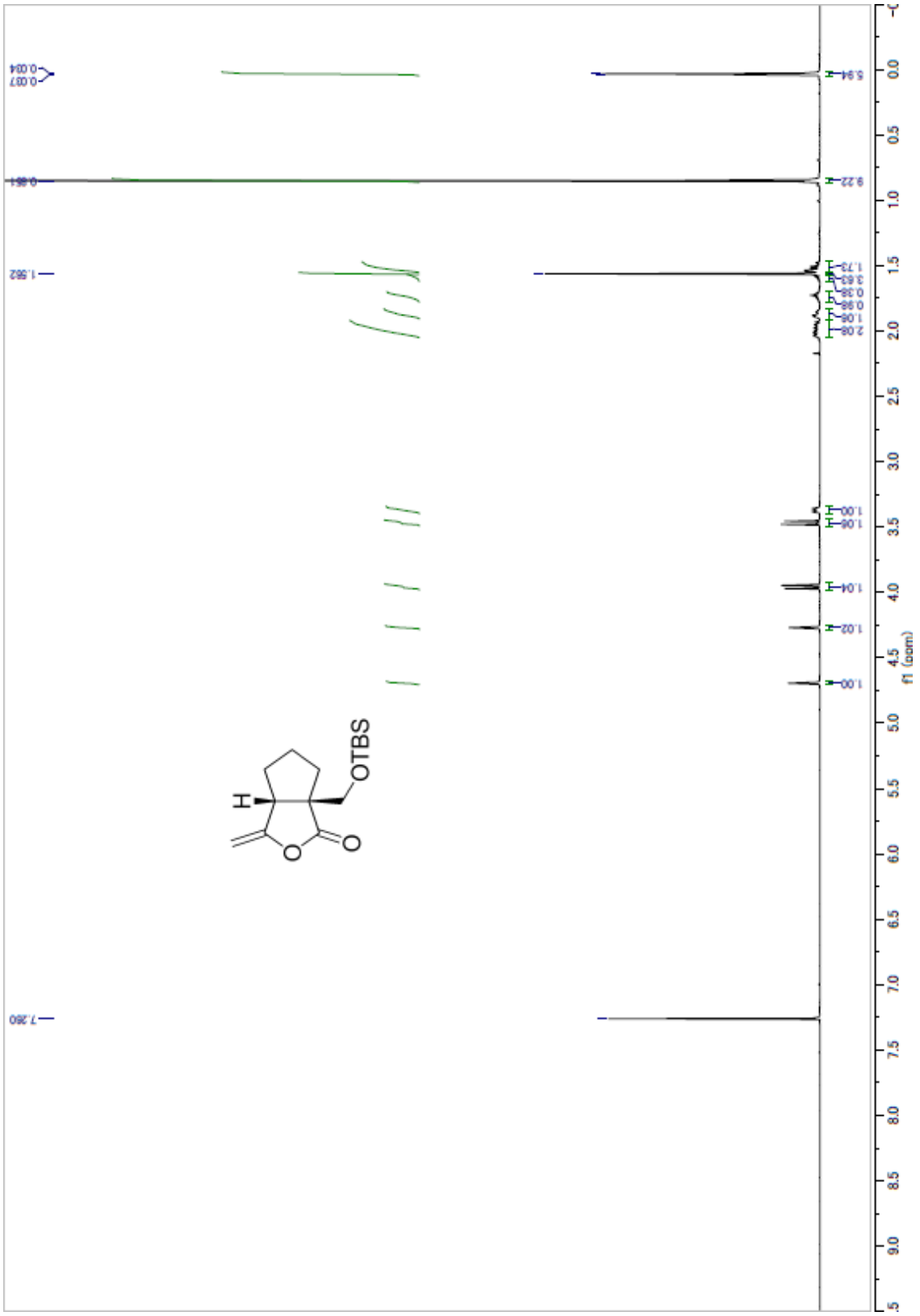

BnO
H
CO2H
O
O
f1 (ppm)

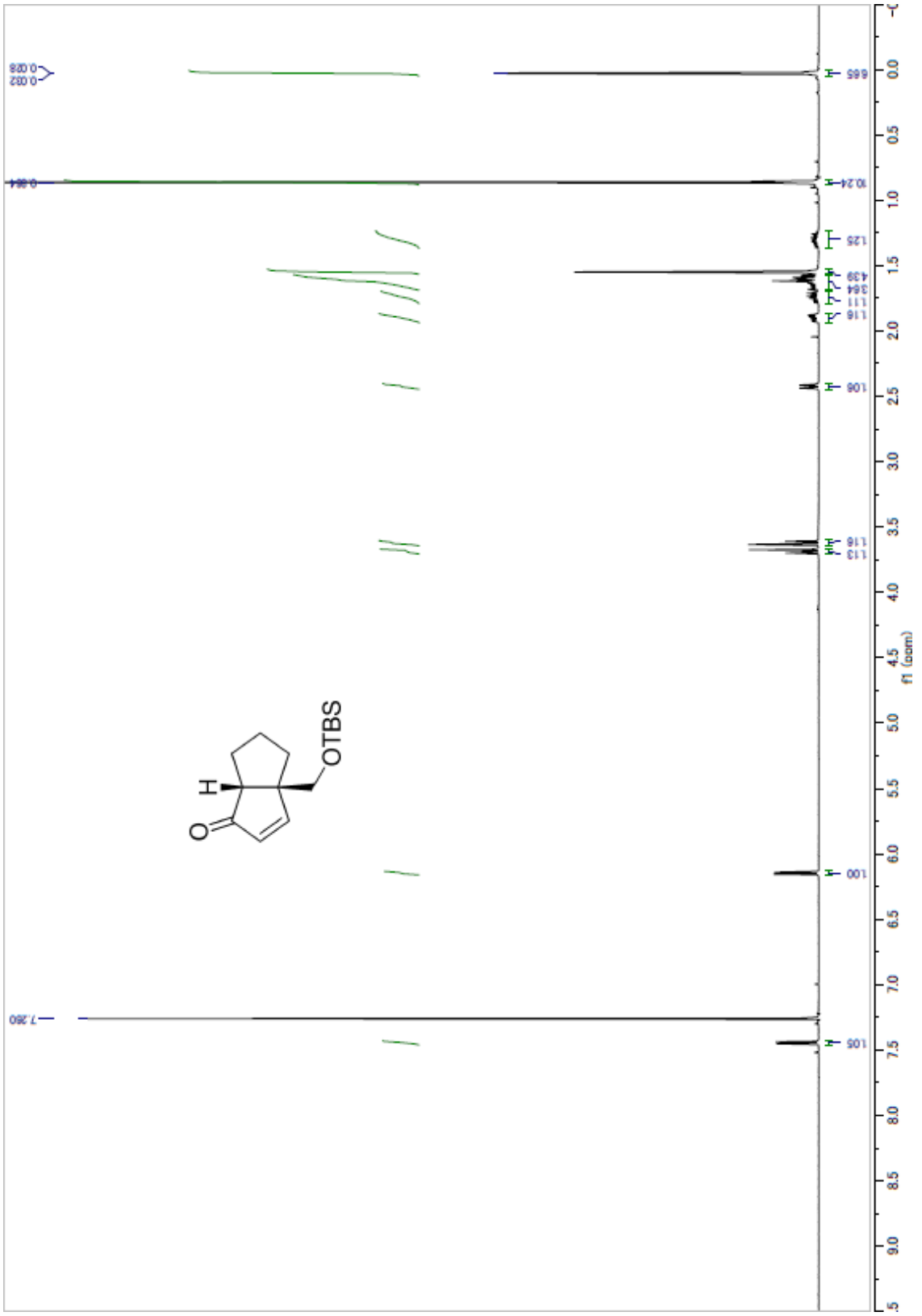

7.260
4.54
2.02
1.00
0.28
1.00
0.97
2.06
1.00
0.47
1.38
4.15
2.38
0.57
1.02
f1 (ppm)
BnO
H
O
O
OH

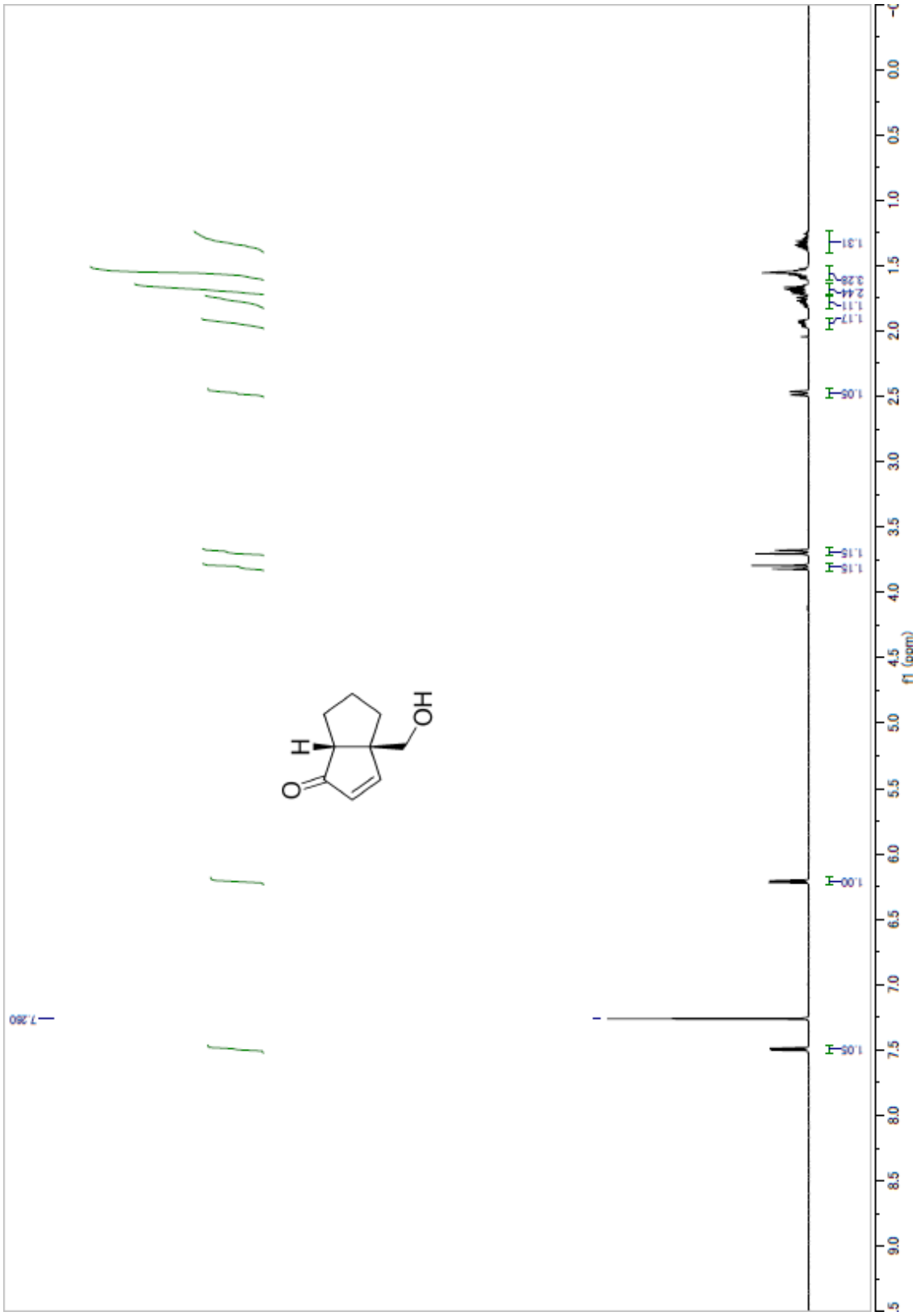

OTBS
H
BnO
O
O
f1 (ppm)

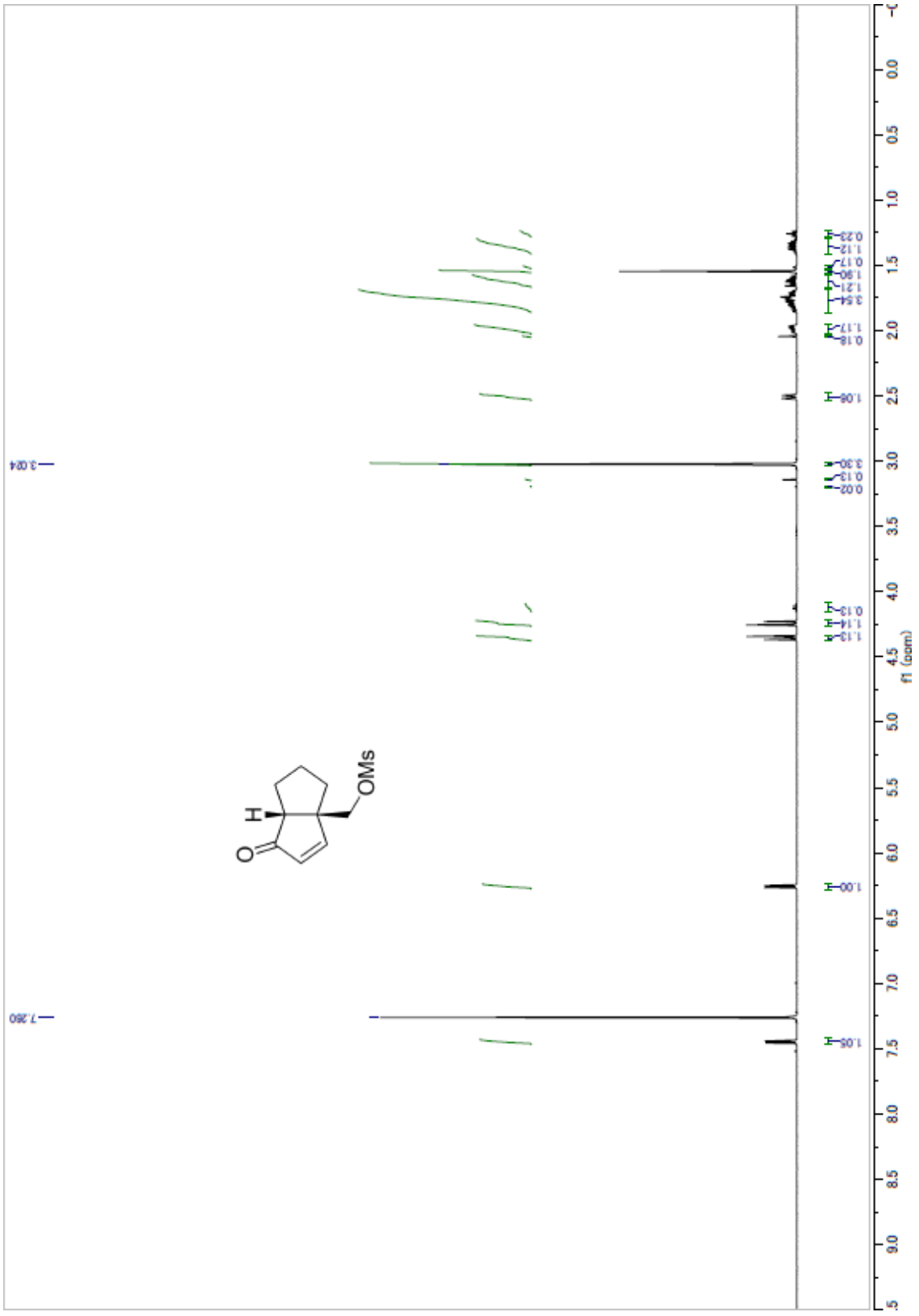

OTBS
H
O
O
HO
f1 (ppm)

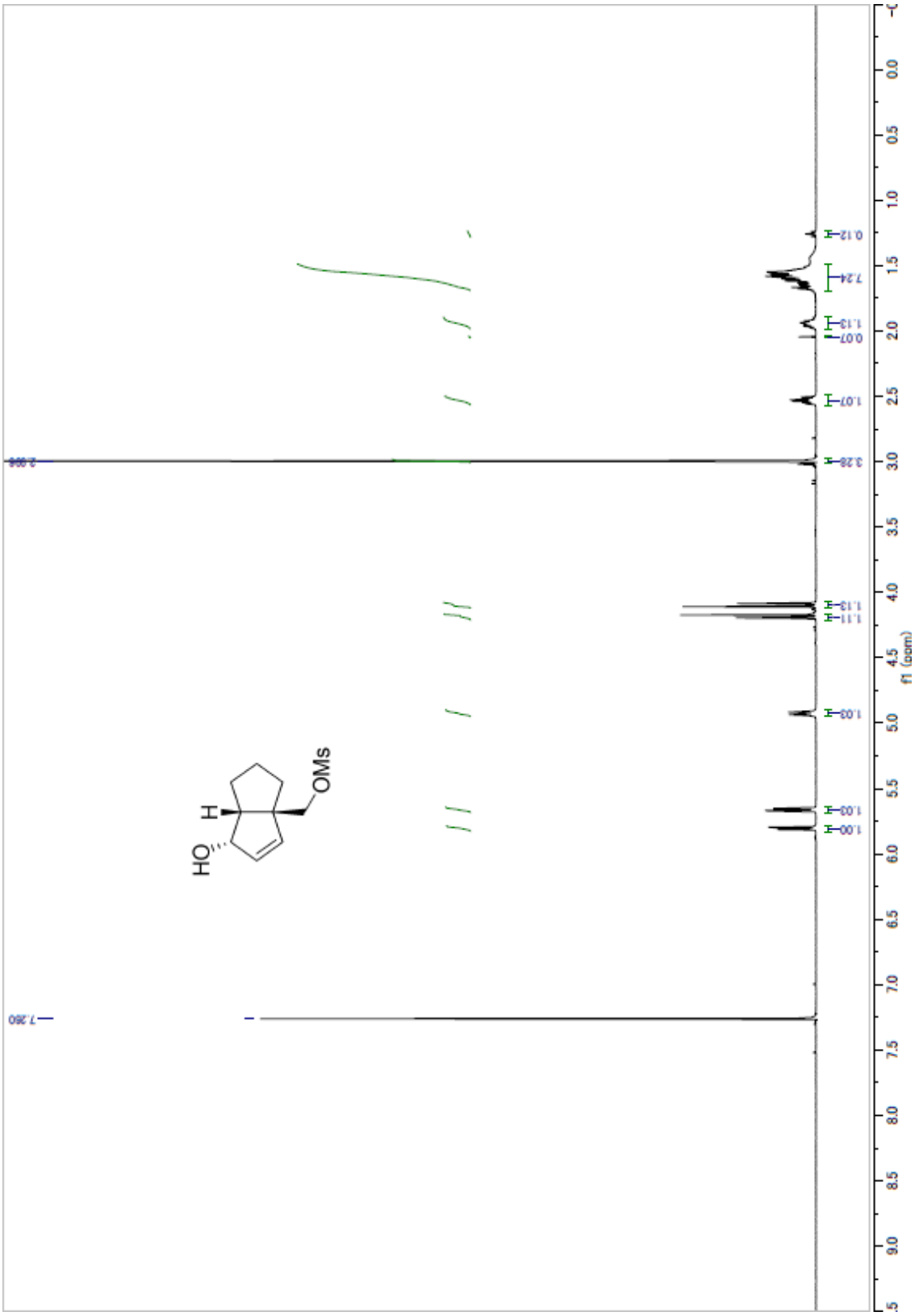

OTBS
H
O
O
I
f1 (ppm)

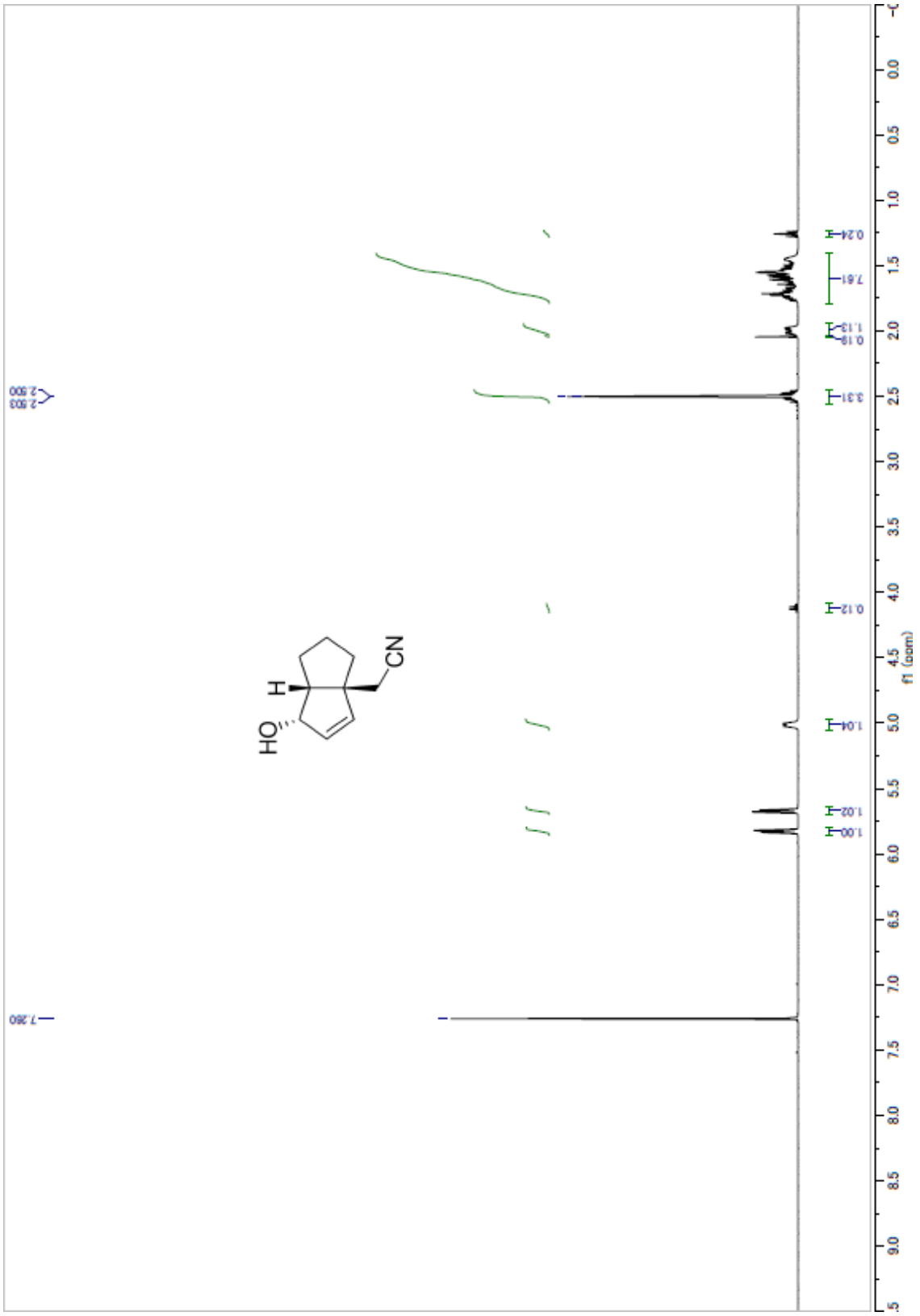

OTBS
H
O
O
f1 (ppm)

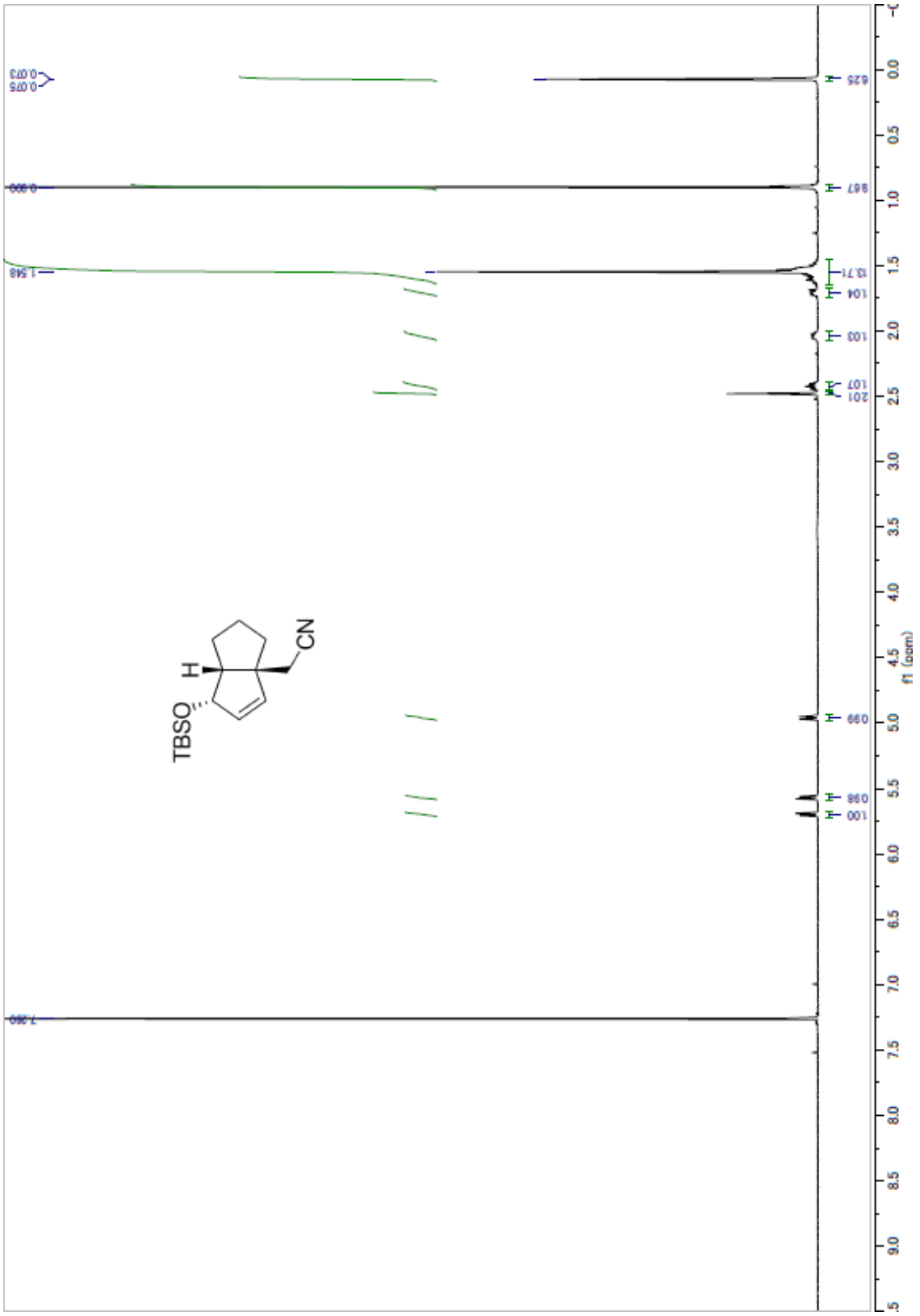

OTBS
H
O
f1 (ppm)

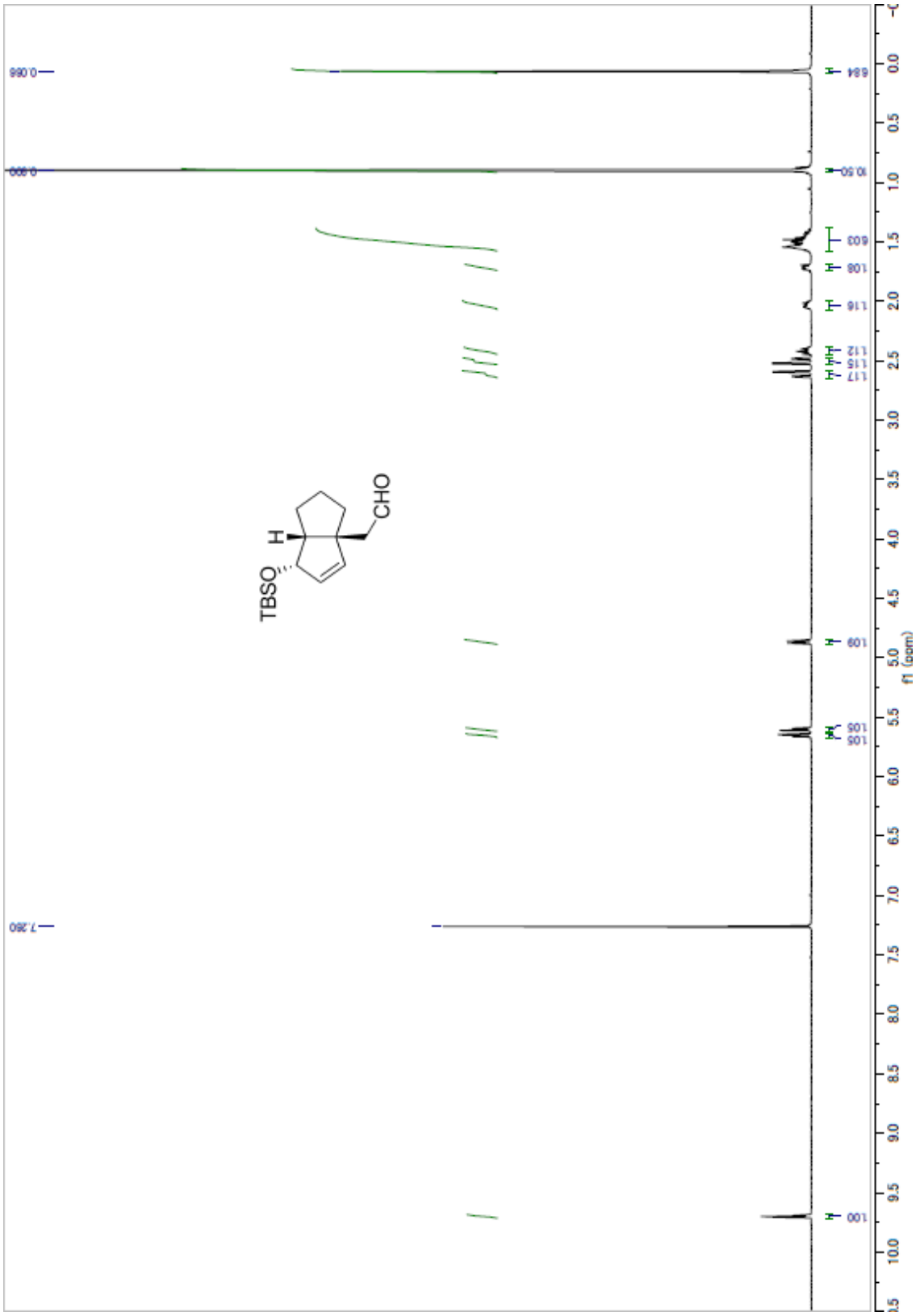

7.260
1.05
1.00
1.15
1.15
1.05
2.44
1.11
1.17
1.31
f1 (ppm)

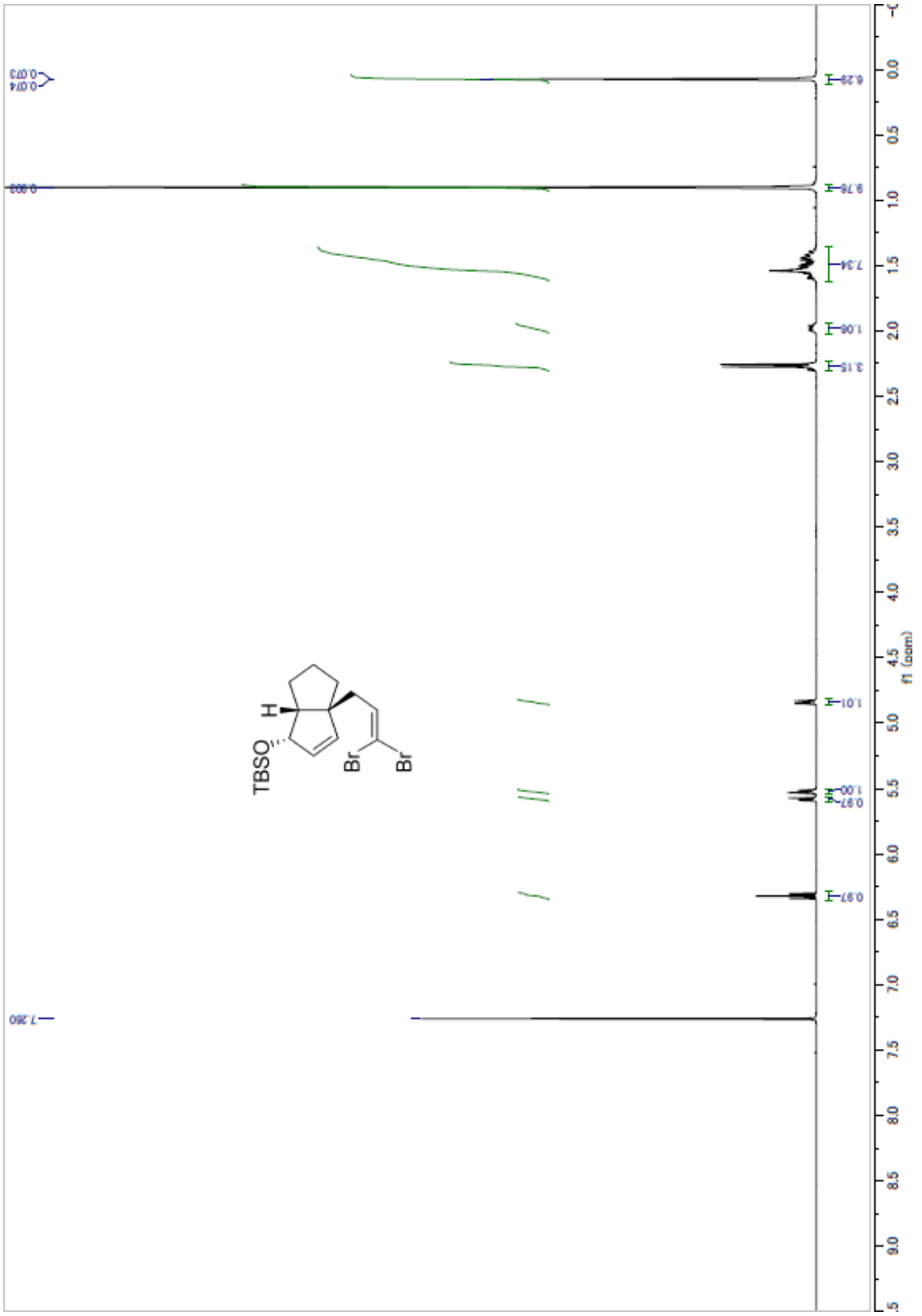

OMs
H
O
f1 (ppm)

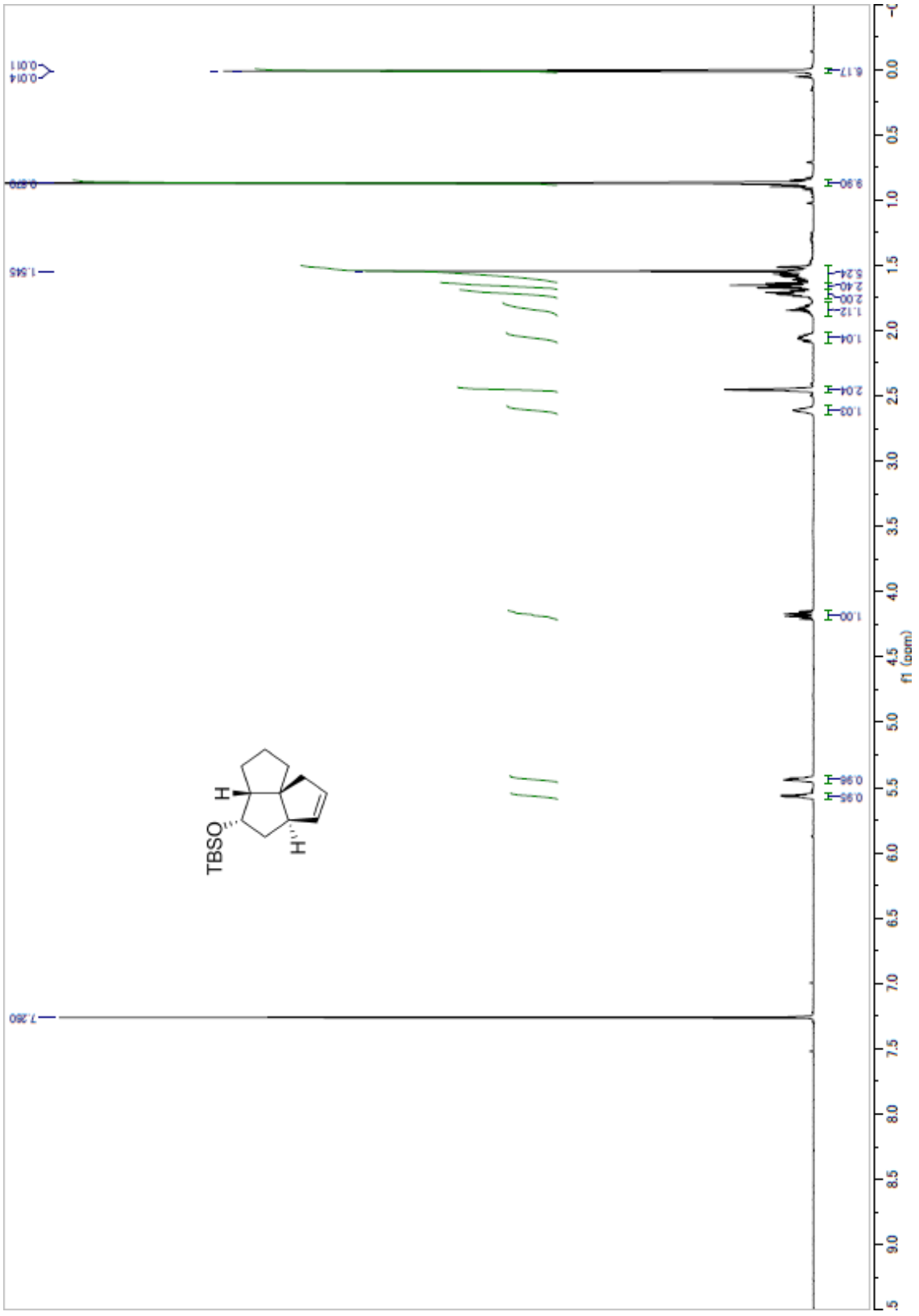

OMs
H
HO
f1 (ppm)

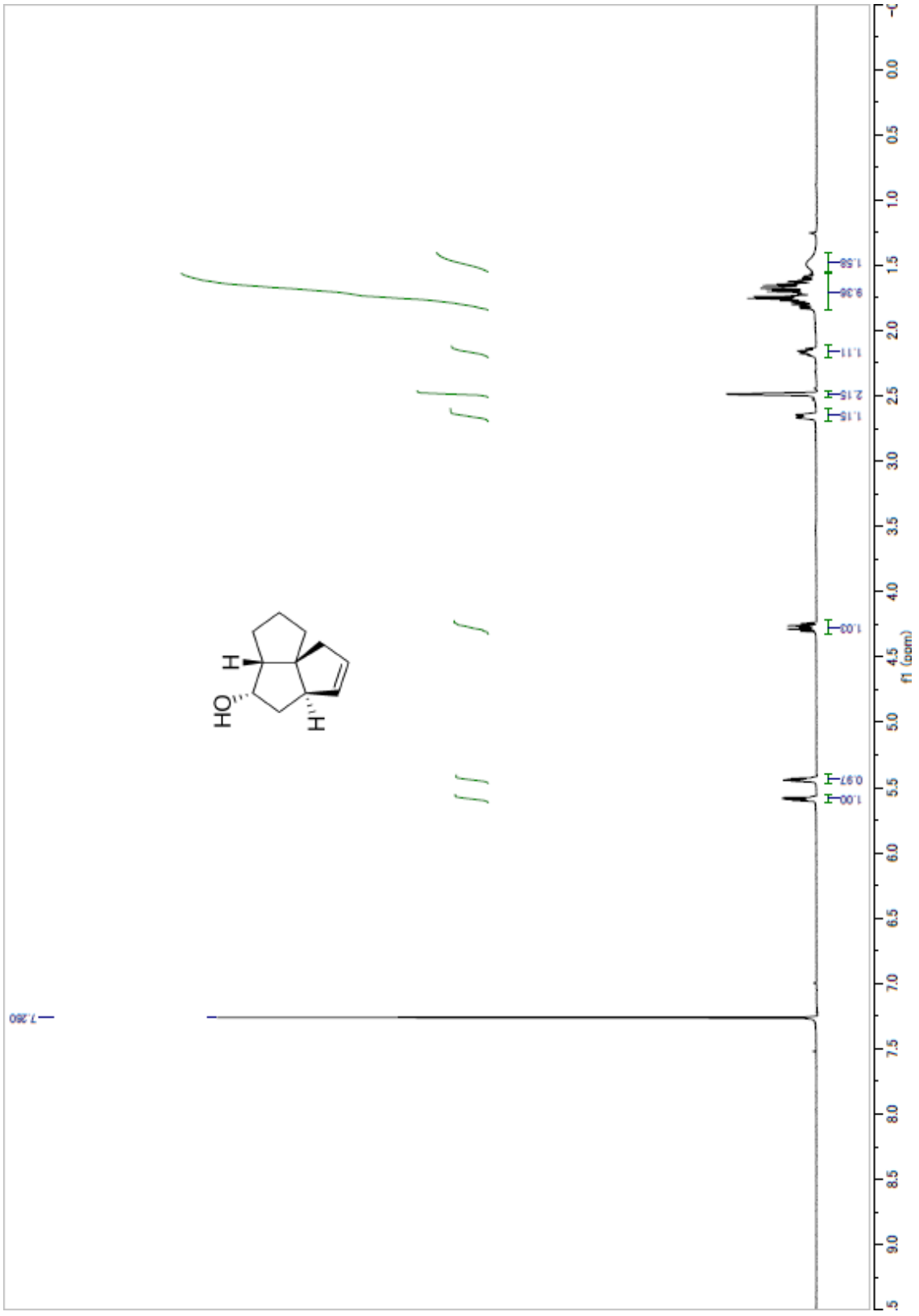

7.260
2.803
2.800
0.24
7.61
0.19
1.13
3.31
0.12
1.04
1.02
1.00
f1 (ppm)
HO
H
CN

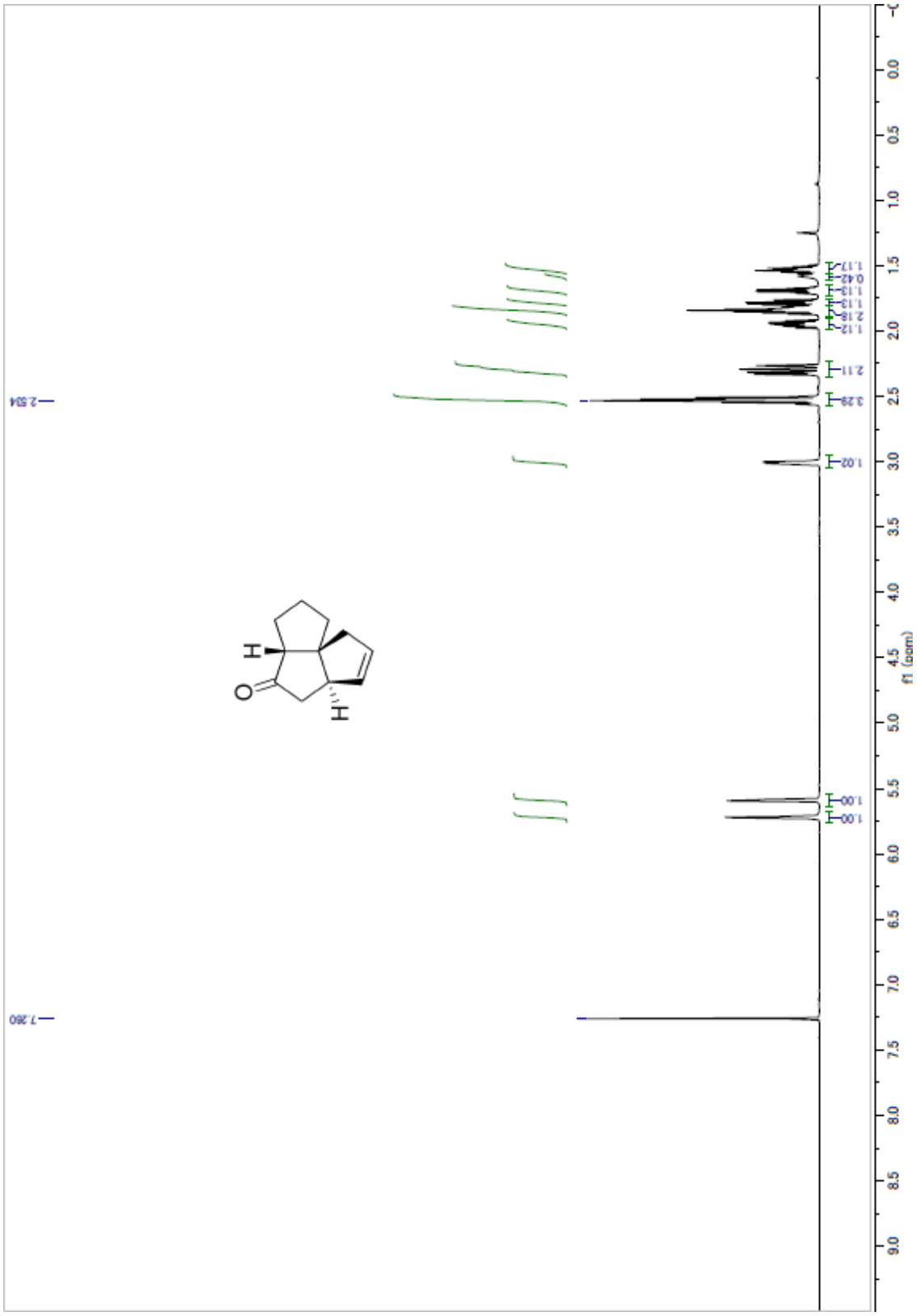

TBSO
H
CN
f1 (ppm)

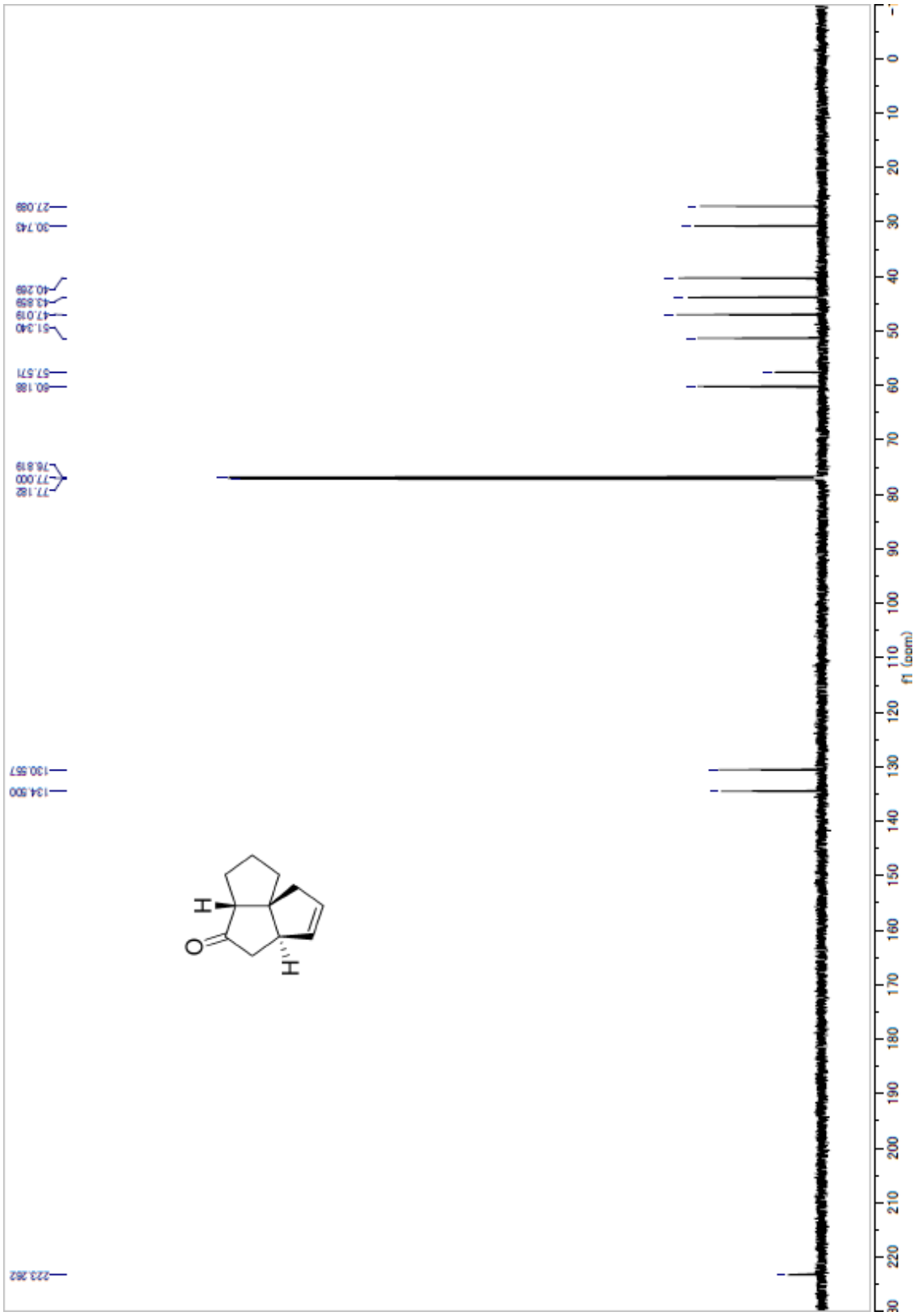

TBSO
H
CHO
f1 (ppm)

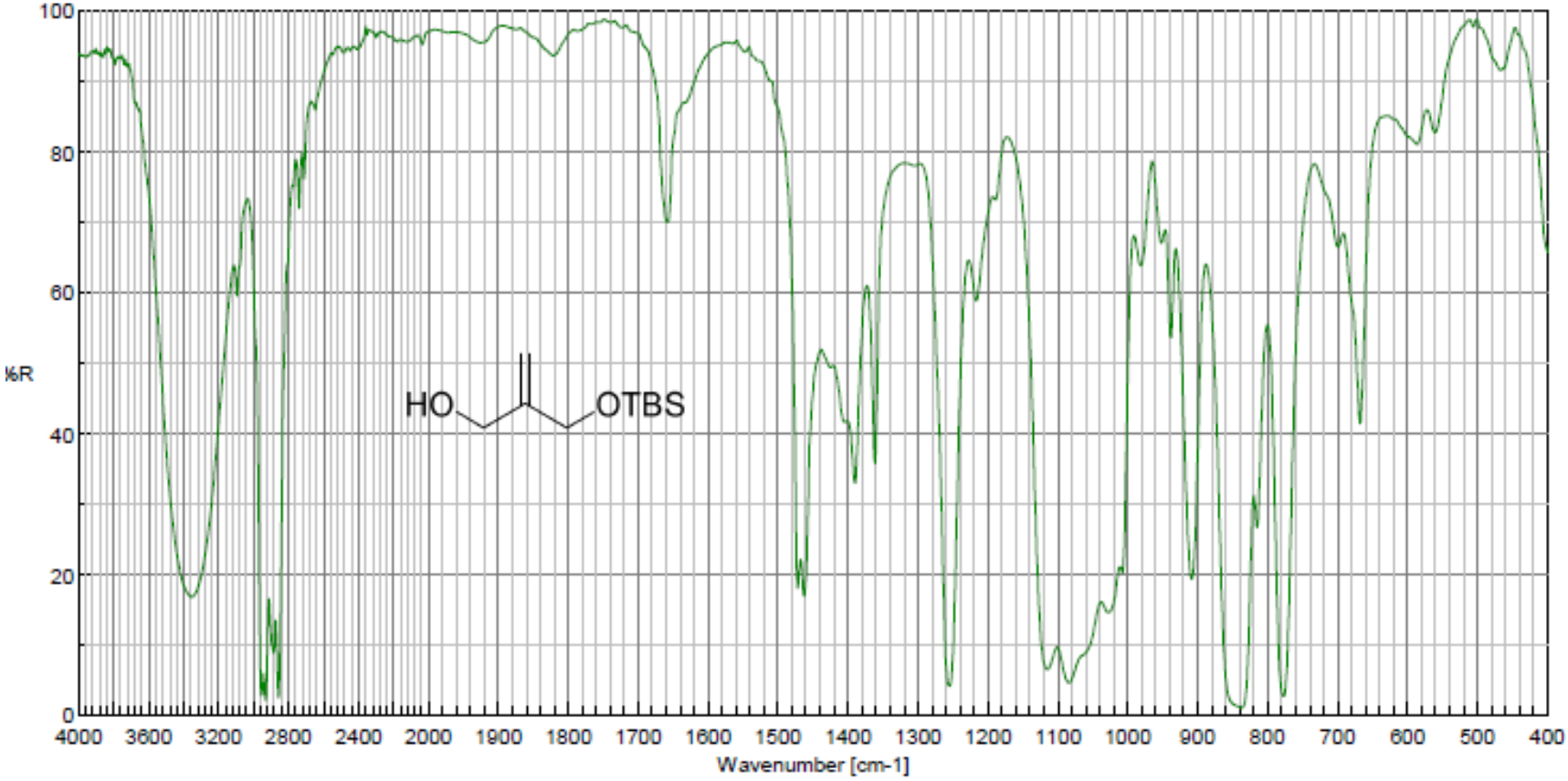

TBSO
H
Br
Br
f1 (ppm)


TBSO
H
H
f1 (ppm)

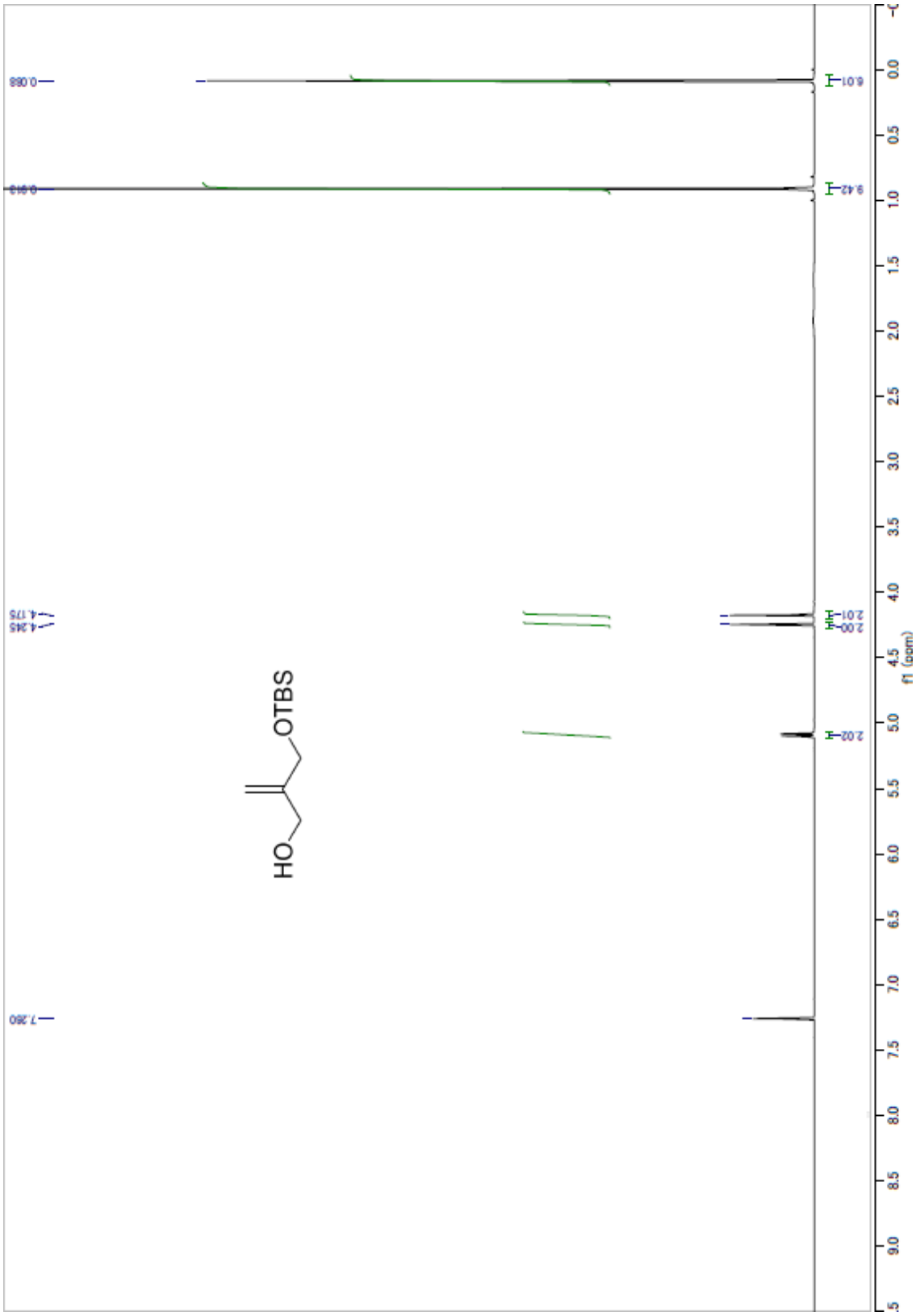

7.260
1.58
9.36
1.11
2.15
1.15
1.00
0.97
1.00
f1 (ppm)

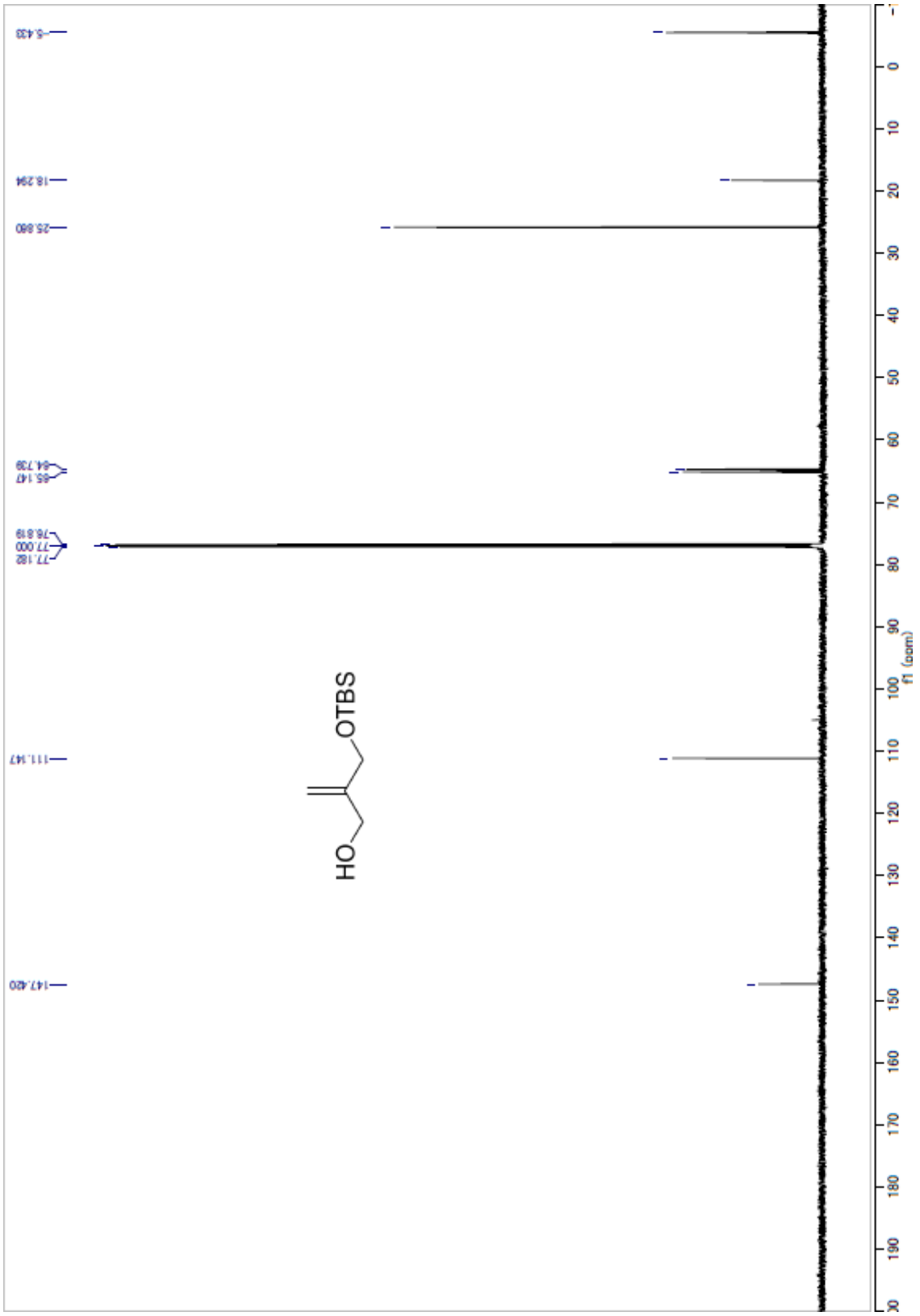

7.260
2.504
1.17
0.42
1.13
1.13
2.18
1.12
2.11
3.29
1.02
1.00
1.00
f1 (ppm)
H
O
H

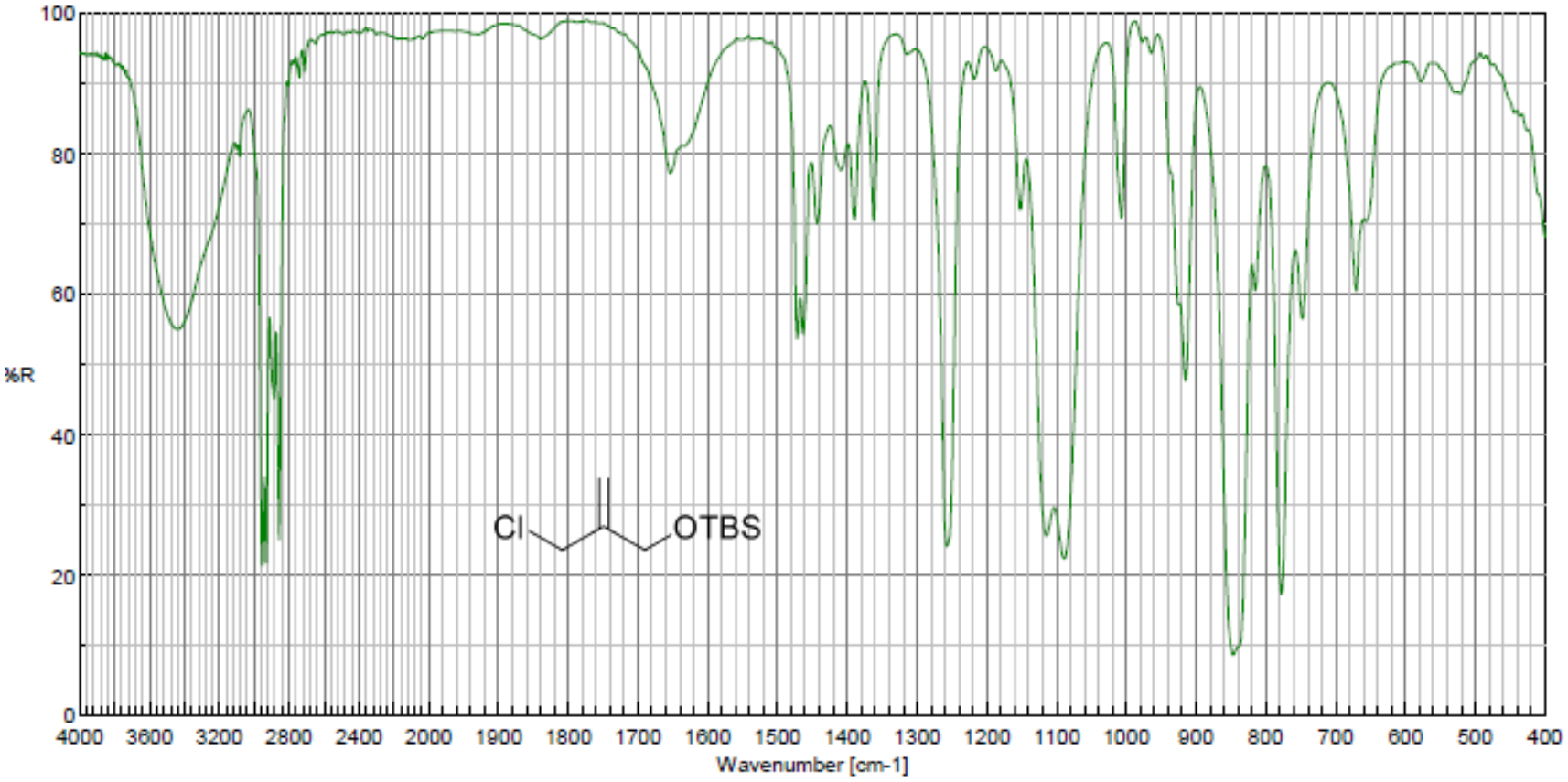

223.262
134.500
130.557
77.182
77.000
76.819
60.188
57.571
51.340
47.019
43.859
40.269
30.743
27.089
f1 (ppm)



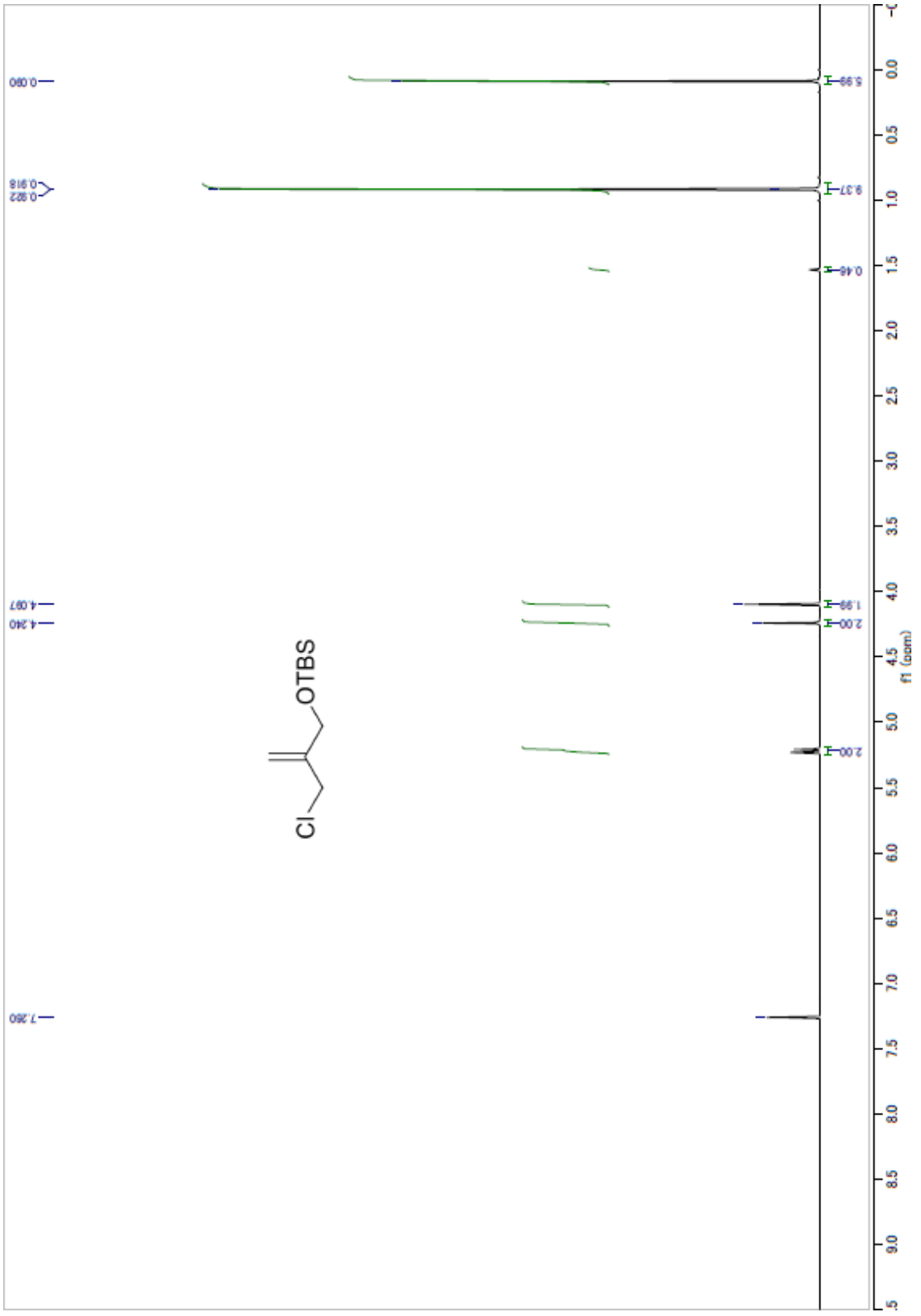
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

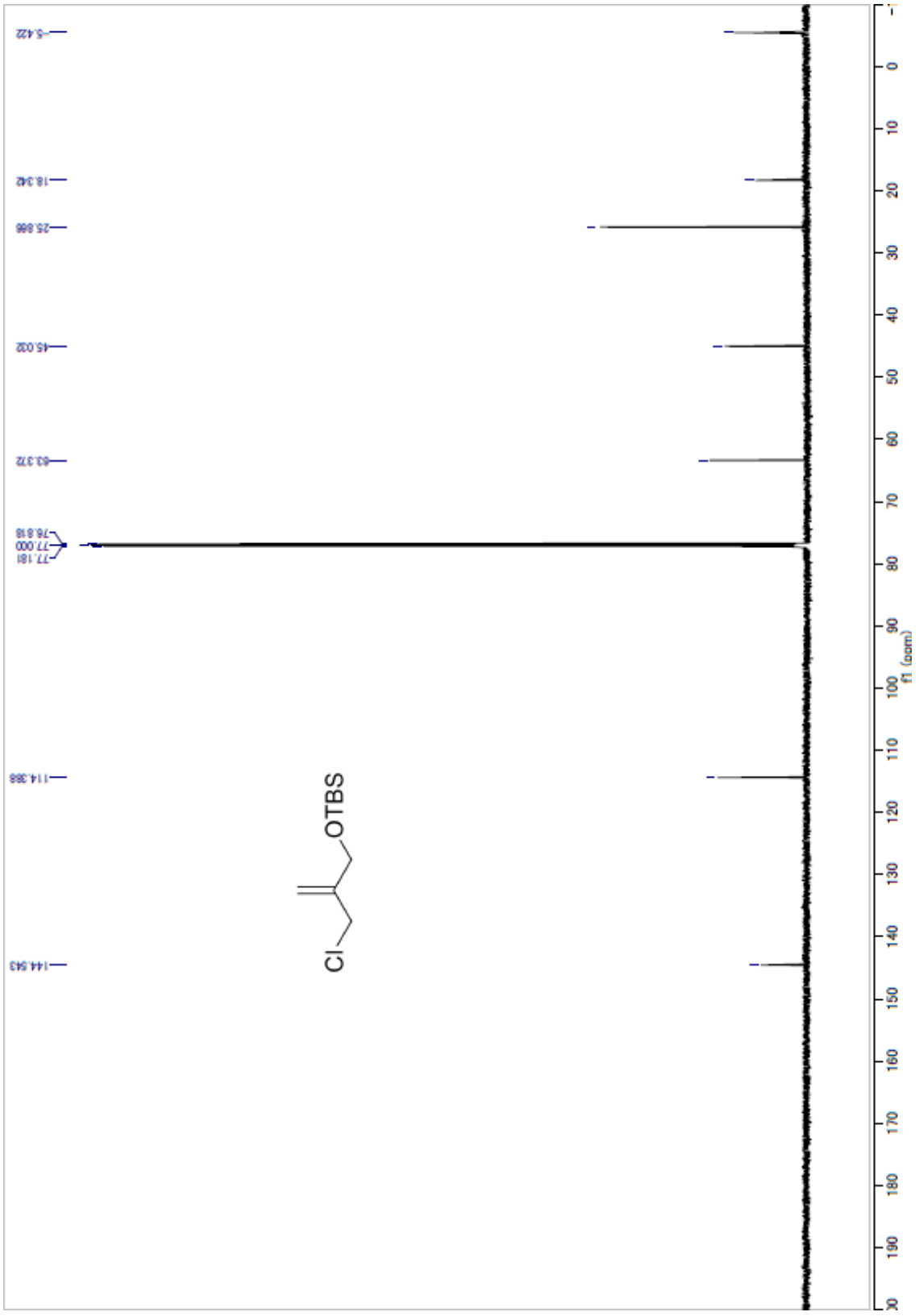

OTBS
HO
f1 (ppm)

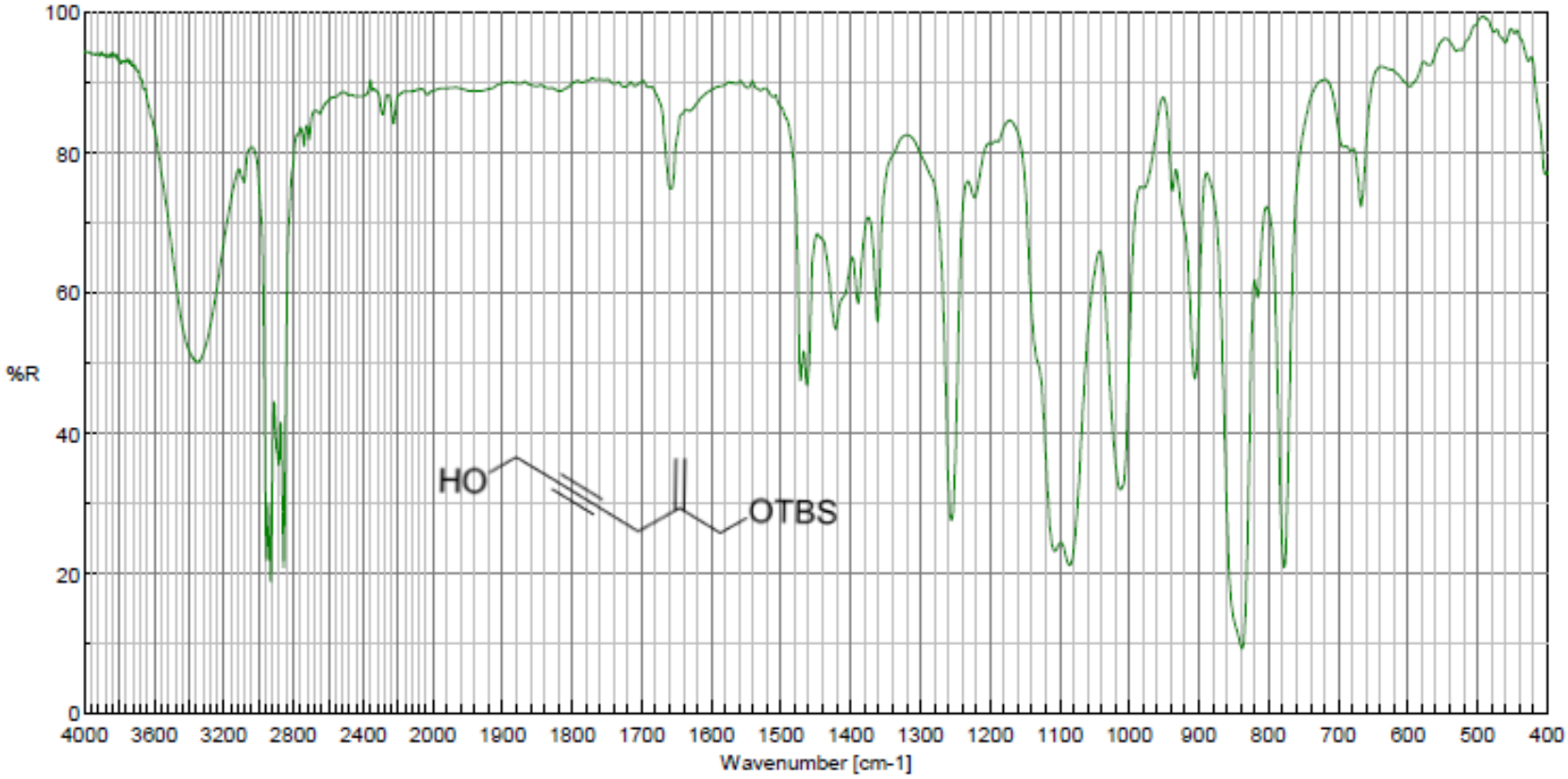

-5.420
18.294
25.880
64.739
65.147
77.182
77.000
76.819
111.147
147.420
HO
OTBS
f1 (ppm)



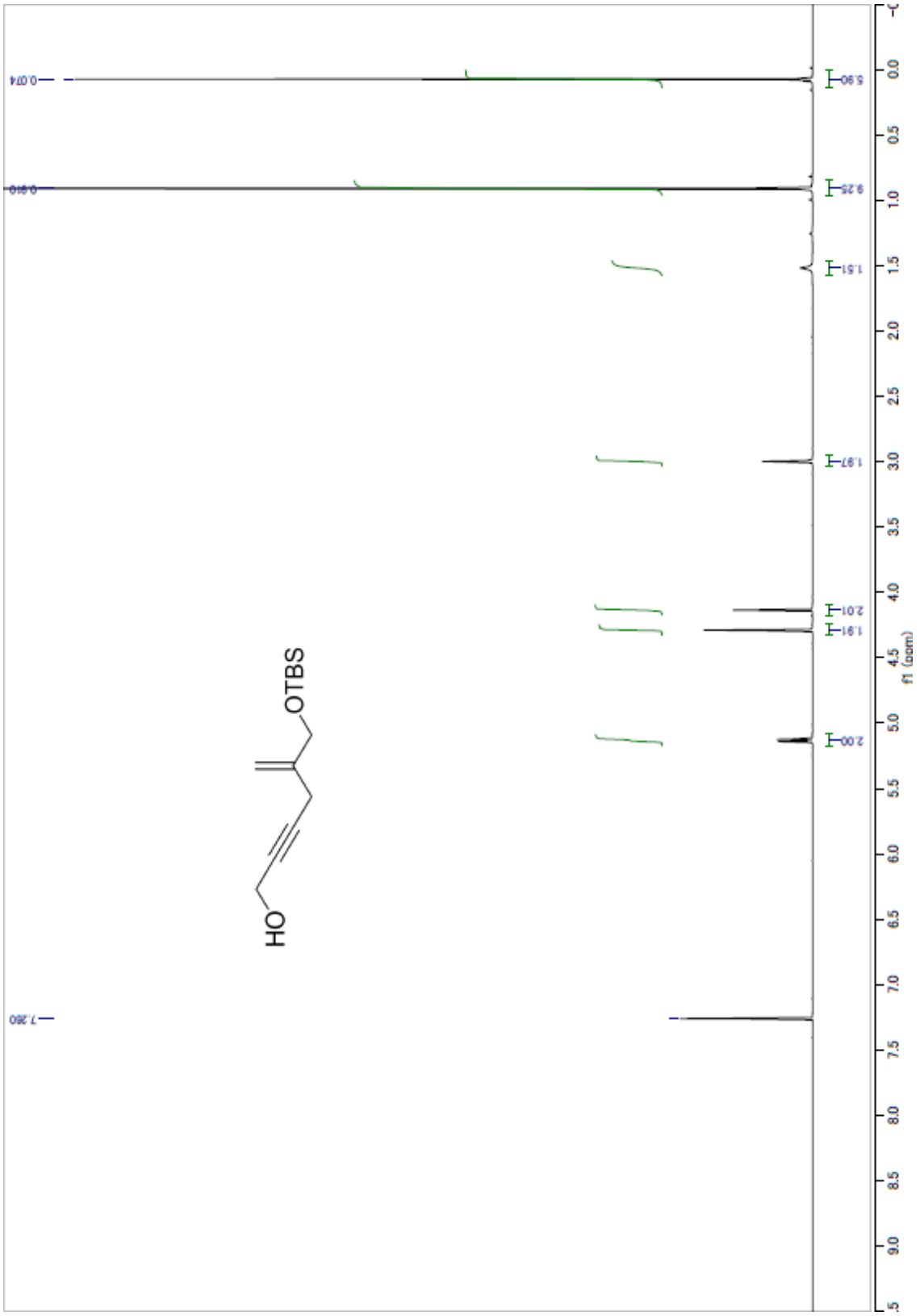
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

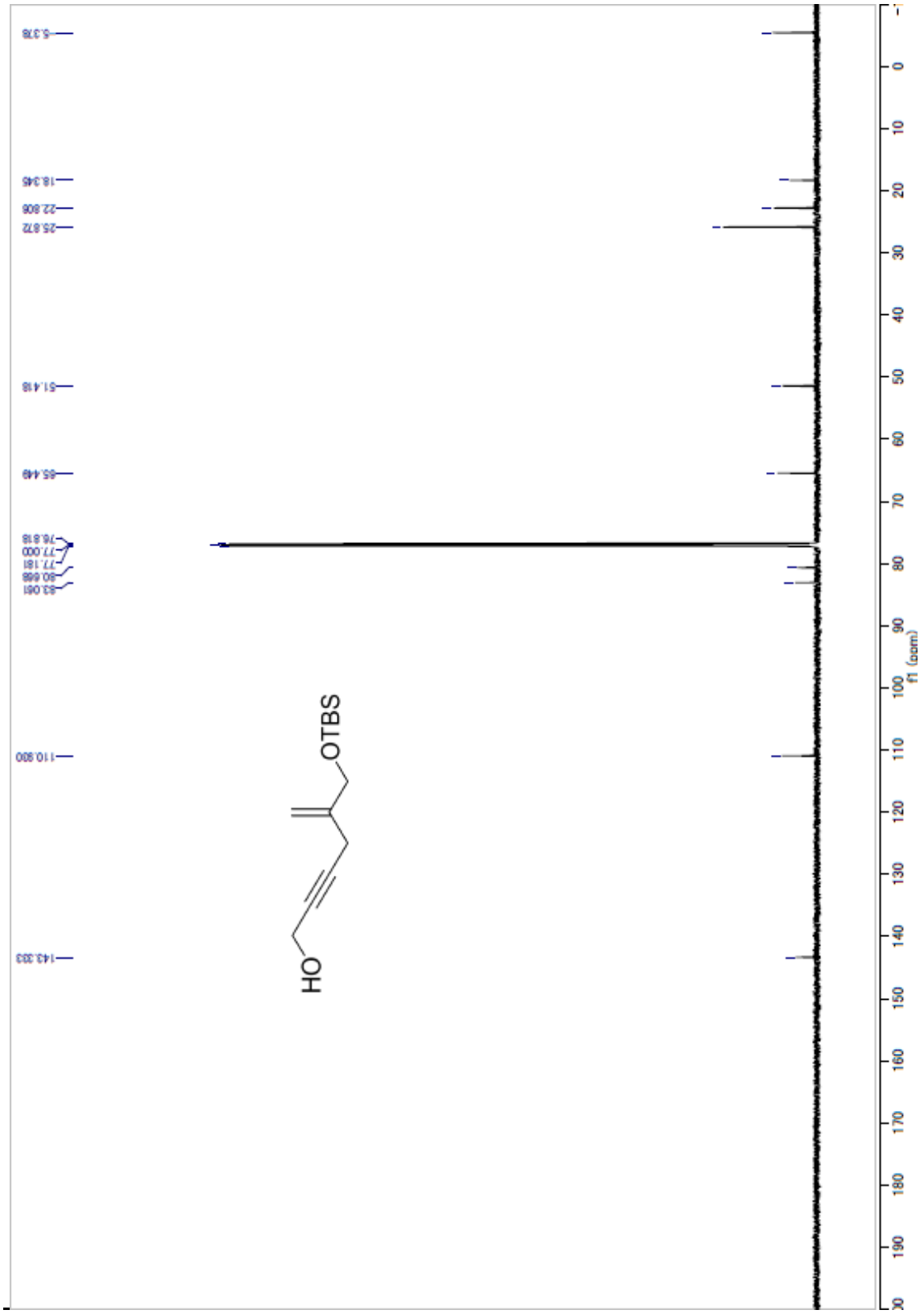

OTBS
Cl
f1 (ppm)

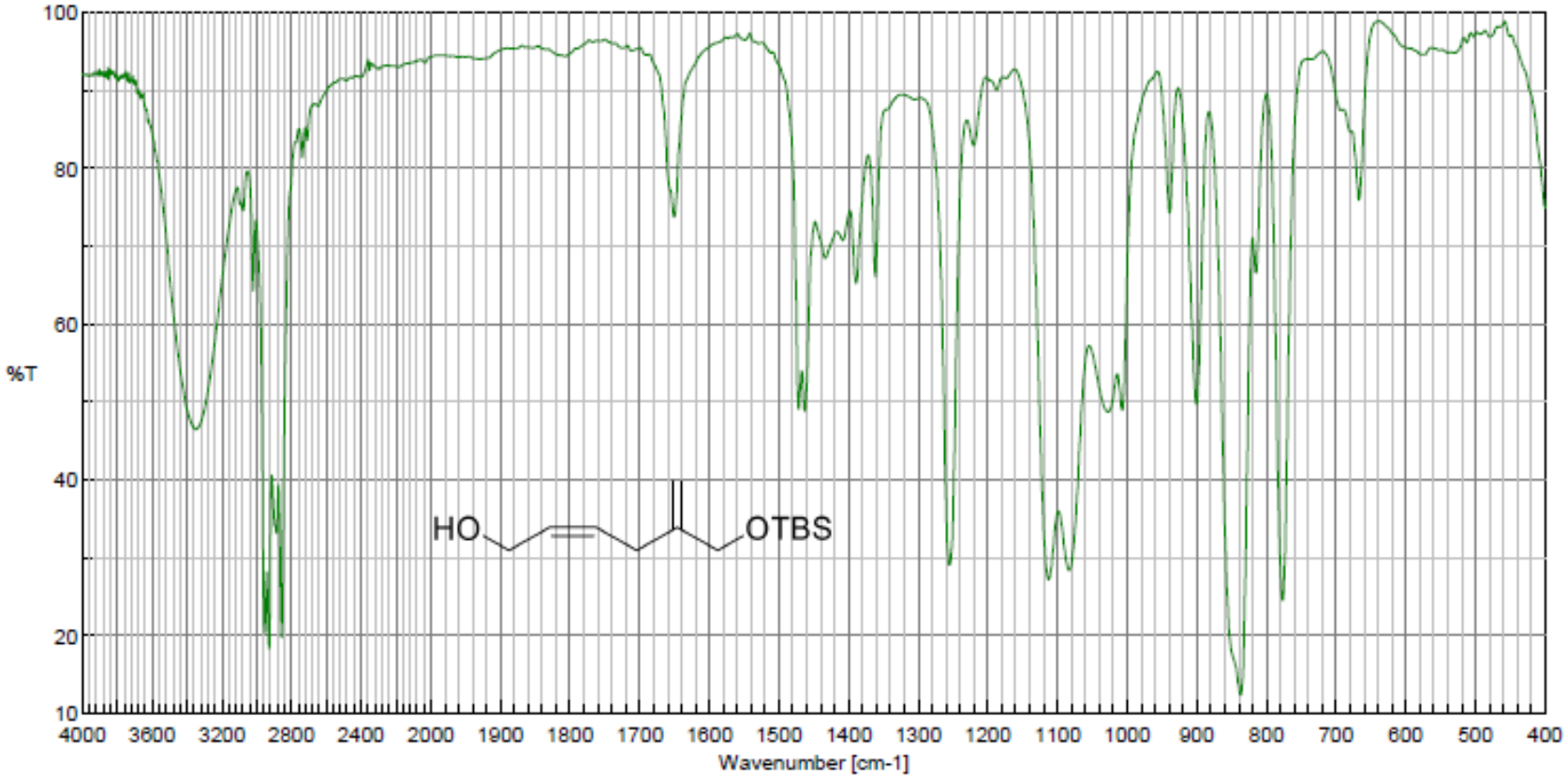

-5.422
18.342
25.886
45.022
63.372
76.818
77.000
77.181
114.388
144.043
OTBS
Cl
f1 (ppm)



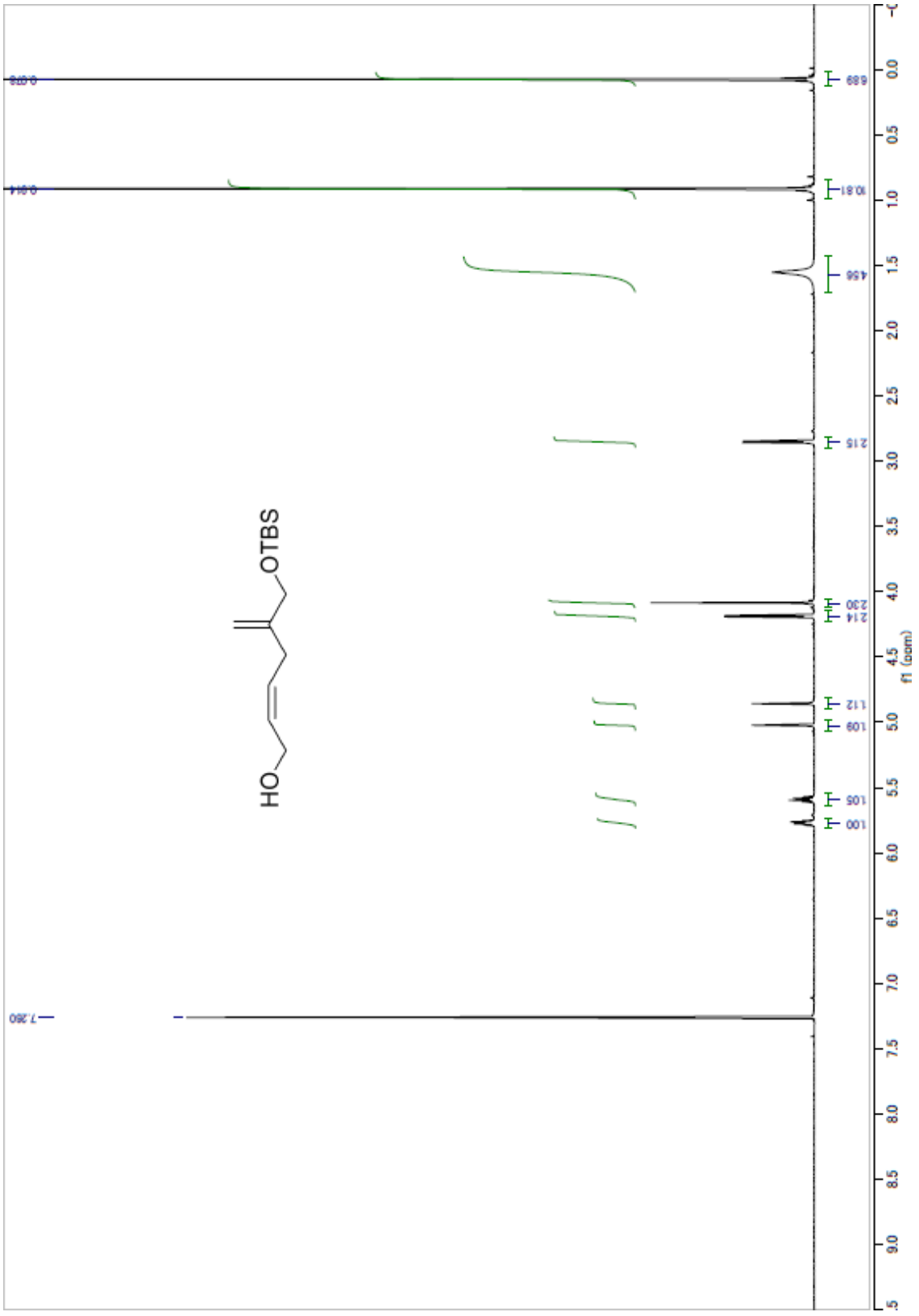
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

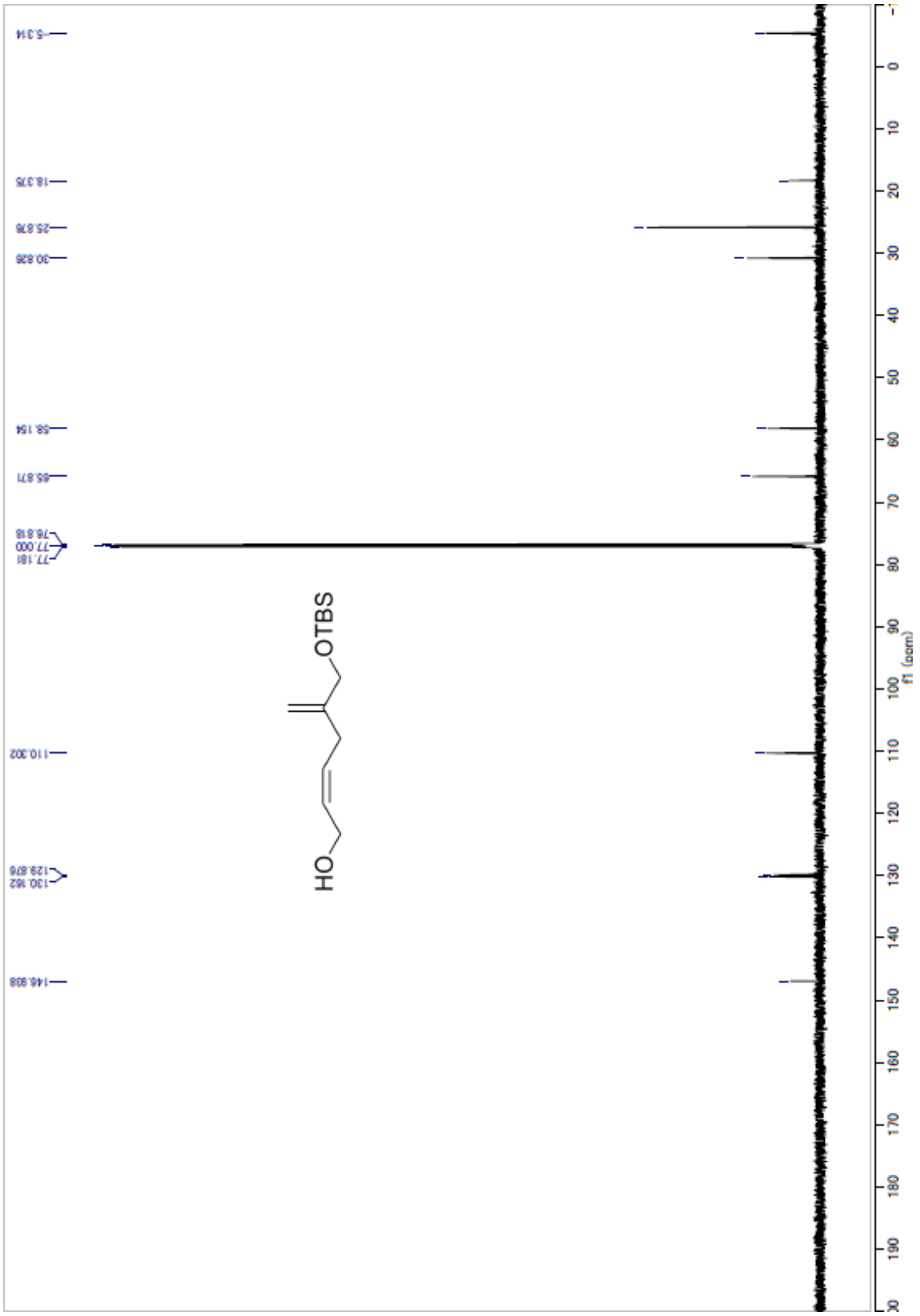

OTBS
HO
7.260
0.874
0.074
5.90
9.25
1.51
1.97
2.01
1.91
2.00
f1 (ppm)

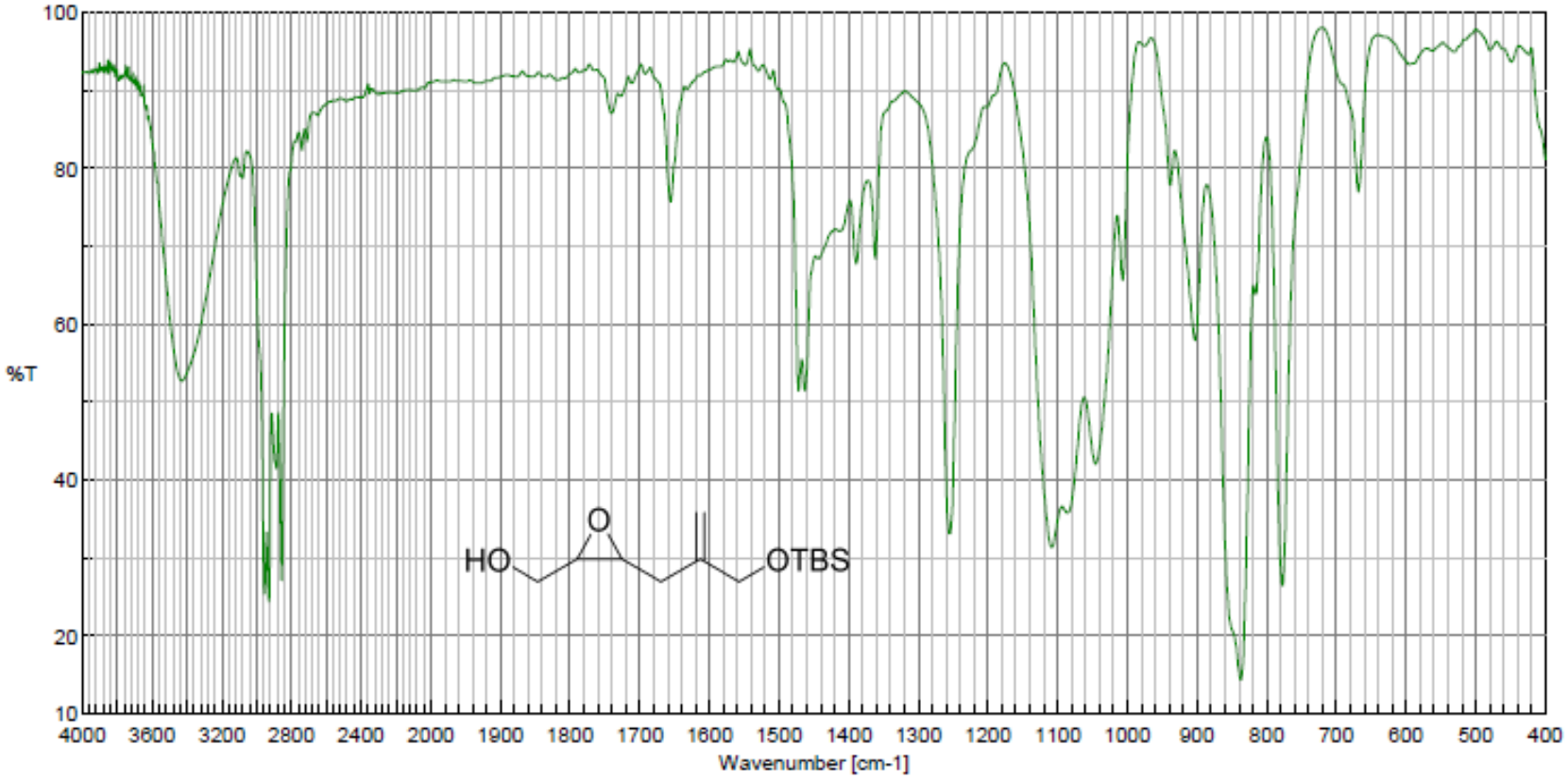

-5.378
18.346
22.806
25.872
51.418
65.449
76.818
77.000
77.181
80.668
83.061
110.800
143.333
OTBS
HO
f1 (ppm)



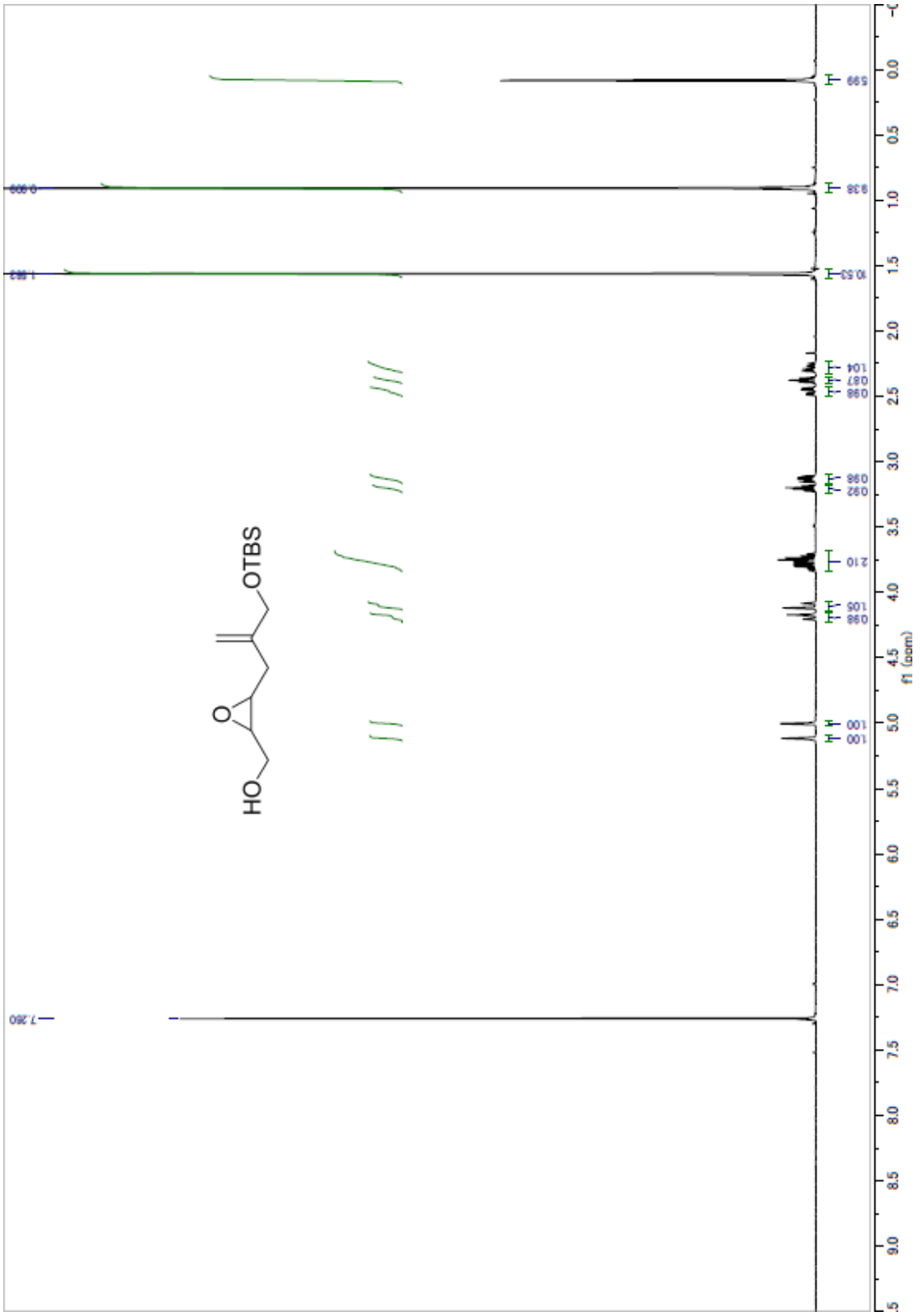
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

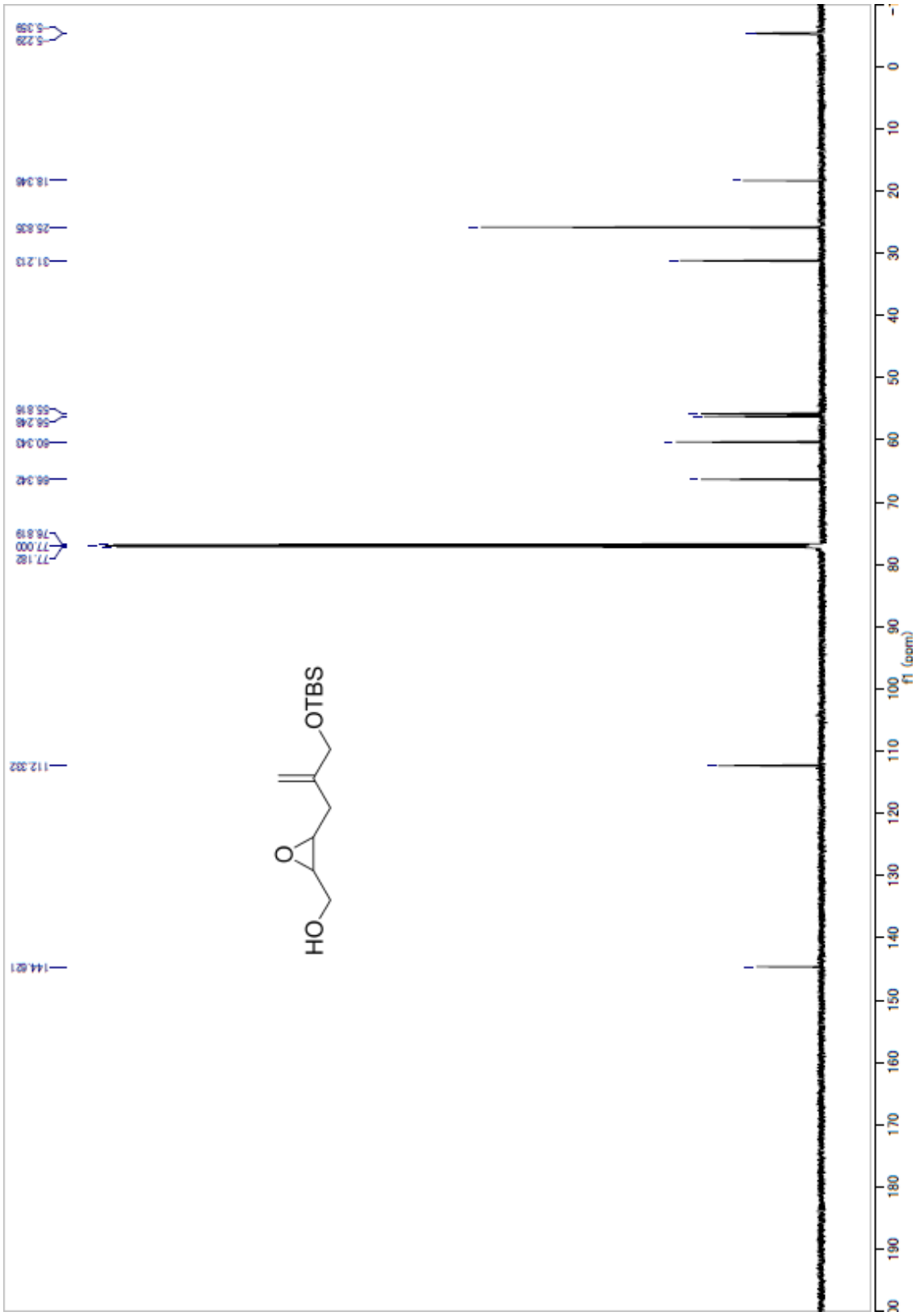

OTBS
HO
f1 (ppm)

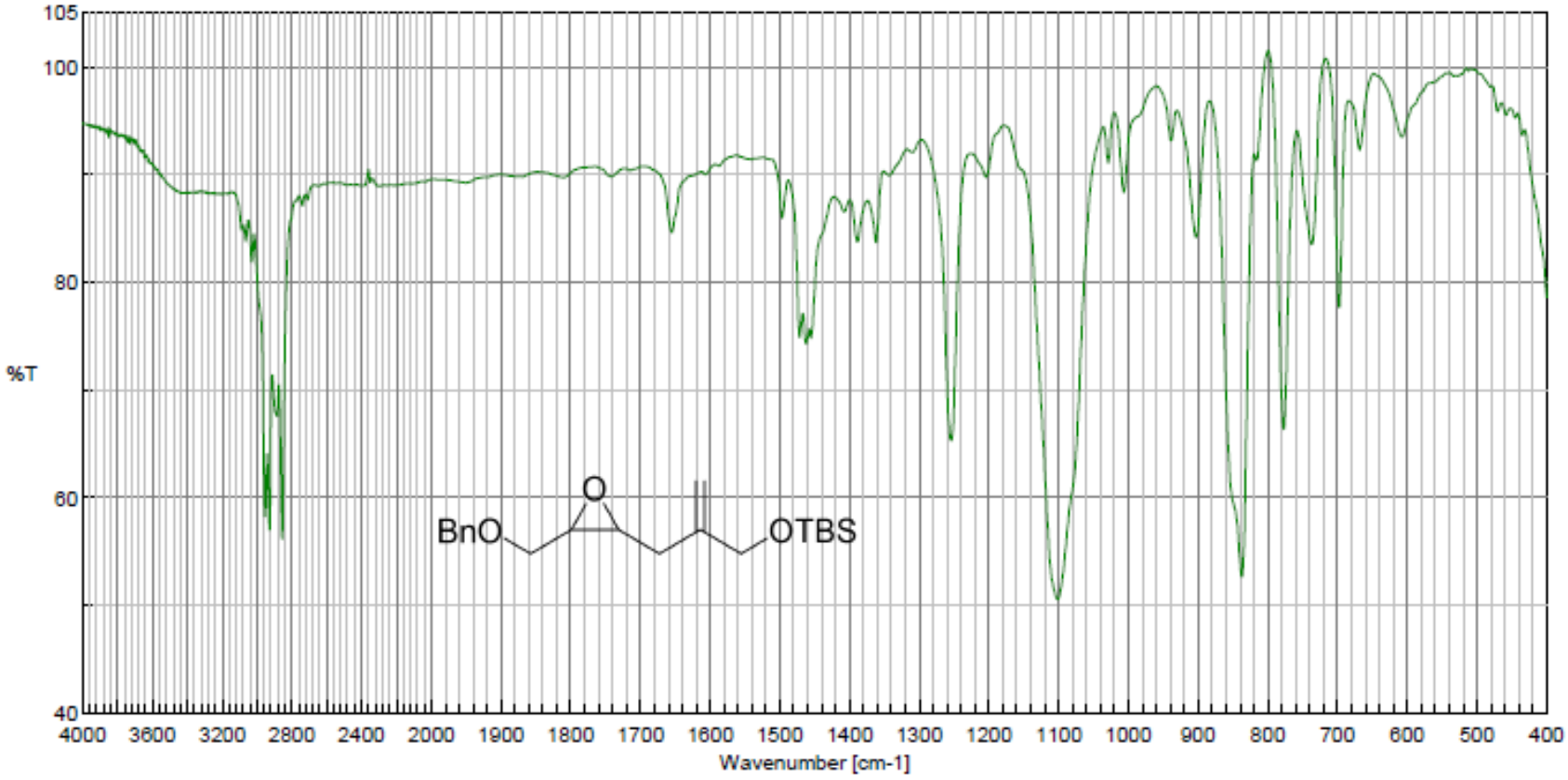

-5.314
18.375
25.878
30.826
58.154
65.871
76.818
77.000
77.181
110.302
129.876
130.162
146.808
OTBS
HO
f1 (ppm)



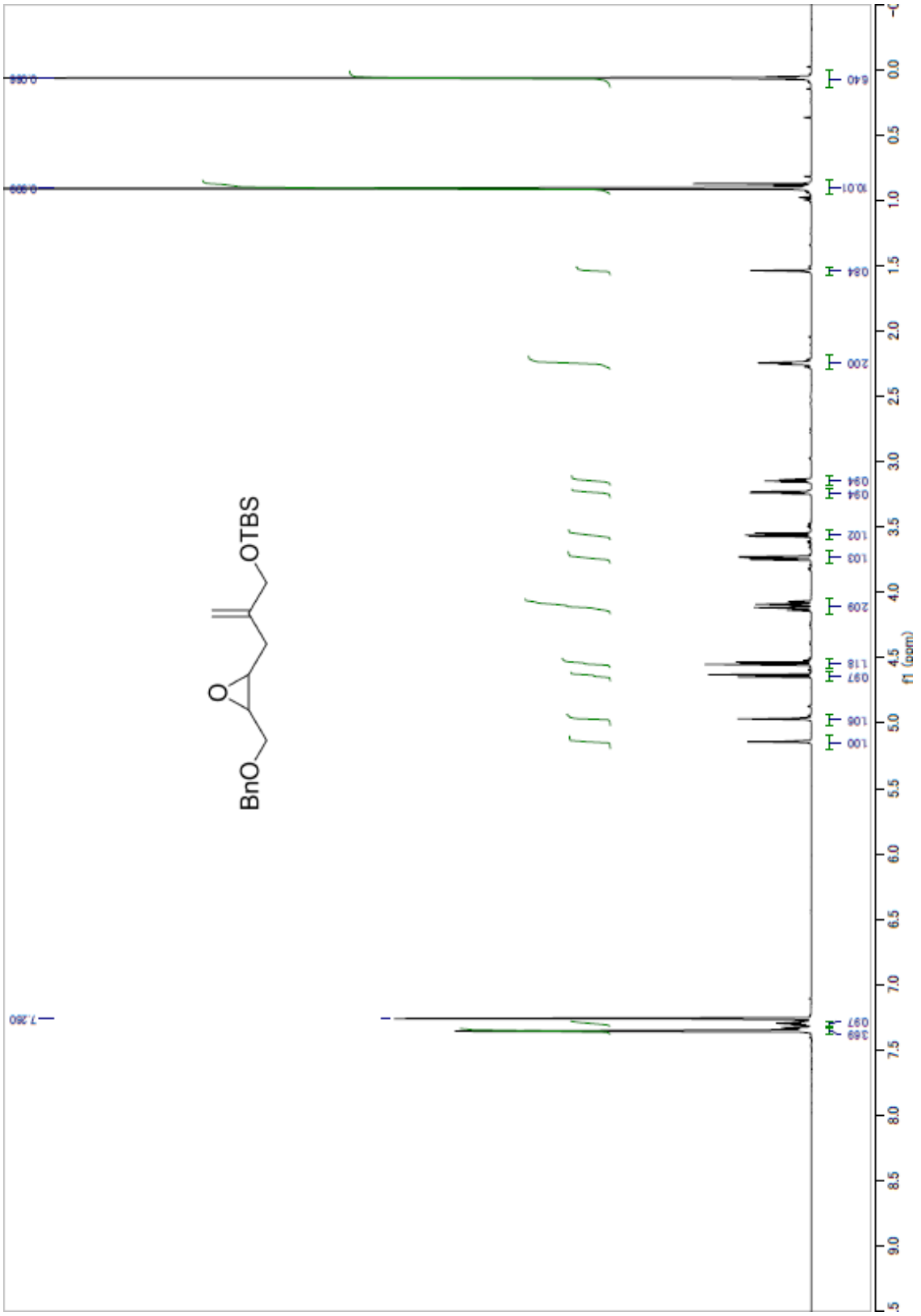
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

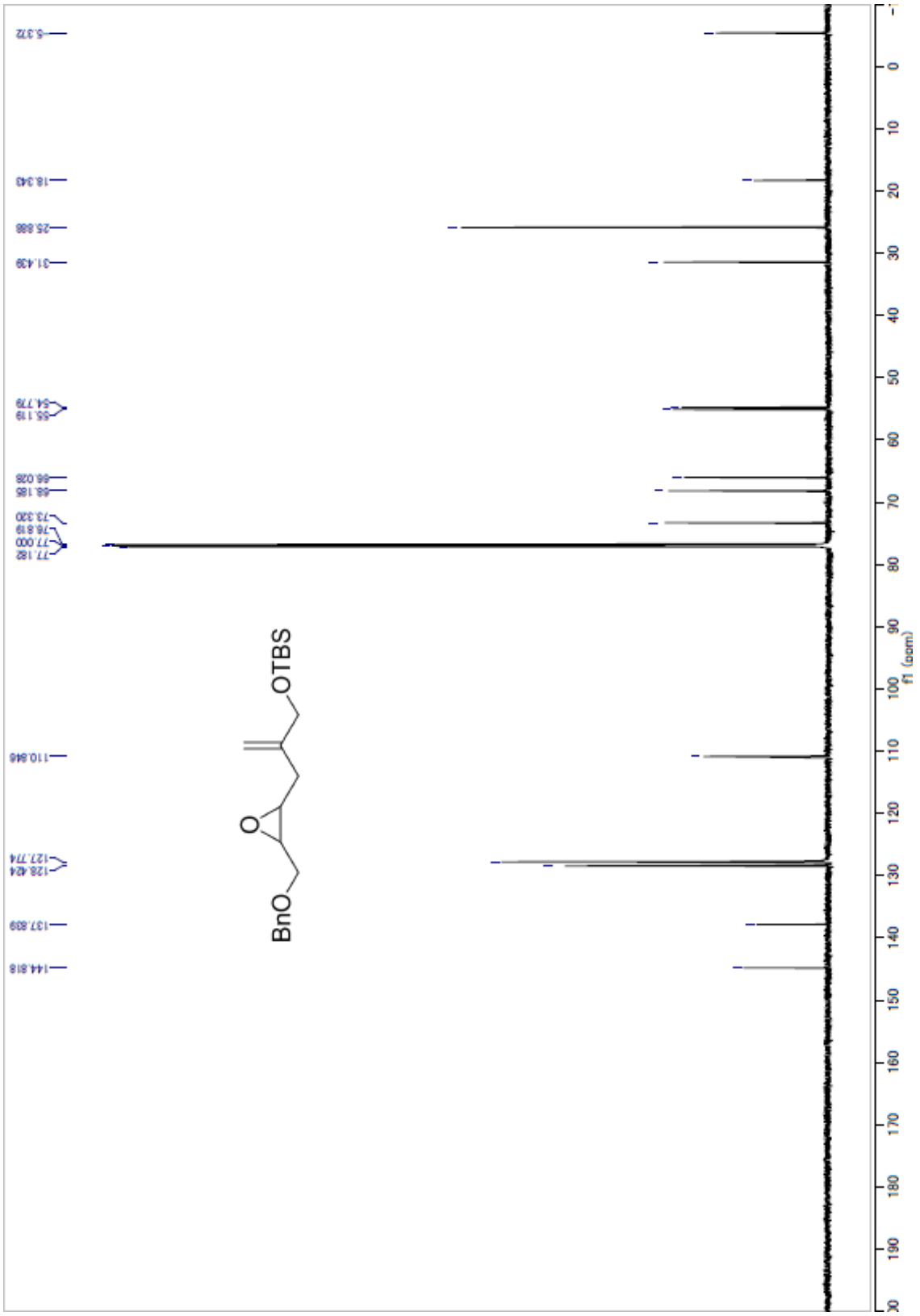

OTBS
HO
O
f1 (ppm)

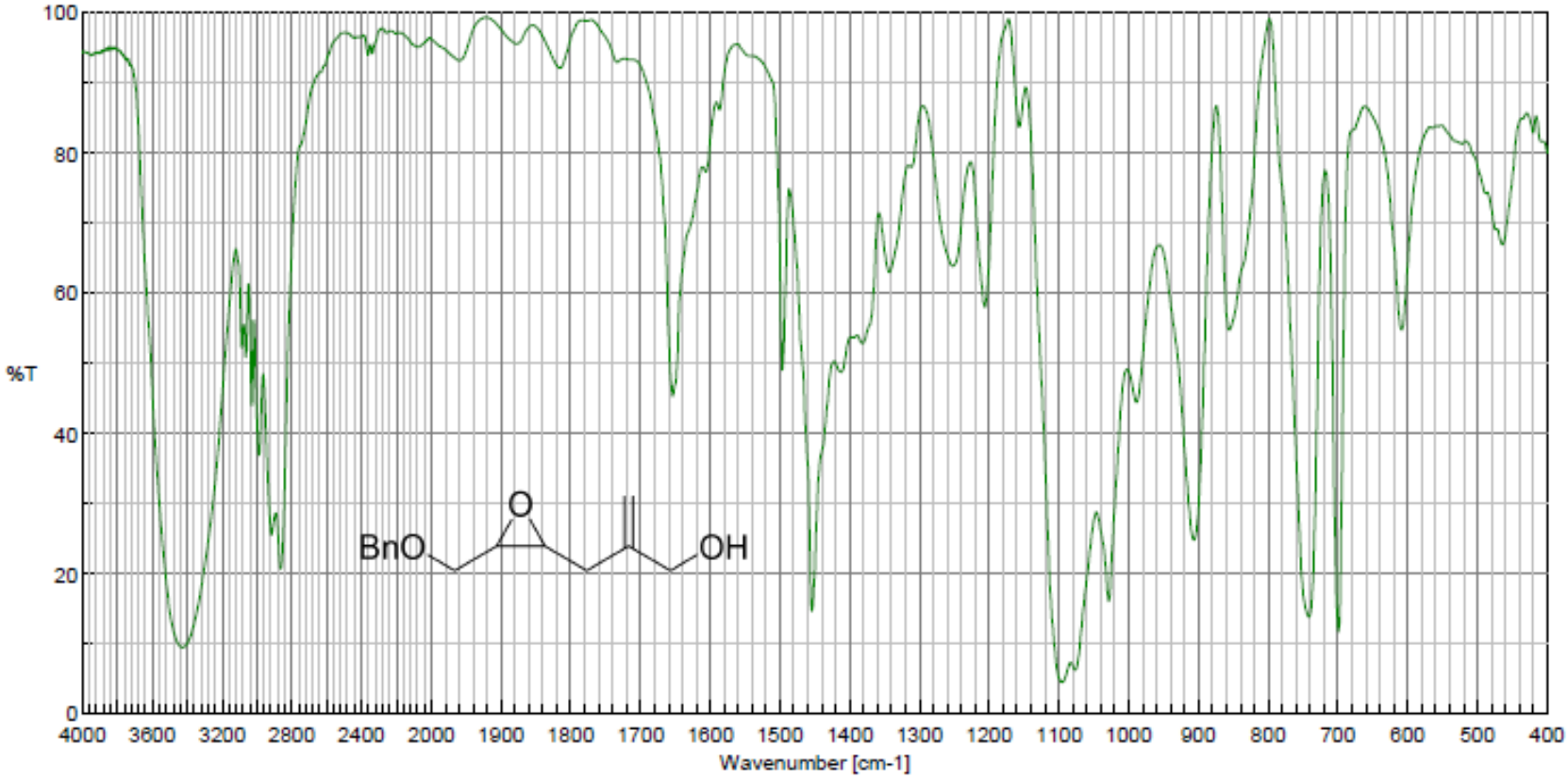

-5.359
-5.229
18.346
25.835
31.213
55.816
56.246
60.340
66.342
76.819
77.000
77.182
112.332
144.021
OTBS
HO
O
f1 (ppm)



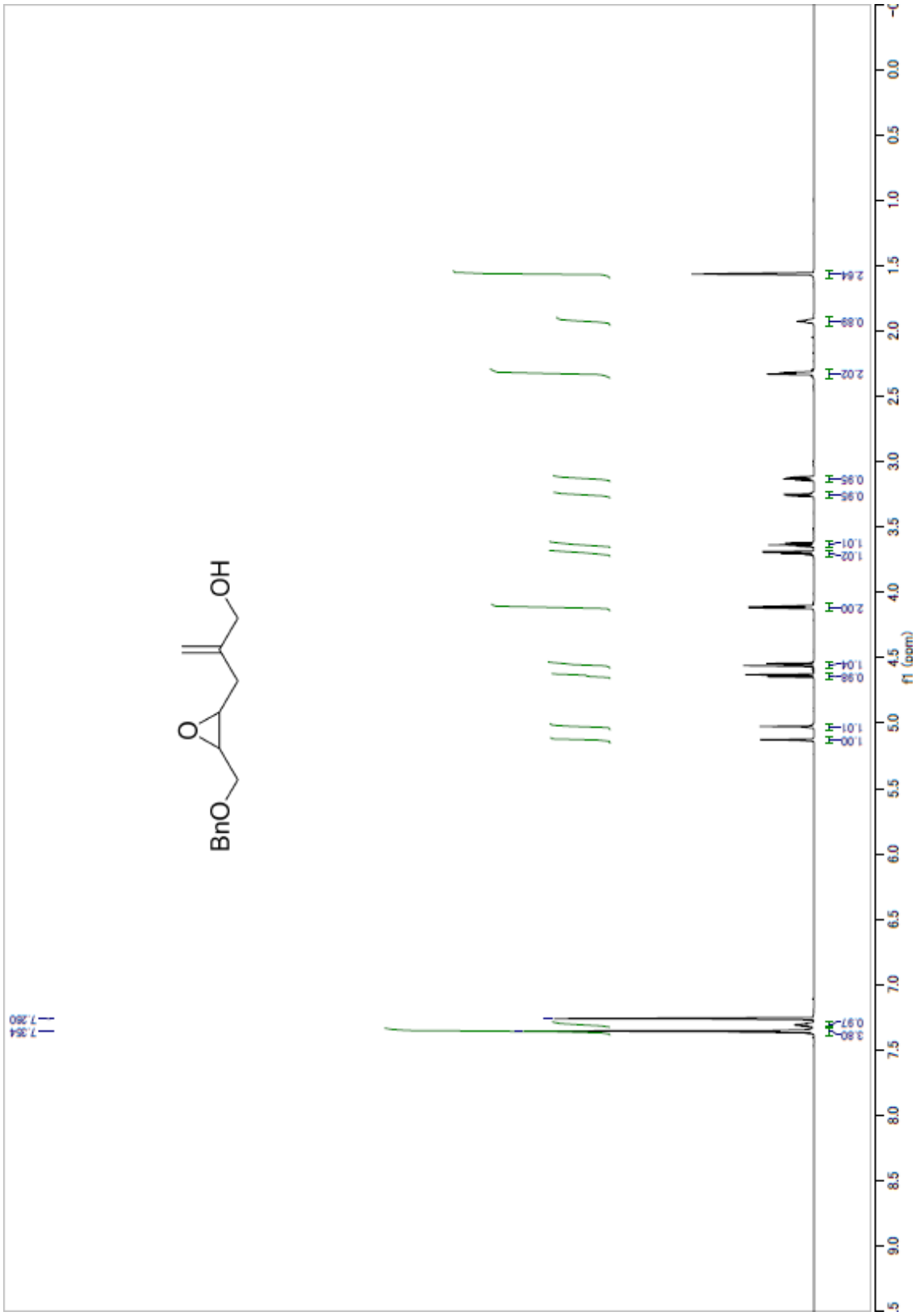
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

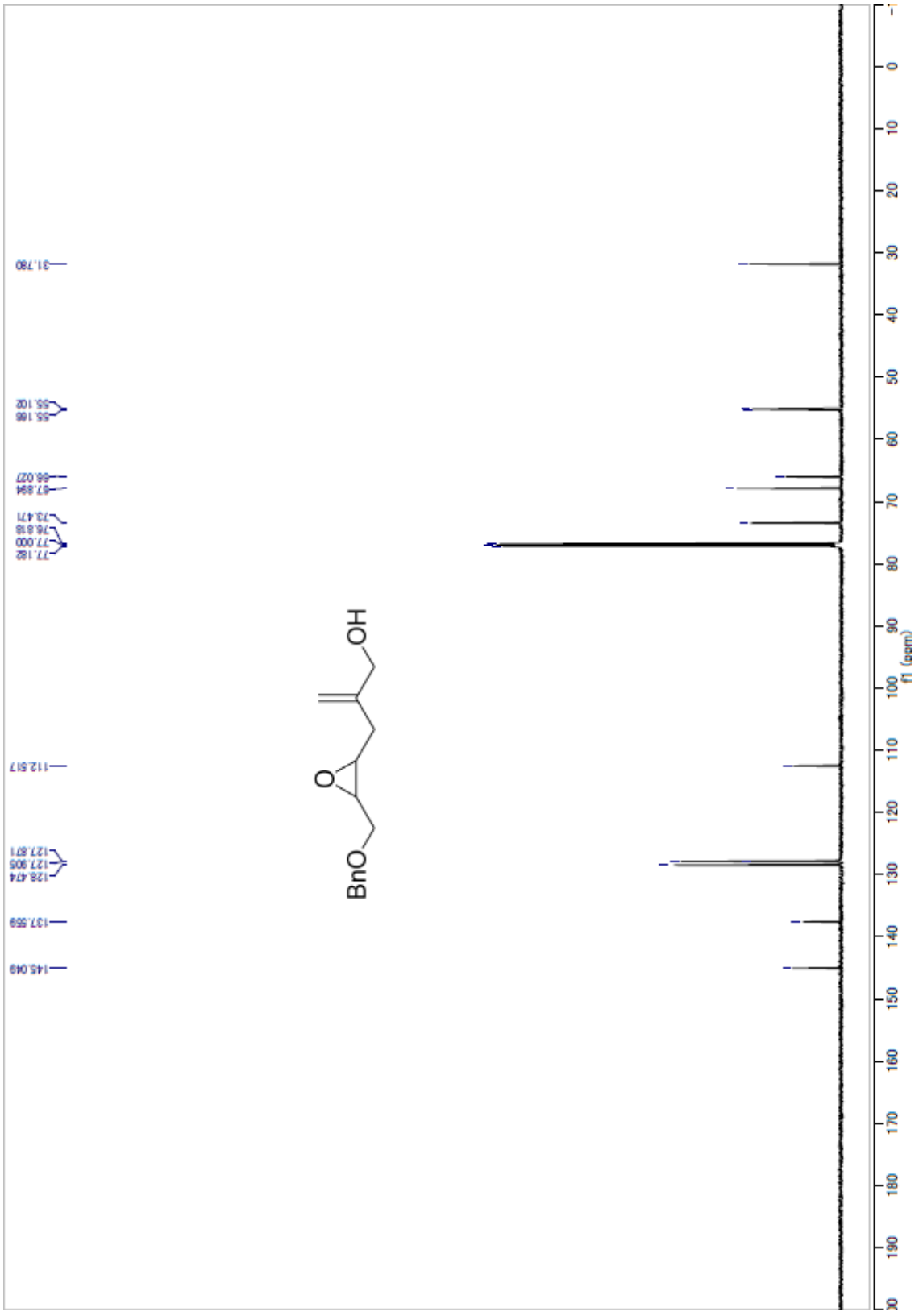

OTBS
BnO
O
f1 (ppm)

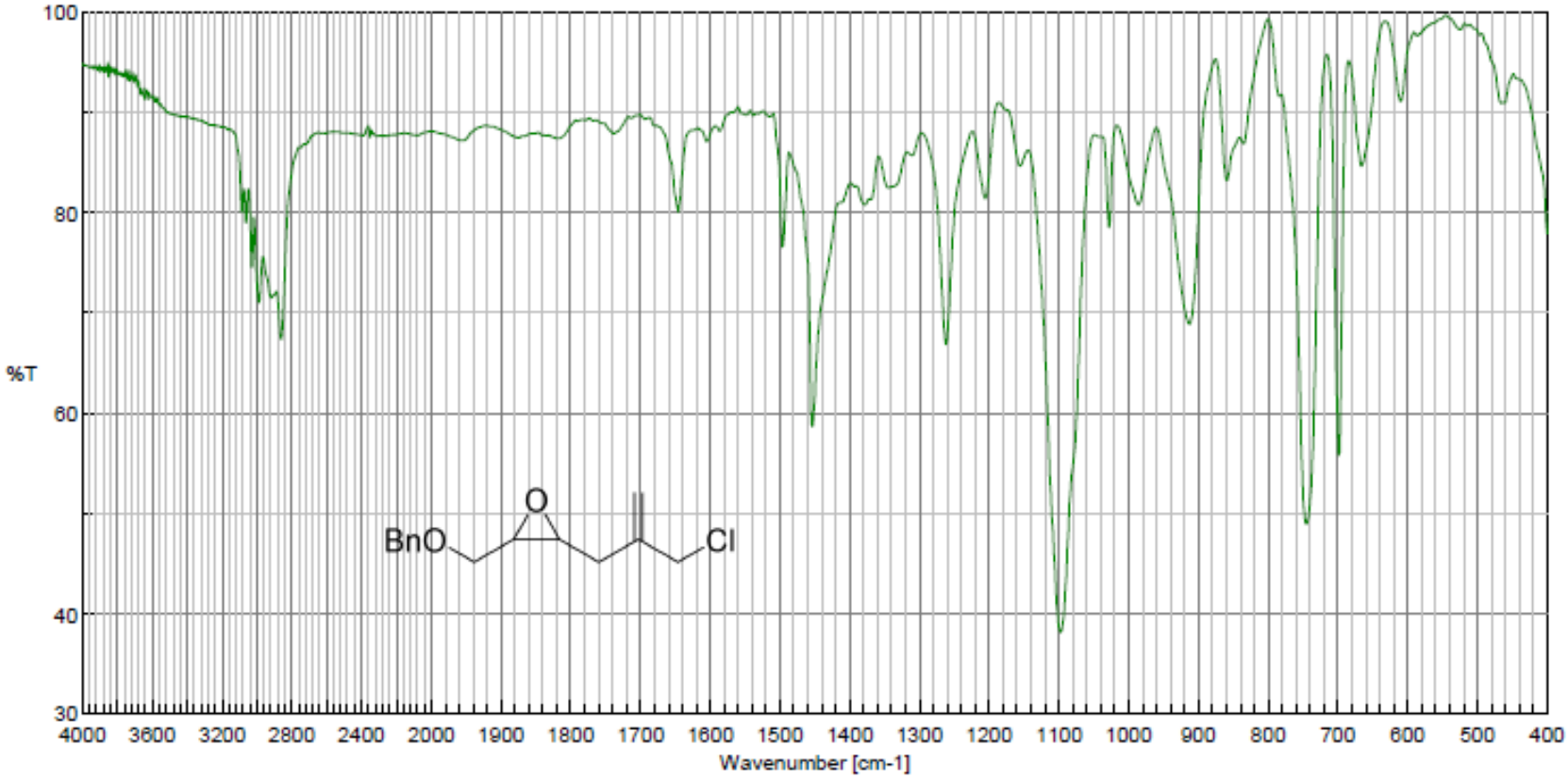

-5.372
18.343
25.888
31.439
55.119
54.779
66.028
66.185
73.320
76.819
77.000
77.182
110.846
127.774
128.424
137.809
144.818
OTBS
BnO
O
f1 (ppm)



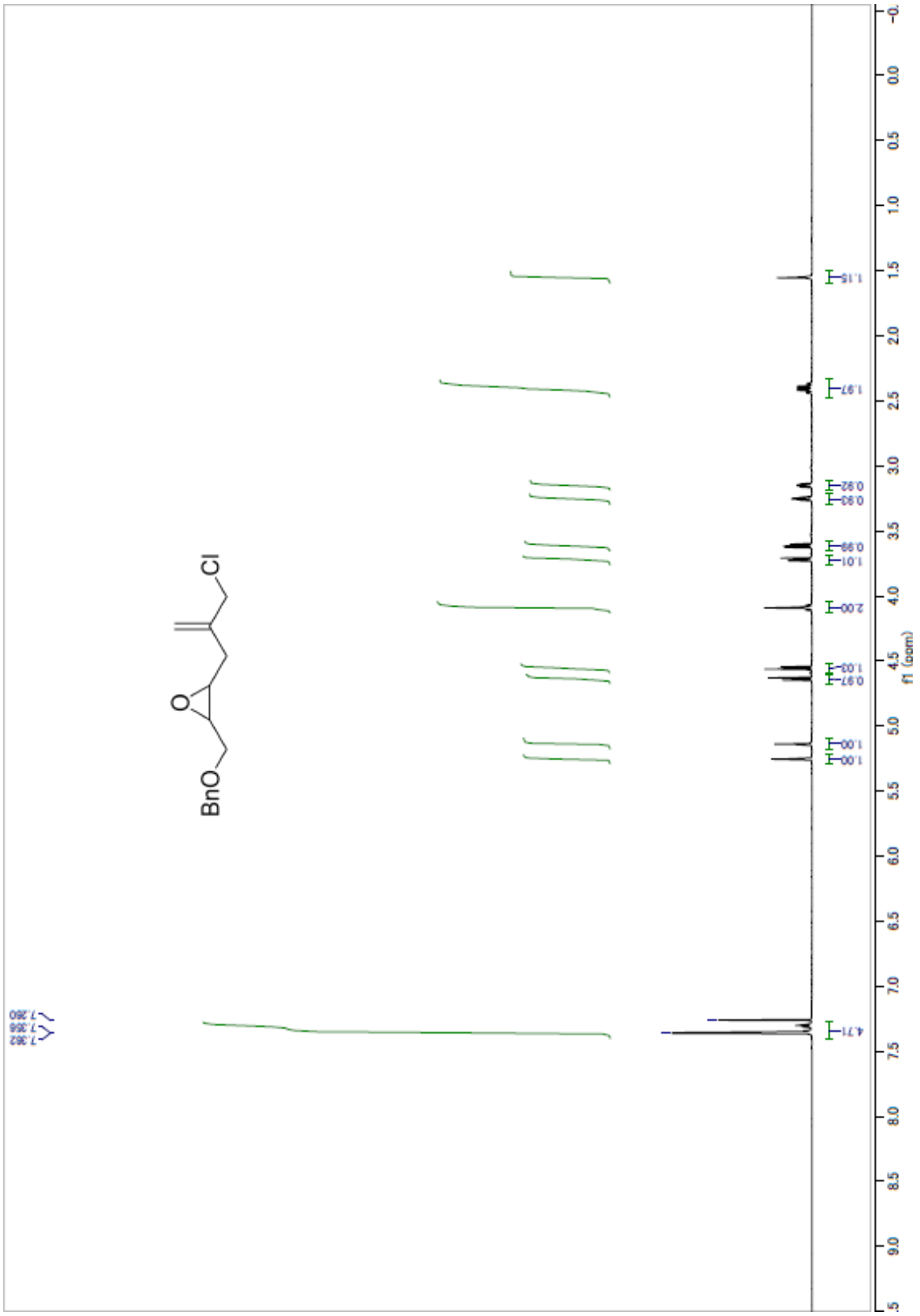
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

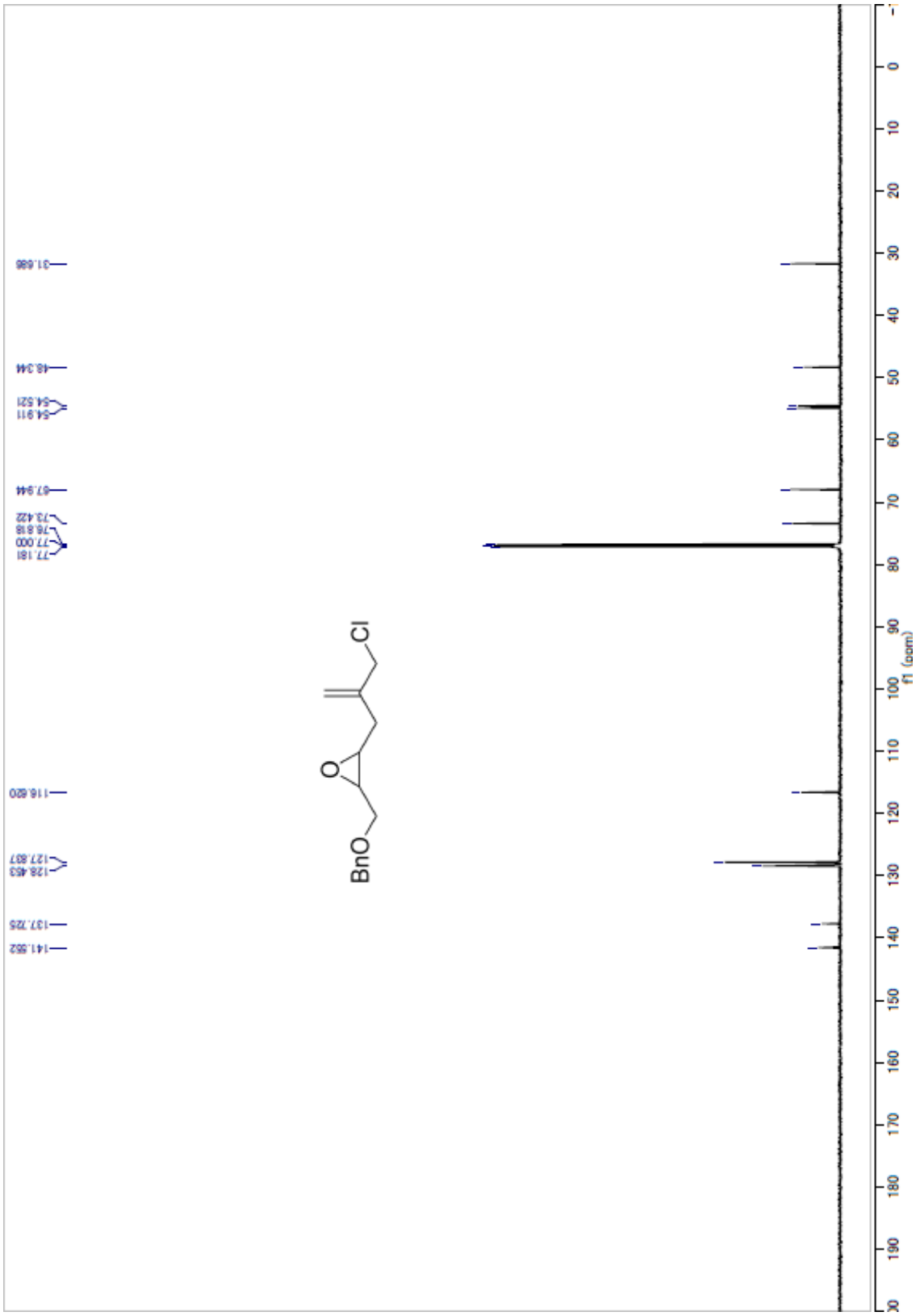

OH
O
BnO
7.364
7.280
2.64
0.89
2.02
0.95
0.95
1.01
1.02
2.00
0.98
1.04
1.00
1.01
3.80
0.97
f1 (ppm)

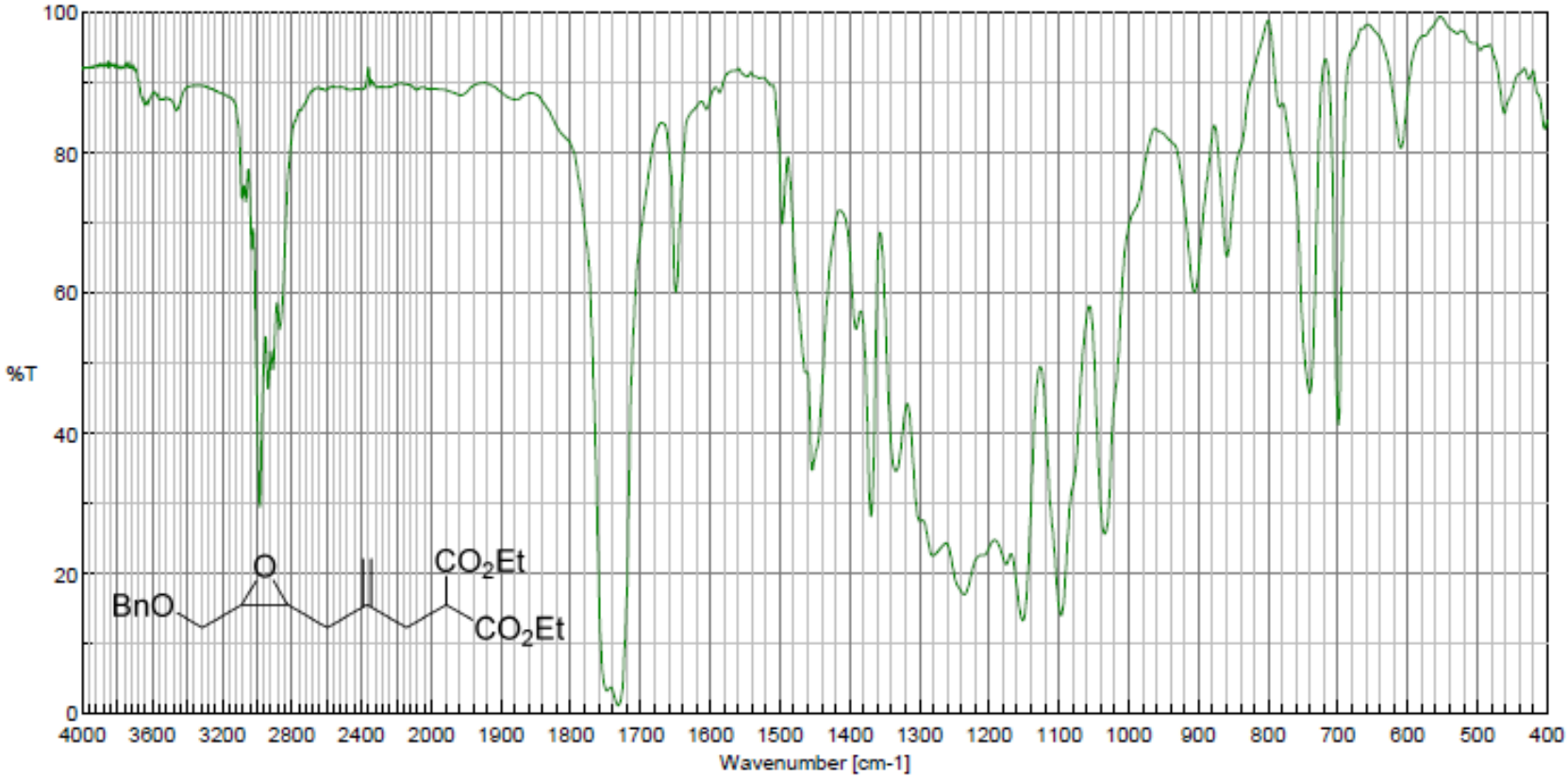

OH
O
BnO
f1 (ppm)



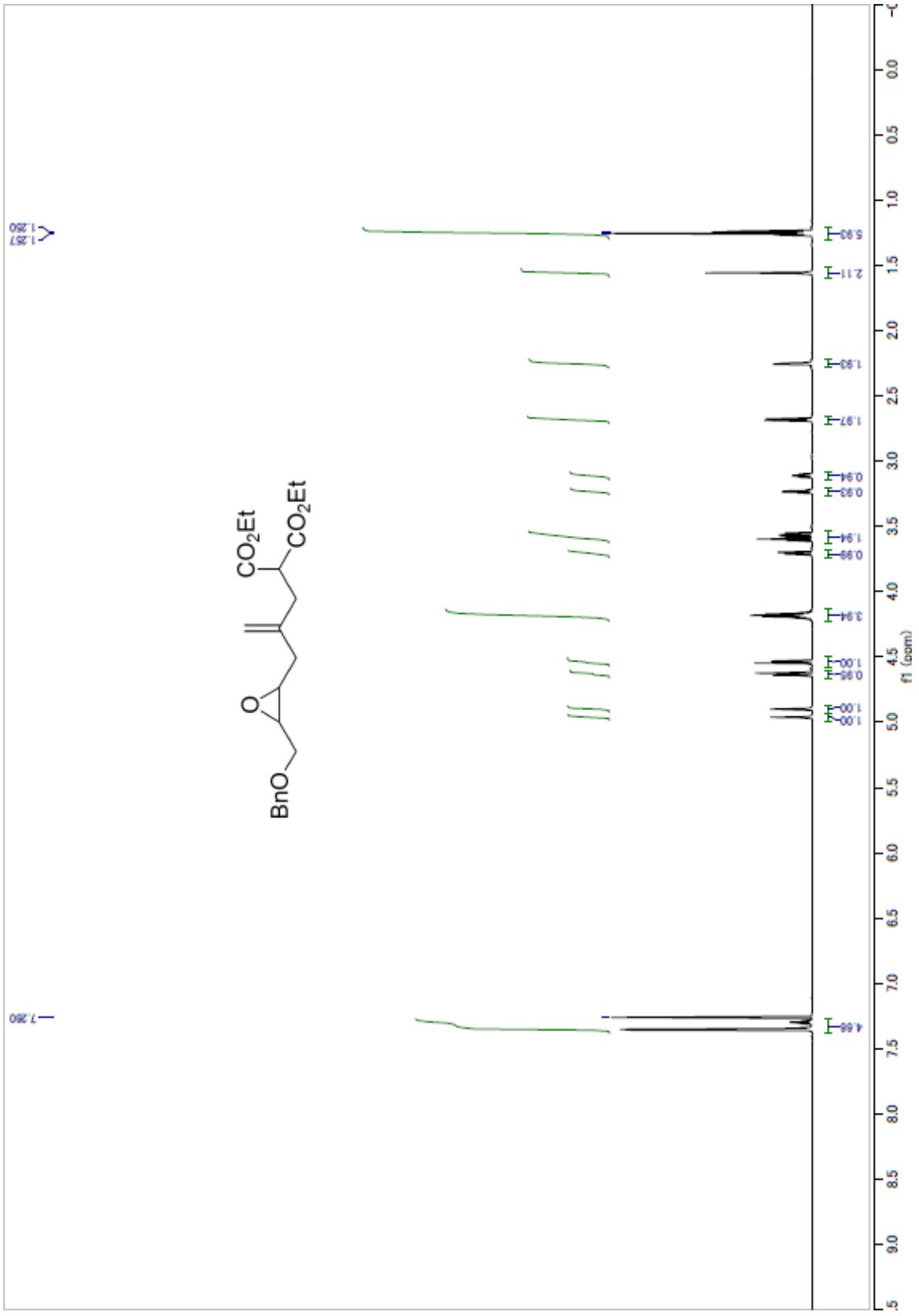
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

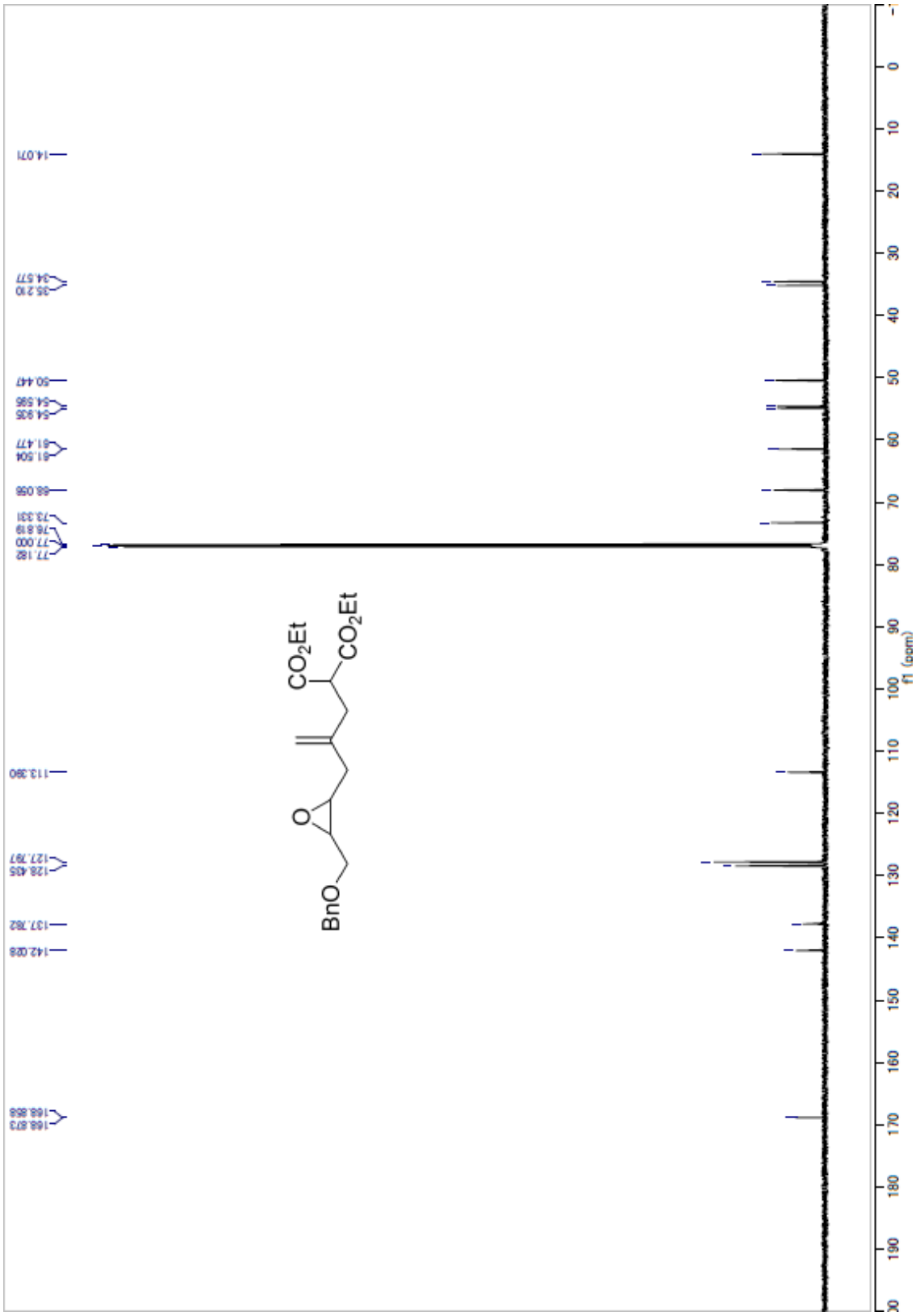

BnO
Cl
7.362
7.358
7.360
4.71
1.00
1.00
0.97
1.00
2.00
1.01
0.99
0.80
0.92
1.97
1.15
f1 (ppm)

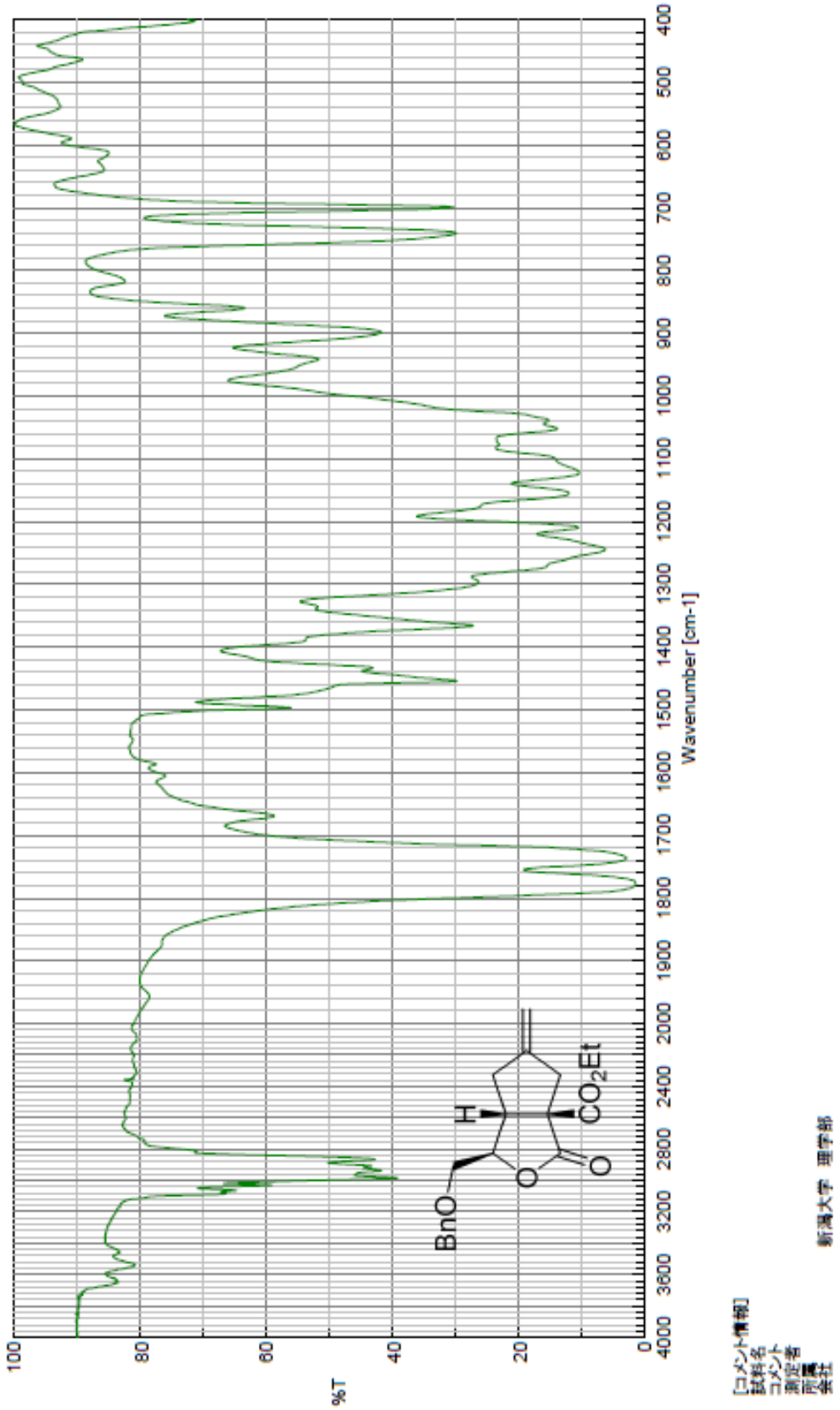

31.686
48.344
54.911
54.521
67.944
73.422
76.818
77.000
77.181
116.820
127.807
128.453
137.725
141.552
Cl
O
BnO
f1 (ppm)

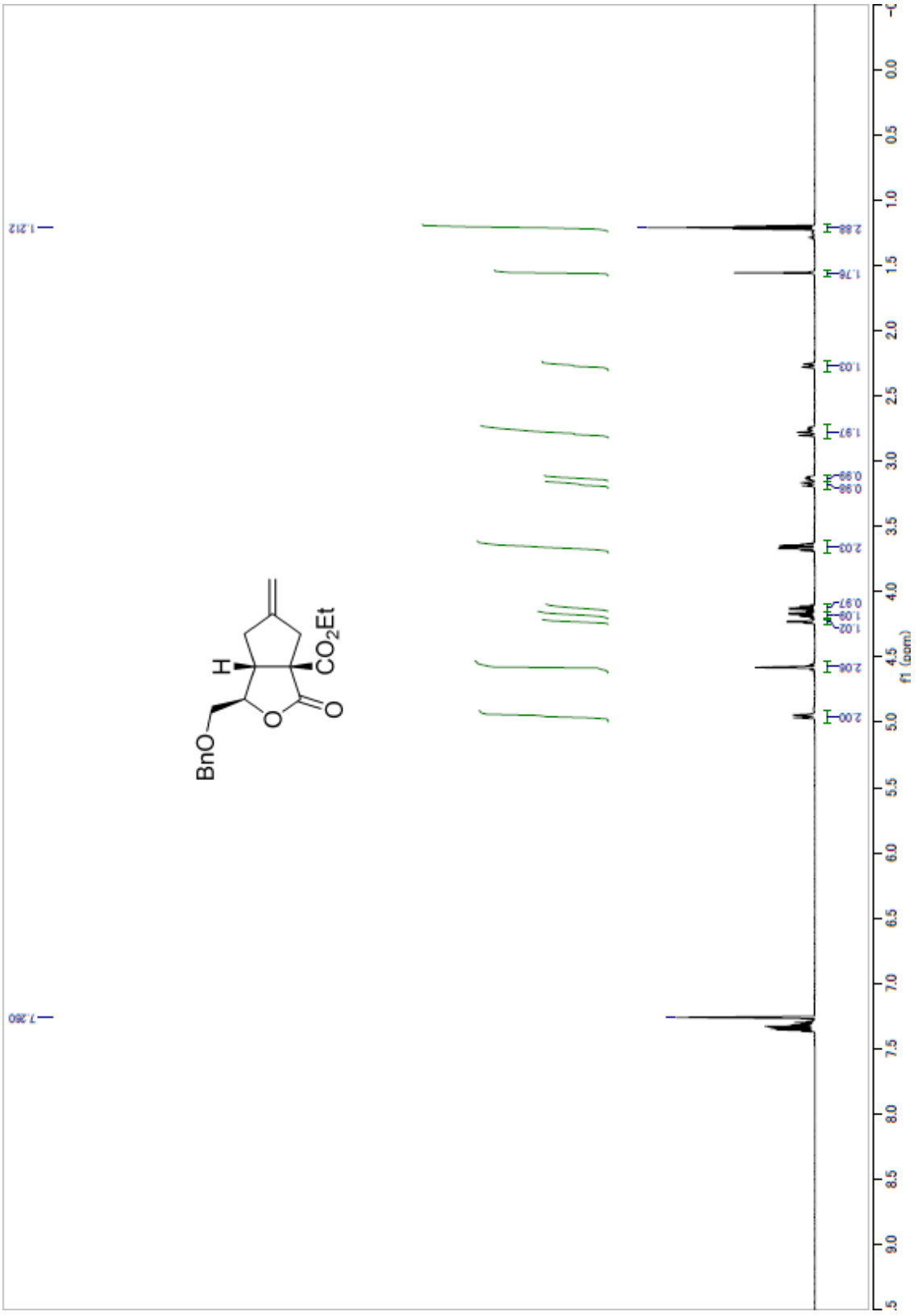


[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

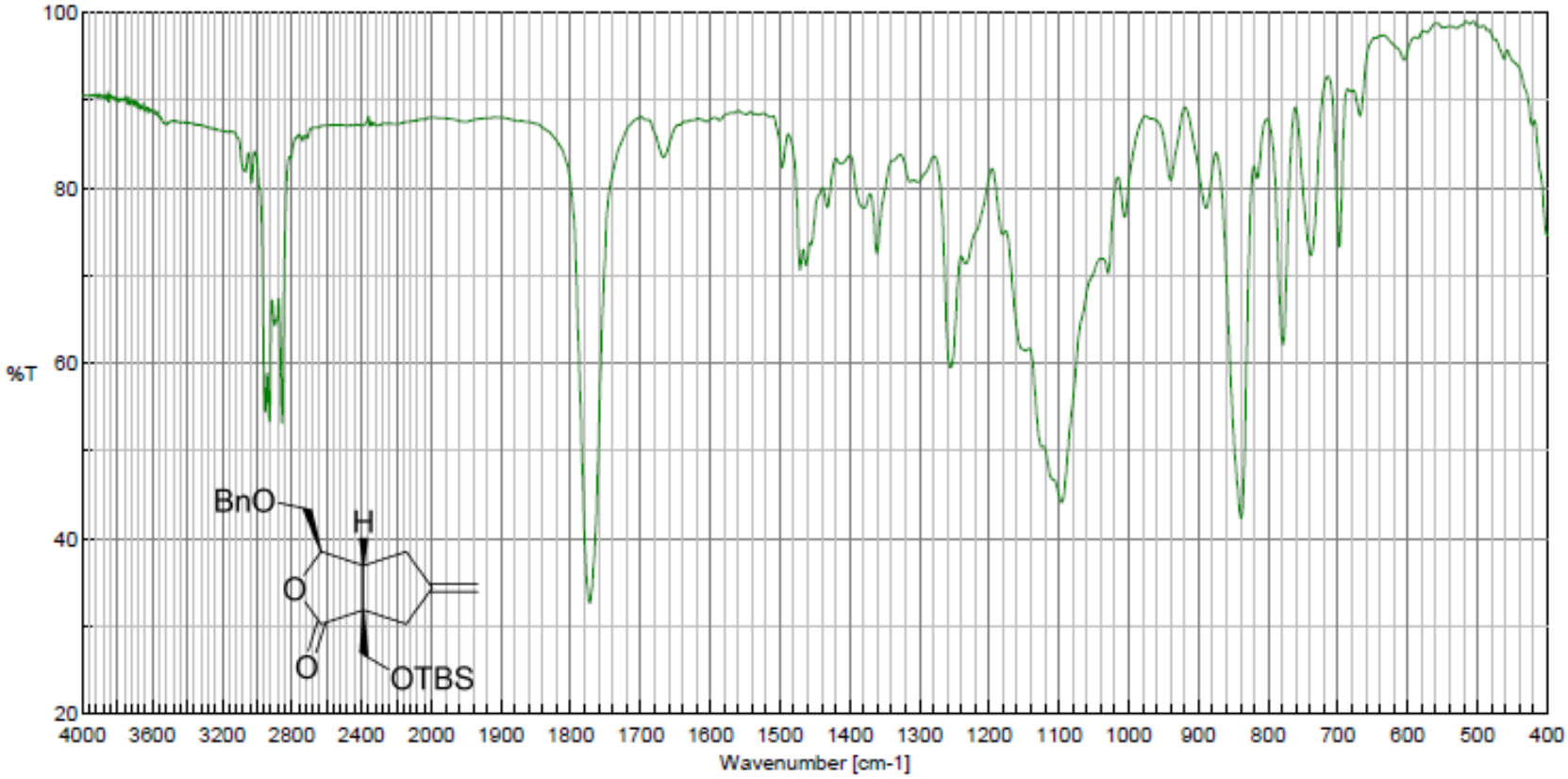

CO2Et
CO2Et
O
BnO
1.257
1.250
7.260
6.90
2.11
1.80
1.97
0.94
0.93
1.94
0.99
3.94
1.00
0.95
1.00
4.66
f1 (ppm)


14.071
35.210
34.577
50.447
54.925
54.586
61.504
61.477
68.058
73.331
76.819
77.000
77.182
113.380
127.797
128.435
137.782
142.028
166.873
166.826
CO2Et
CO2Et
O
BnO
f1 (ppm)

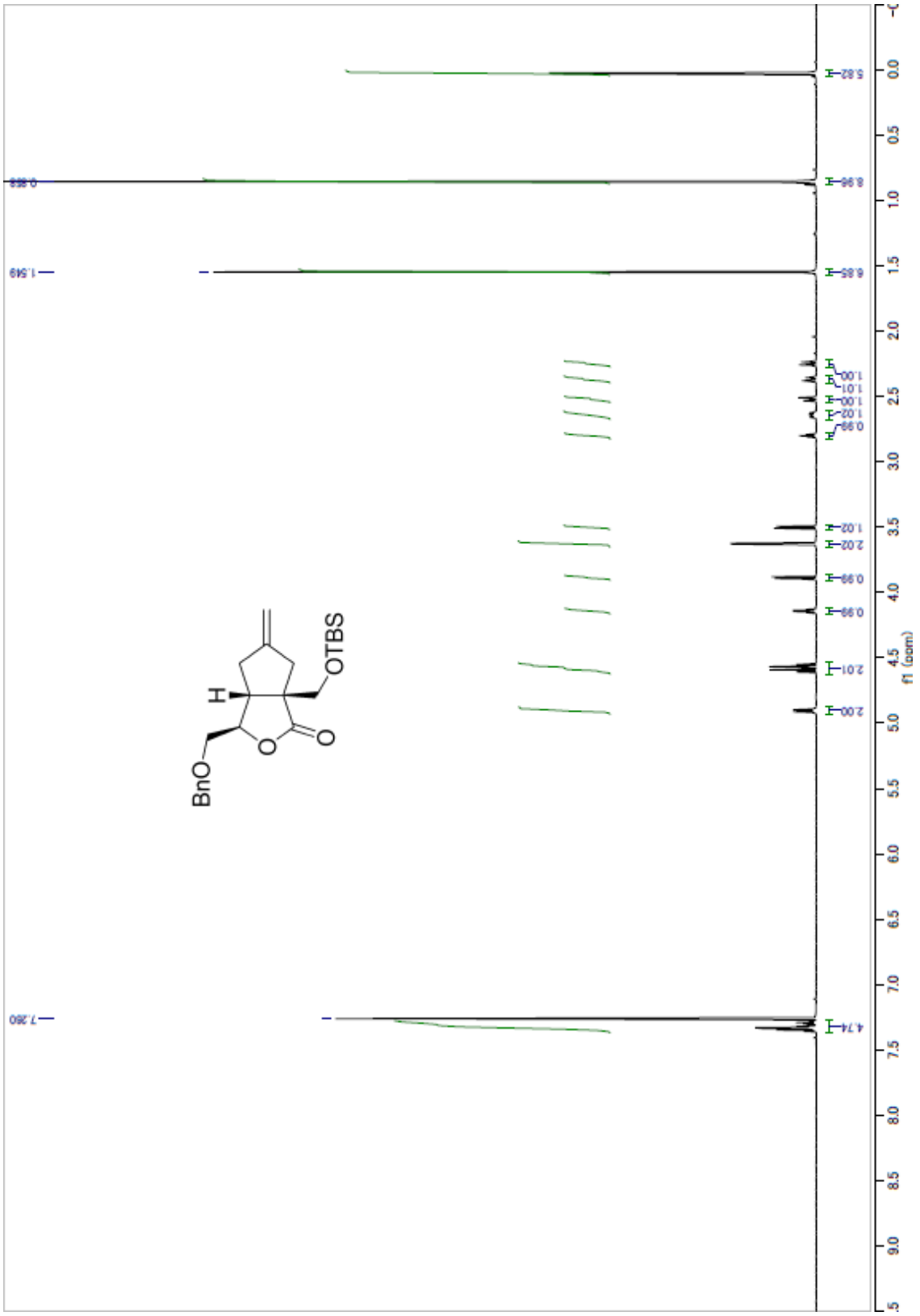

100
80
60
40
20
0
%T
4000
3600
3200
2800
2400
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
Wavenumber [cm-1]
BnO
H
O
O
CO2Et
[コメント情報]
試料名
コメント
測定者
所属
会社
新潟大学　理学部

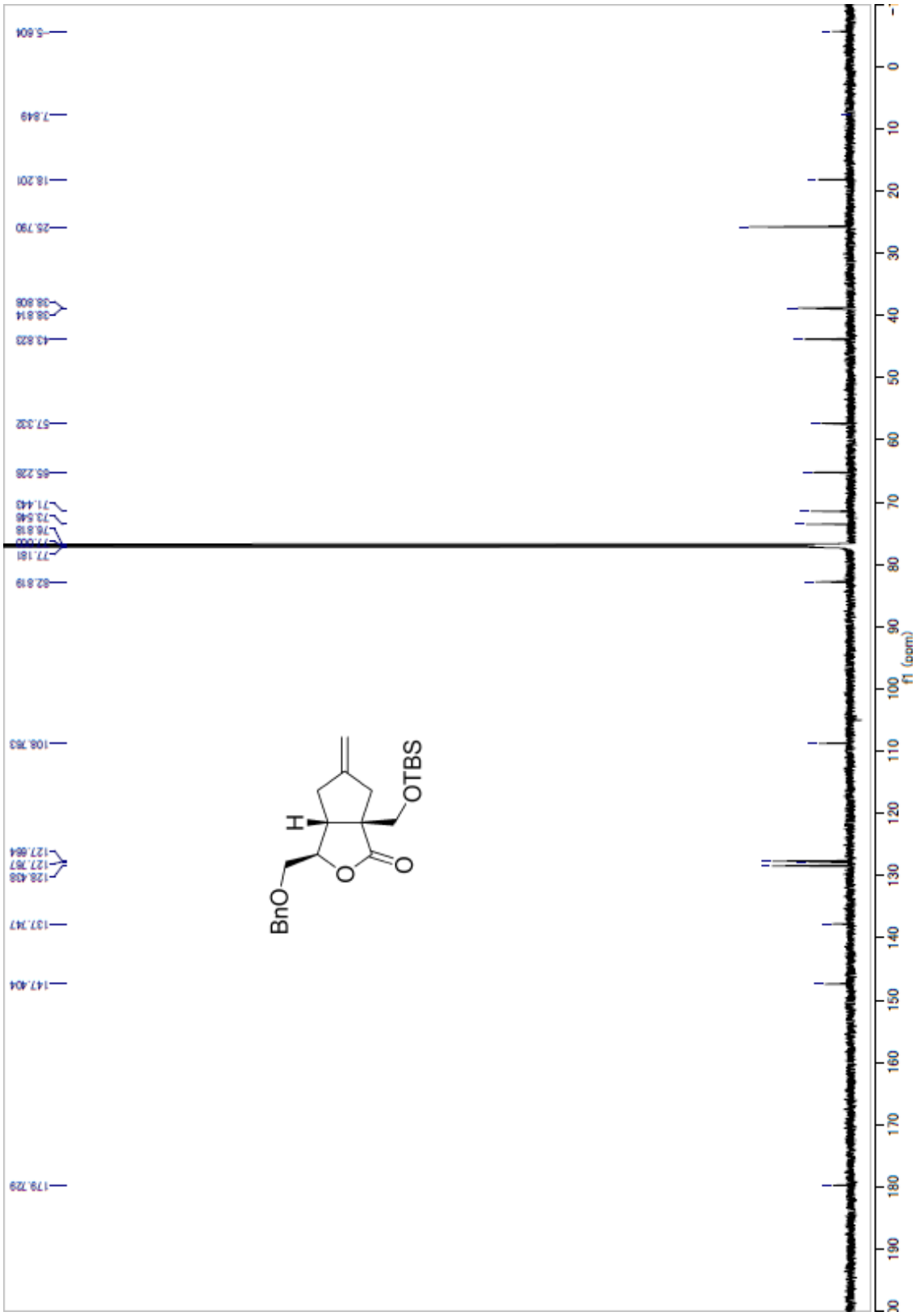

BnO
H
CO2Et
O
O
7.260
1.212
2.88
1.76
1.03
1.97
0.98
2.03
0.97
1.02
1.00
2.06
2.00
f1 (ppm)

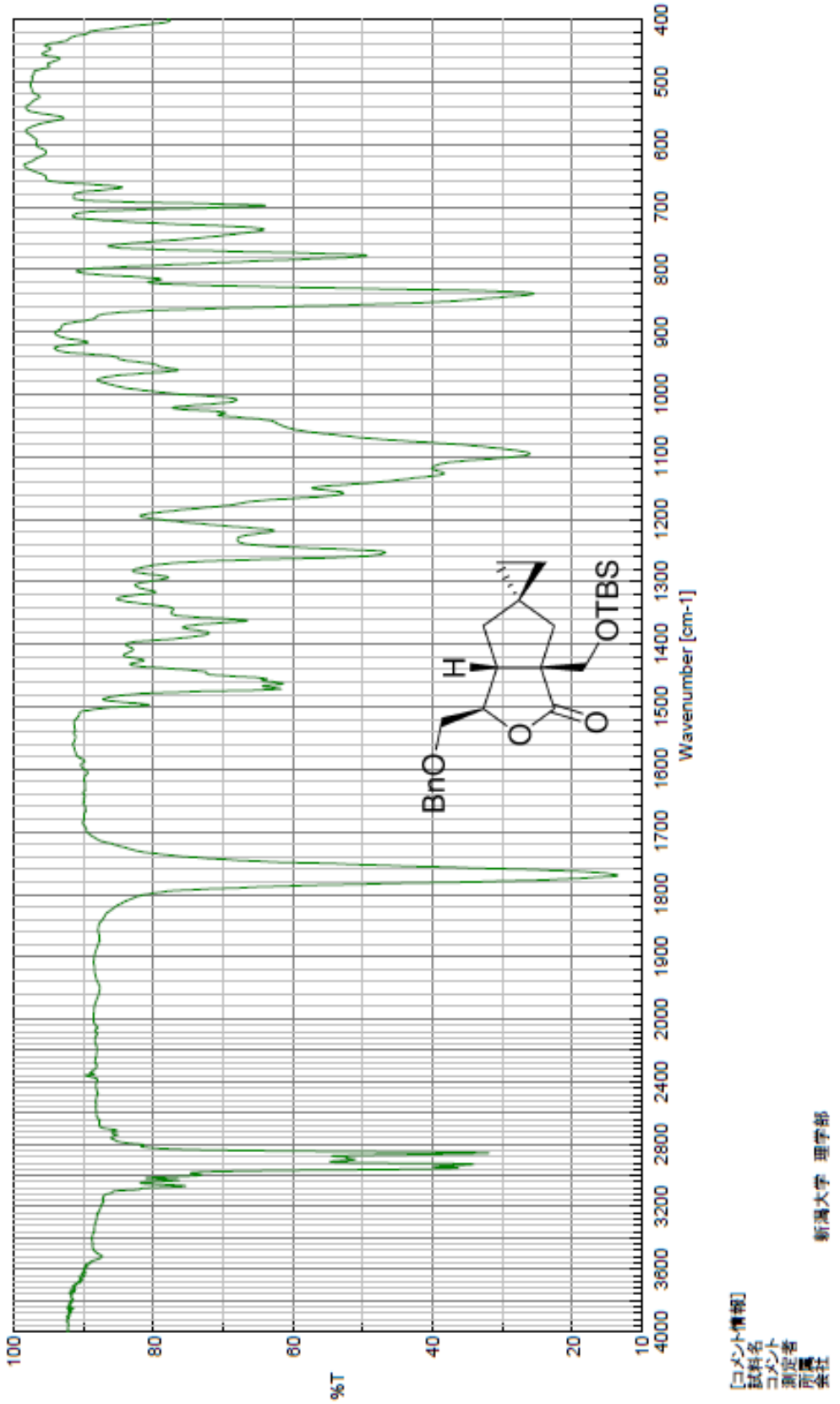

13.928
39.121
40.416
46.961
60.861
62.282
70.695
73.613
76.819
77.000
77.182
83.372
109.305
127.719
127.886
128.469
137.512
146.029
169.840
174.965
BnO
H
O
O
CO2Et
f1 (ppm)

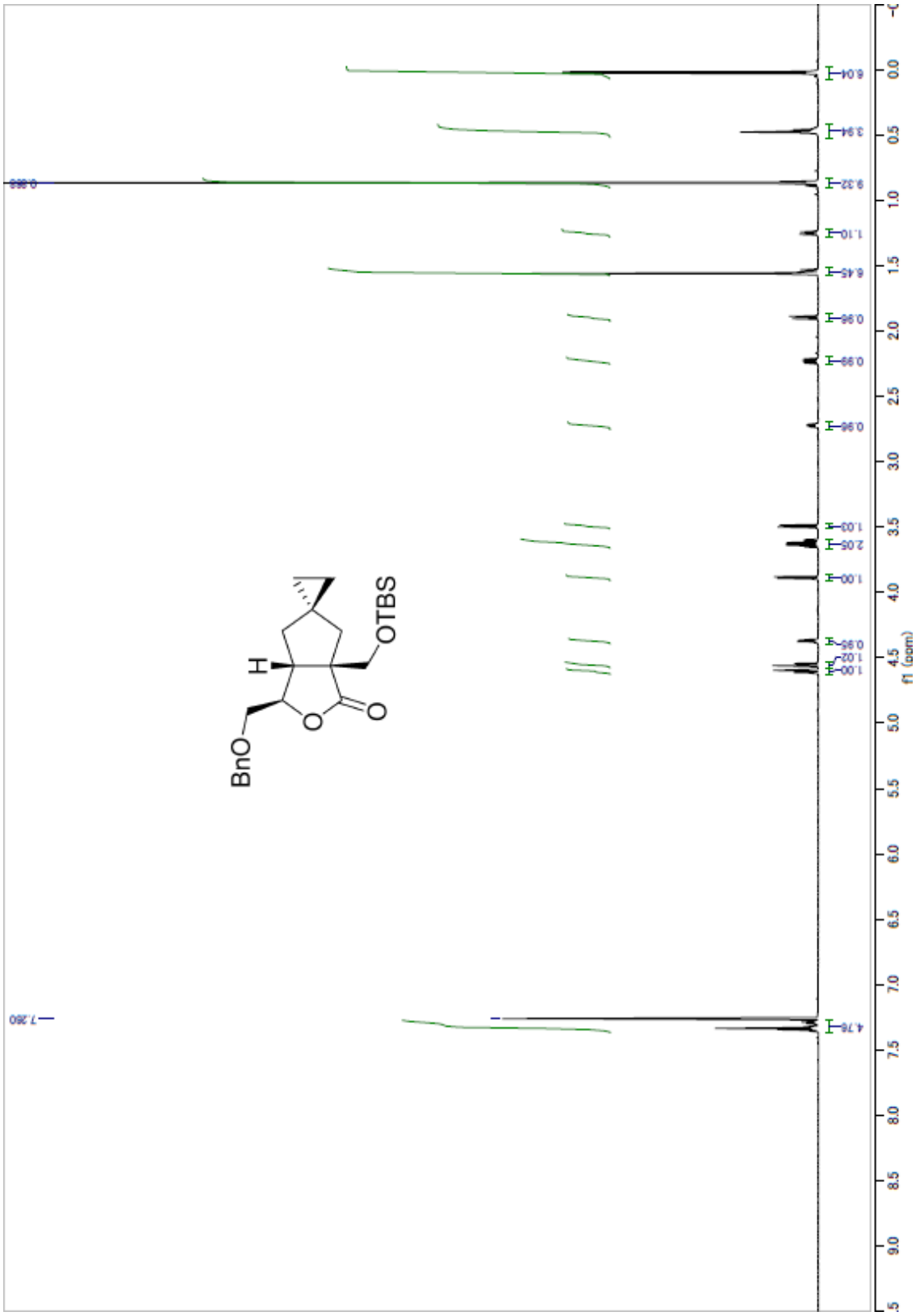


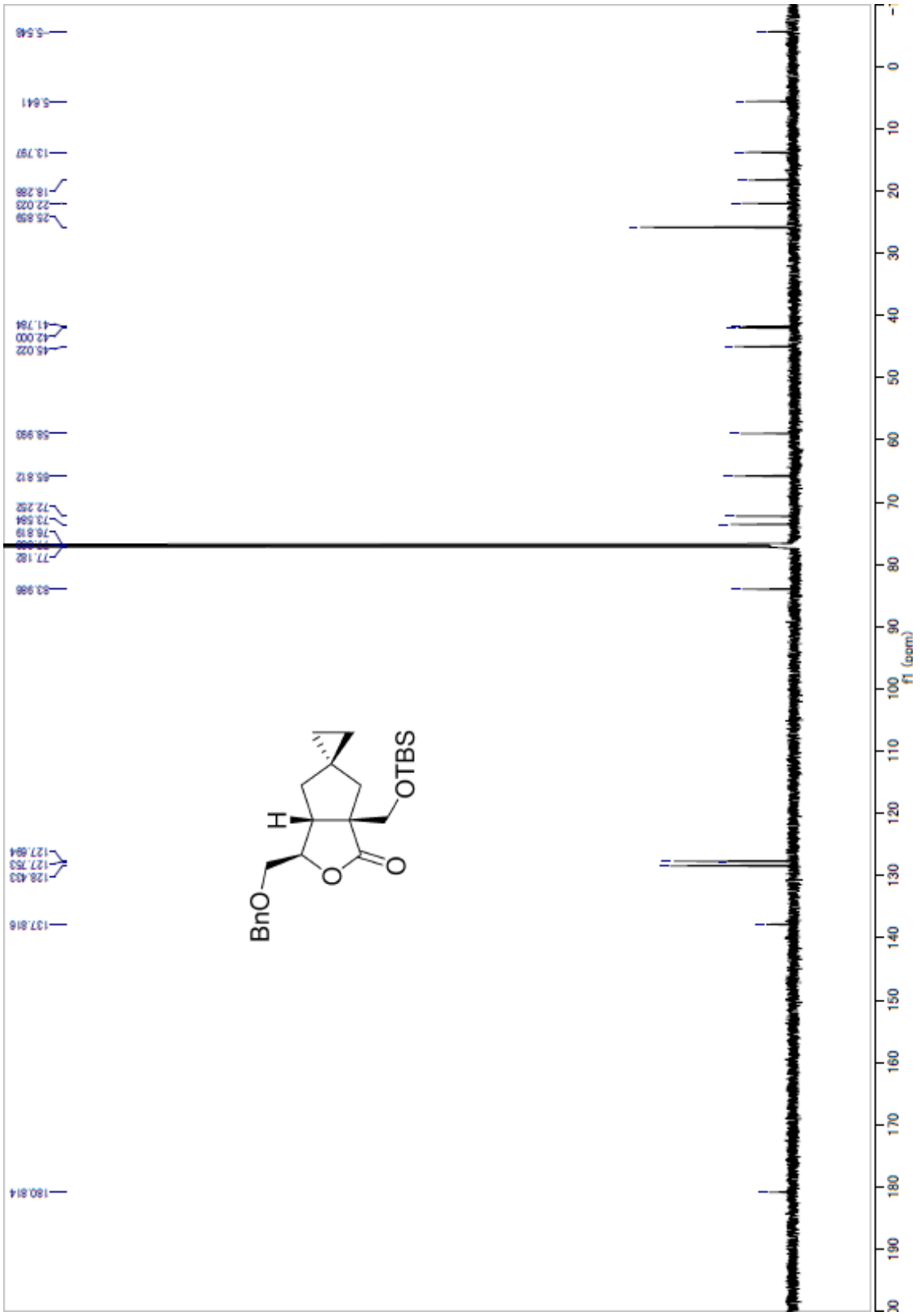
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

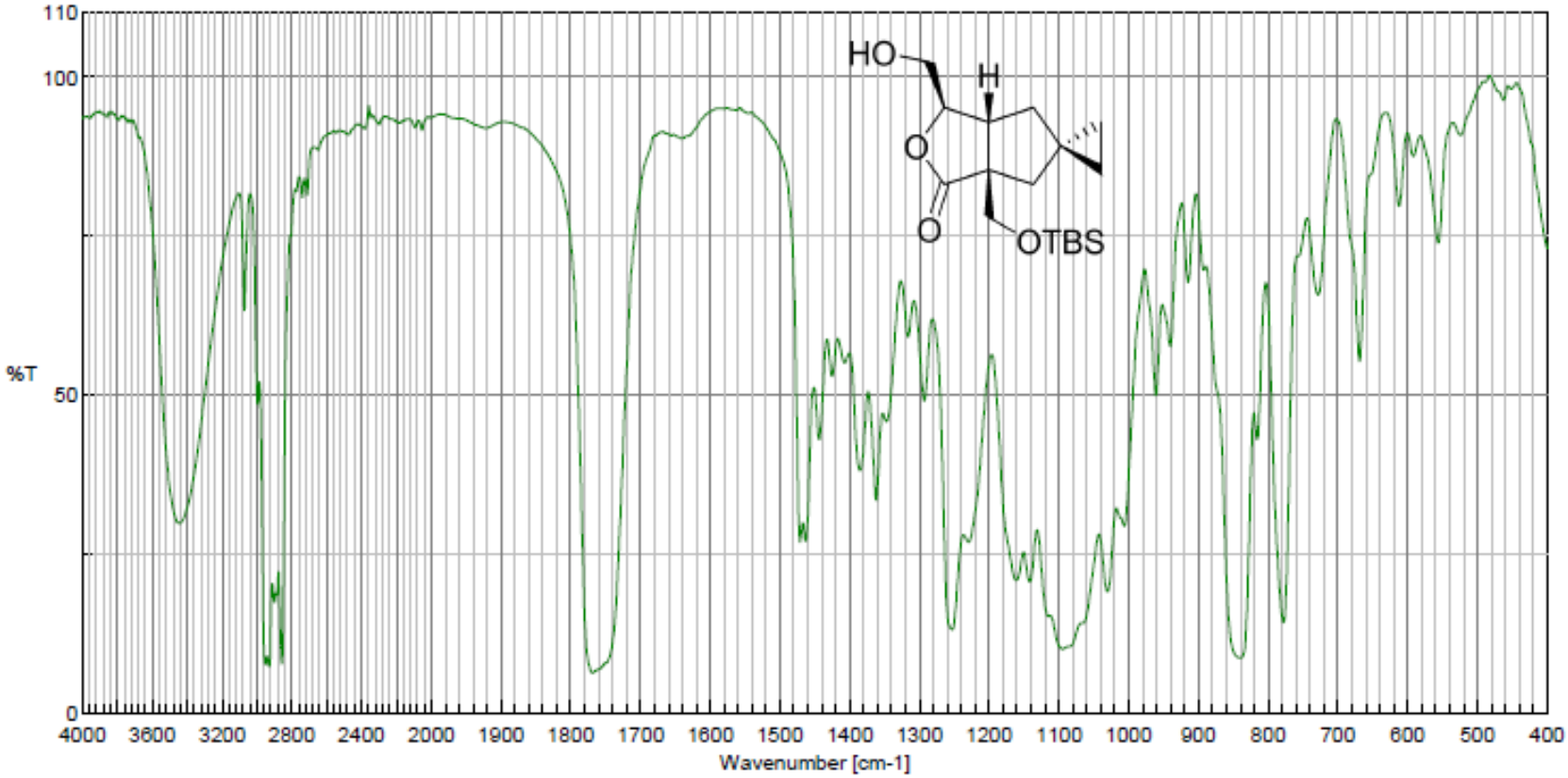

OTBS
H
O
O
BnO
f1 (ppm)


OTBS
H
O
O
BnO
f1 (ppm)

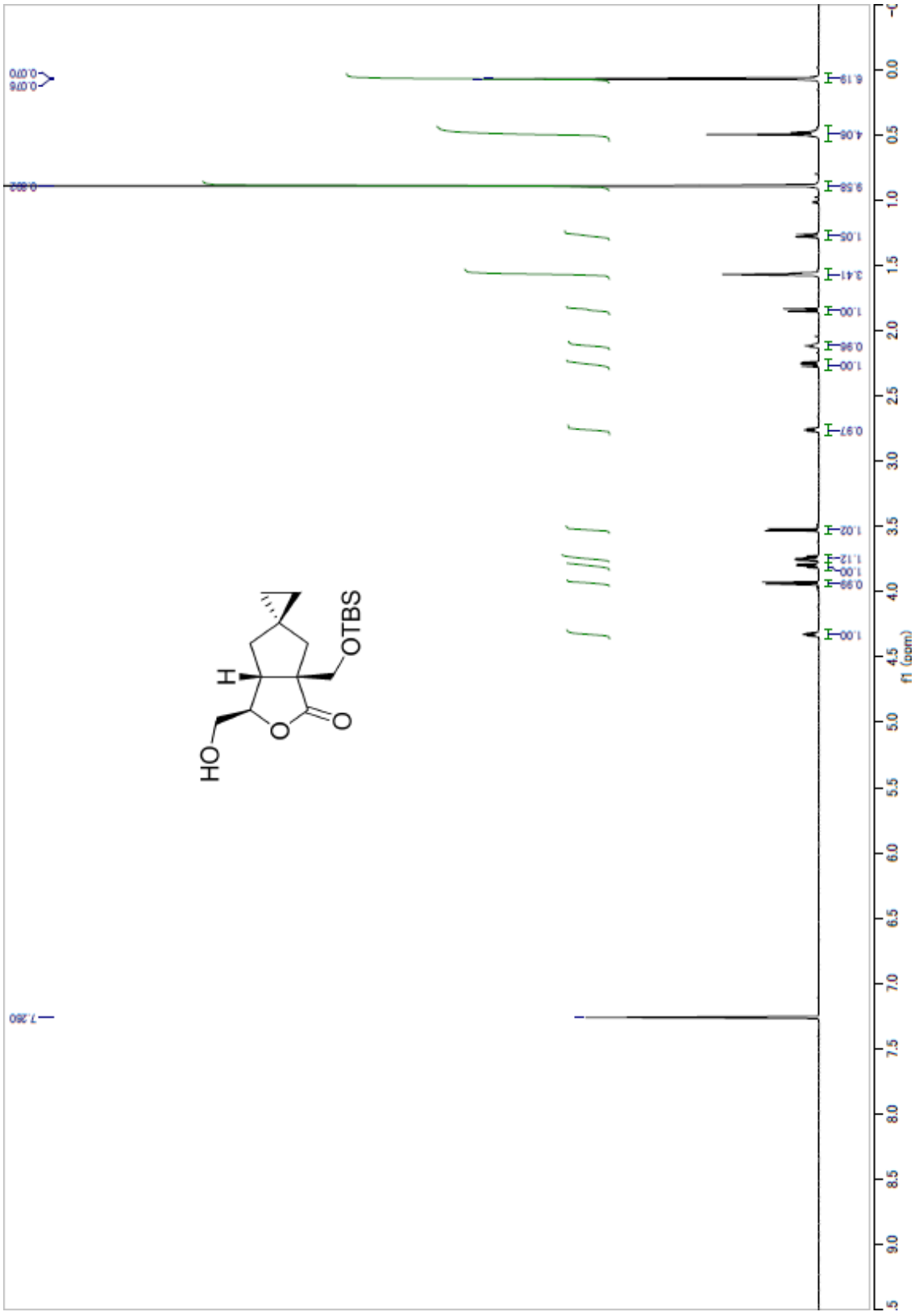

100
80
60
40
20
10
%T
4000
3600
3200
2800
2400
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
Wavenumber [cm-1]
BnO
H
O
O
OTBS
[コメント情報]
試料名
コメント
測定者
所属
会社
新潟大学　理学部

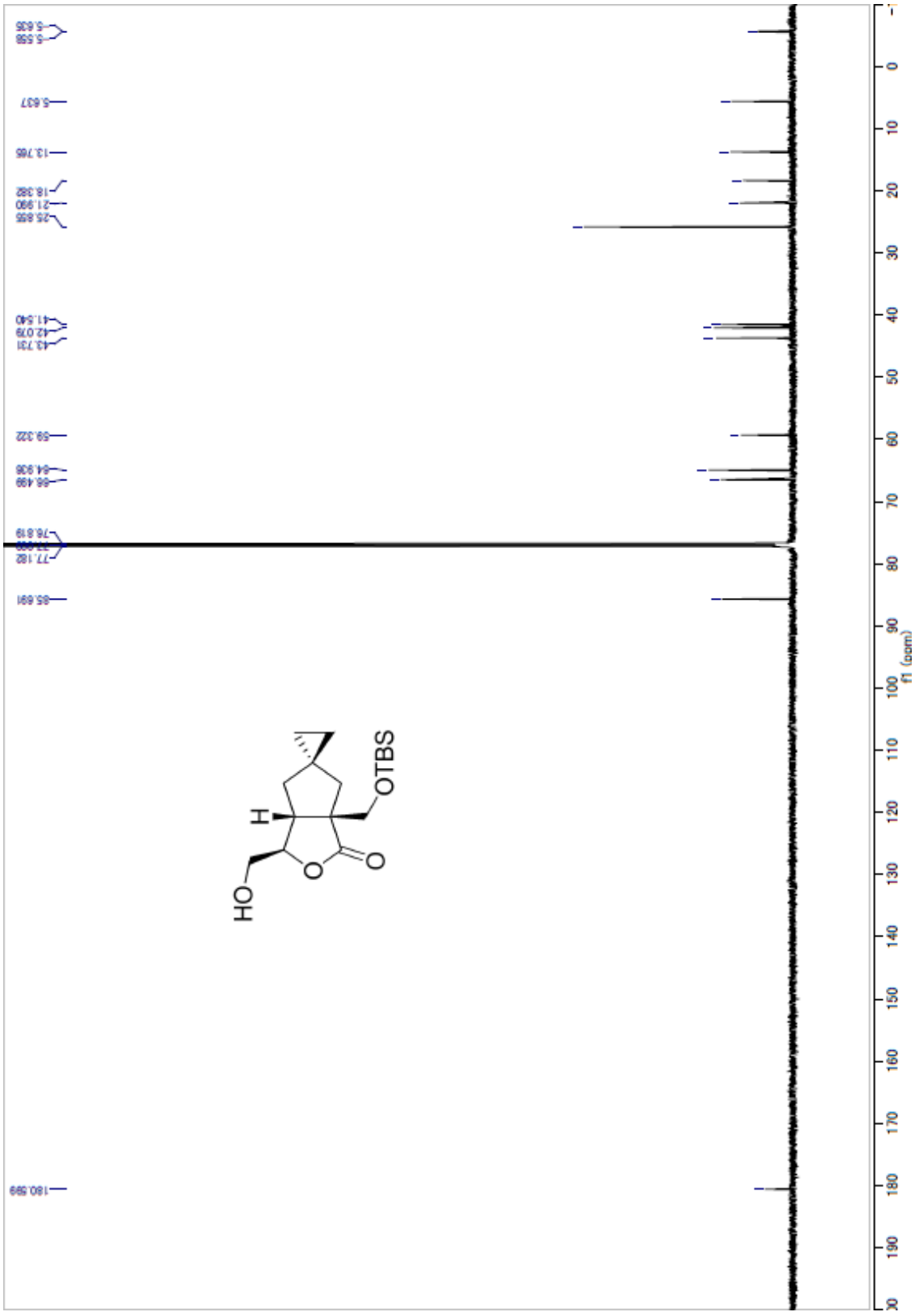

OTBS
H
O
O
BnO
f1 (ppm)

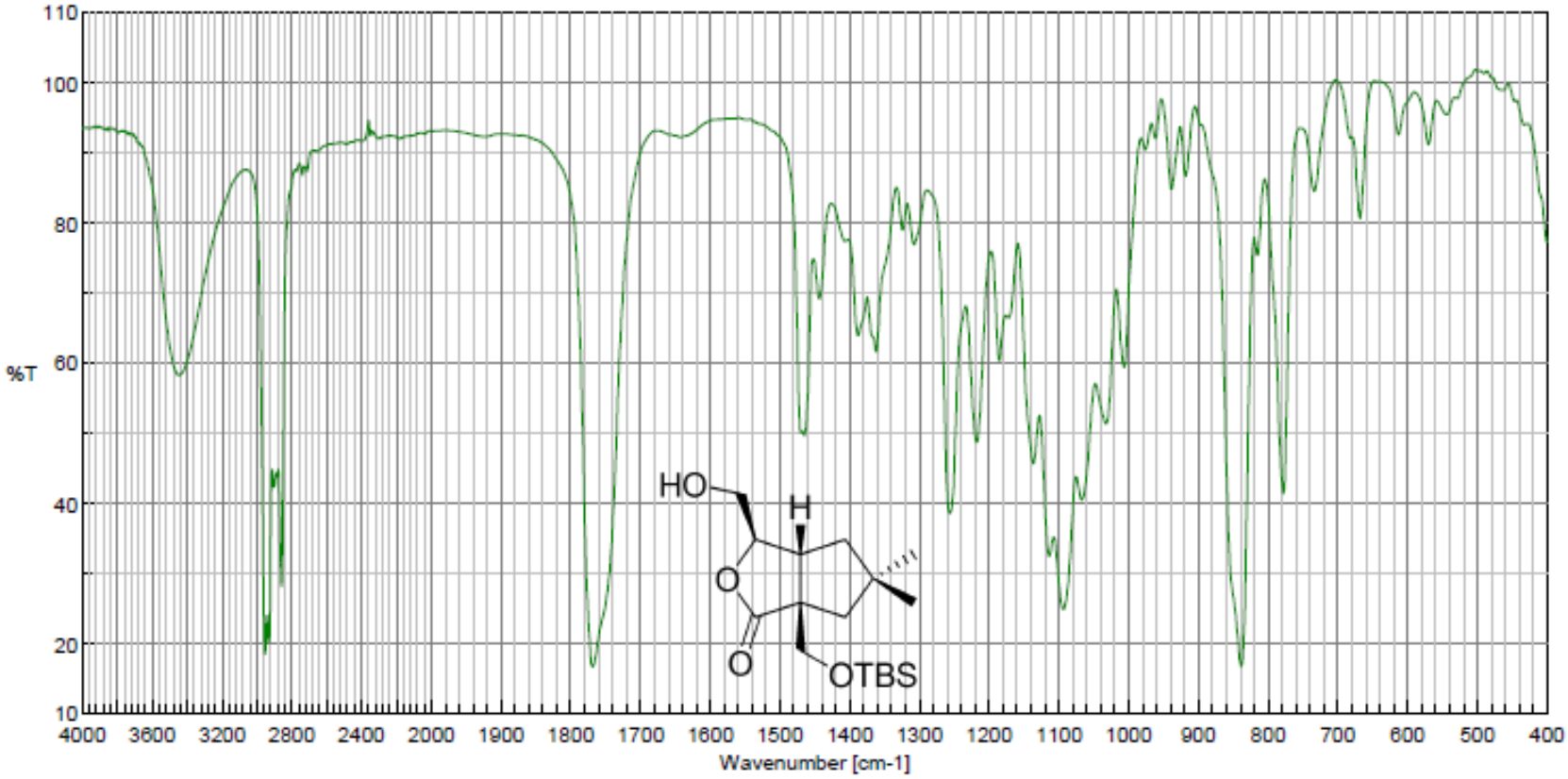

-5.548
-5.641
13.797
18.288
22.023
25.859
41.784
42.000
45.022
58.980
65.812
72.252
73.584
76.819
77.182
83.986
127.894
127.753
128.403
137.816
180.814
OTBS
H
O
O
BnO
f1 (ppm)



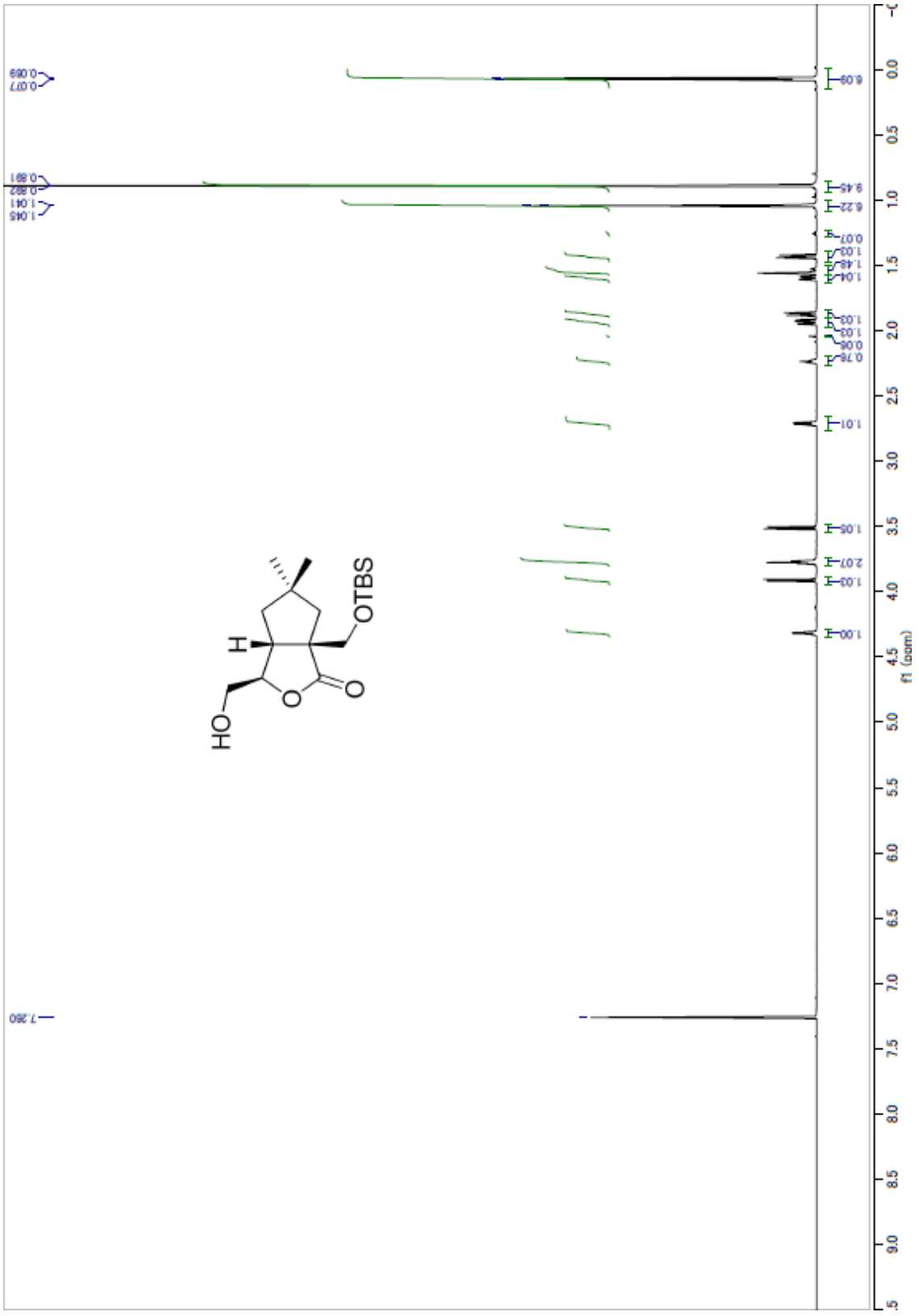
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

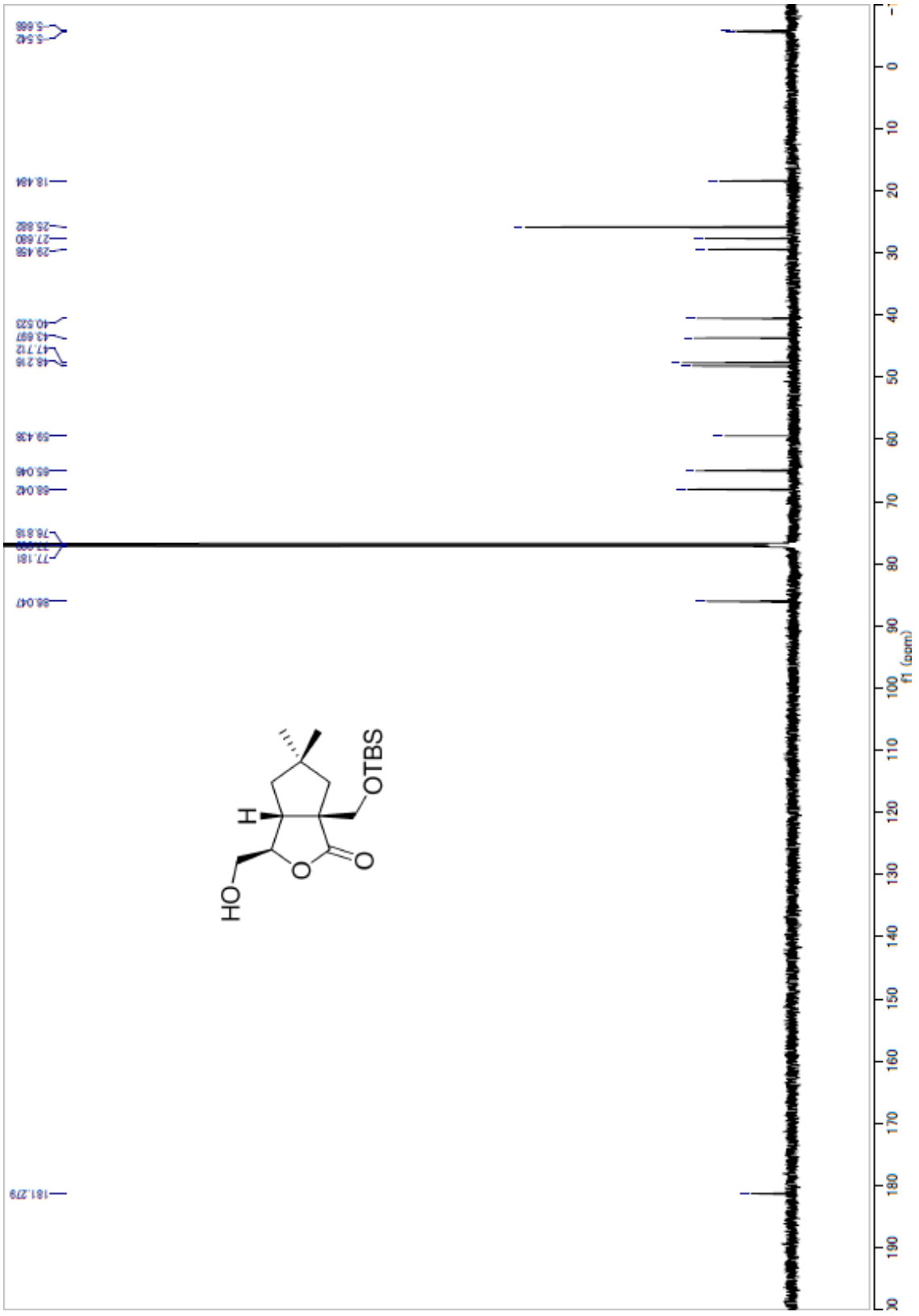

OTBS
H
O
O
HO
f1 (ppm)

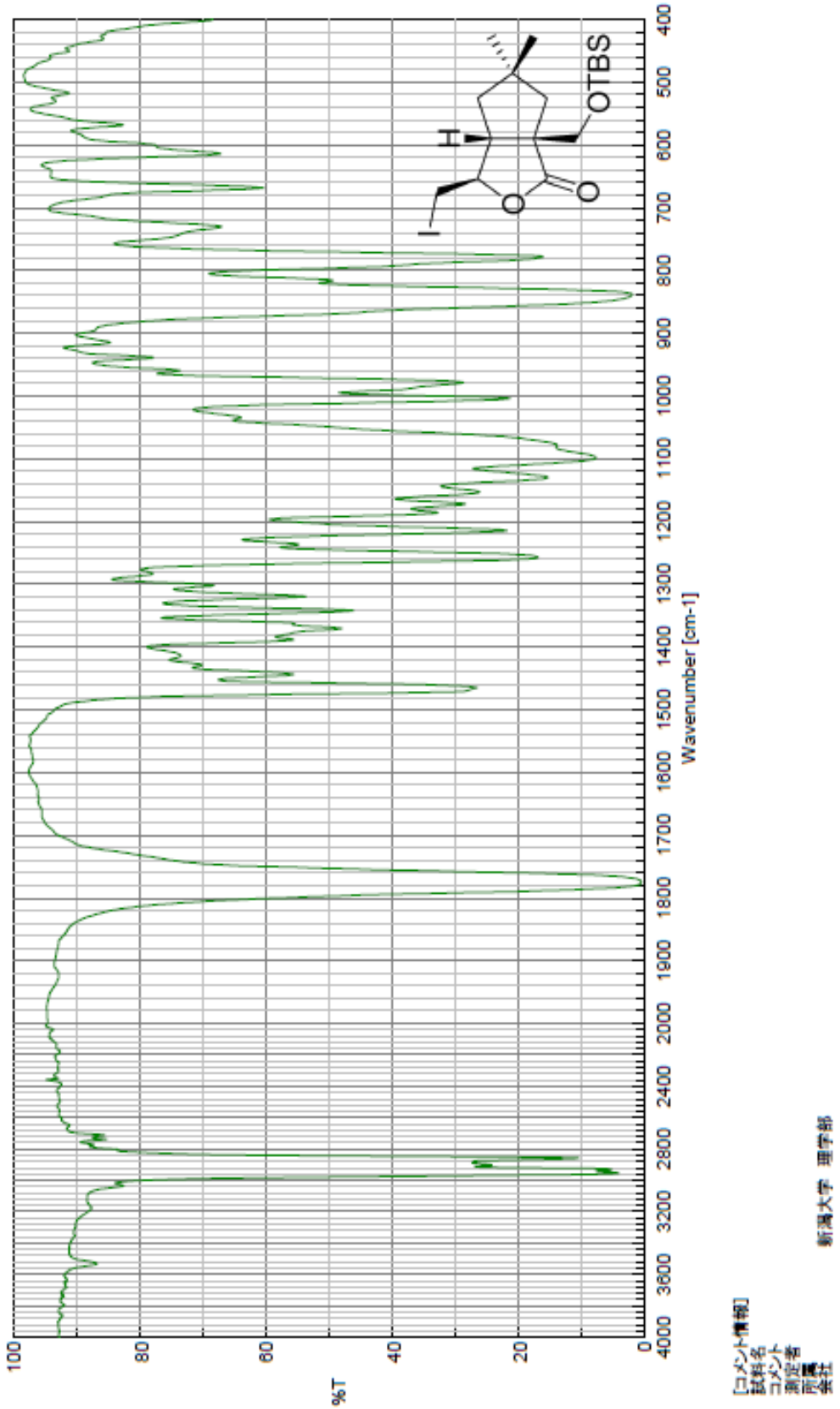

-5.626
-5.588
-5.637
-13.766
-18.382
-21.990
-25.855
-41.540
-42.079
-43.731
-59.322
-64.936
-66.490
-76.819
-77.000
-77.182
-85.691
-180.599
OTBS
H
O
O
HO
f1 (ppm)

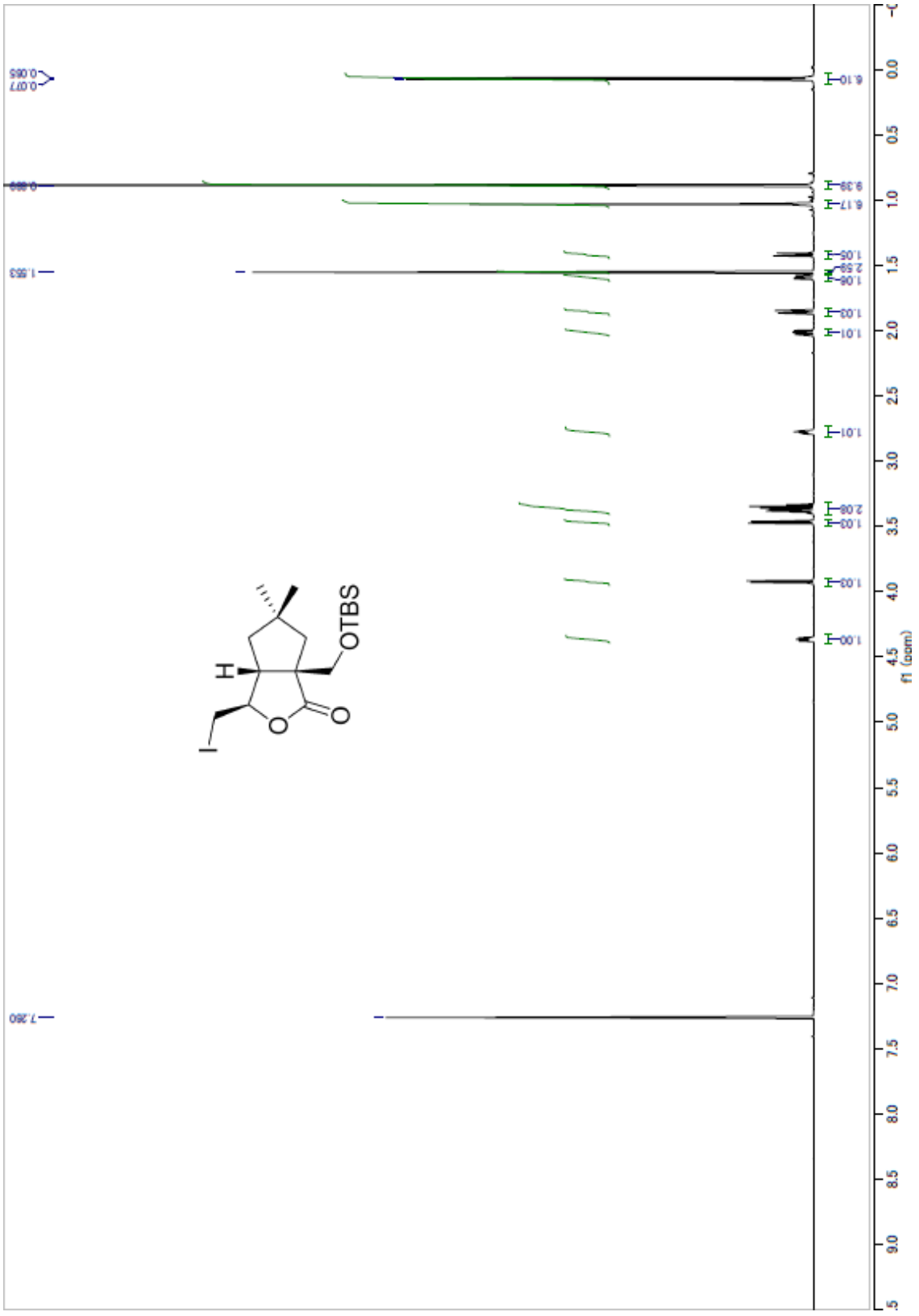


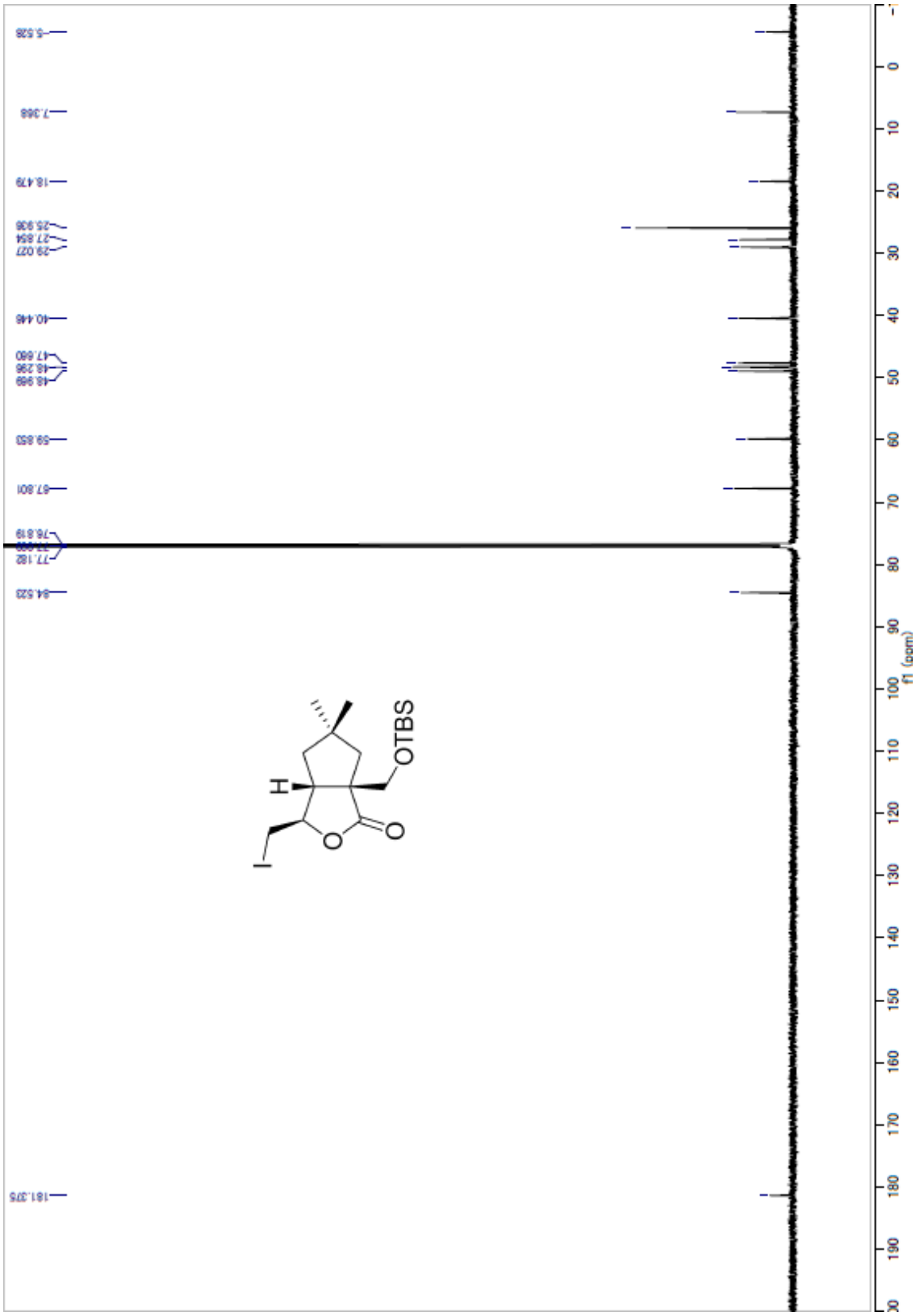
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

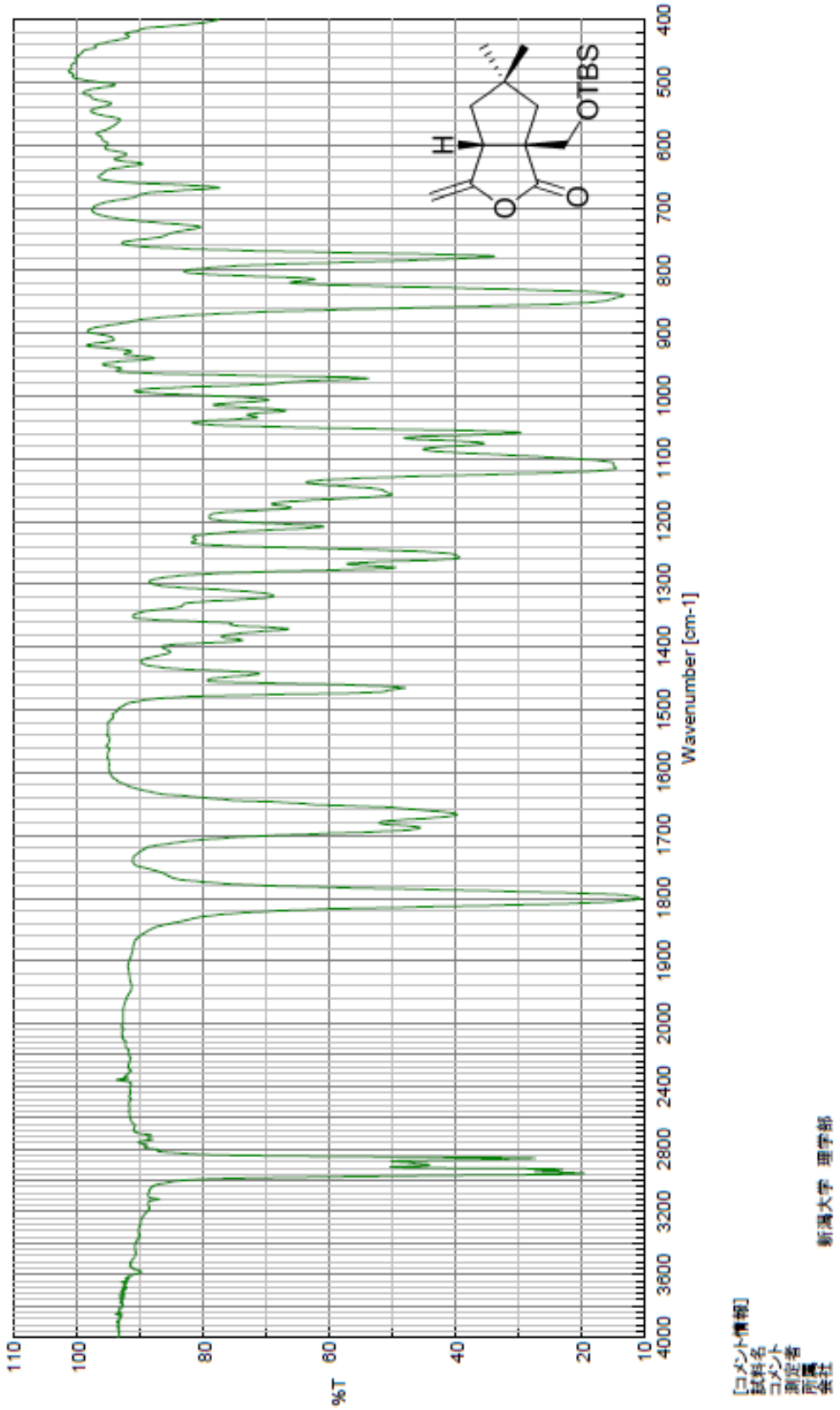

OTBS
H
HO
O
O
f1 (ppm)

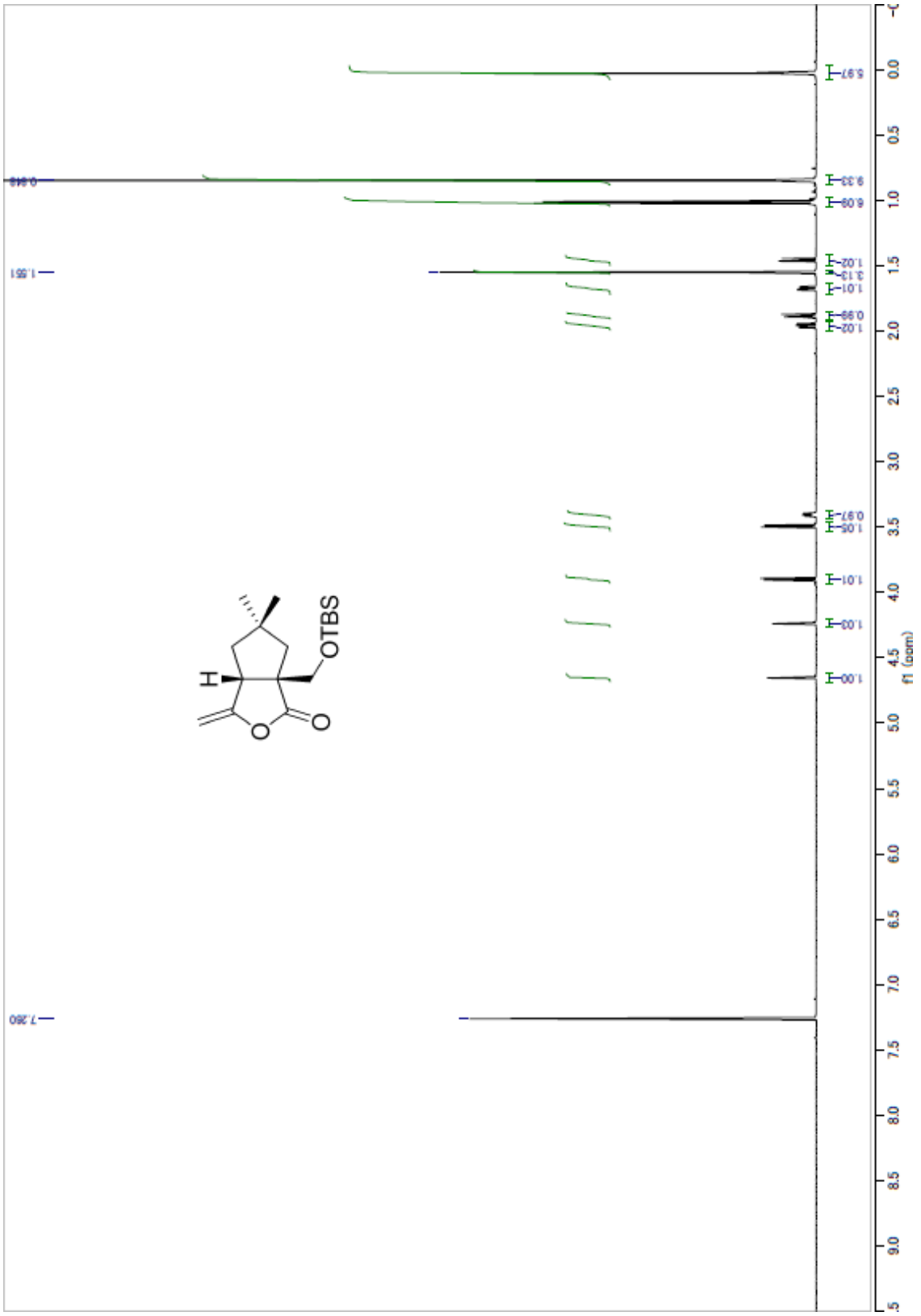

-5.542
-5.668
18.484
25.882
27.680
29.458
40.520
43.697
47.712
48.216
59.438
65.046
66.042
76.818
77.000
77.181
86.047
181.279
OTBS
H
O
O
HO
f1 (ppm)

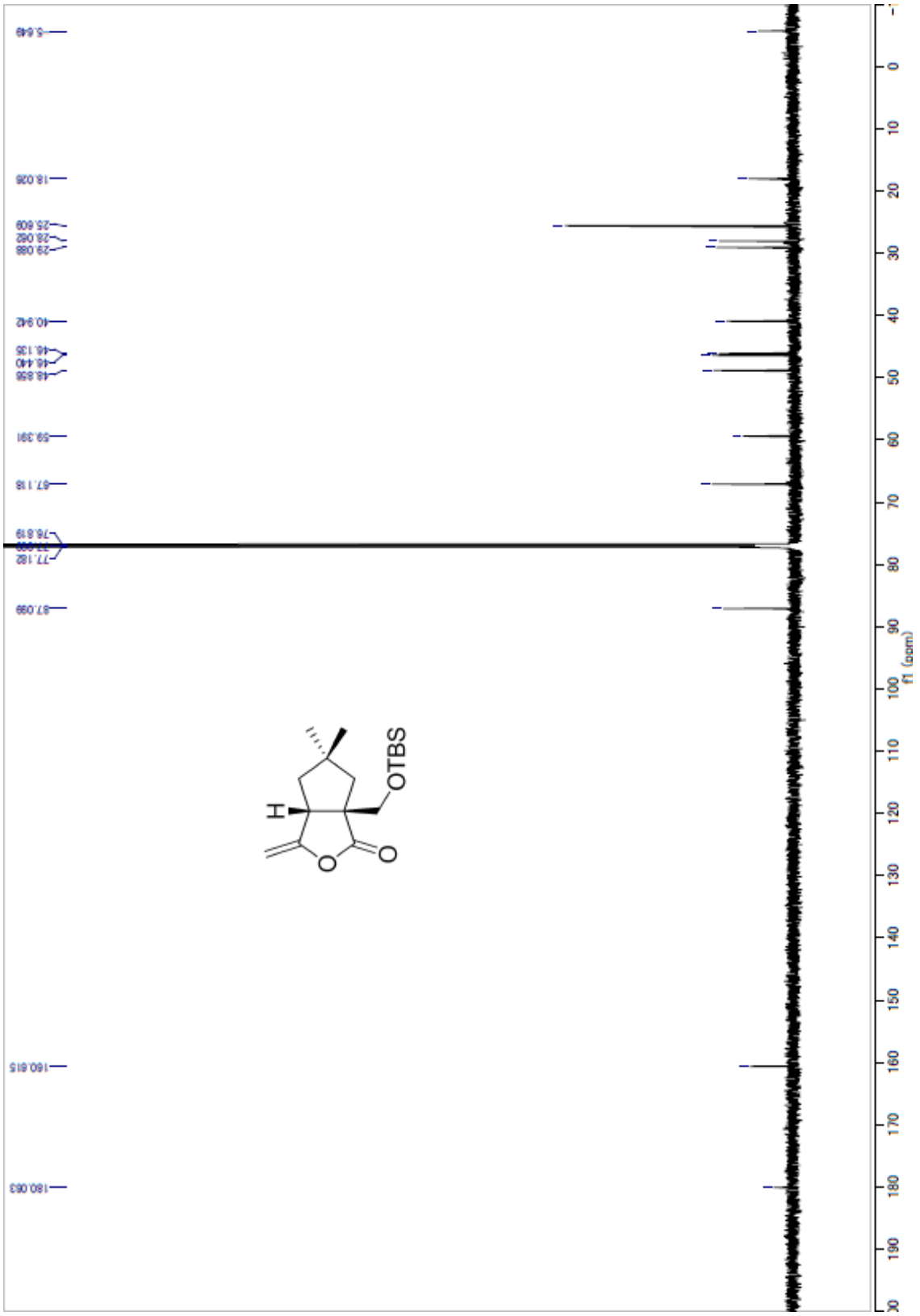

OTBS
H
O
O
I
%T
Wavenumber [cm-1]
100
80
60
40
20
0
4000
3600
3200
2800
2400
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
[コメント情報]
試料名
コメント
測定者
所属
会社
新潟大学　理学部

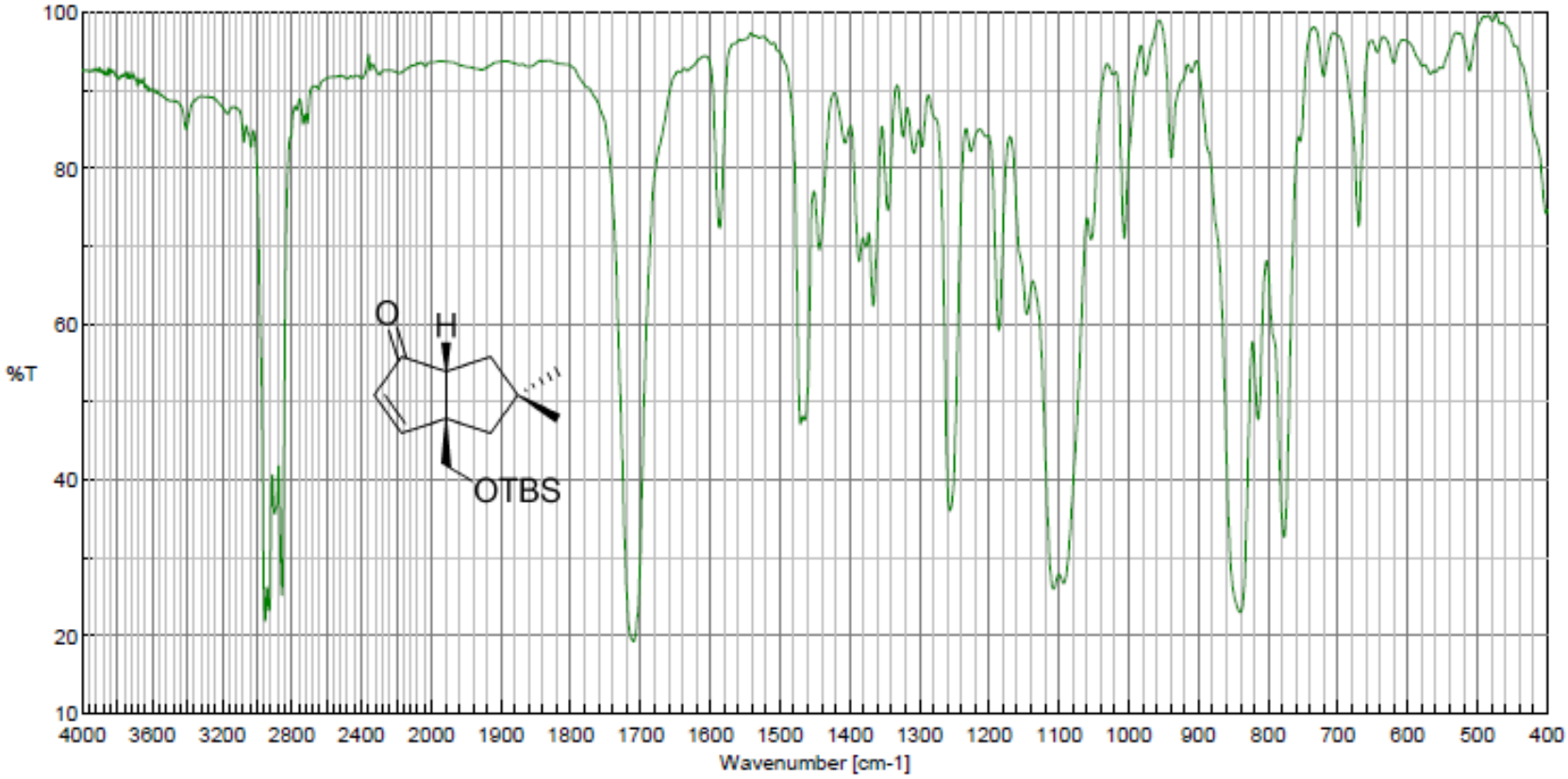

OTBS
H
O
O
f1 (ppm)


-5.528
7.366
18.479
25.926
27.854
29.027
40.446
47.660
58.296
58.969
59.850
67.801
76.819
77.000
77.182
84.520
181.375
OTBS
H
O
O
I
f1 (ppm)

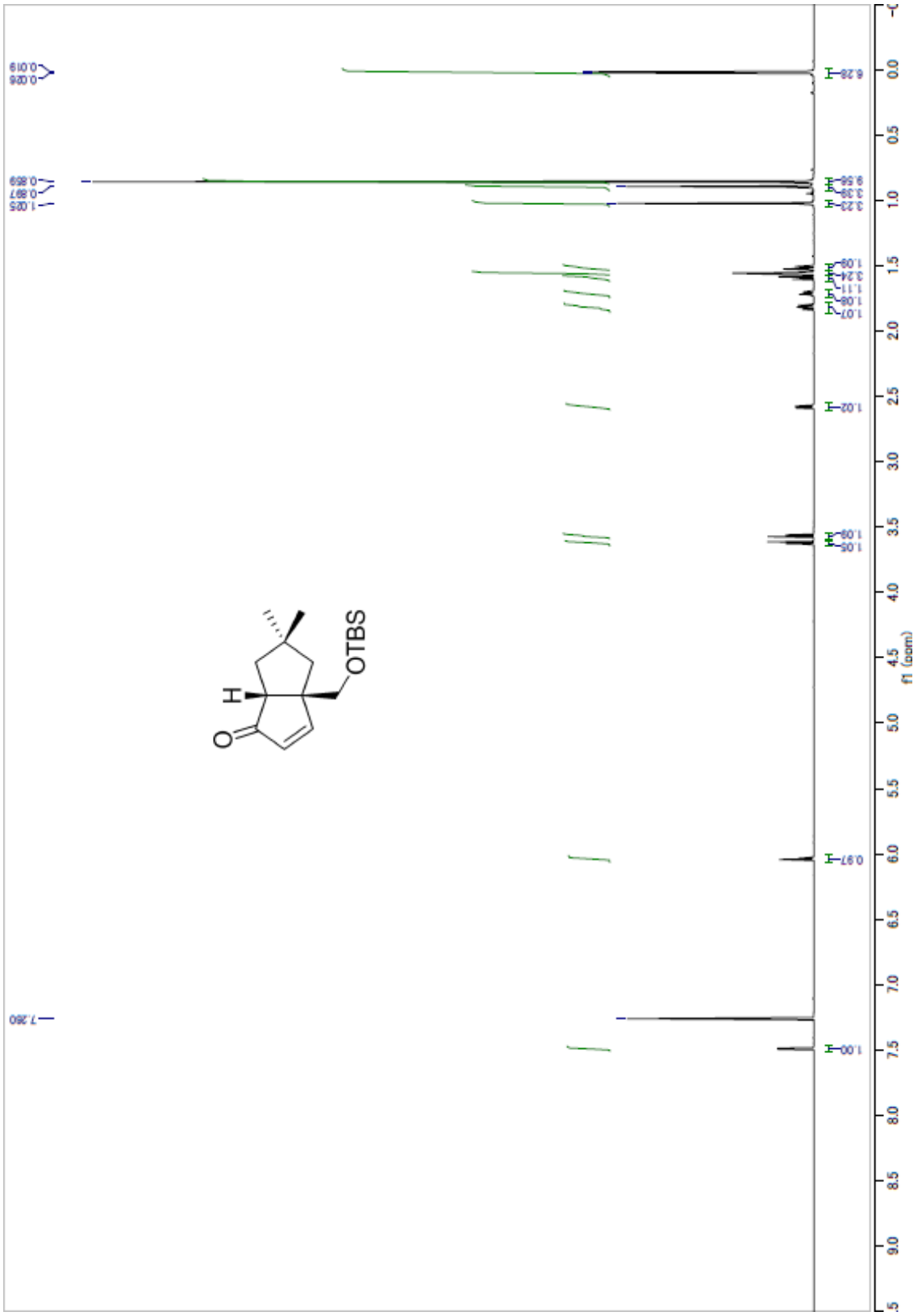

OTBS
H
O
O
%T
Wavenumber [cm-1]
[コメント情報]
試料名
コメント
測定者
所属
会社
新潟大学　理学部

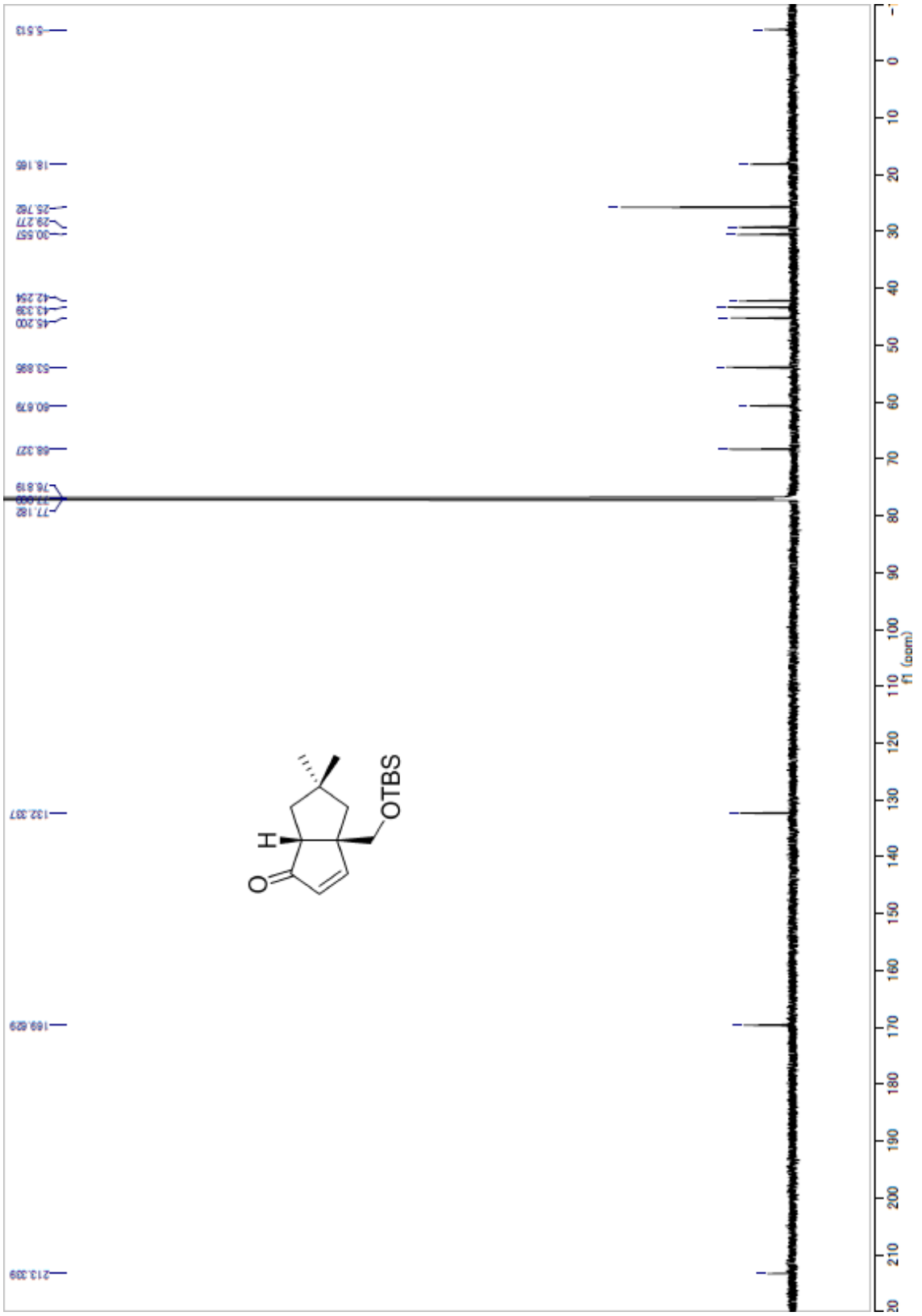

OTBS
H
O
O
f1 (ppm)

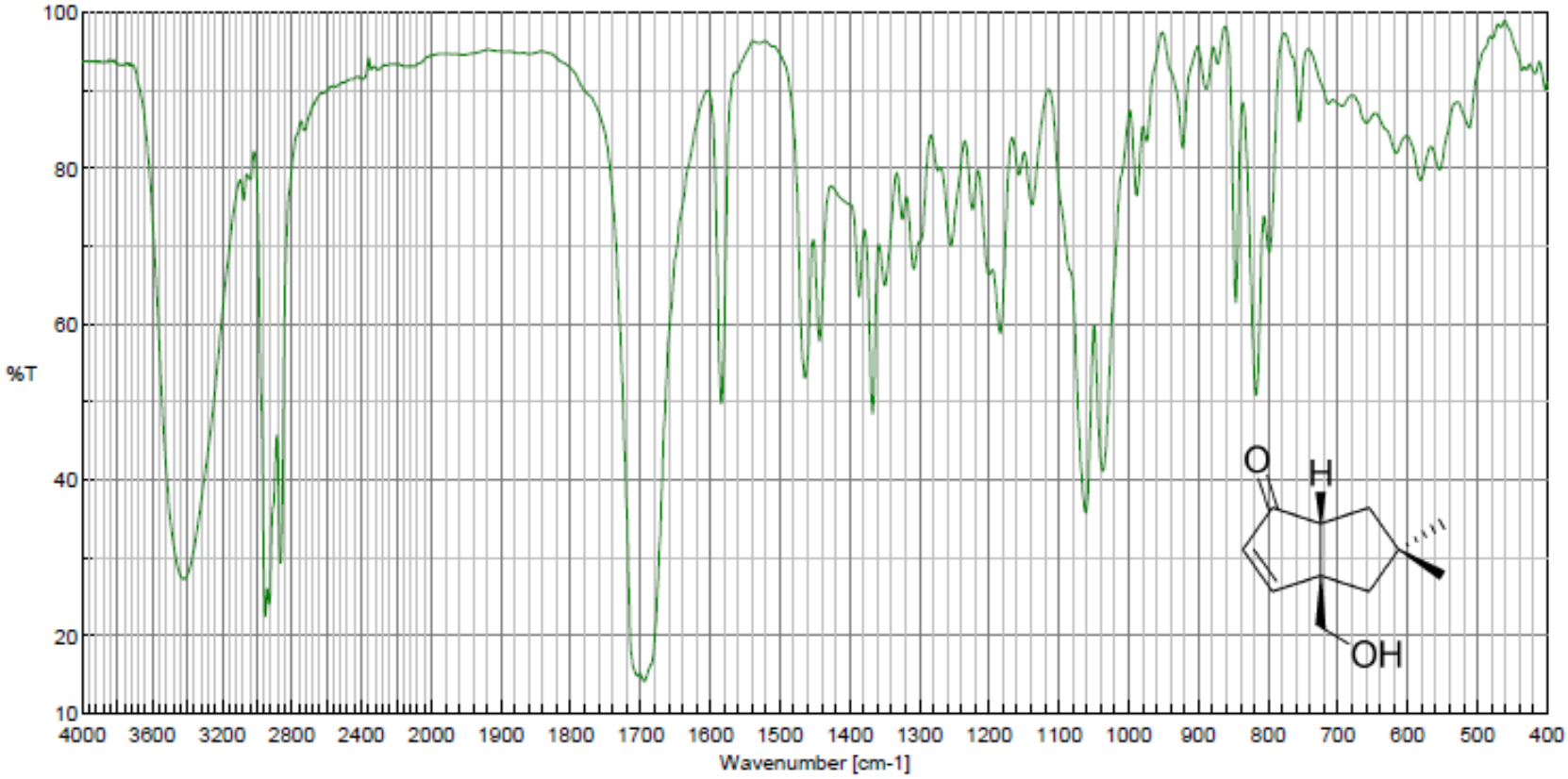

-5.649
18.026
25.609
26.062
29.088
40.942
46.125
46.440
46.856
59.391
67.118
76.819
77.000
77.182
87.099
160.615
180.063
OTBS
H
O
O
f1 (ppm)



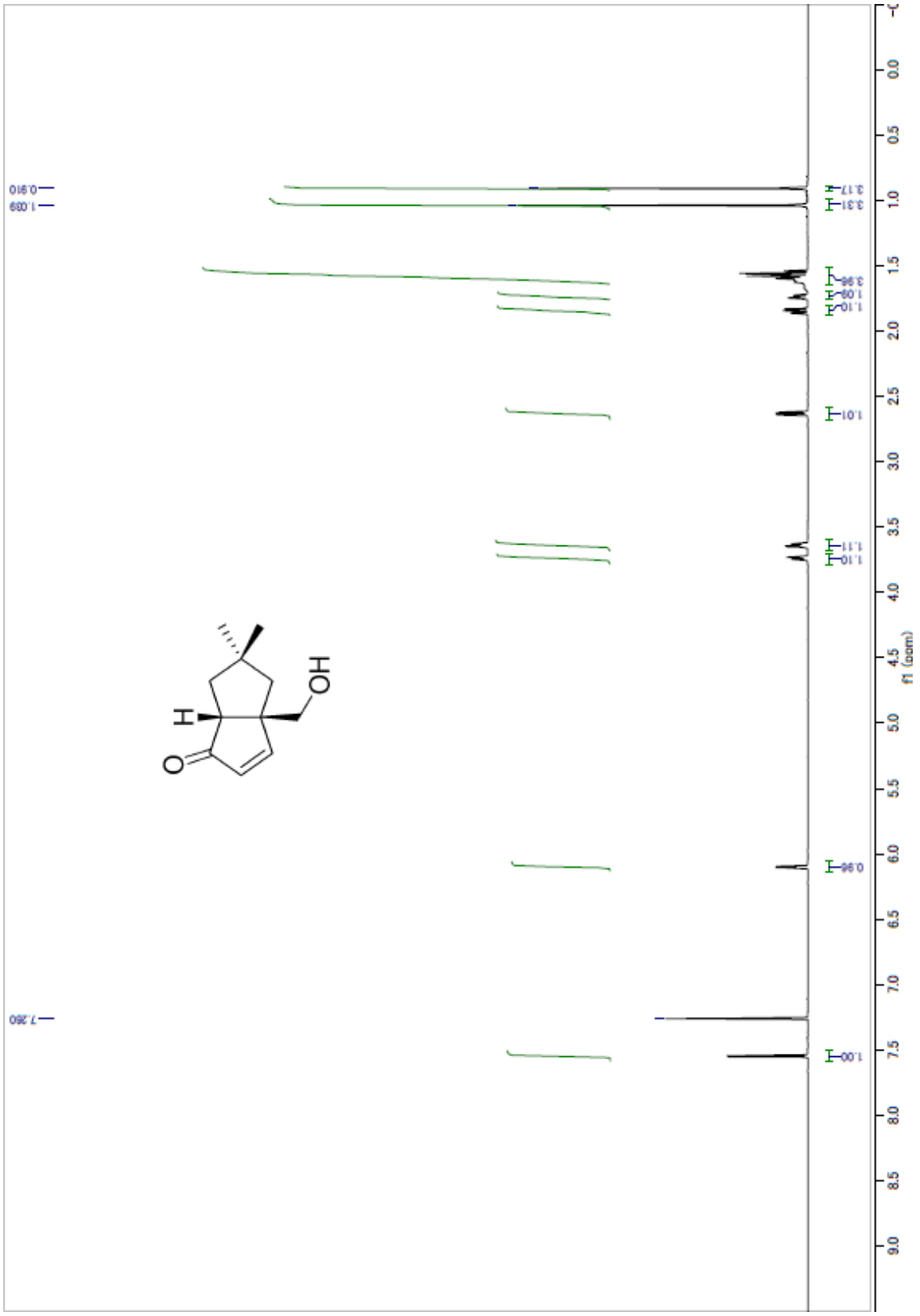
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

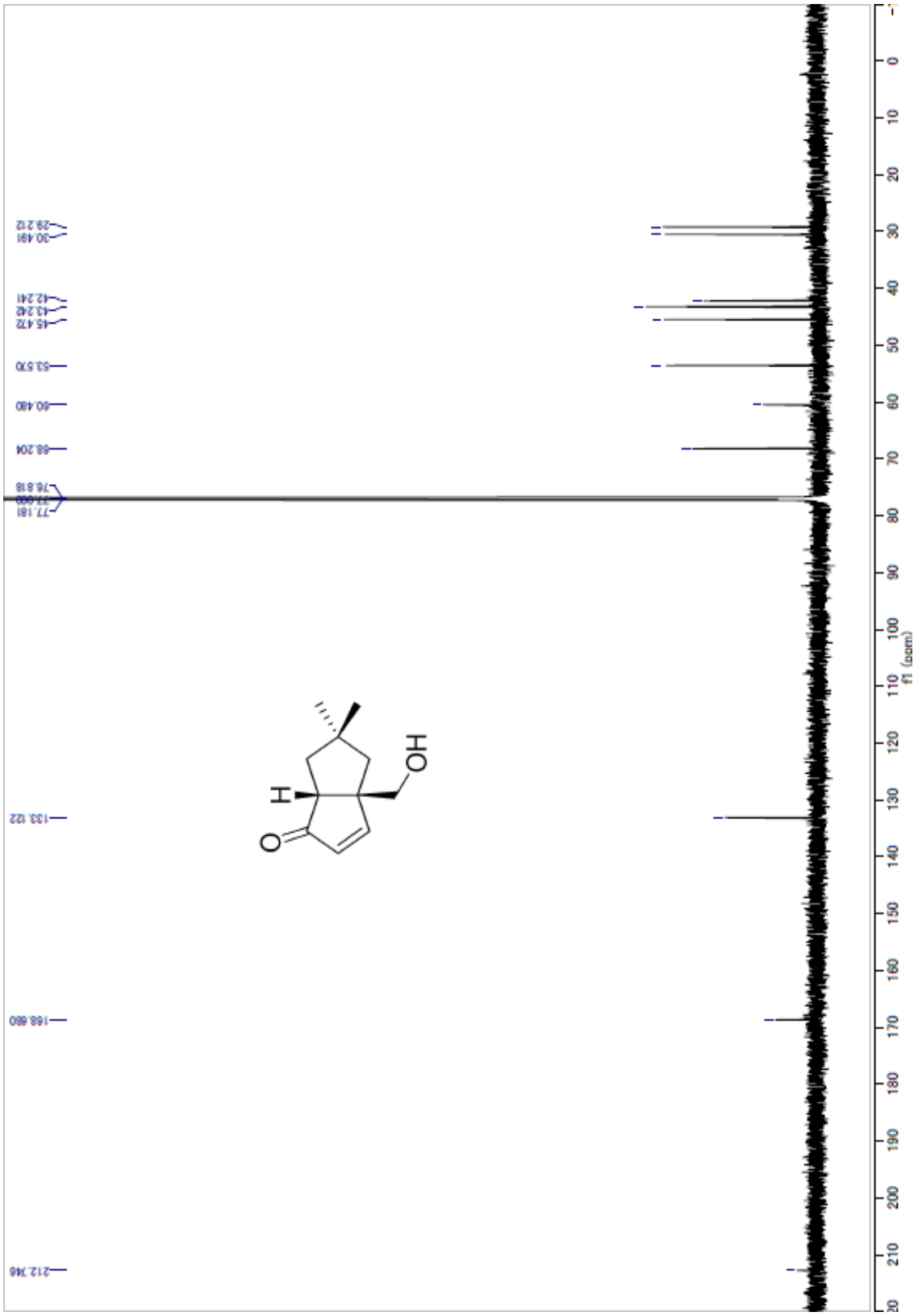

OTBS
H
O
f1 (ppm)

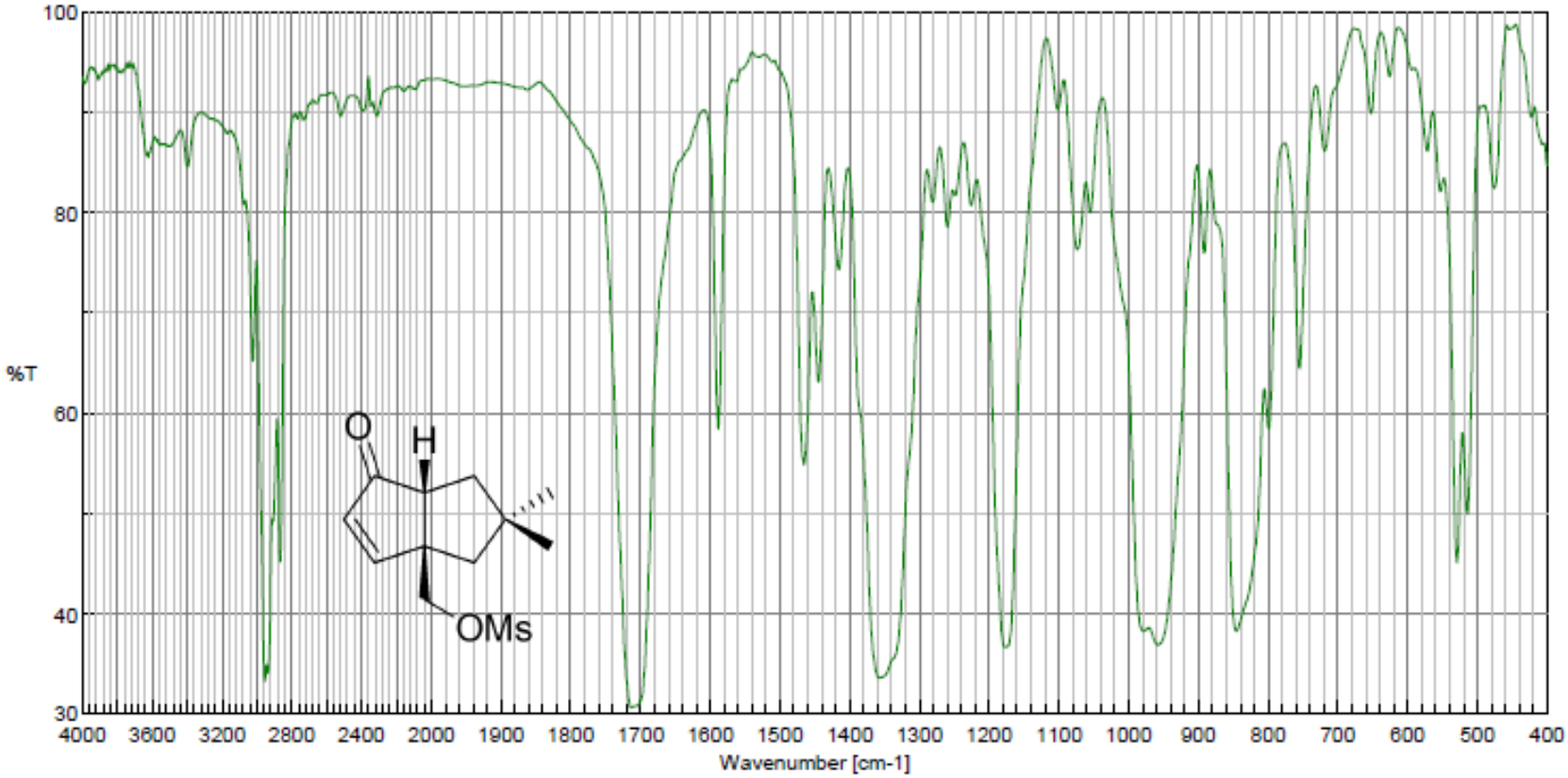

-5.513
18.166
25.762
29.277
30.557
42.254
43.339
45.200
53.886
60.679
68.327
76.819
77.000
77.182
132.337
169.829
213.309
OTBS
H
O
f1 (ppm)



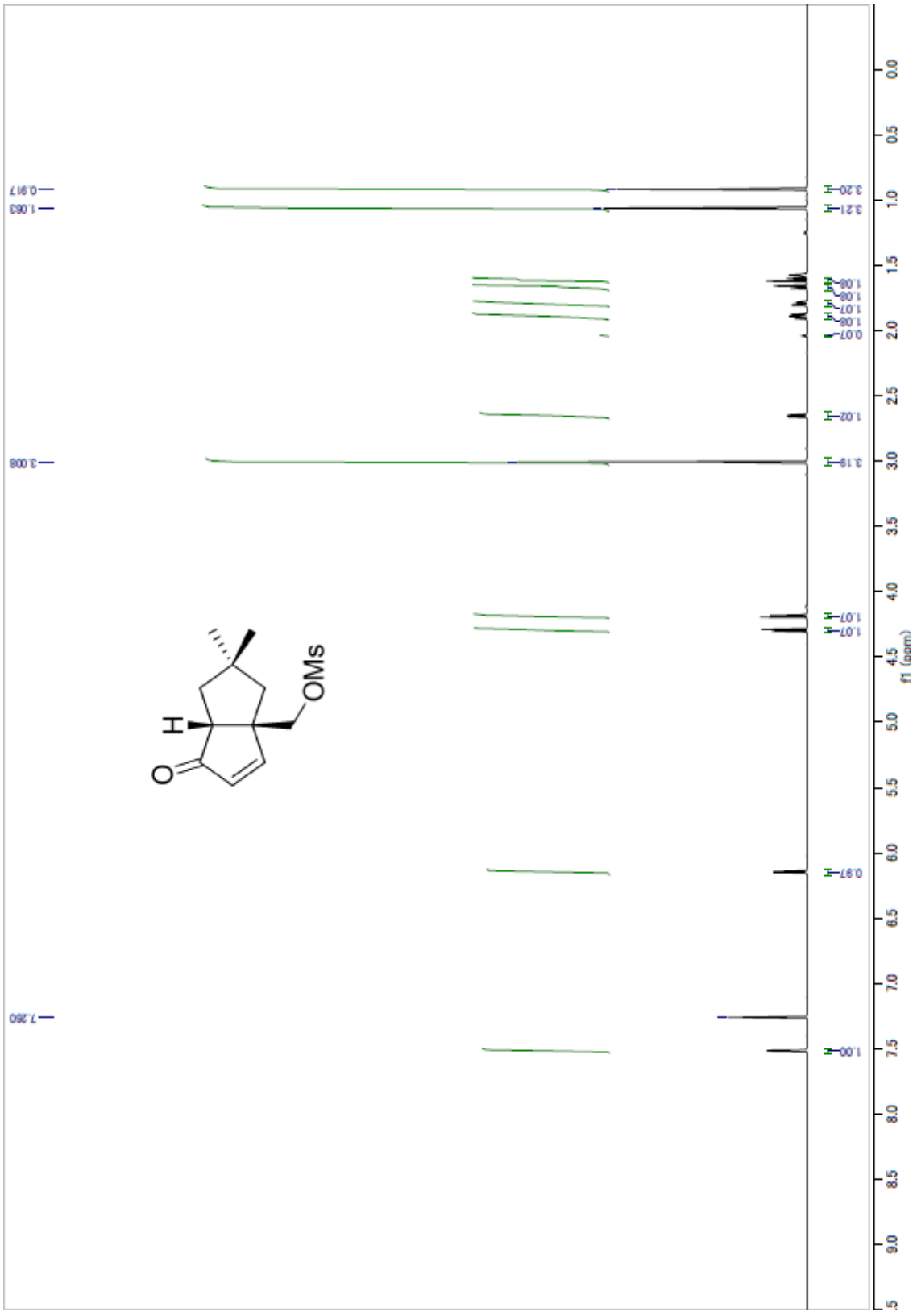
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

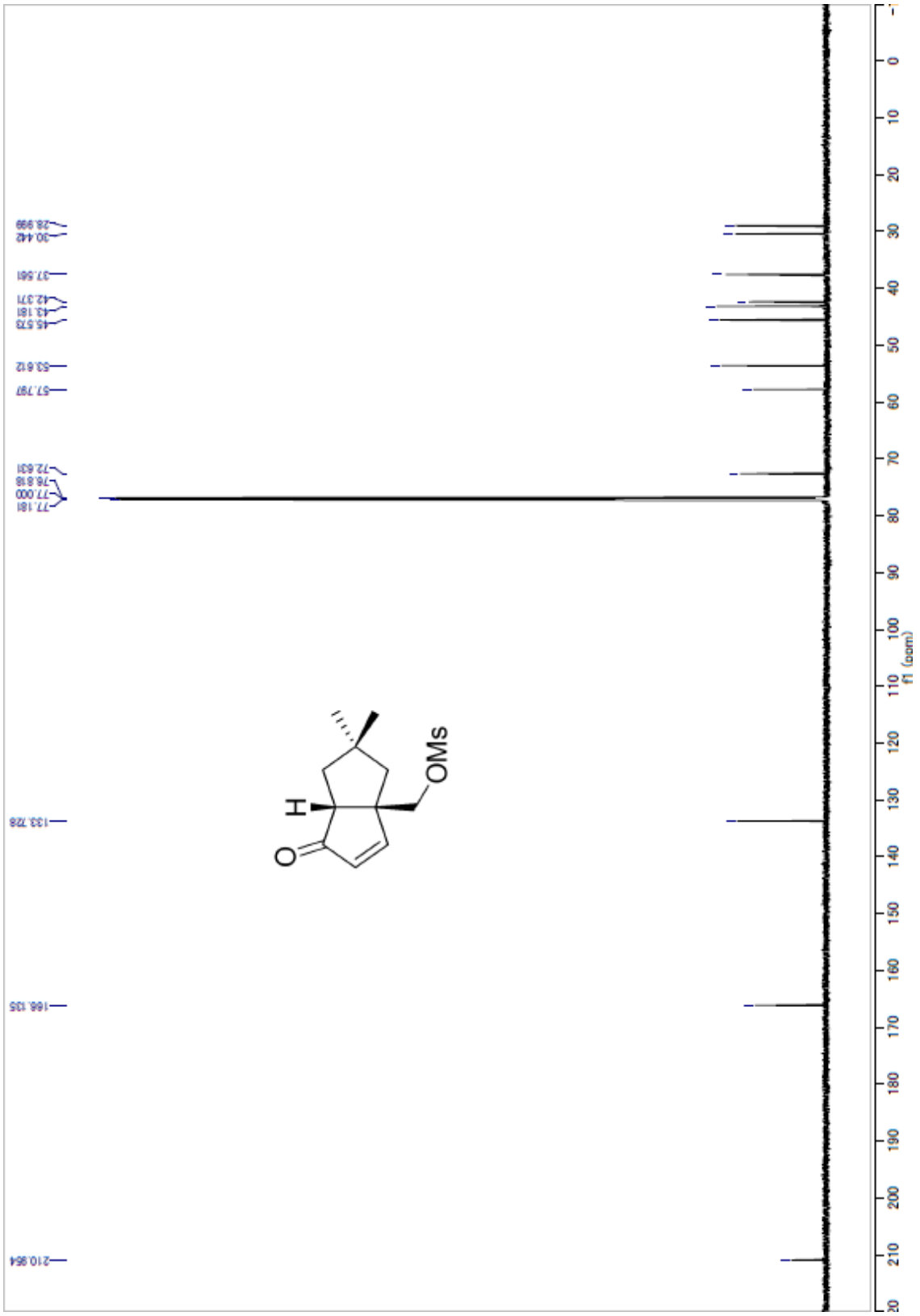

0.910
1.089
7.260
3.17
3.31
3.98
1.09
1.10
1.01
1.10
1.11
0.96
1.00
f1 (ppm)
OH
H
O

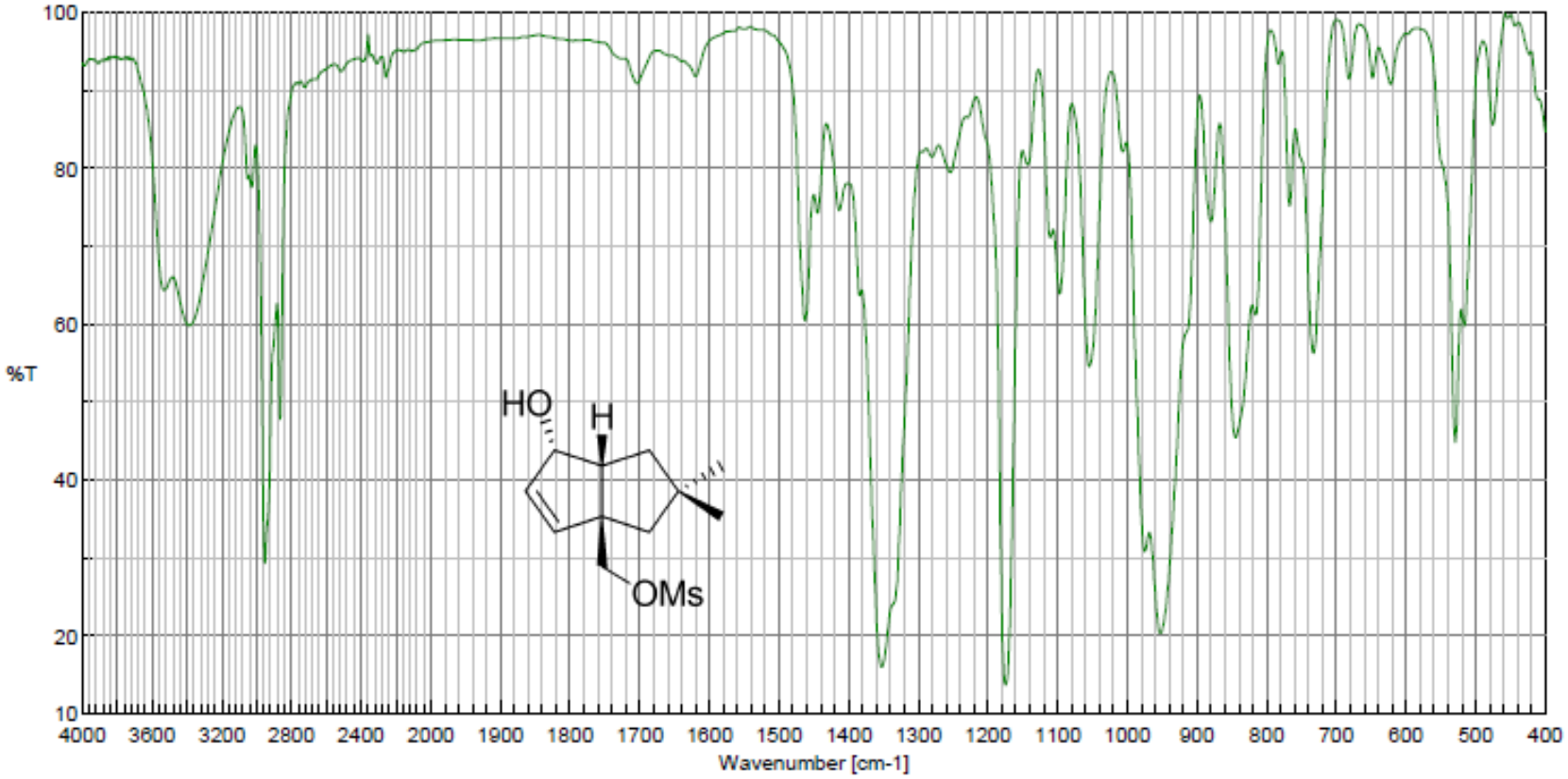

212.746
168.880
133.122
77.181
76.818
68.204
60.480
53.570
45.472
43.240
42.241
30.491
29.212
f1 (ppm)



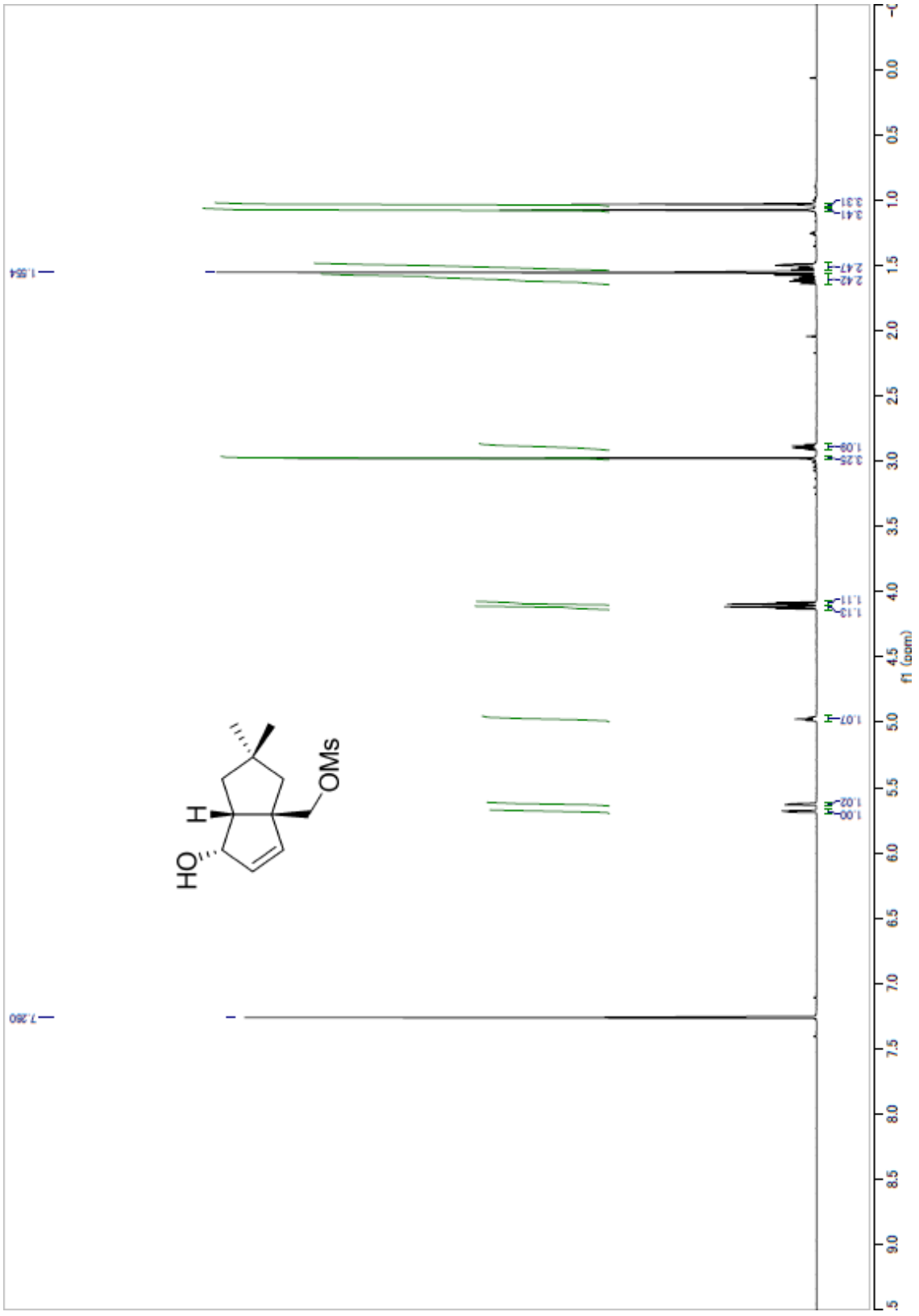
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

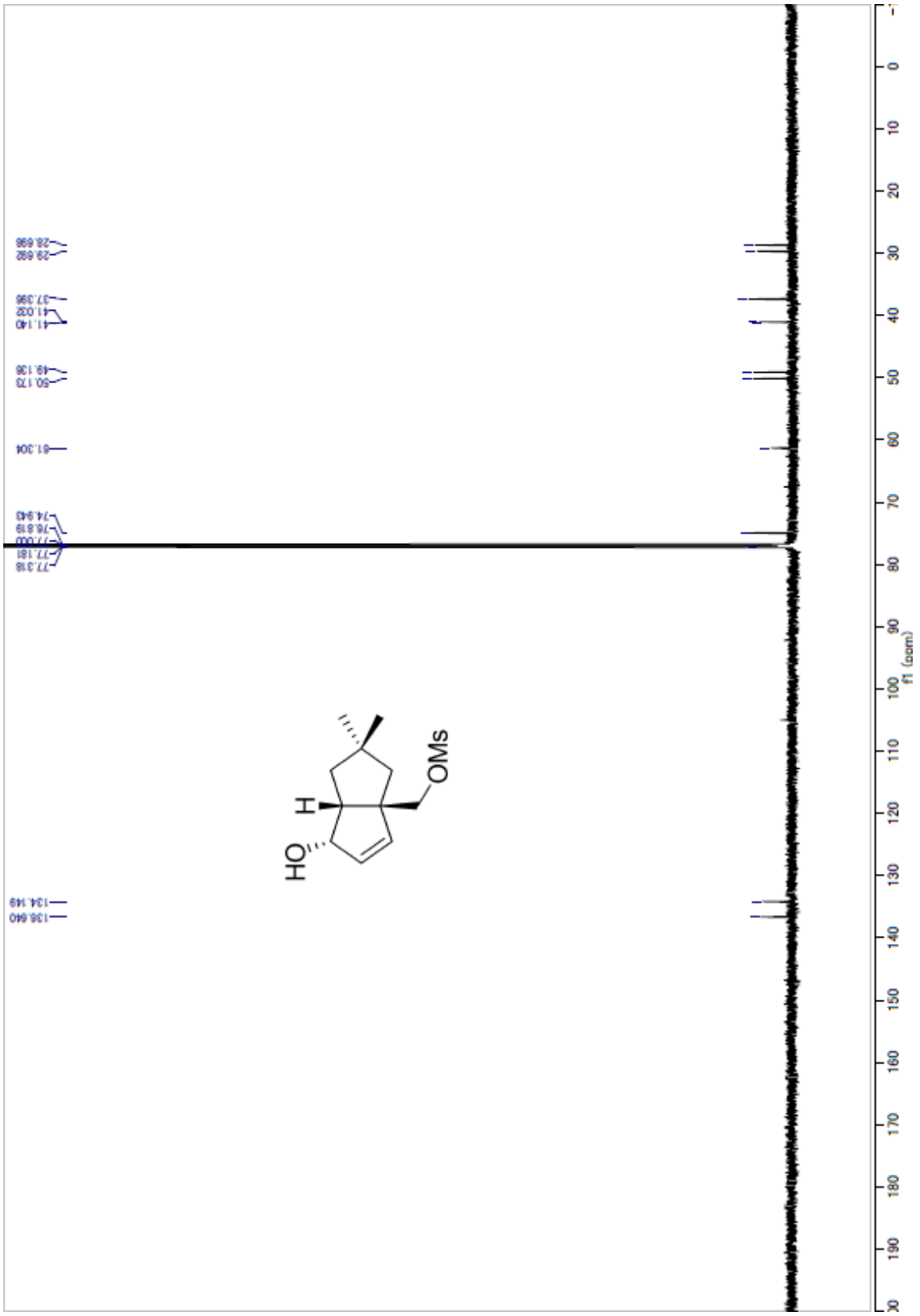

OMs
H
O
f1 (ppm)

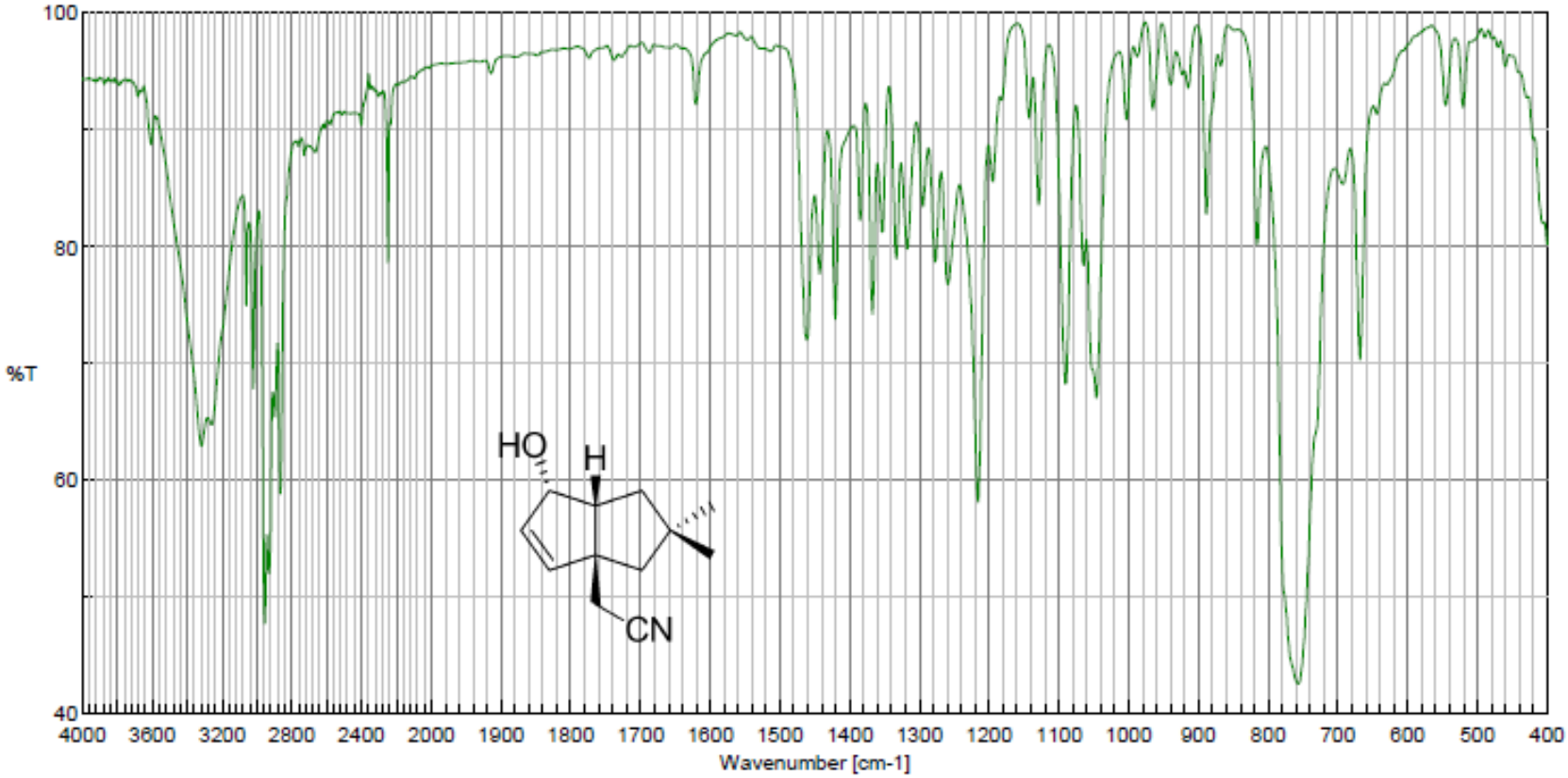

210.864
166.135
133.728
77.181
77.000
76.818
72.631
57.787
53.612
45.570
43.181
42.371
37.561
30.442
28.999
f1 (ppm)
O
H
OMs



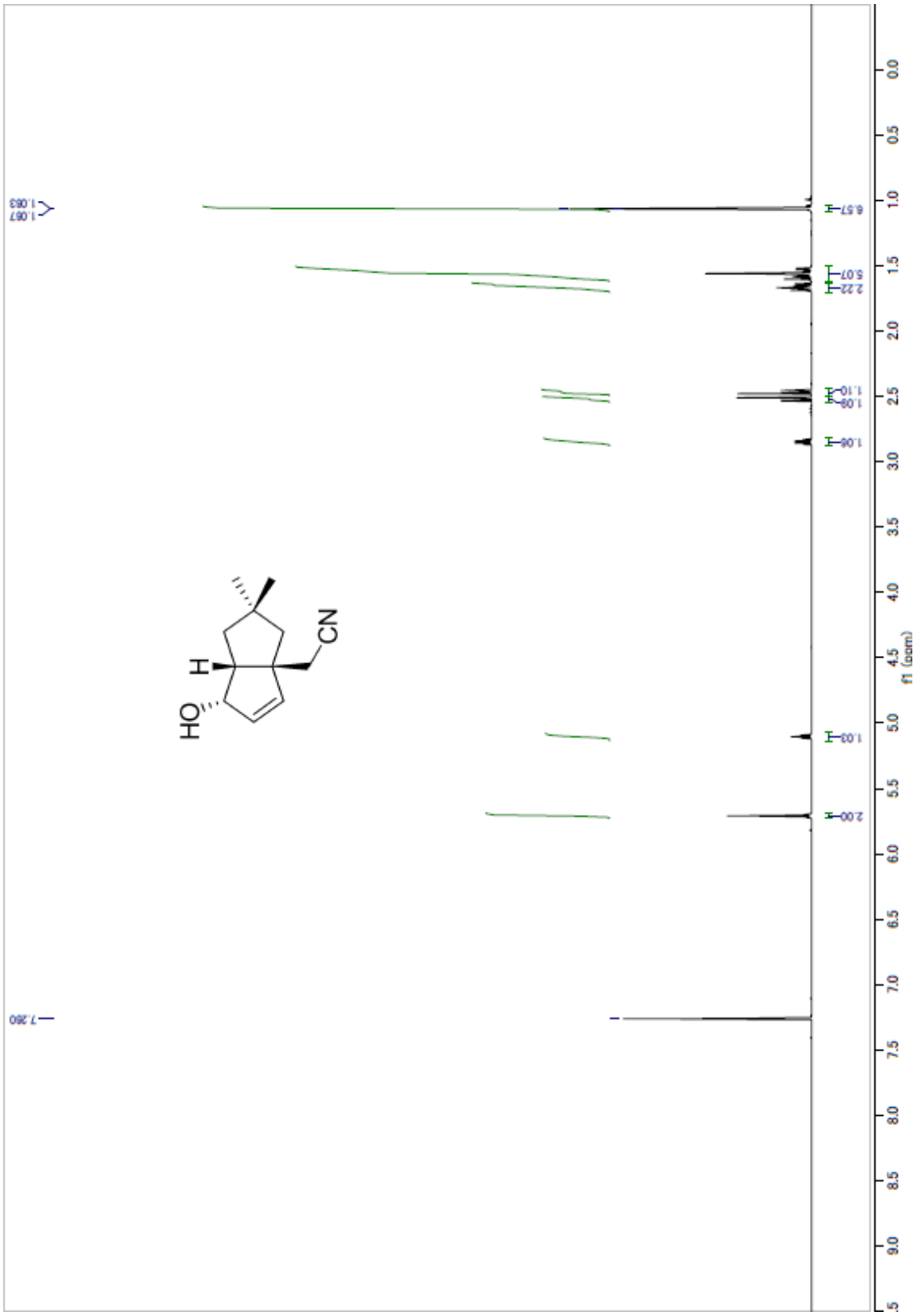
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

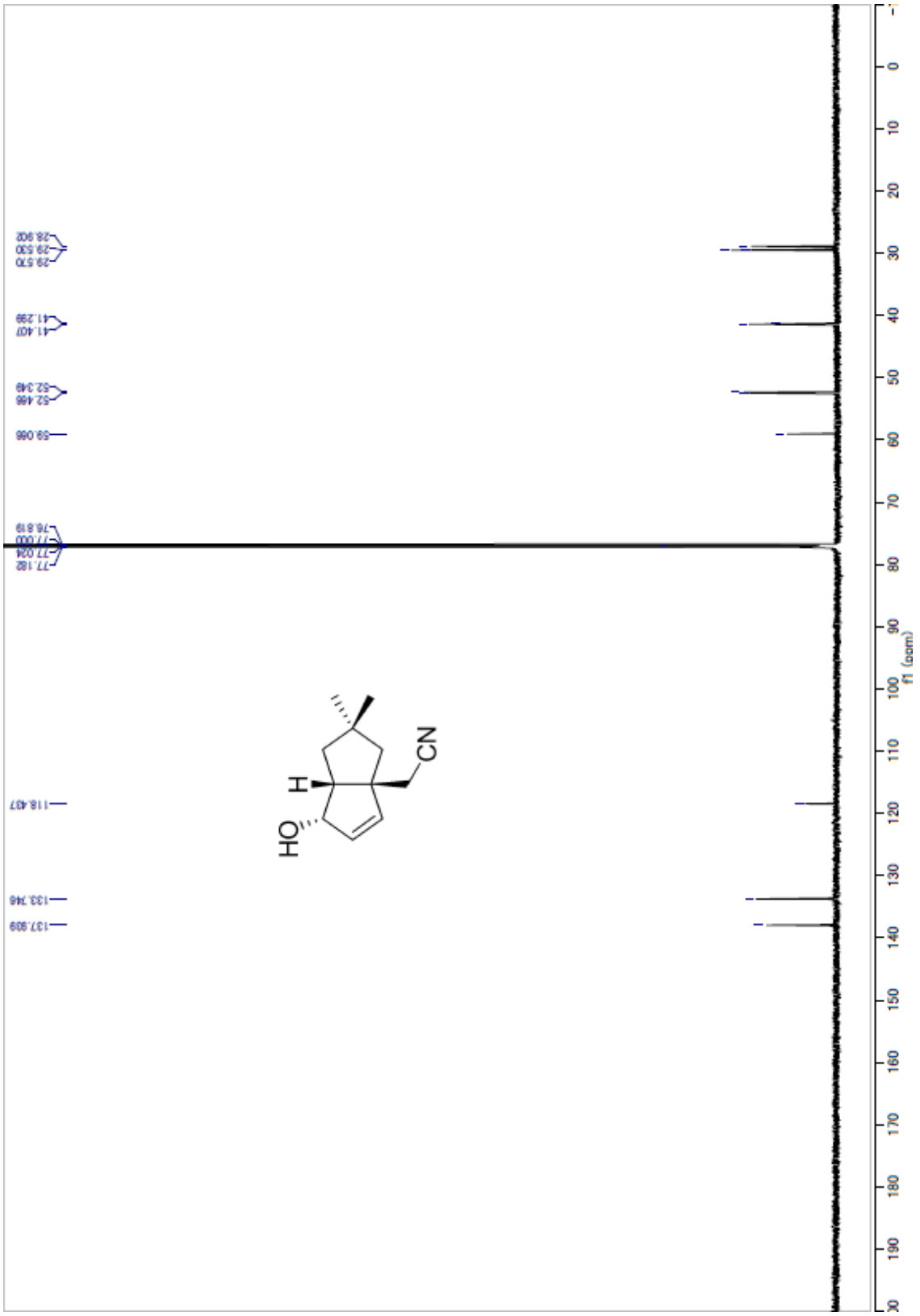

OMs
H
HO
7.260
1.554
3.41
3.31
2.47
2.42
3.25
1.09
1.13
1.11
1.07
1.02
1.00
f1 (ppm)

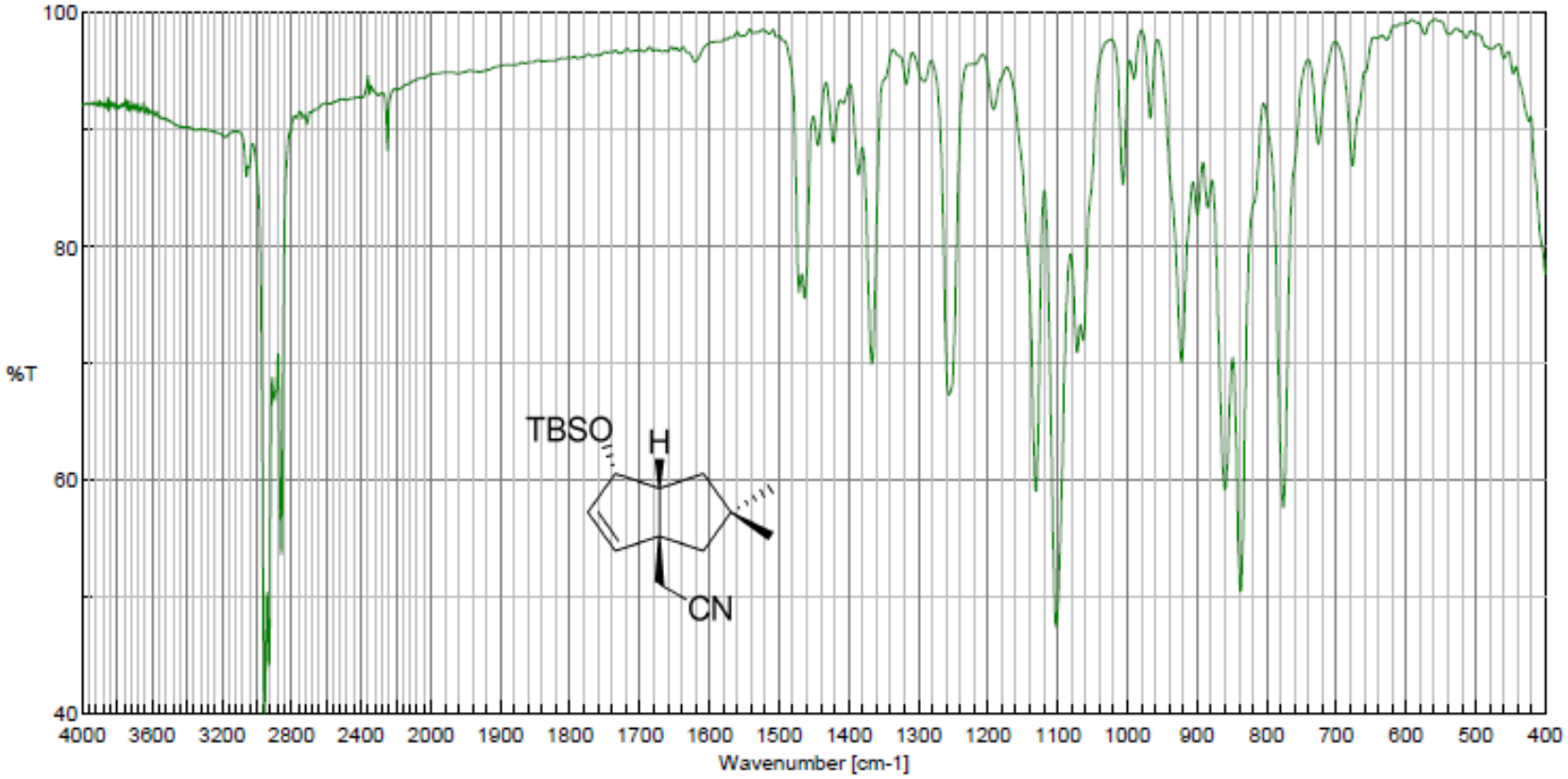

OMs
H
HO
f1 (ppm)



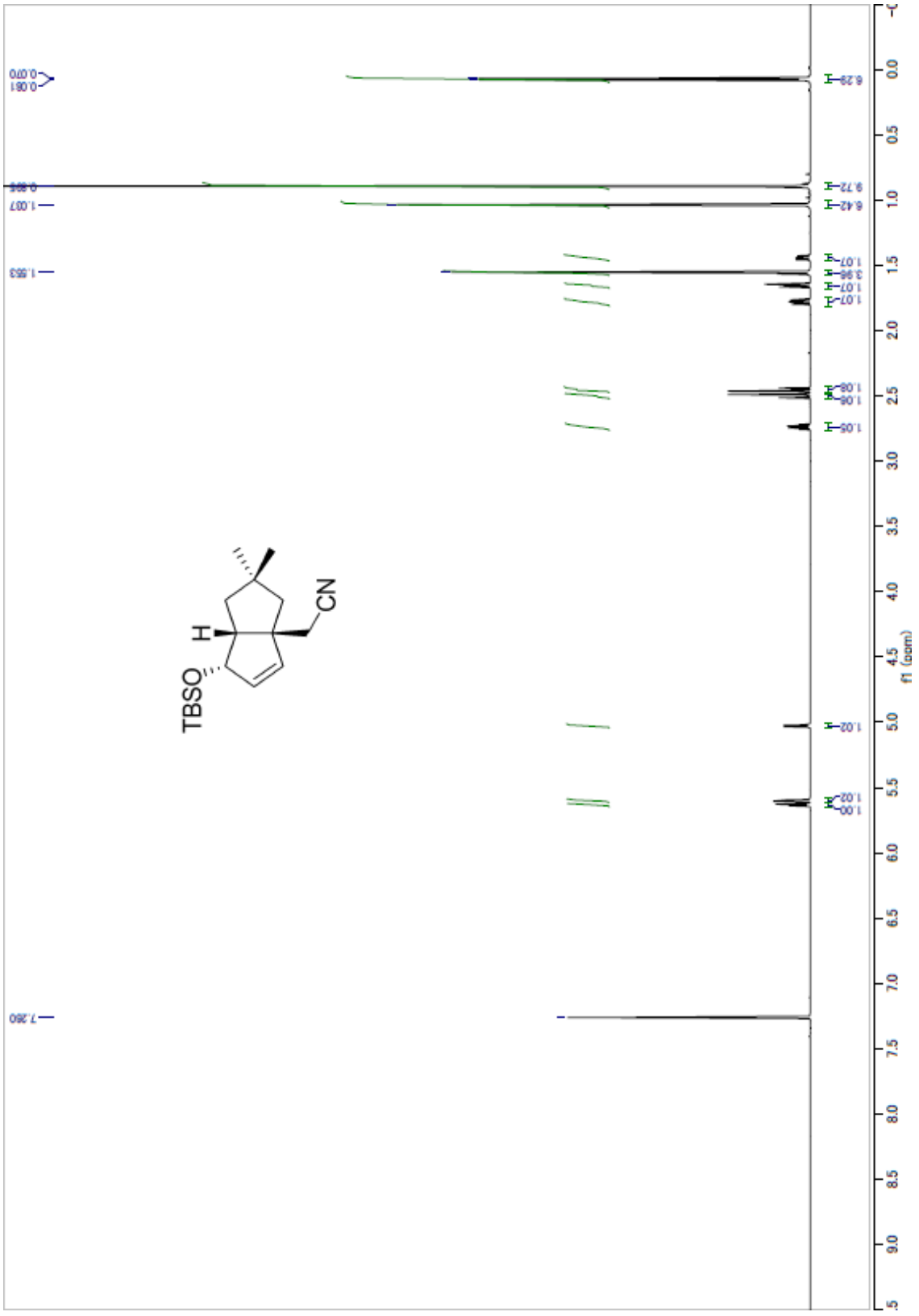
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

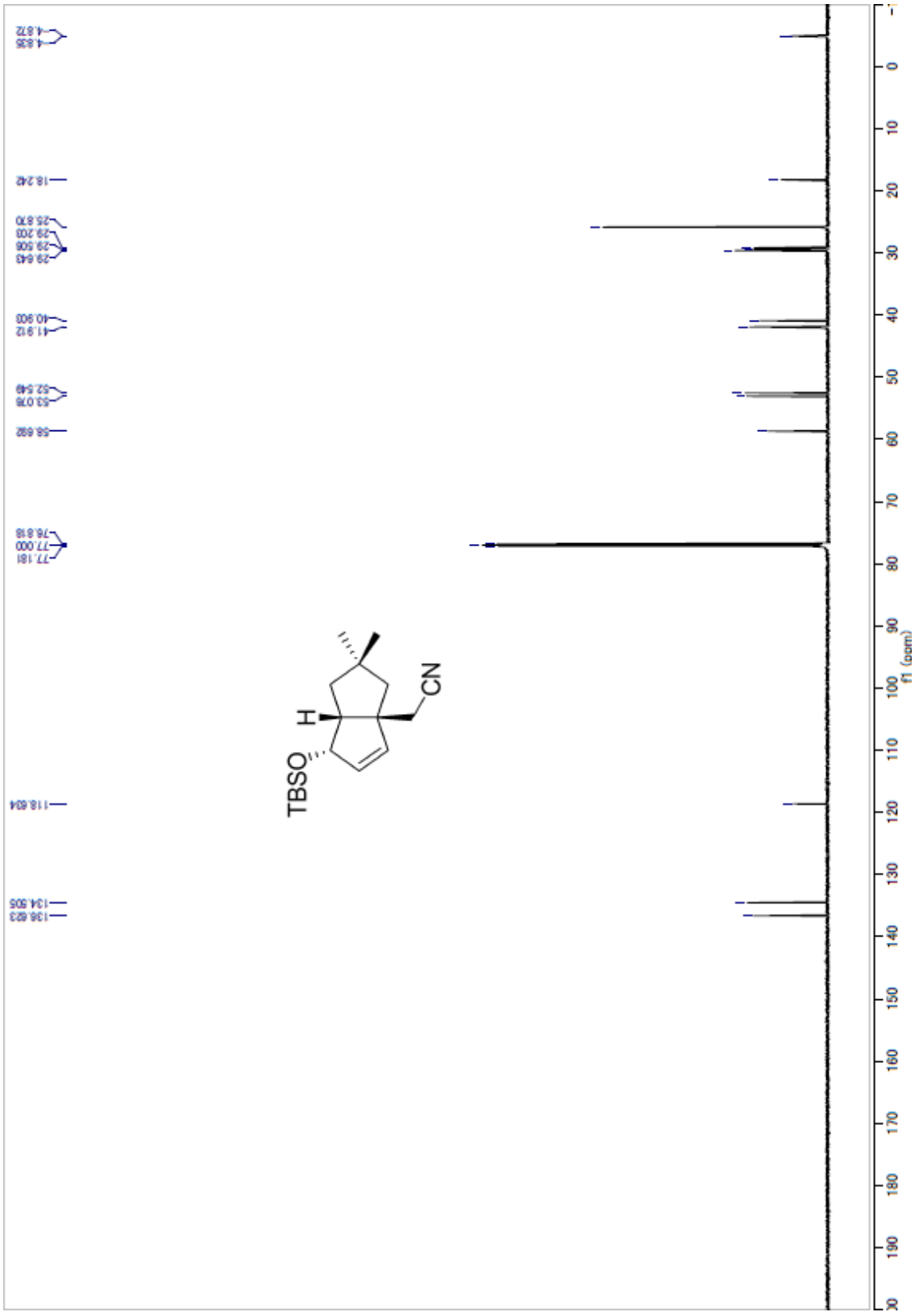

1.083
1.067
7.260
6.57
5.07
2.22
1.09
1.10
1.06
1.03
2.00
HO
H
CN
f1 (ppm)

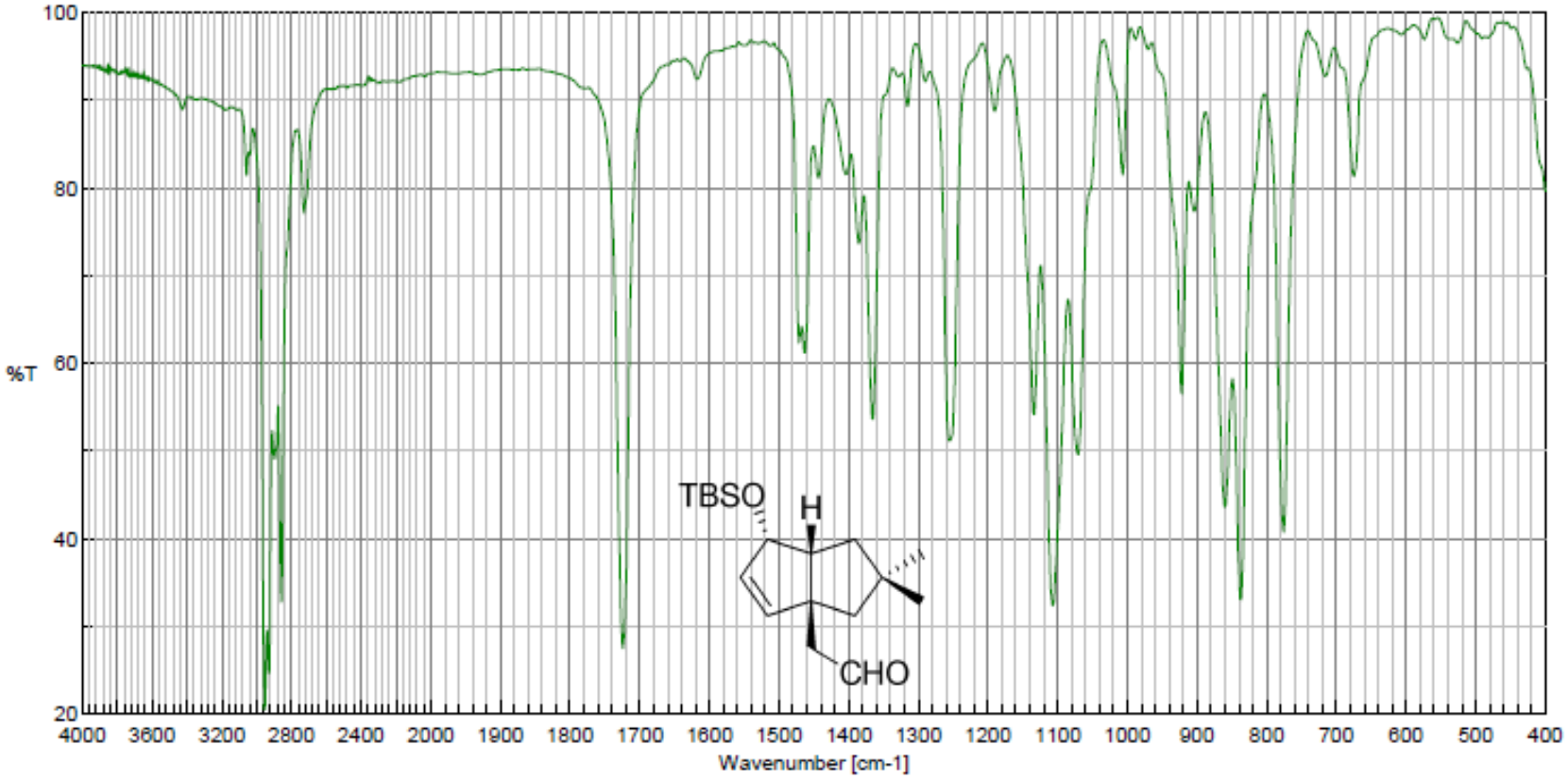

28.902
29.530
29.570
41.299
41.407
52.249
52.466
59.066
76.819
77.000
77.024
77.182
118.437
133.746
137.509
HO
H
CN
f1 (ppm)



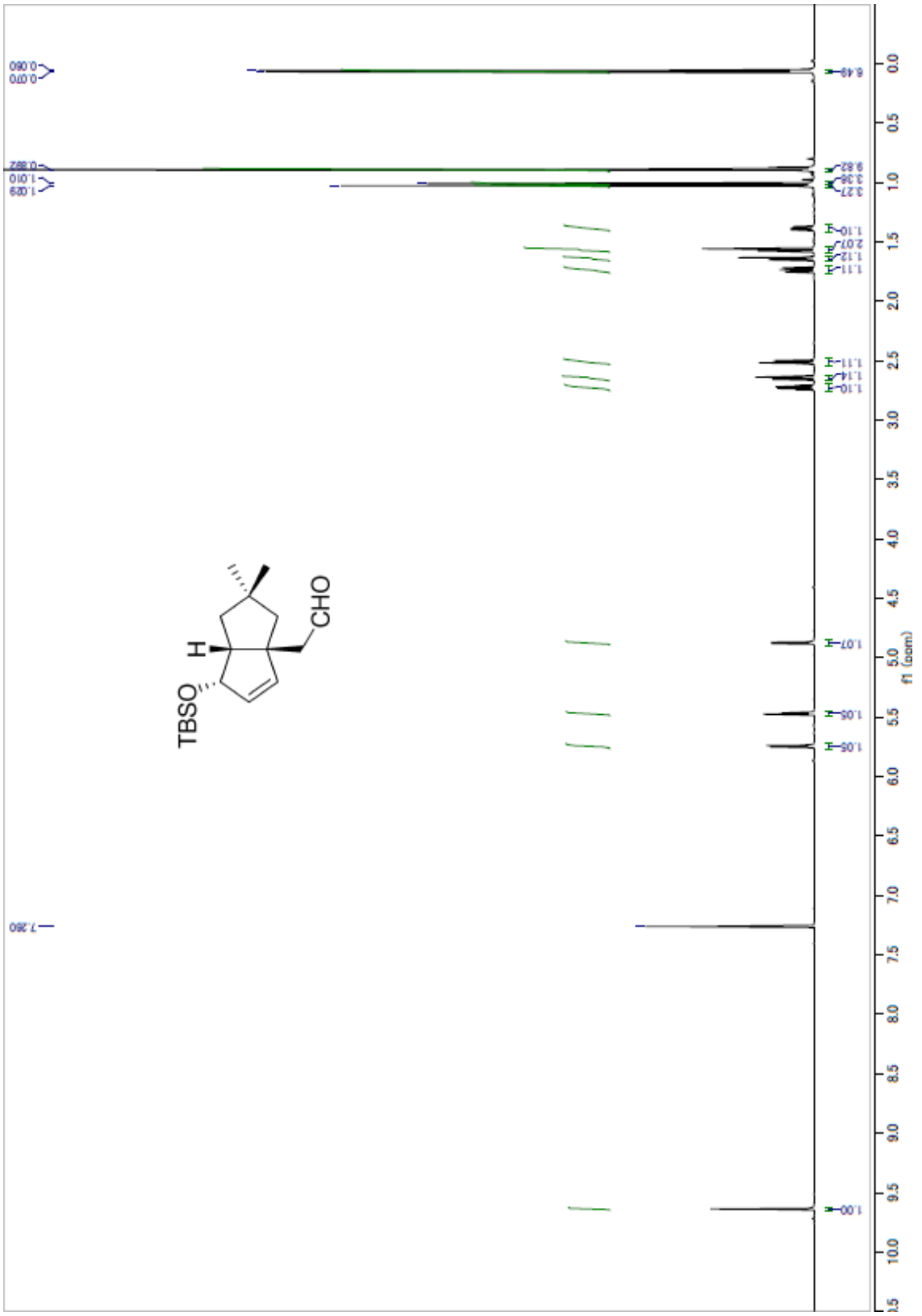
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部


TBSO
H
CN
f1 (ppm)

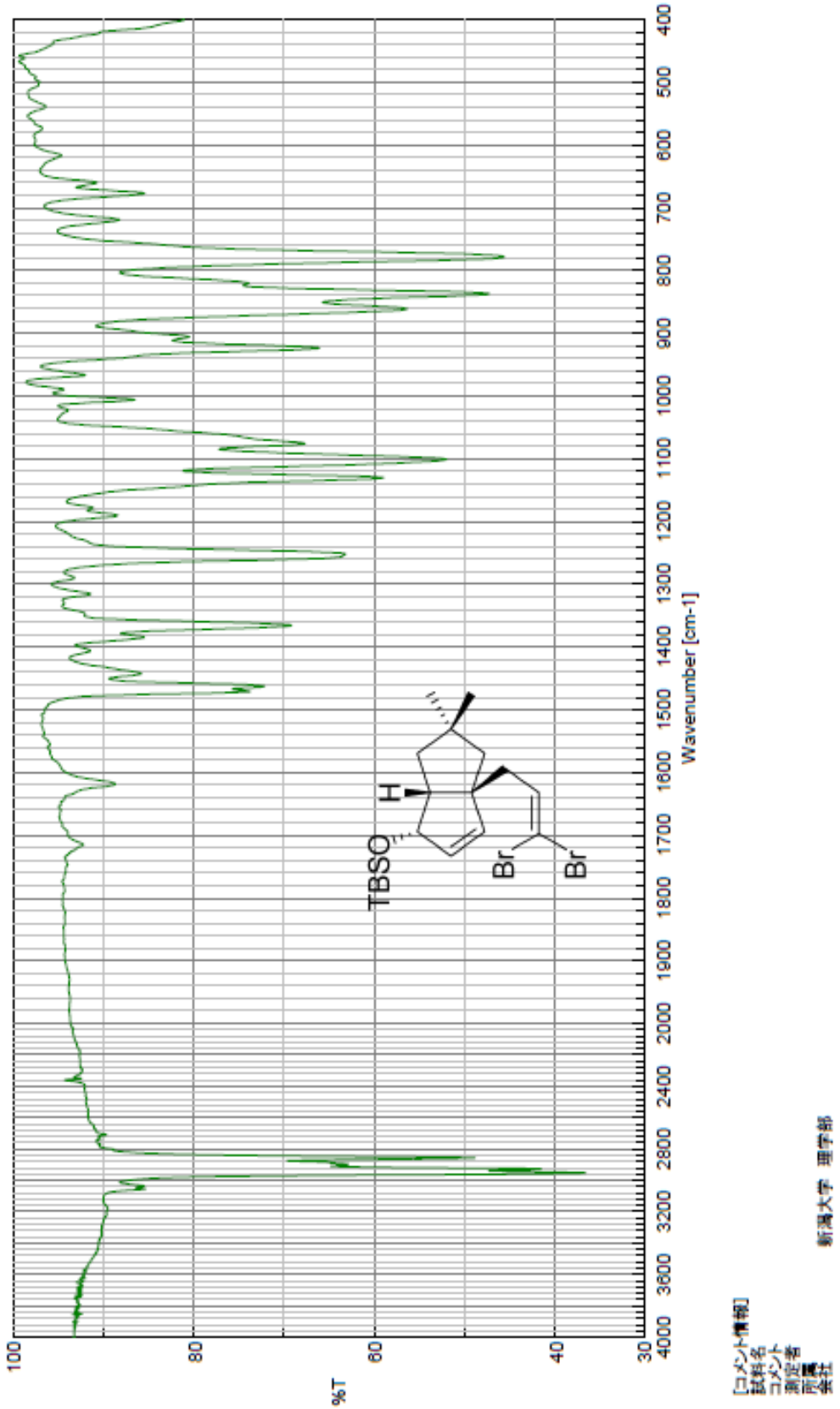

TBSO
H
CN
f1 (ppm)

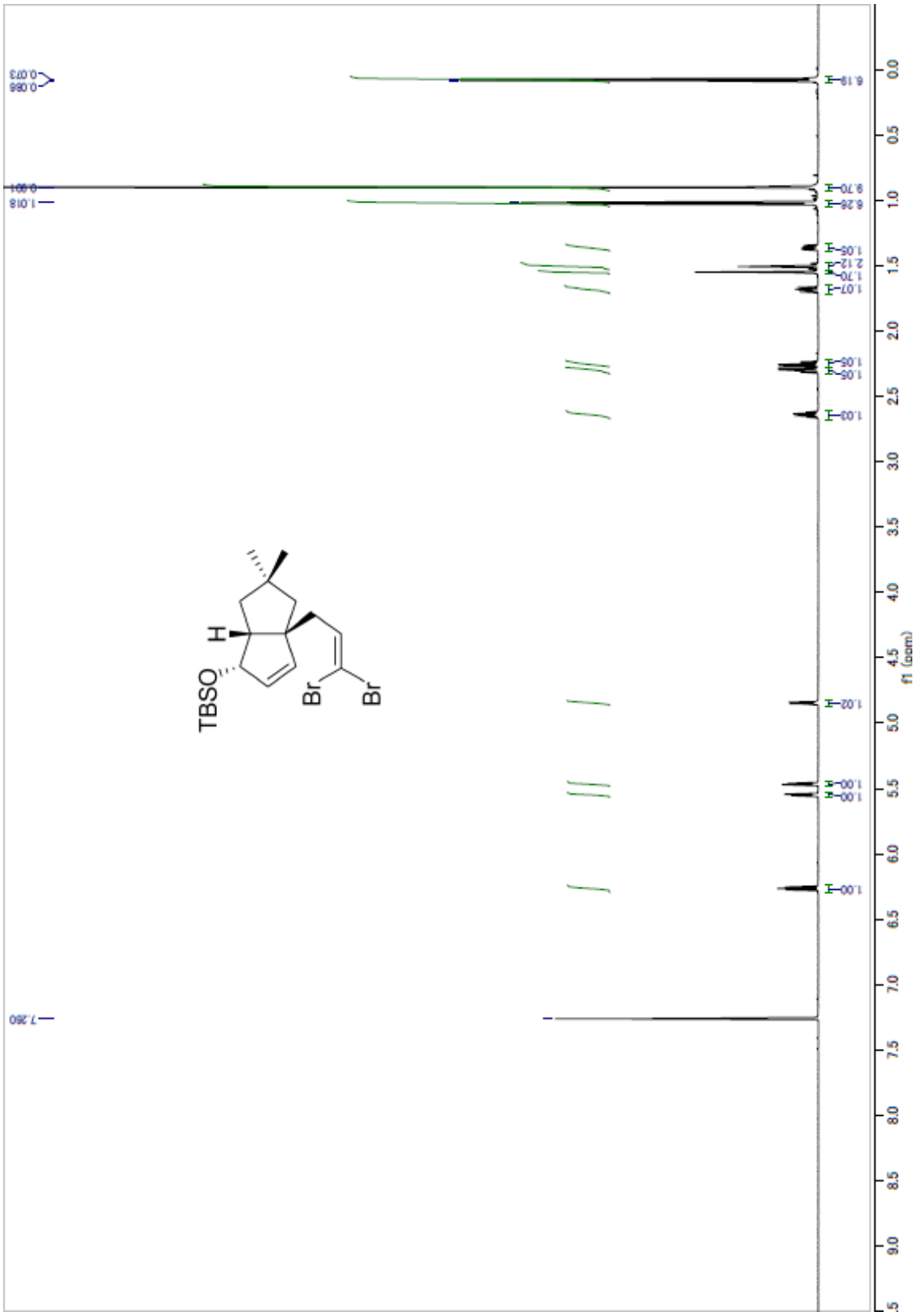


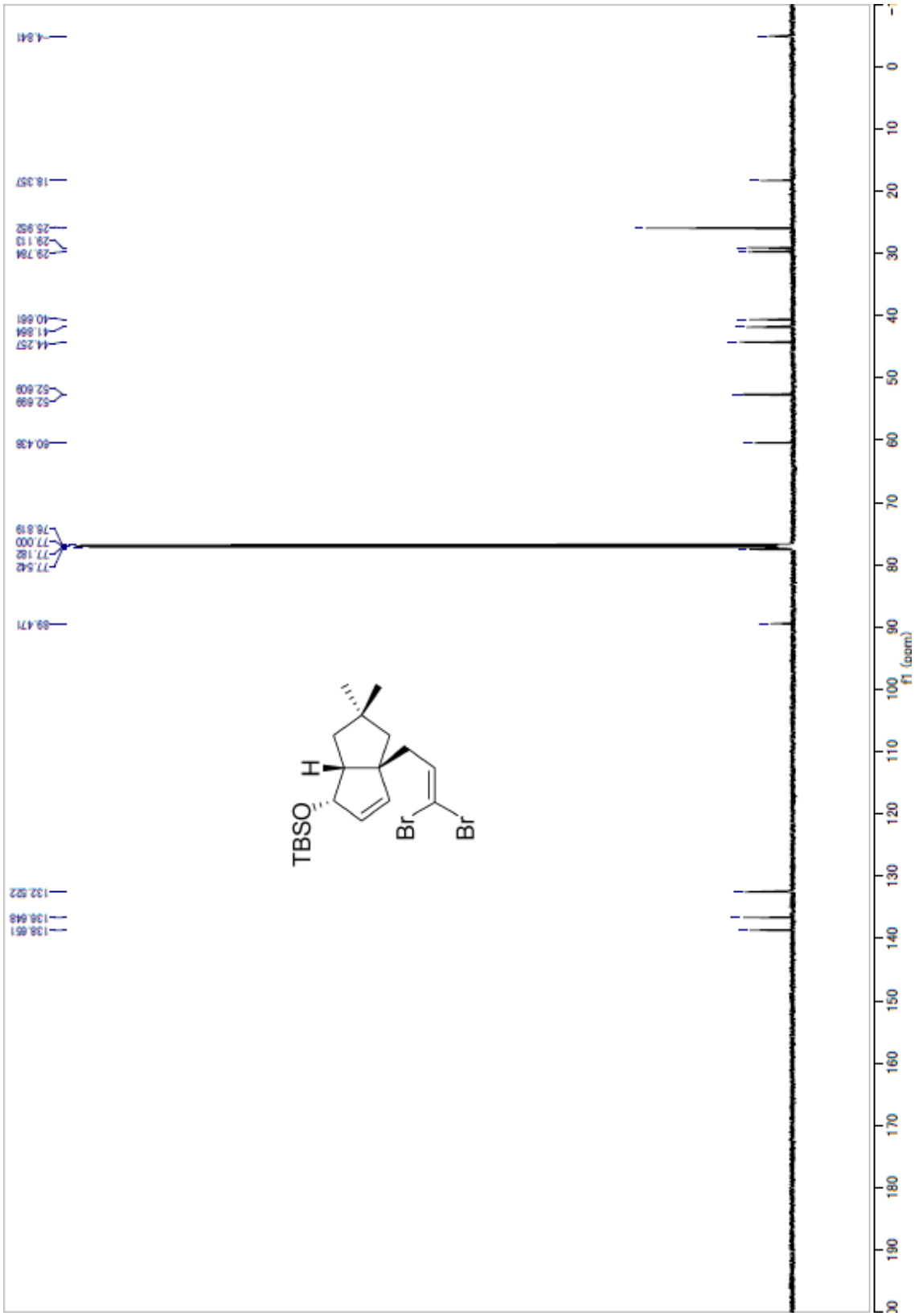
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

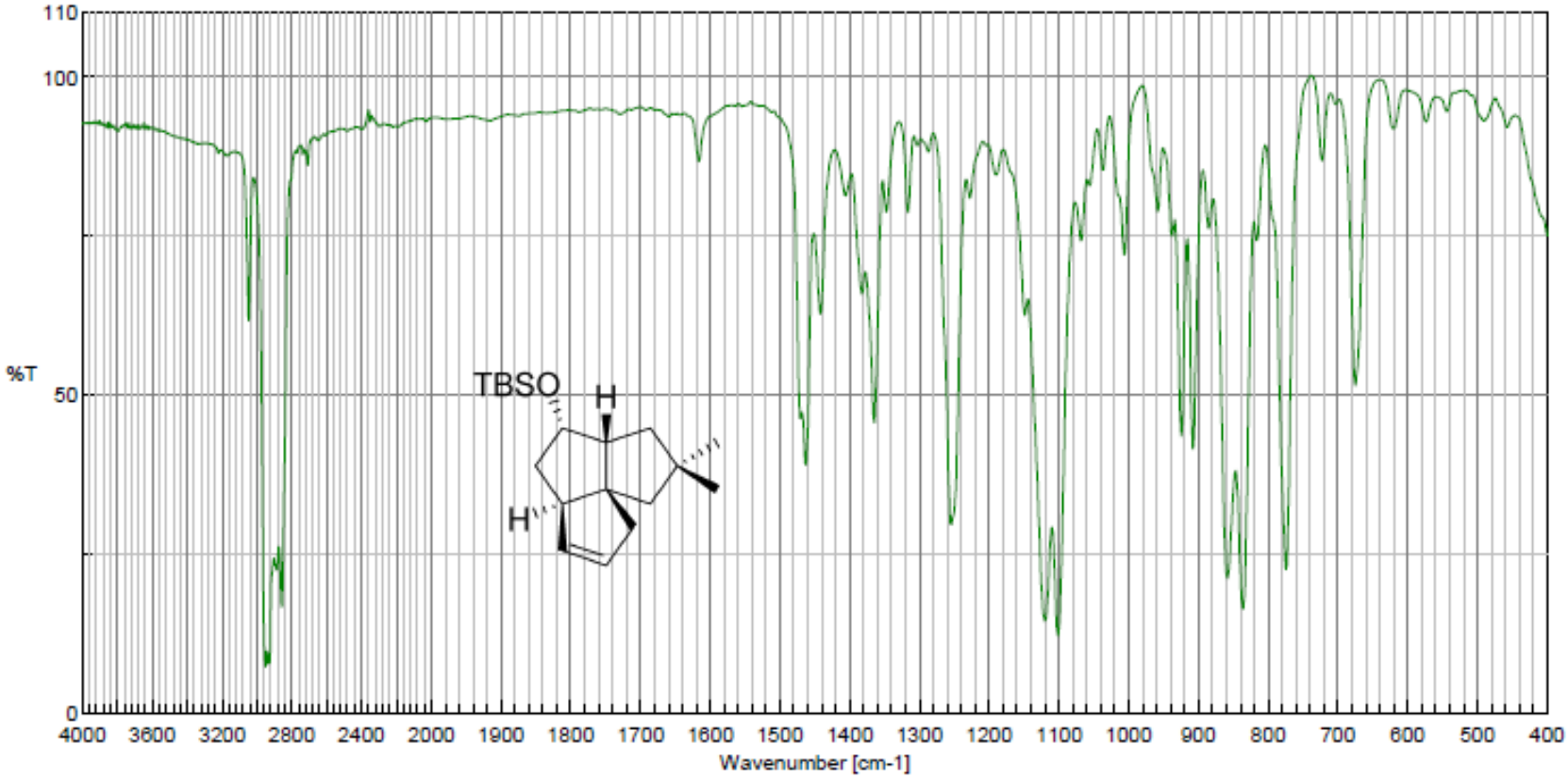

TBSO
H
CHO
f1 (ppm)


TBSO
H
CHO
f1 (ppm)

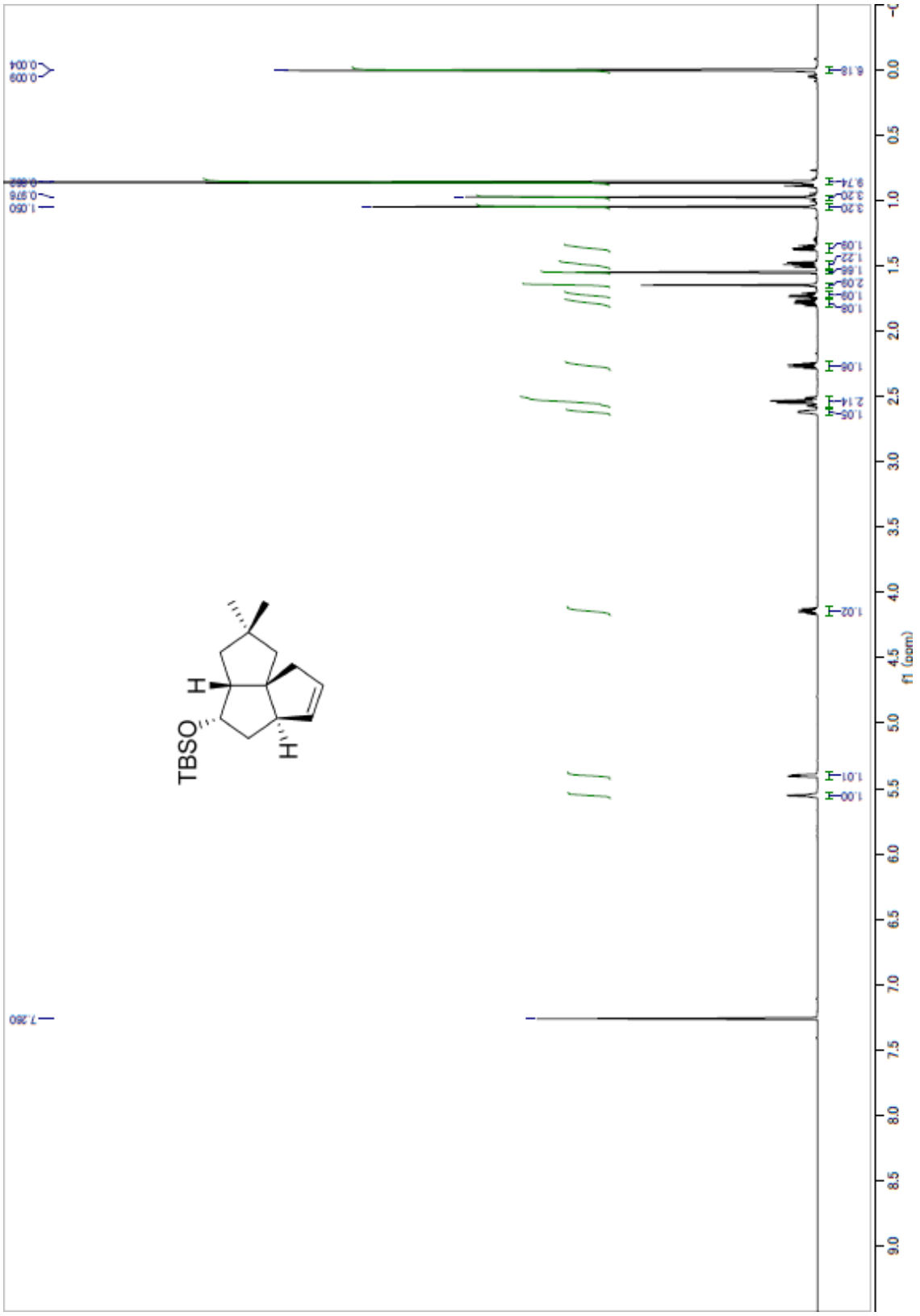

100
80
60
40
%T
4000
3600
3200
2800
2400
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
Wavenumber [cm-1]
TBSO
H
Br
Br
[コメント情報]
試料名
コメント
測定者
所属
会社
新潟大学　理学部

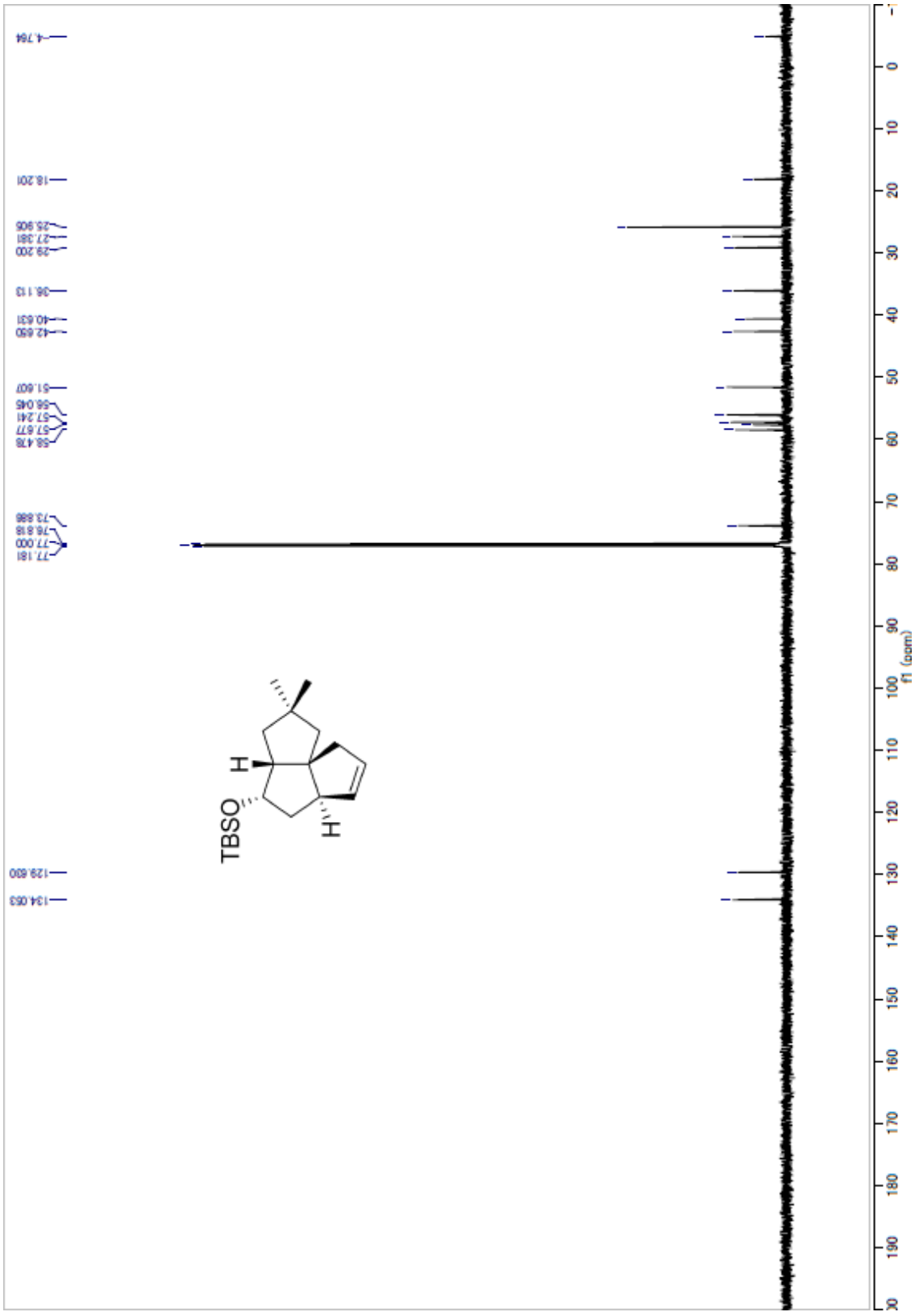

TBSO
H
Br
Br
f1 (ppm)

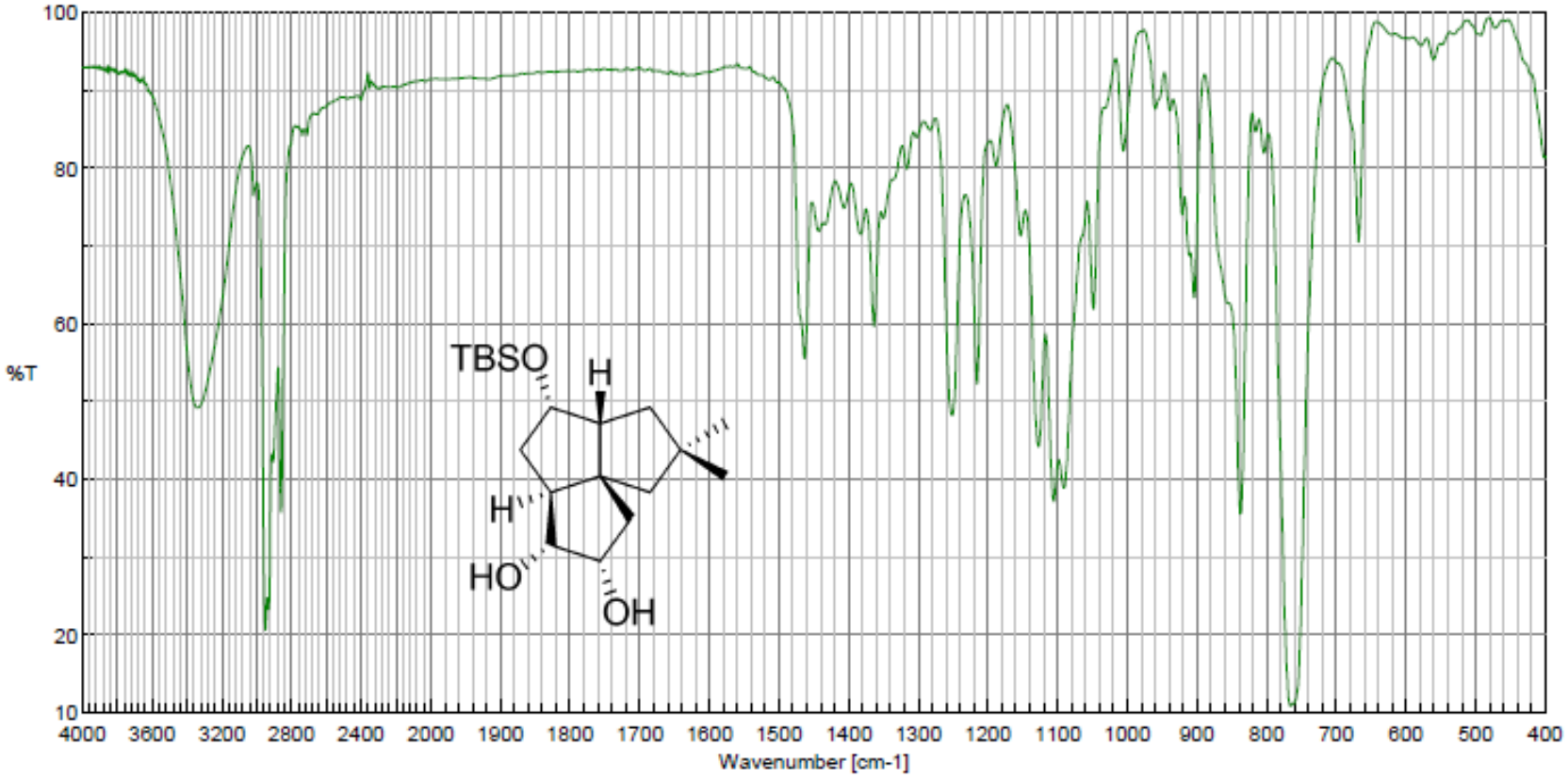

TBSO
H
Br
Br
f1 (ppm)



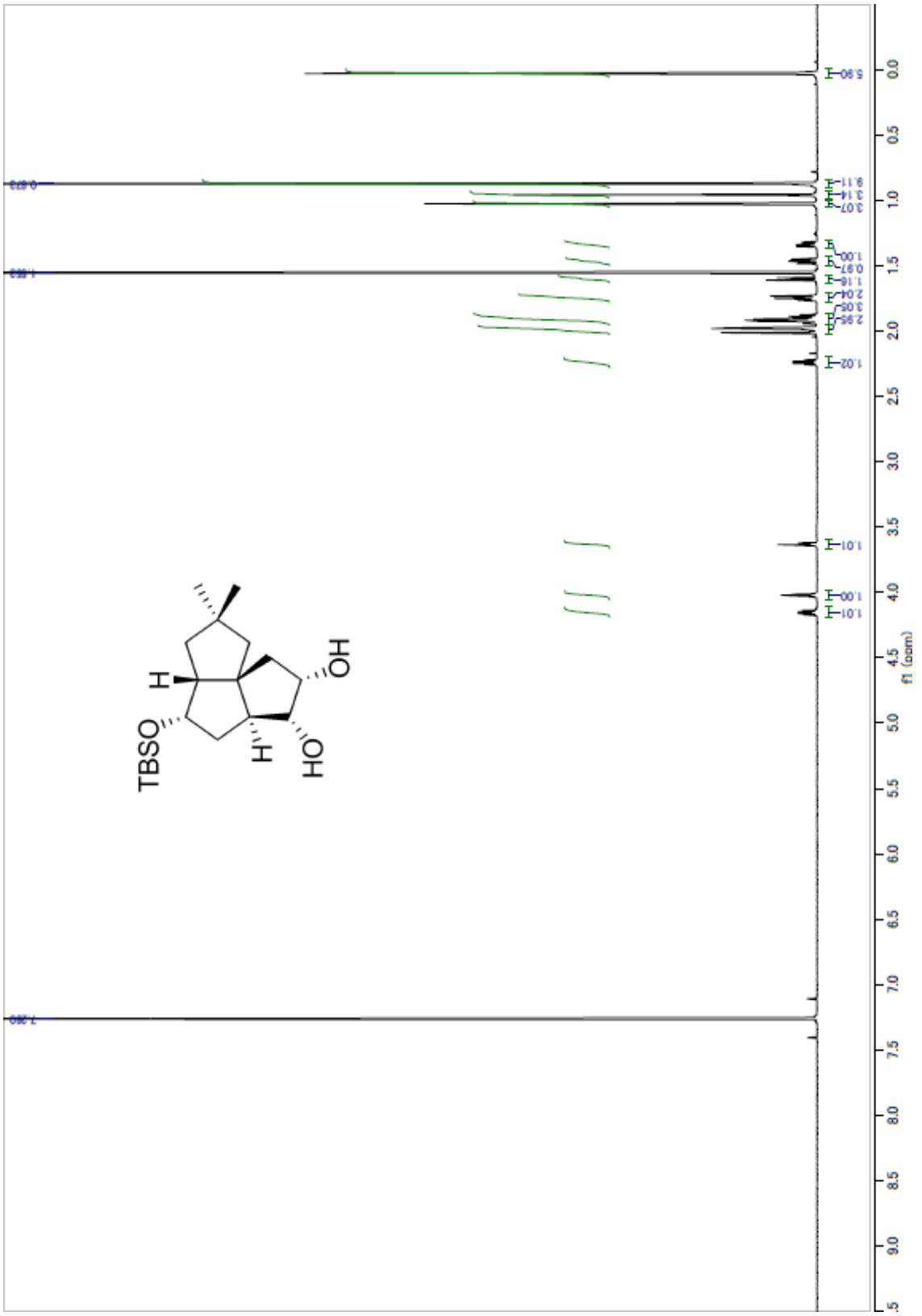
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

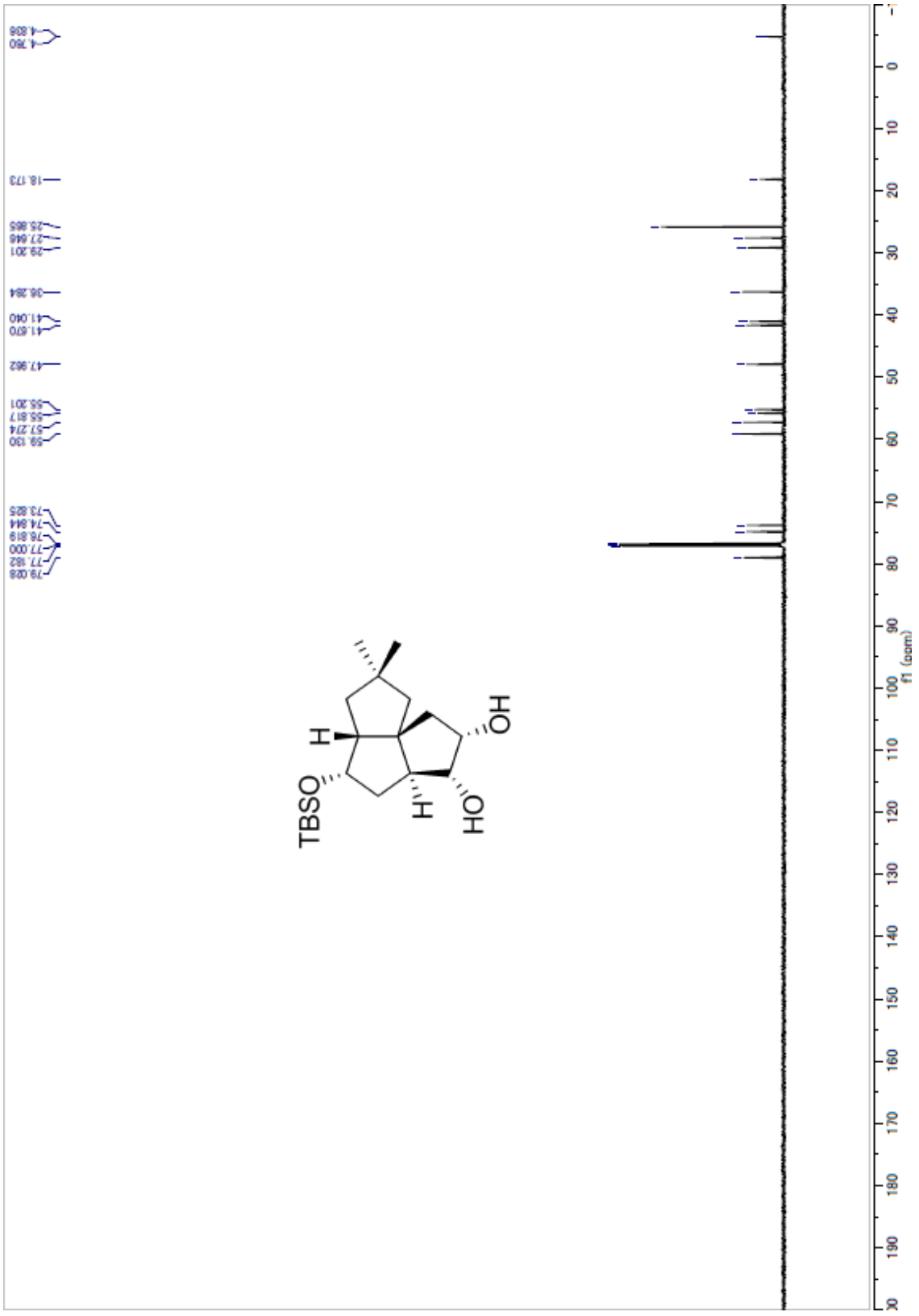

TBSO
H
H
f1 (ppm)

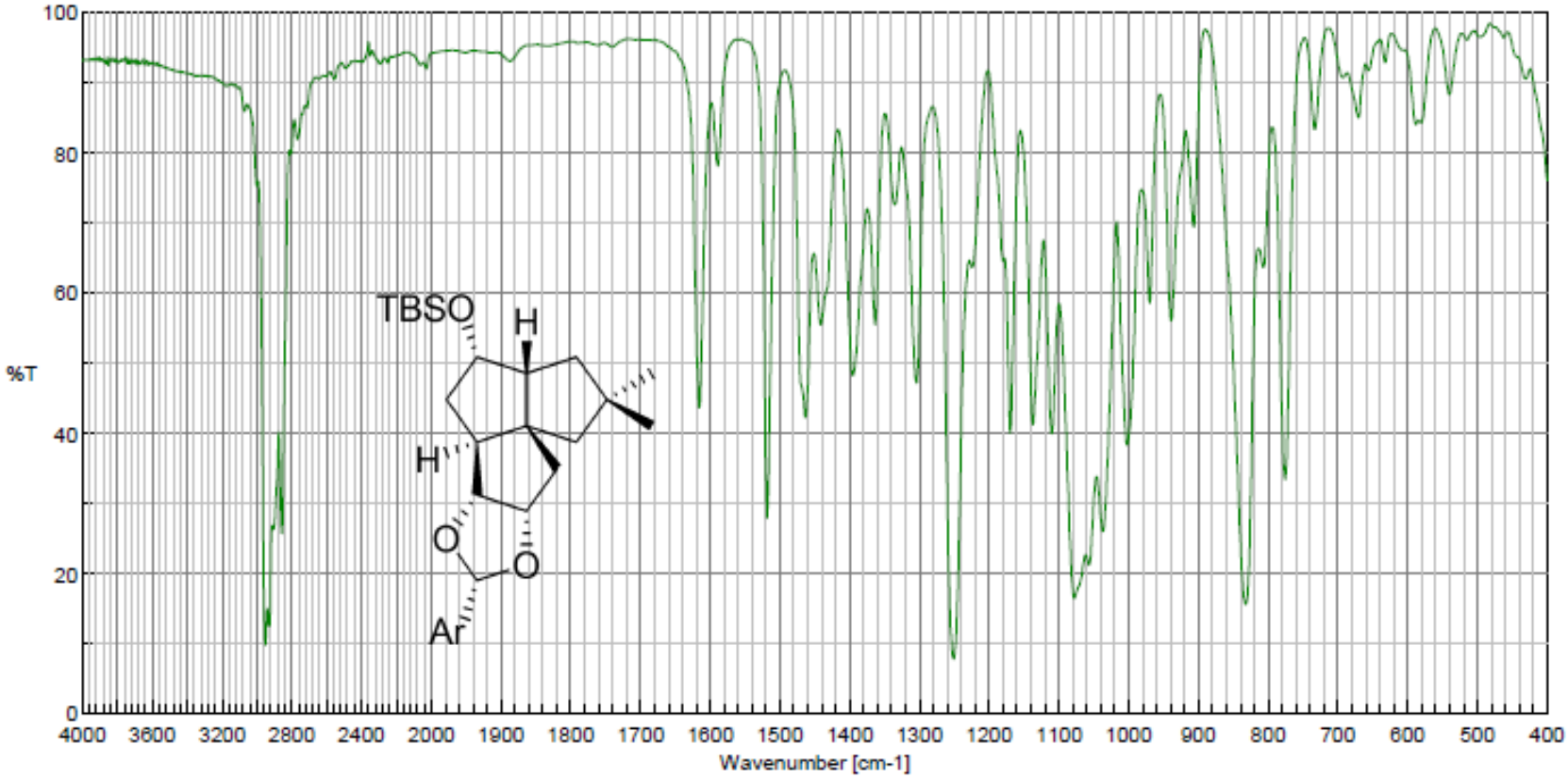

-4.764
18.201
25.905
27.381
29.200
36.113
40.631
42.650
51.607
56.045
57.241
57.677
58.478
73.886
76.818
77.000
77.181
129.600
134.053
TBSO
H
H
f1 (ppm)



[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

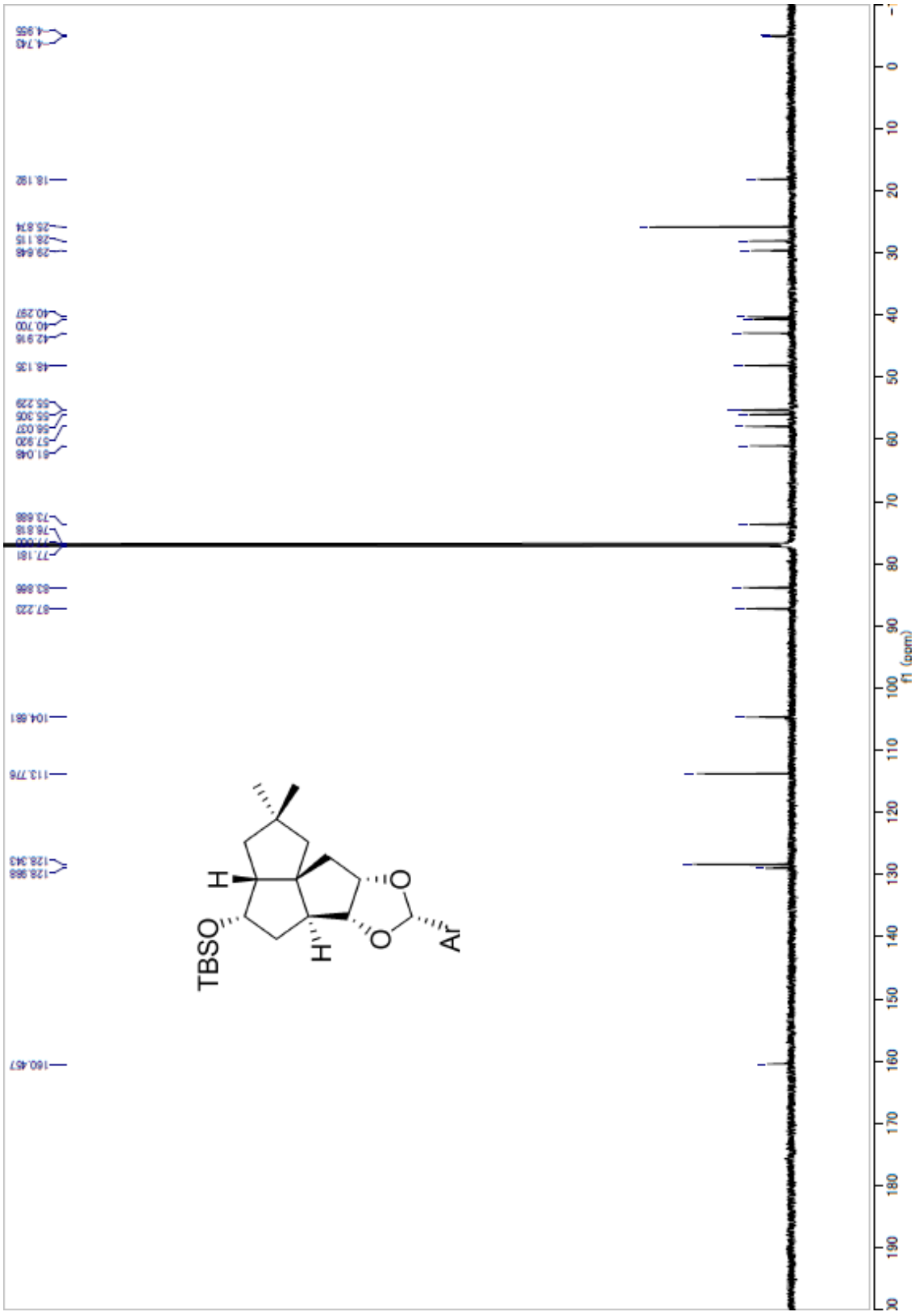

TBSO
H
H
HO
OH
f1 (ppm)

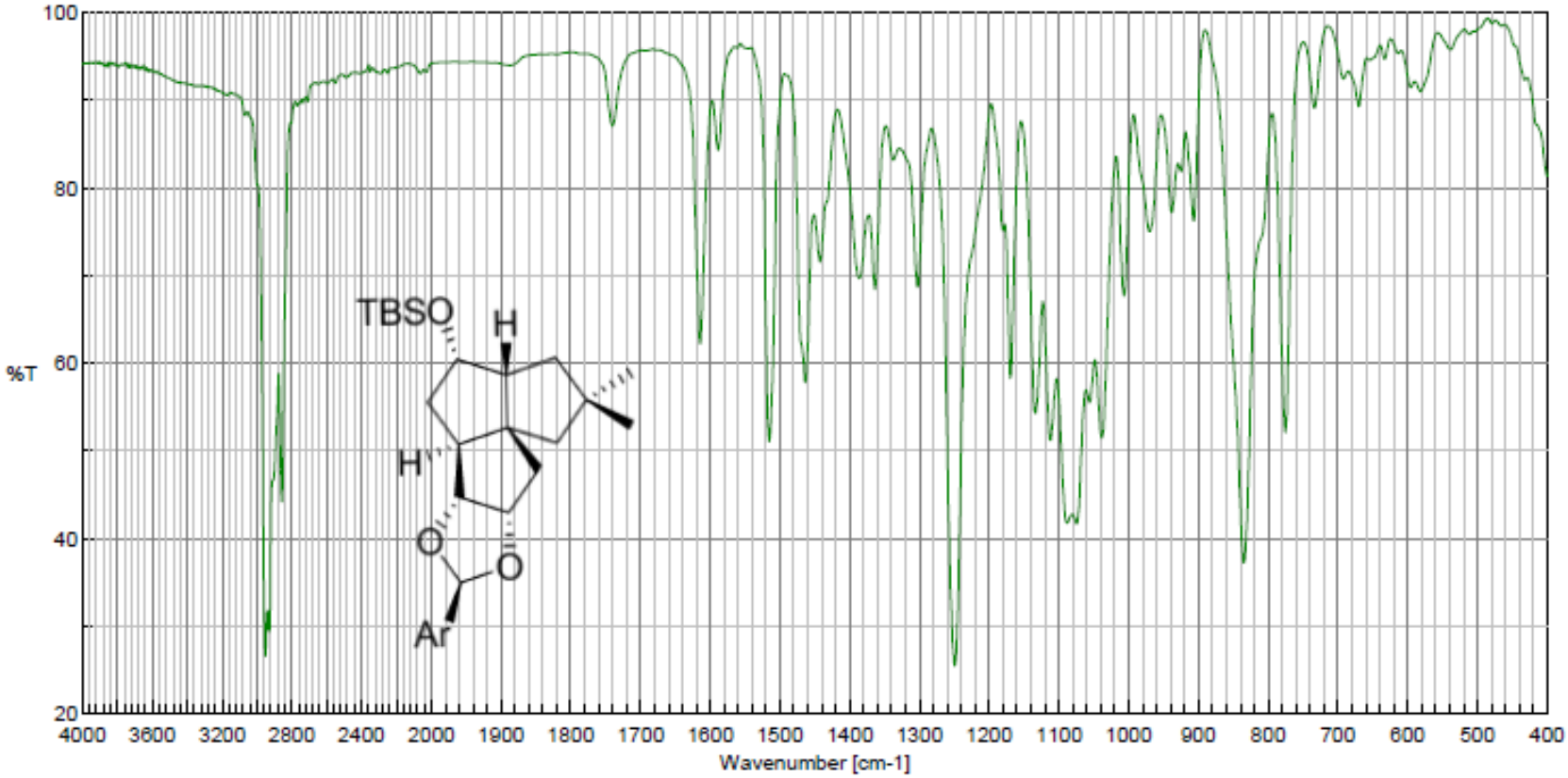

4.808
4.780
18.173
25.865
27.646
29.201
36.284
41.040
41.670
47.962
55.201
55.817
57.274
59.130
73.825
74.844
76.819
77.000
77.182
79.028
TBSO
H
H
HO
OH
f1 (ppm)



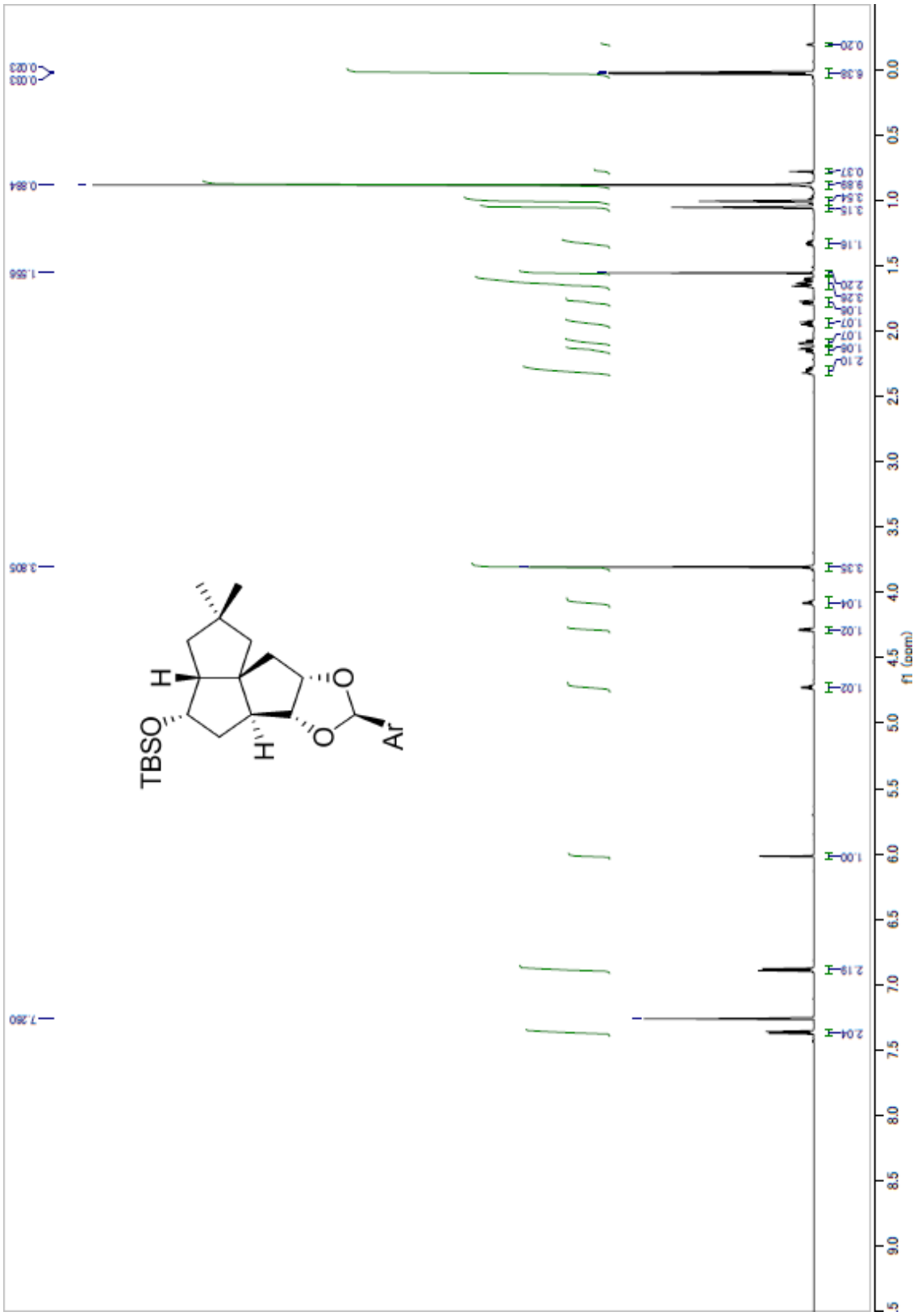
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部


TBSO
H
H
O
O
Ar
f1 (ppm)

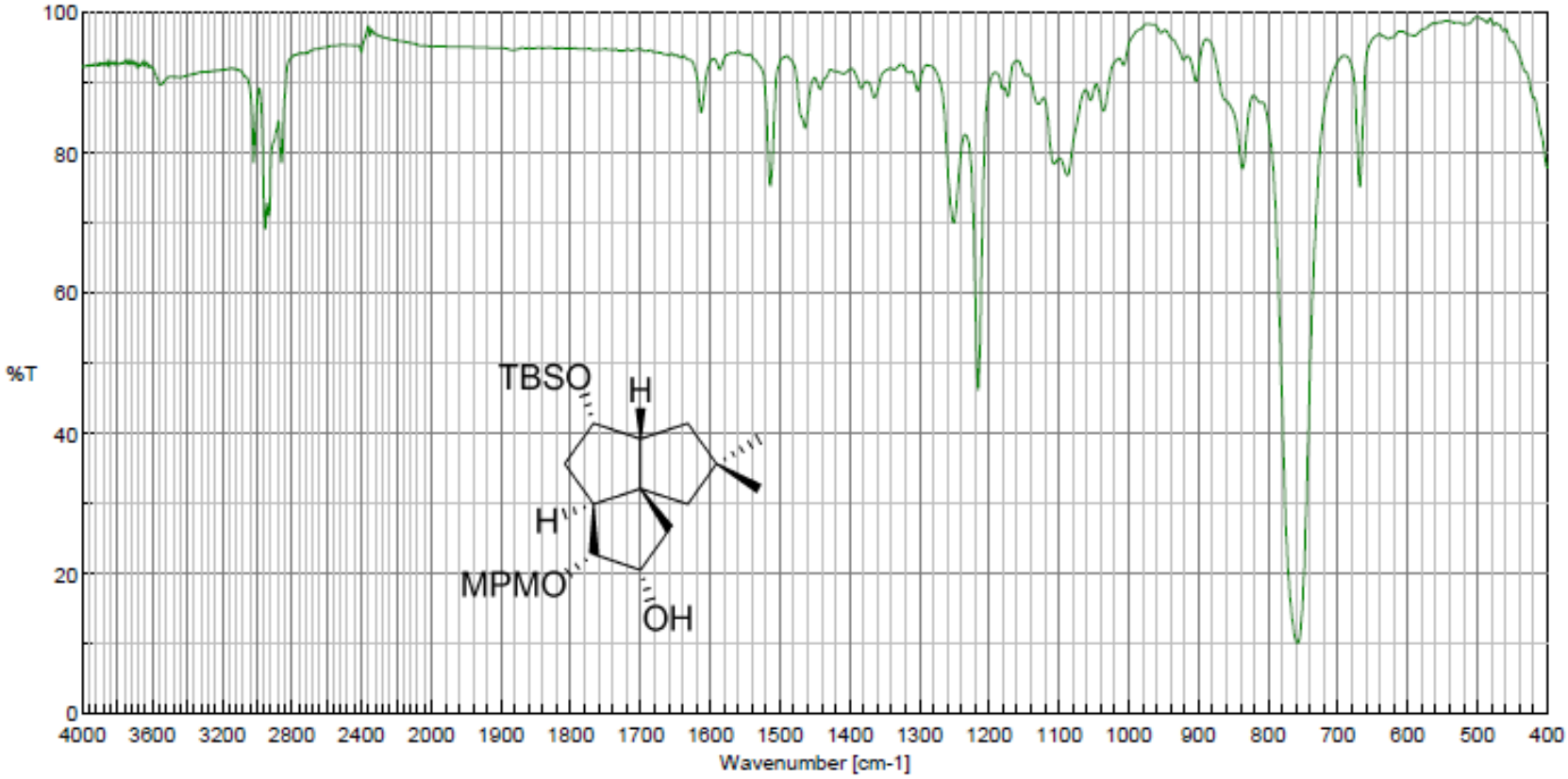

TBSO
H
H
O
O
Ar
f1 (ppm)



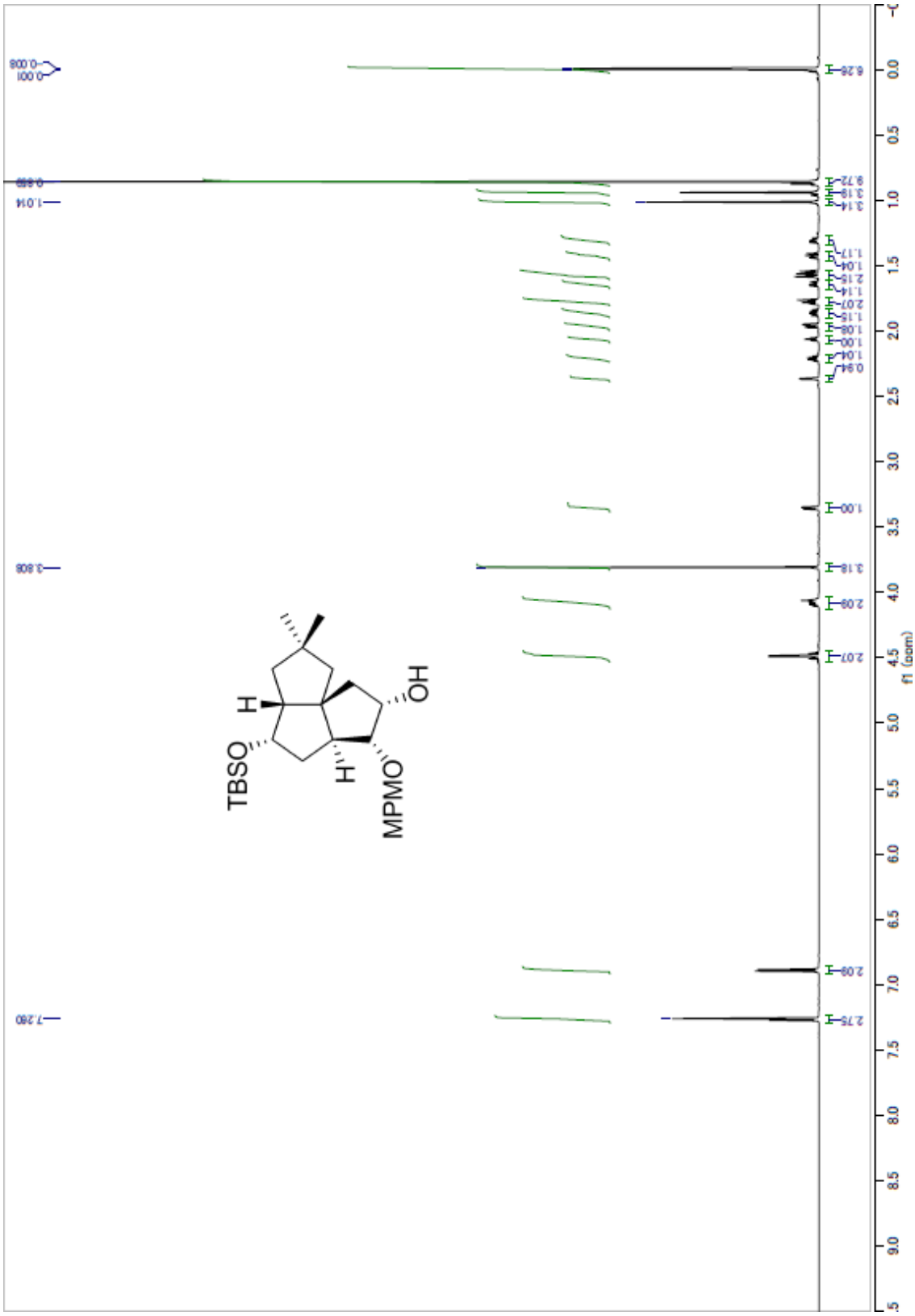
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

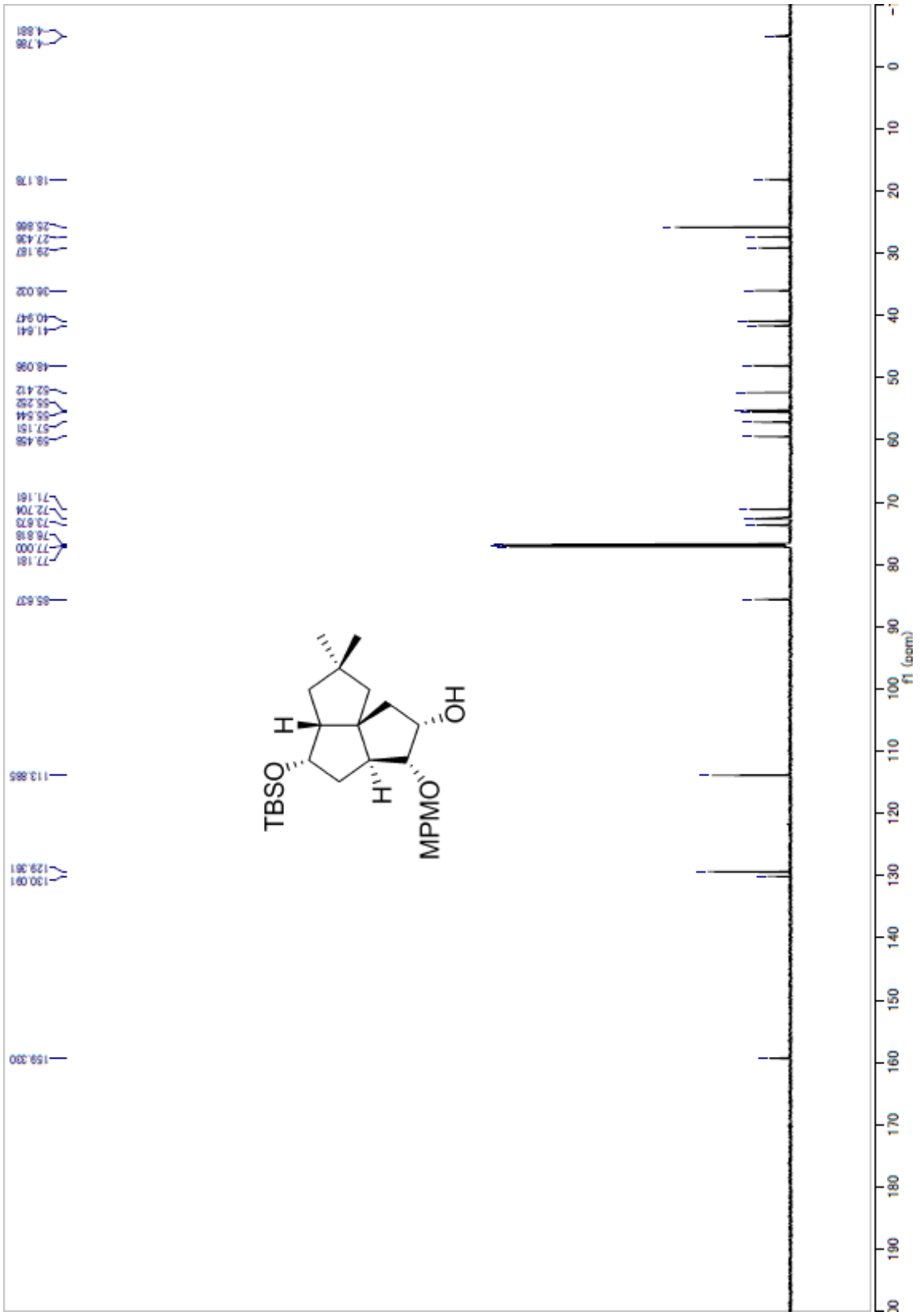

TBSO
H
H
O
O
Ar
f1 (ppm)

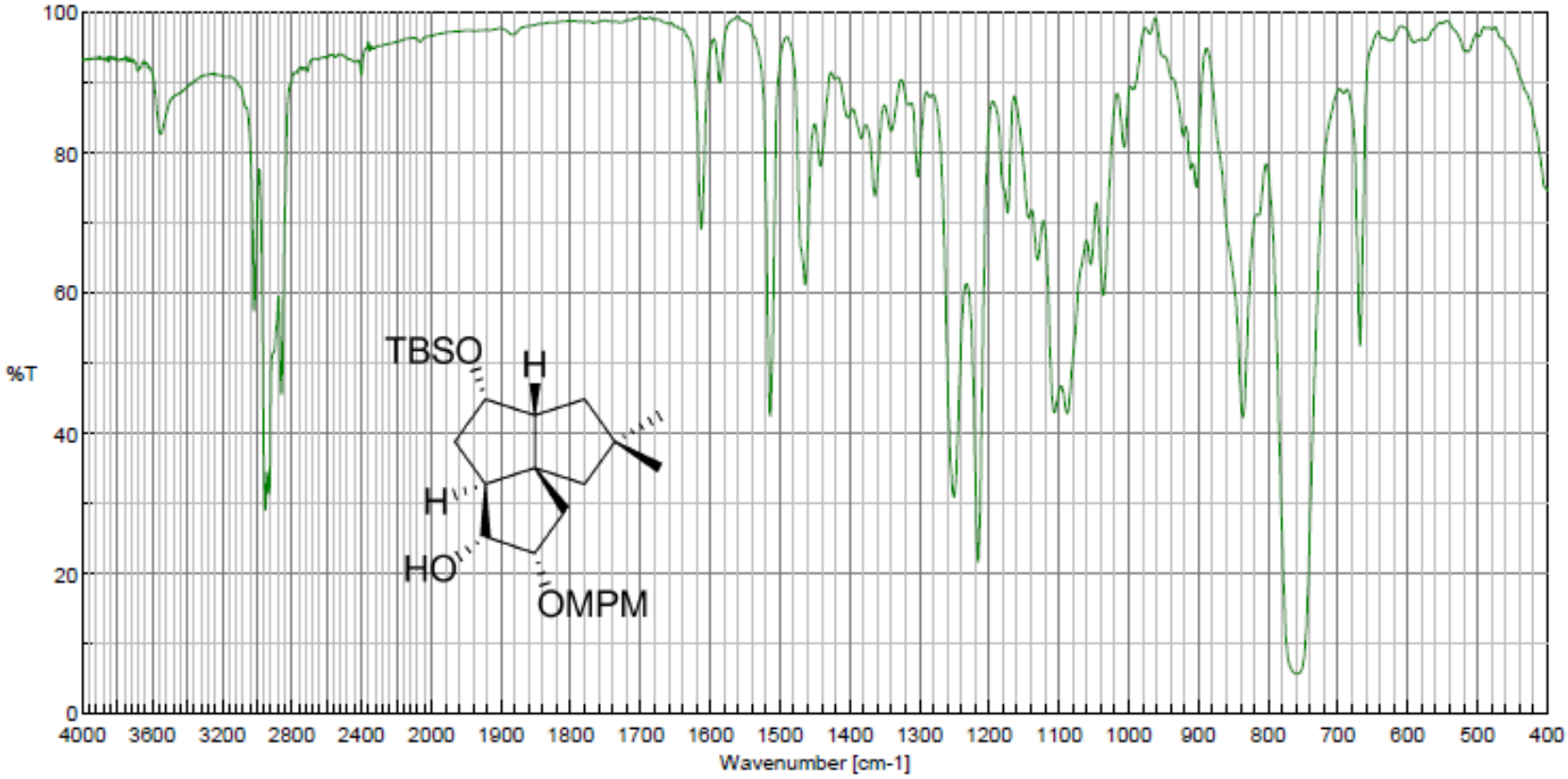

TBSO
H
H
O
O
Ar
f1 (ppm)



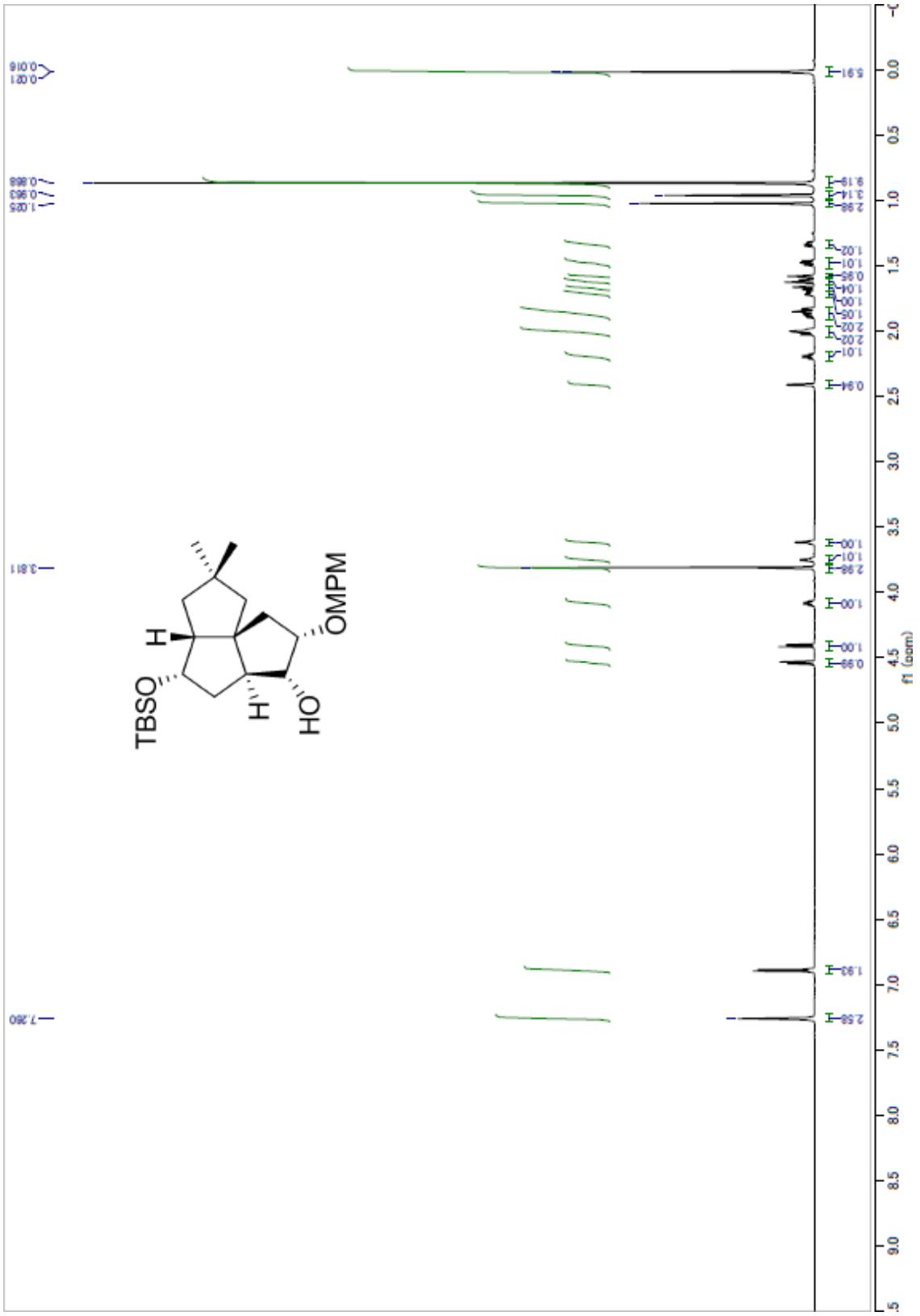
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

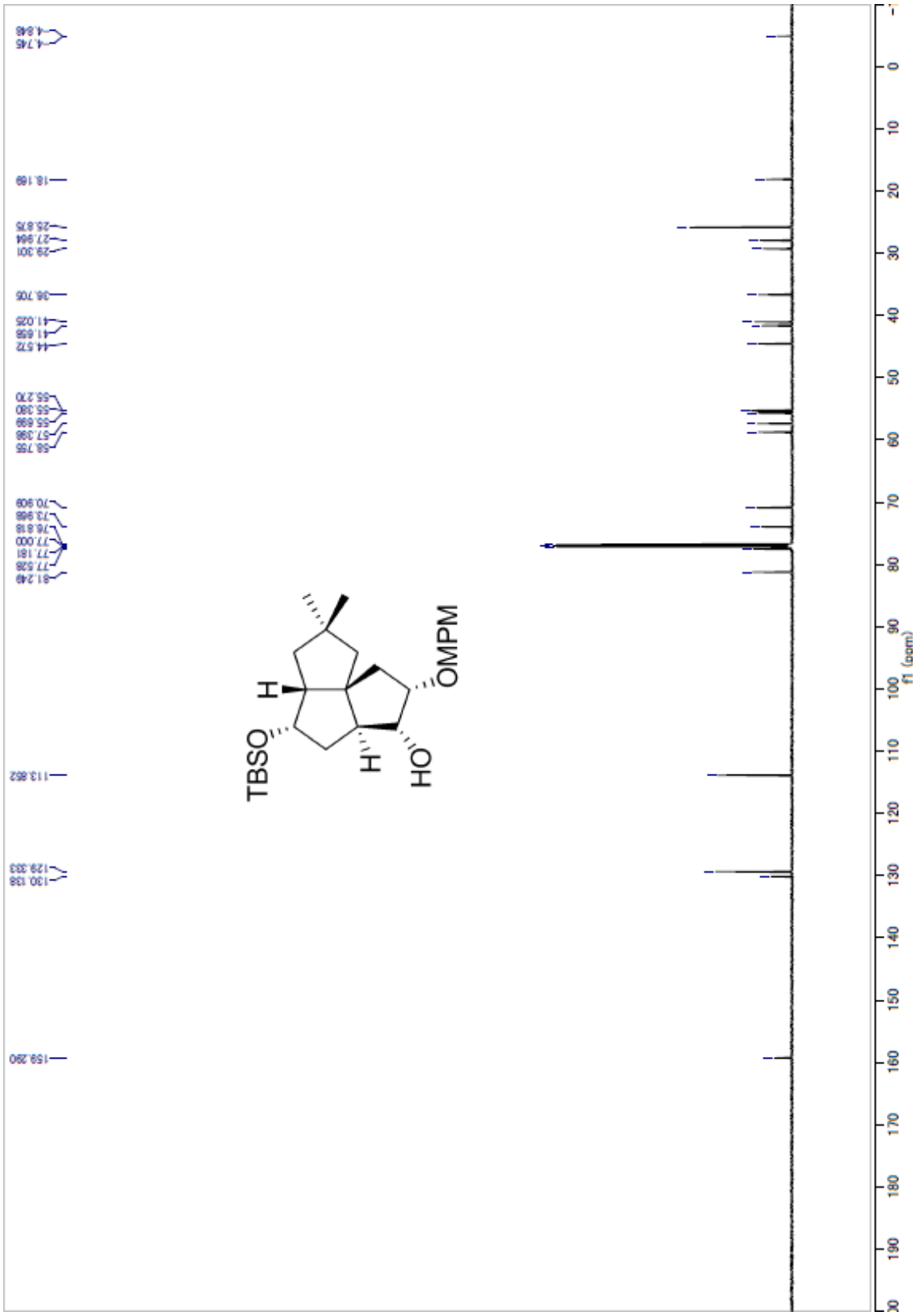

TBSO
H
H
MPMO
OH
f1 (ppm)

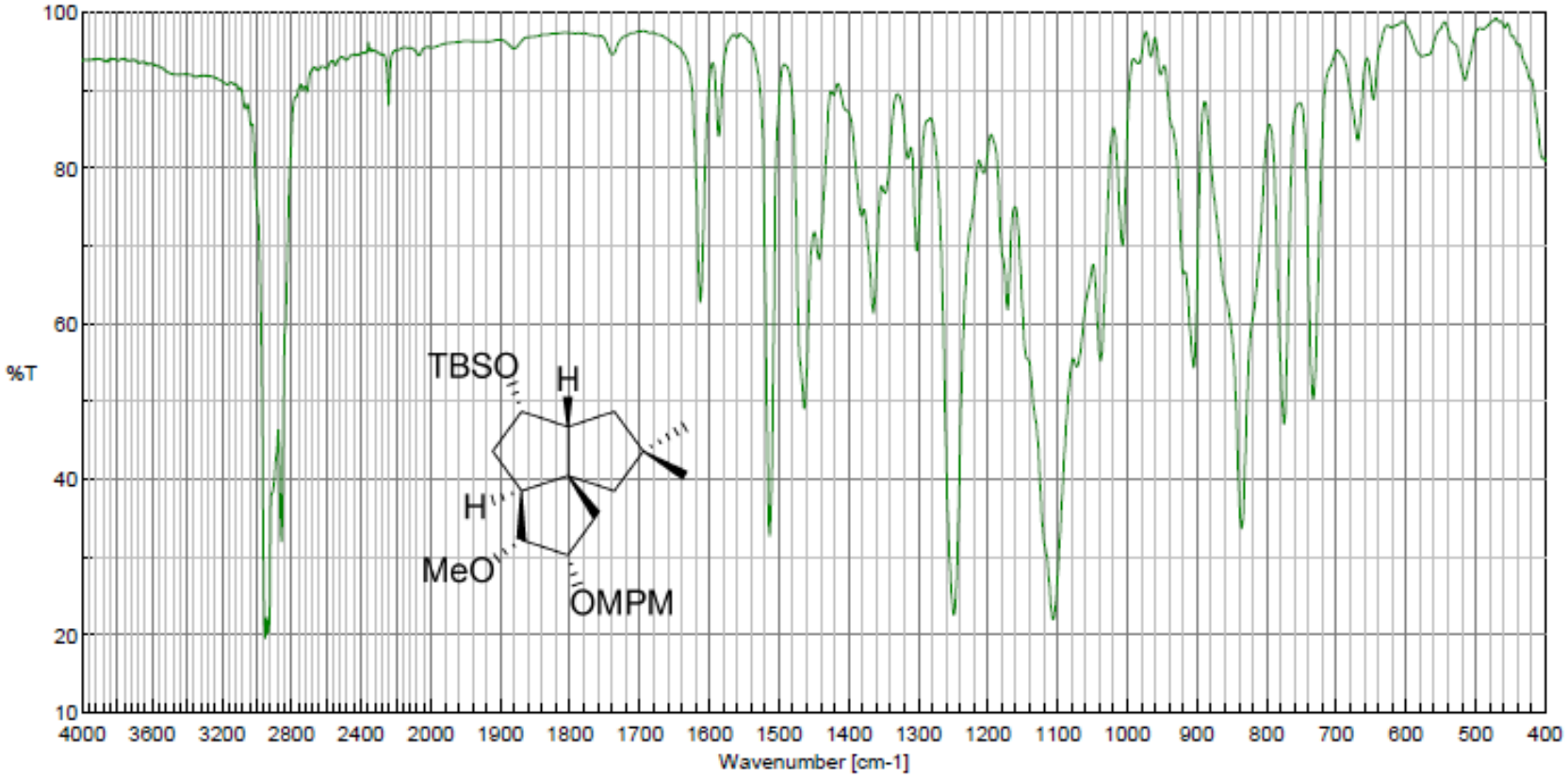

TBSO
H
H
MPMO
OH
f1 (ppm)



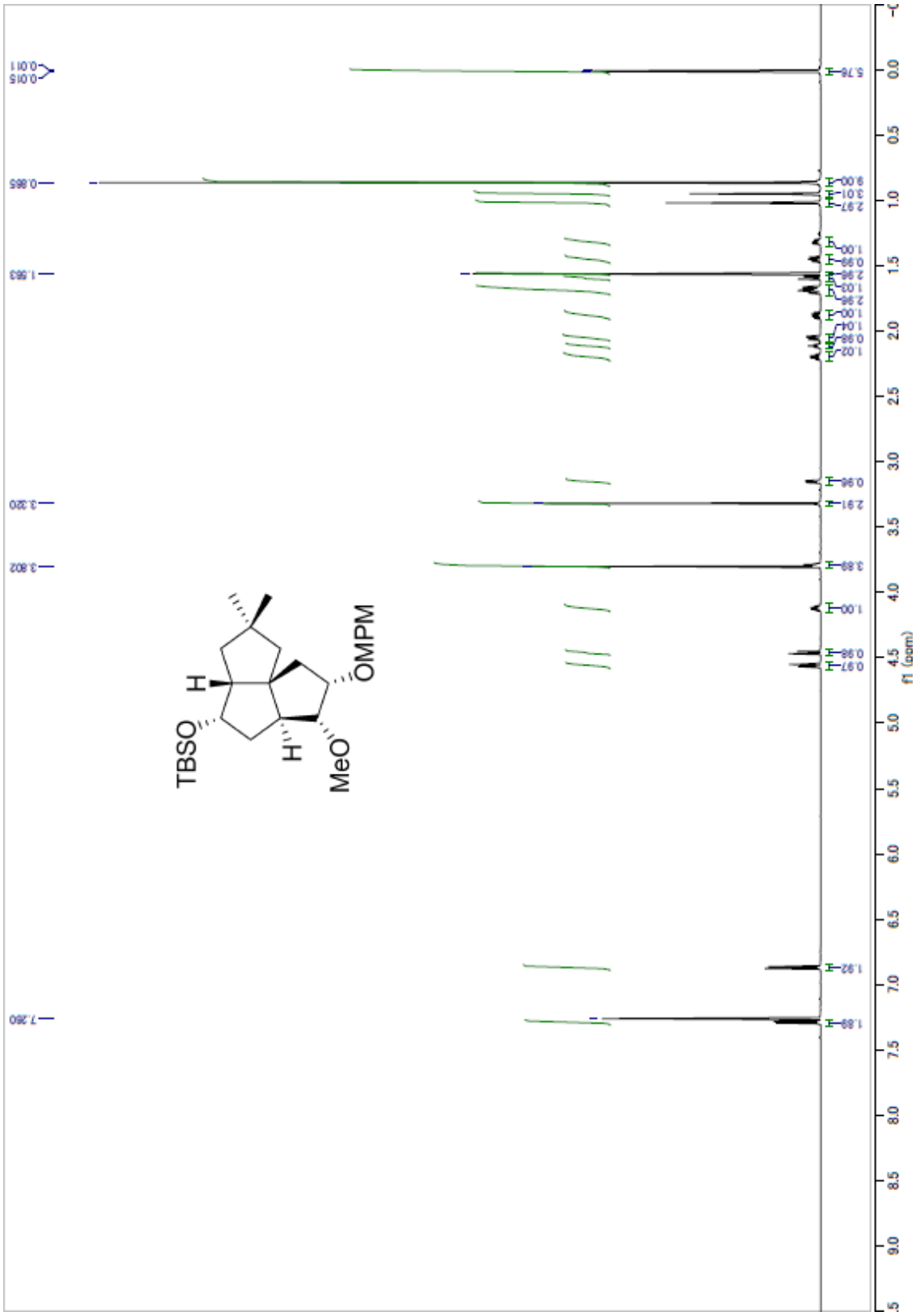
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

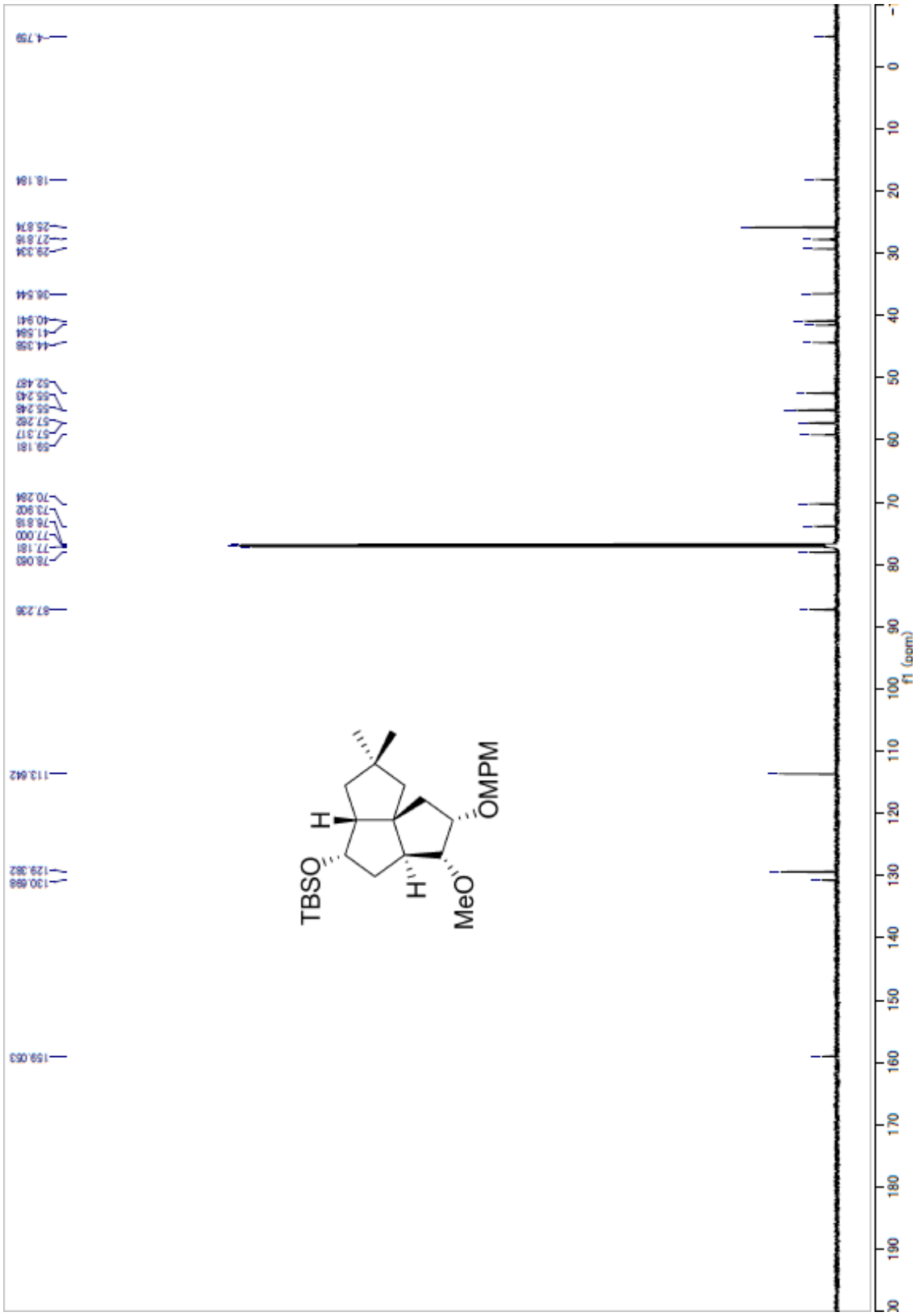

TBSO
H
H
HO
OMPM
f1 (ppm)

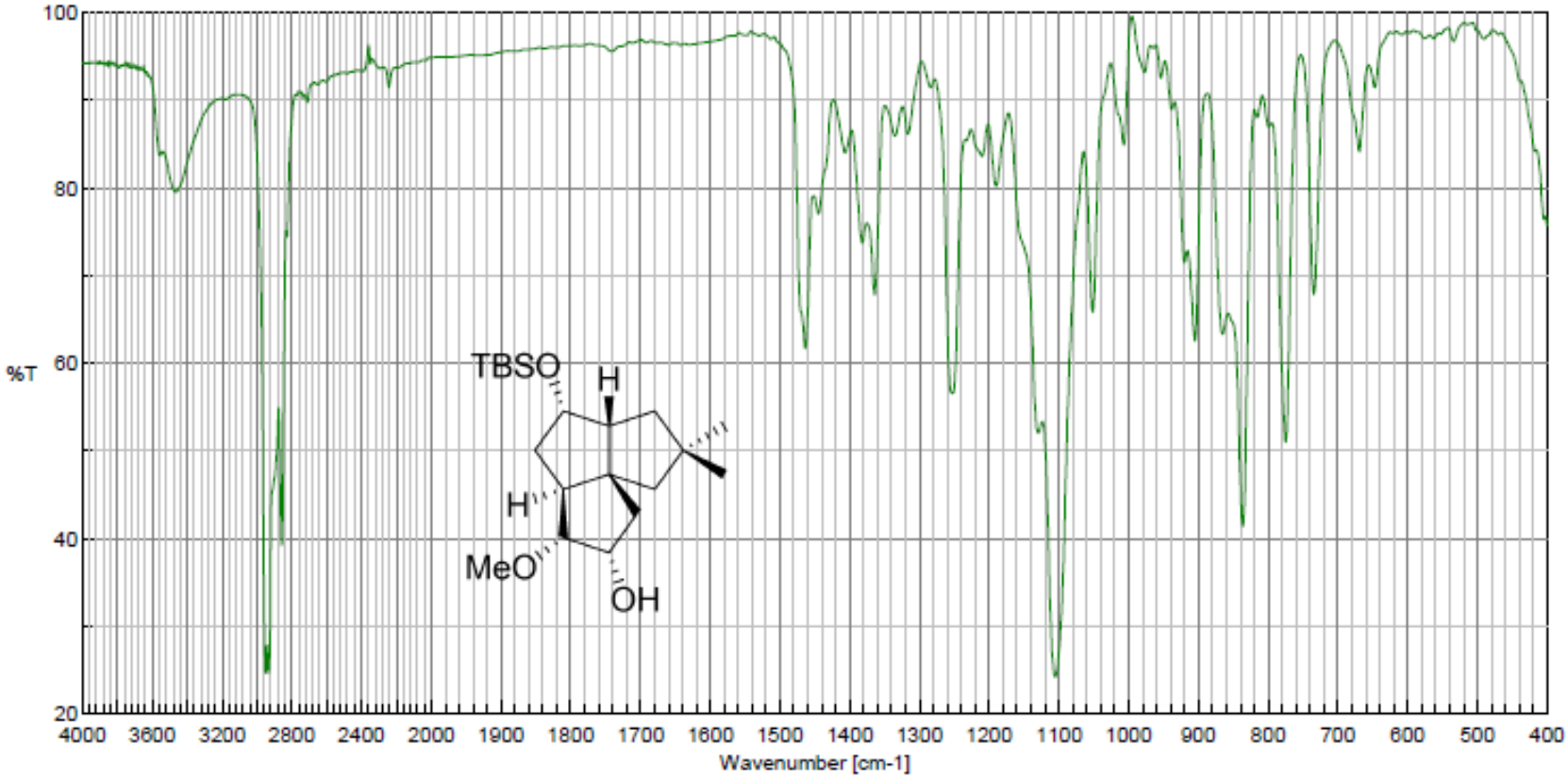

TBSO
H
H
HO
OMPM
f1 (ppm)



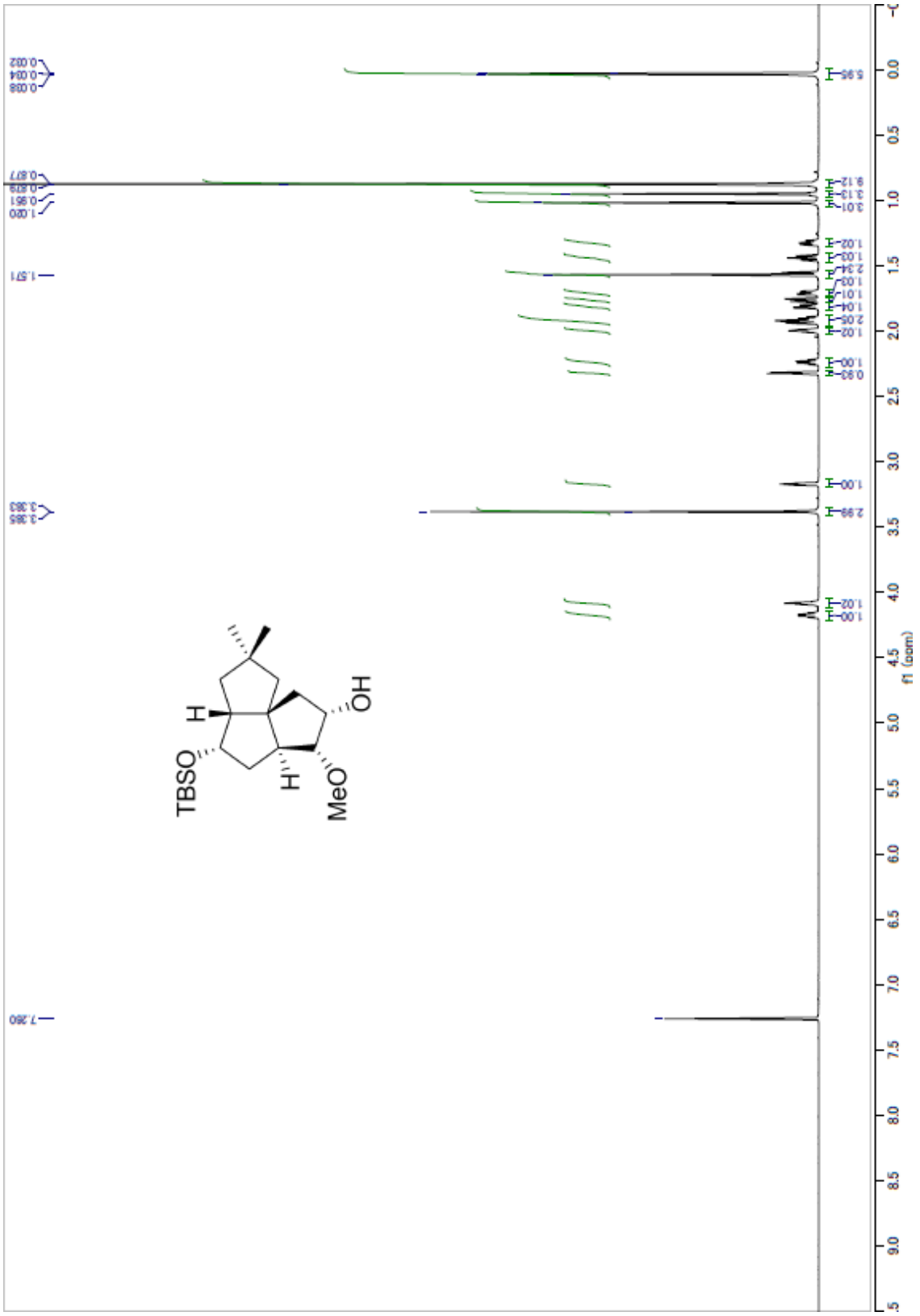
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

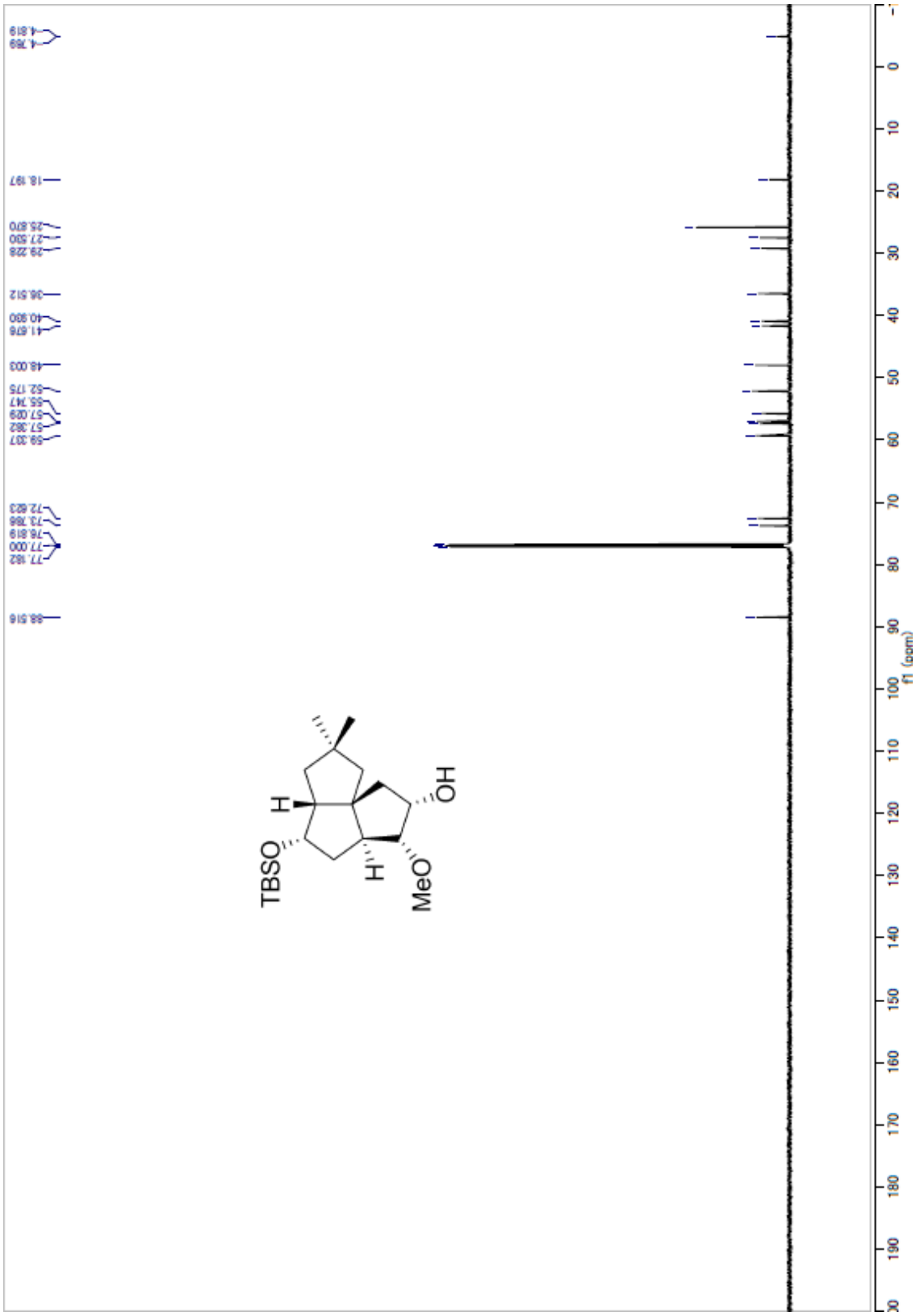

TBSO
H
H
MeO
OMPM
f1 (ppm)

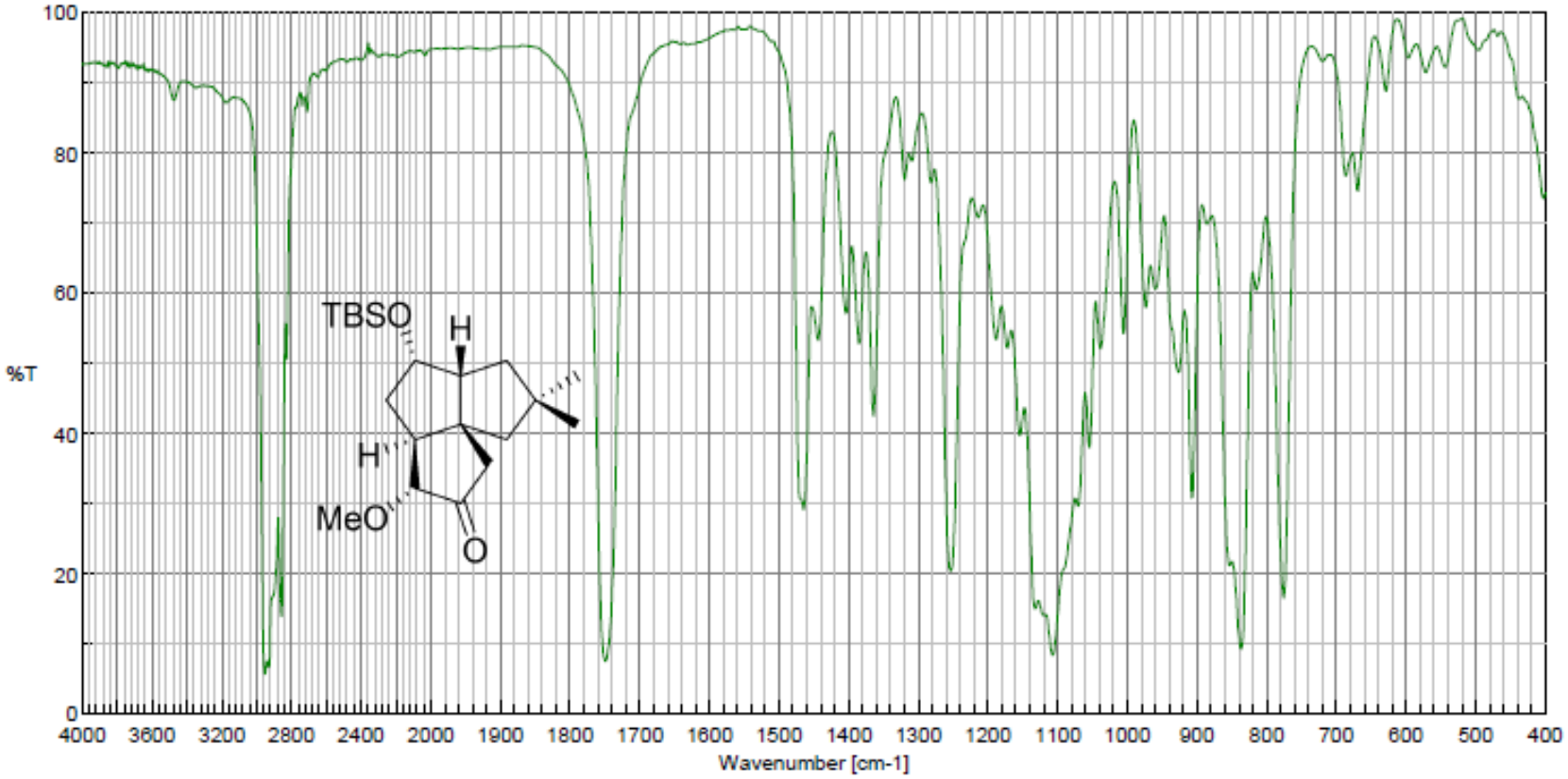

TBSO
H
H
MeO
OMPM
f1 (ppm)



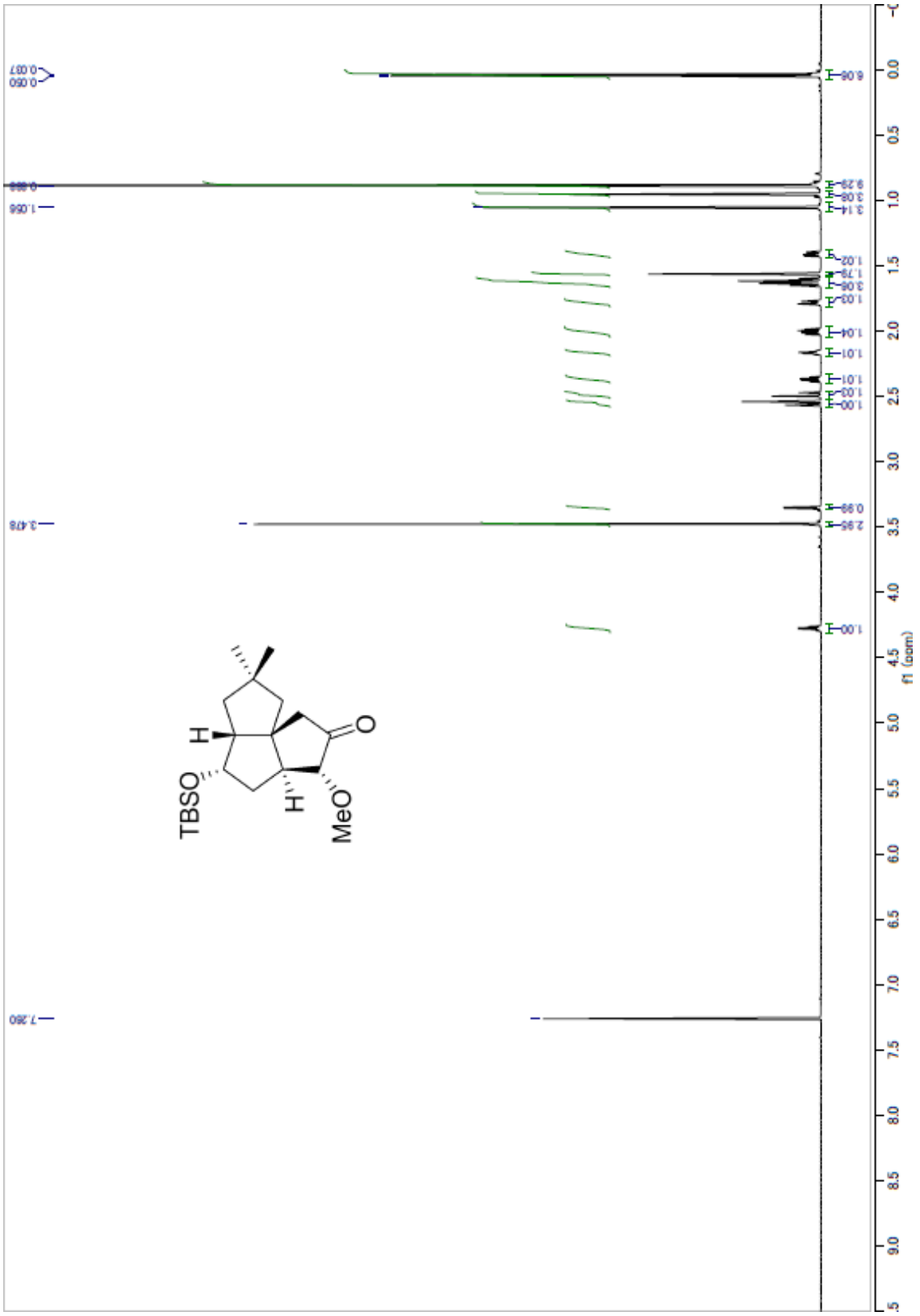
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

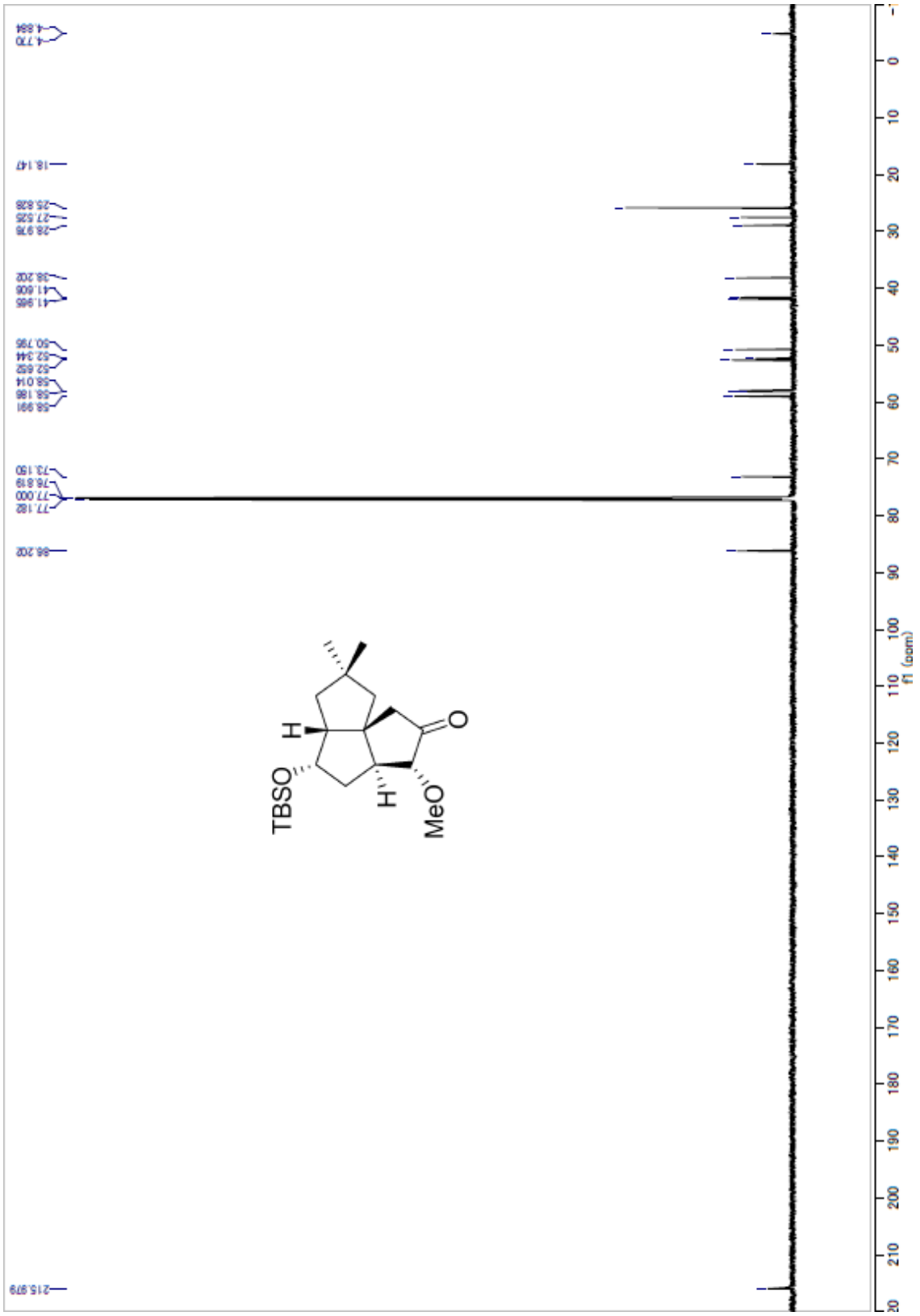

TBSO
H
H
MeO
OH
f1 (ppm)

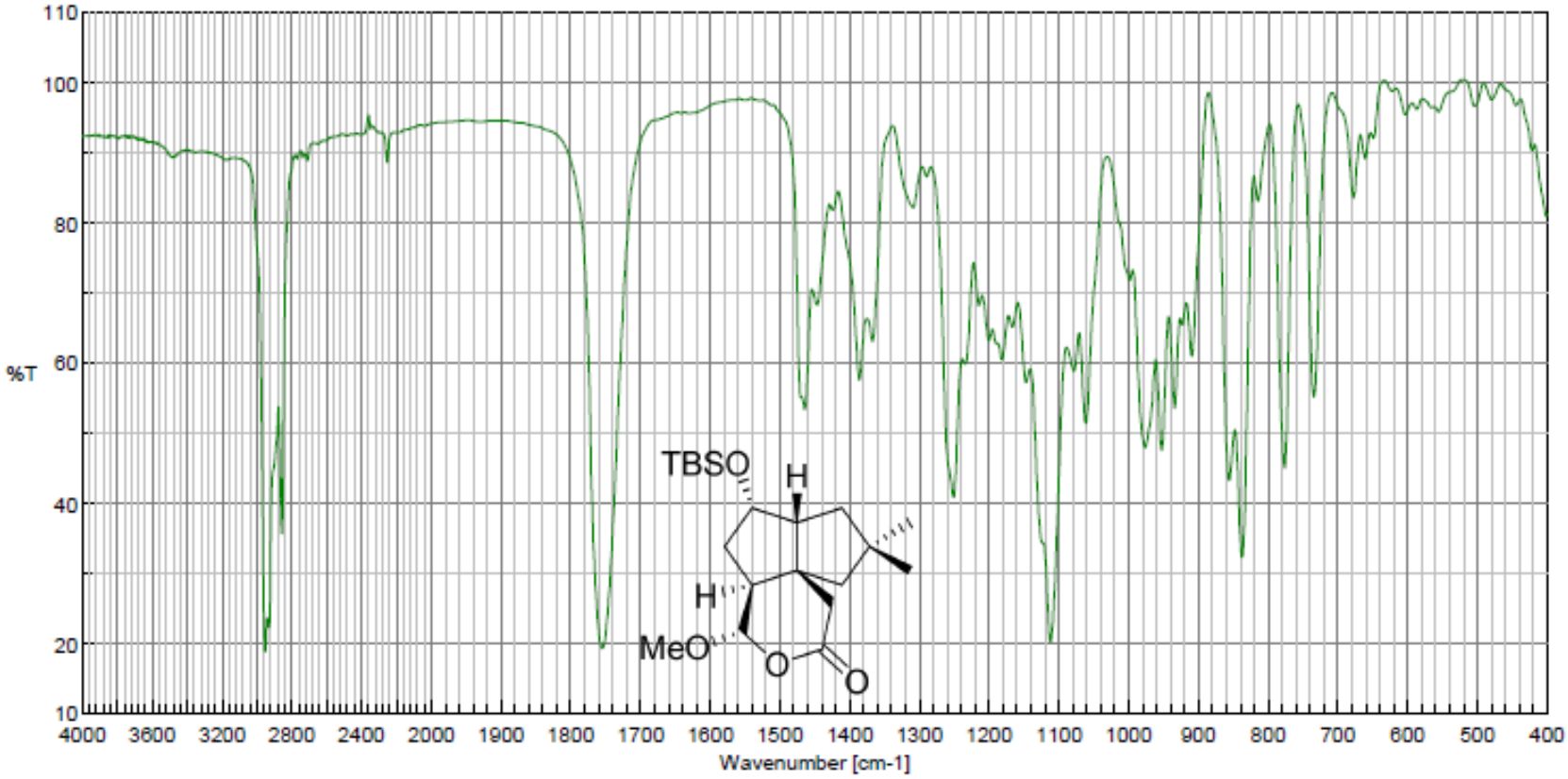

4.819
4.769
18.197
25.870
27.500
29.228
36.512
40.390
41.676
48.003
52.175
55.747
57.029
57.382
59.307
72.823
73.786
76.819
77.000
77.182
88.516
TBSO
H
H
MeO
OH
f1 (ppm)



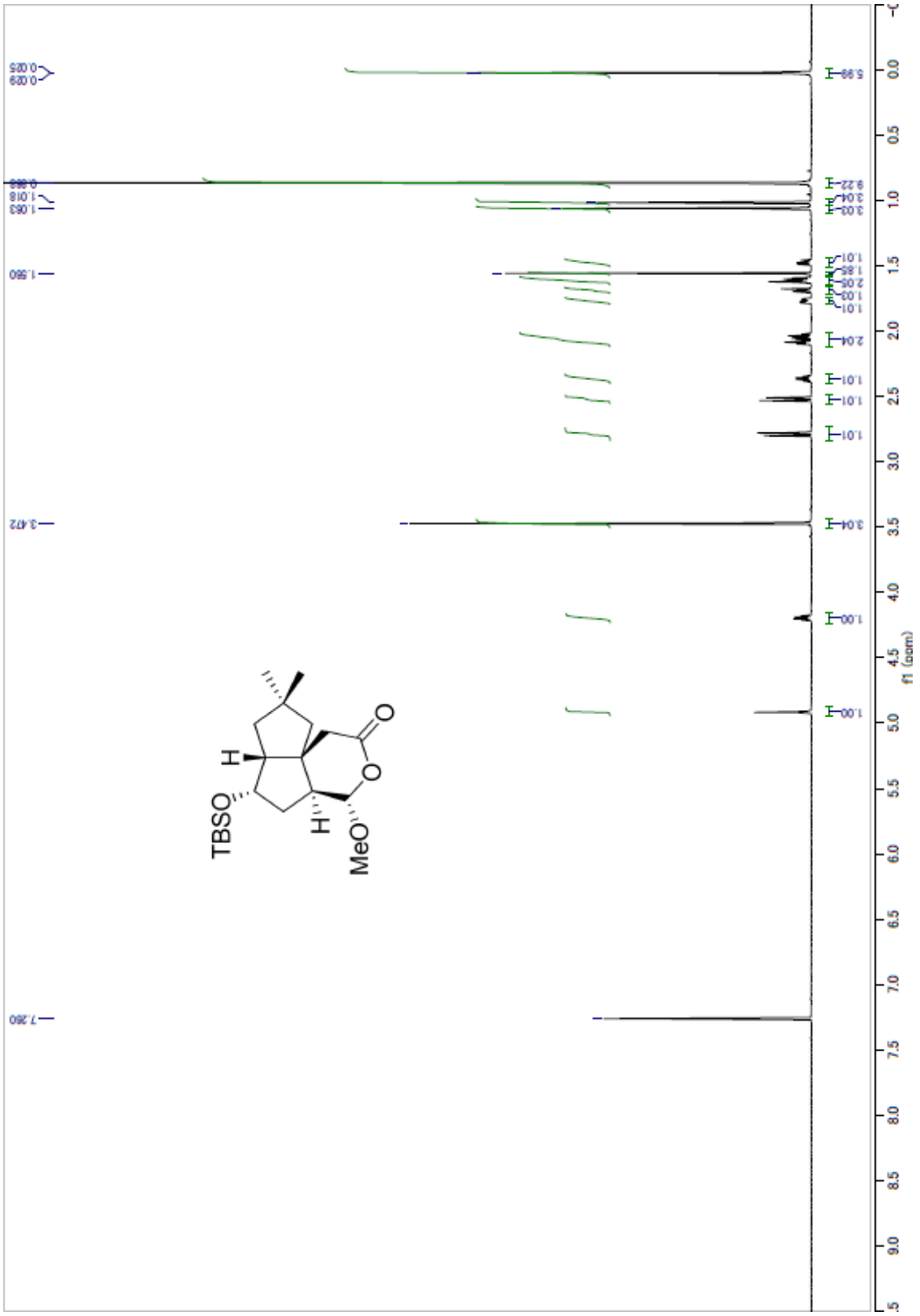
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

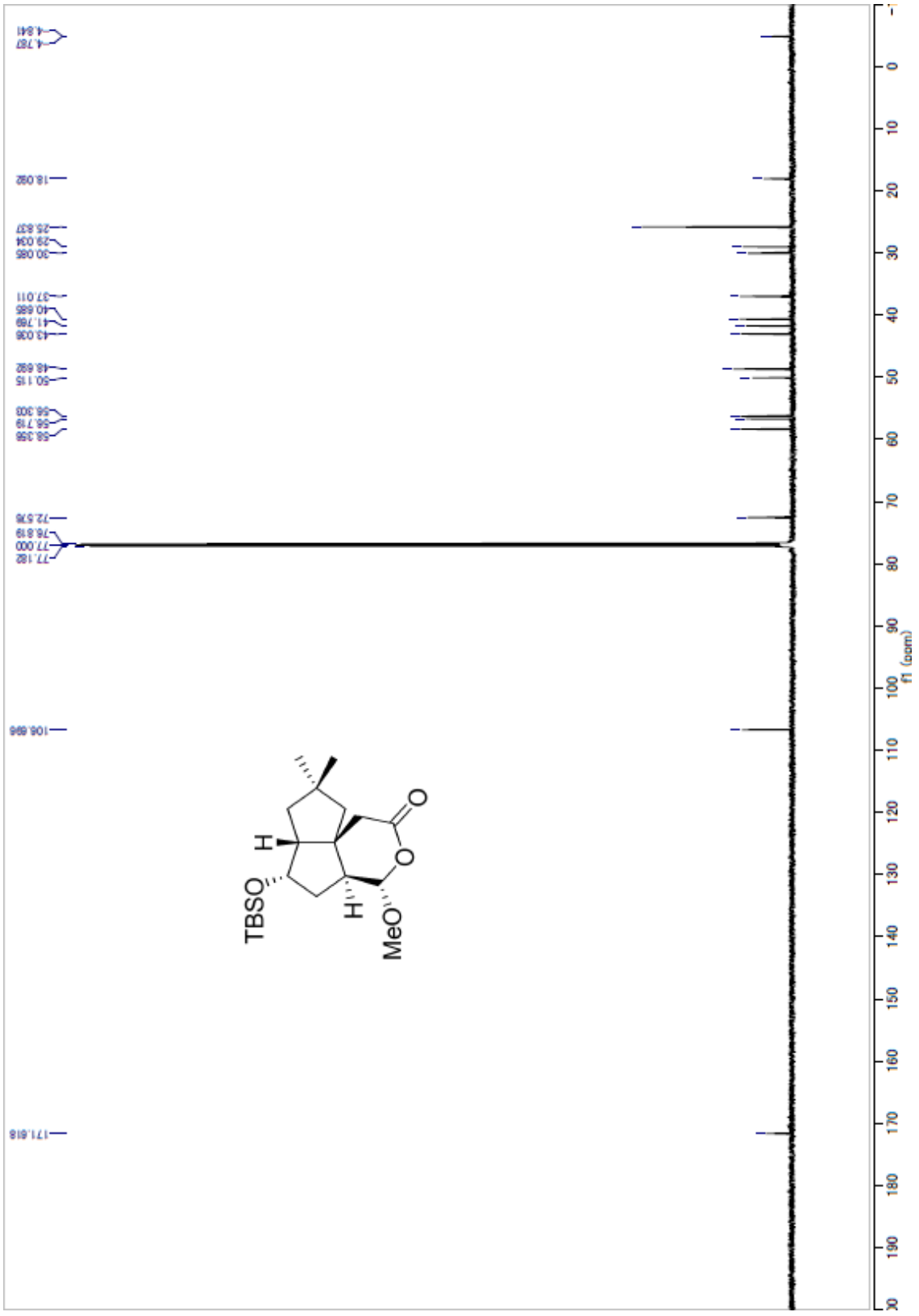

TBSO
H
H
MeO
O
f1 (ppm)

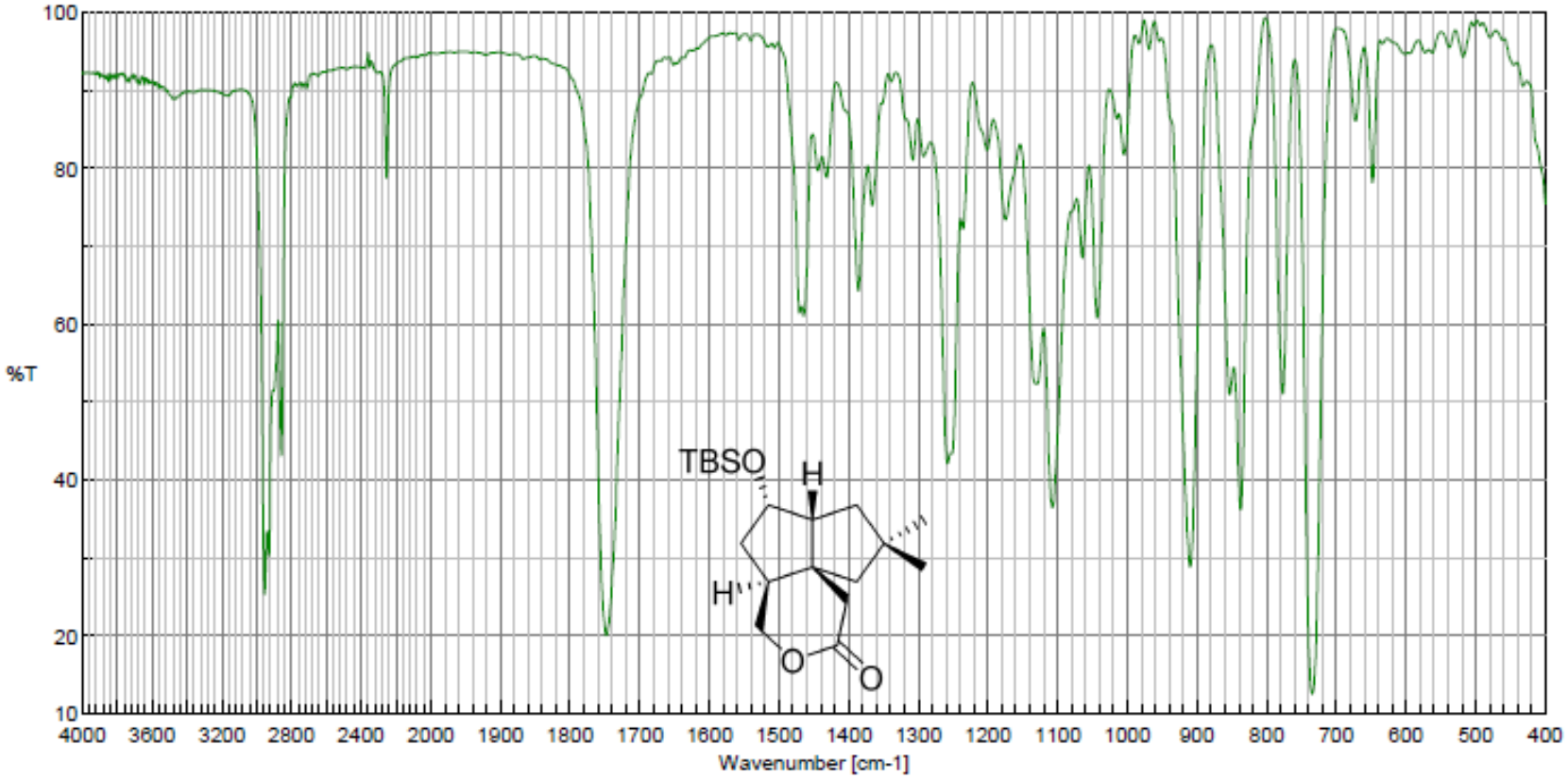

TBSO
H
H
MeO
O
f1 (ppm)



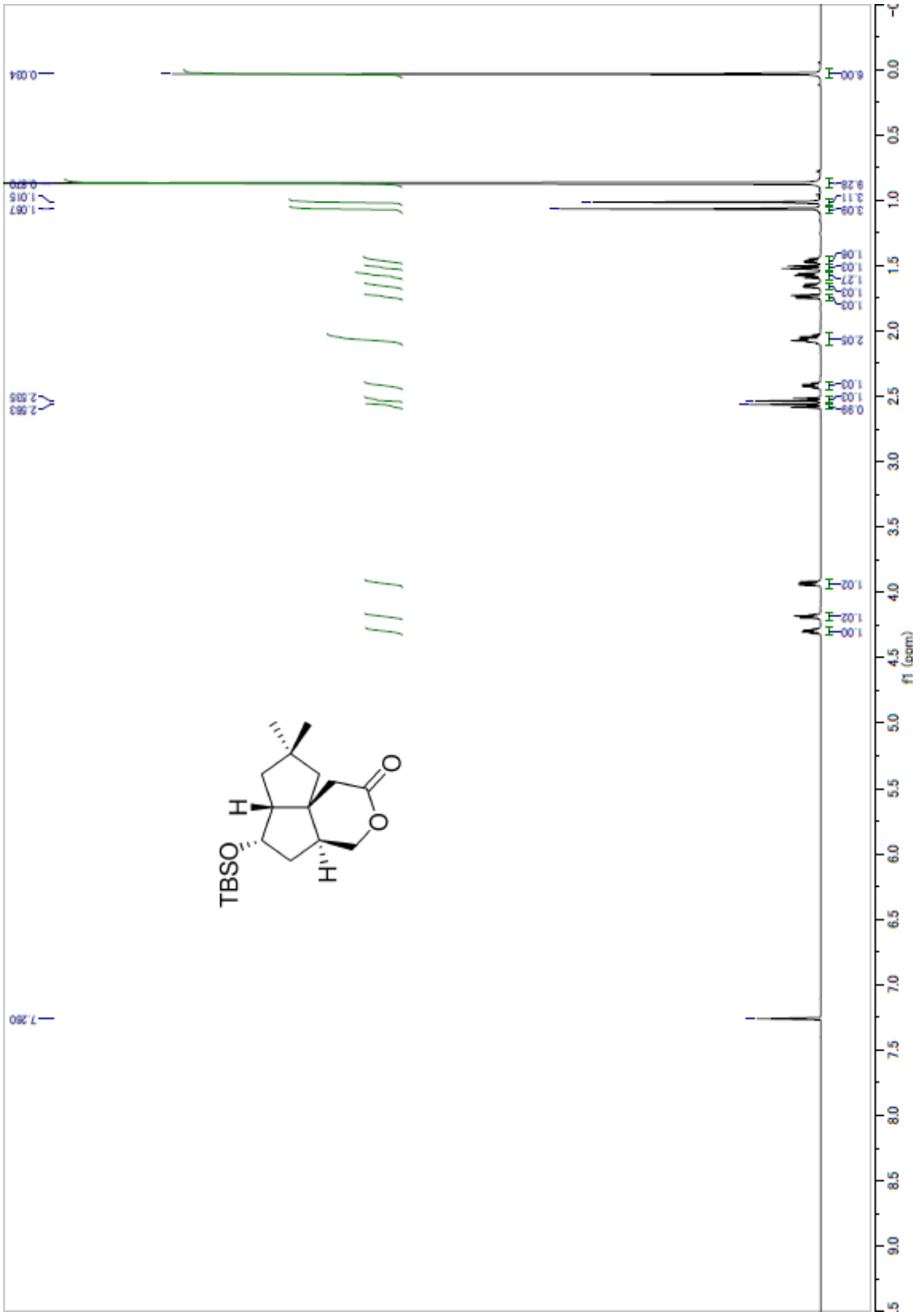
[コメント情報]
試料名 p-HGDHPA THF 10mM
コメント
測定者
所属
会社 新潟大学 理学部

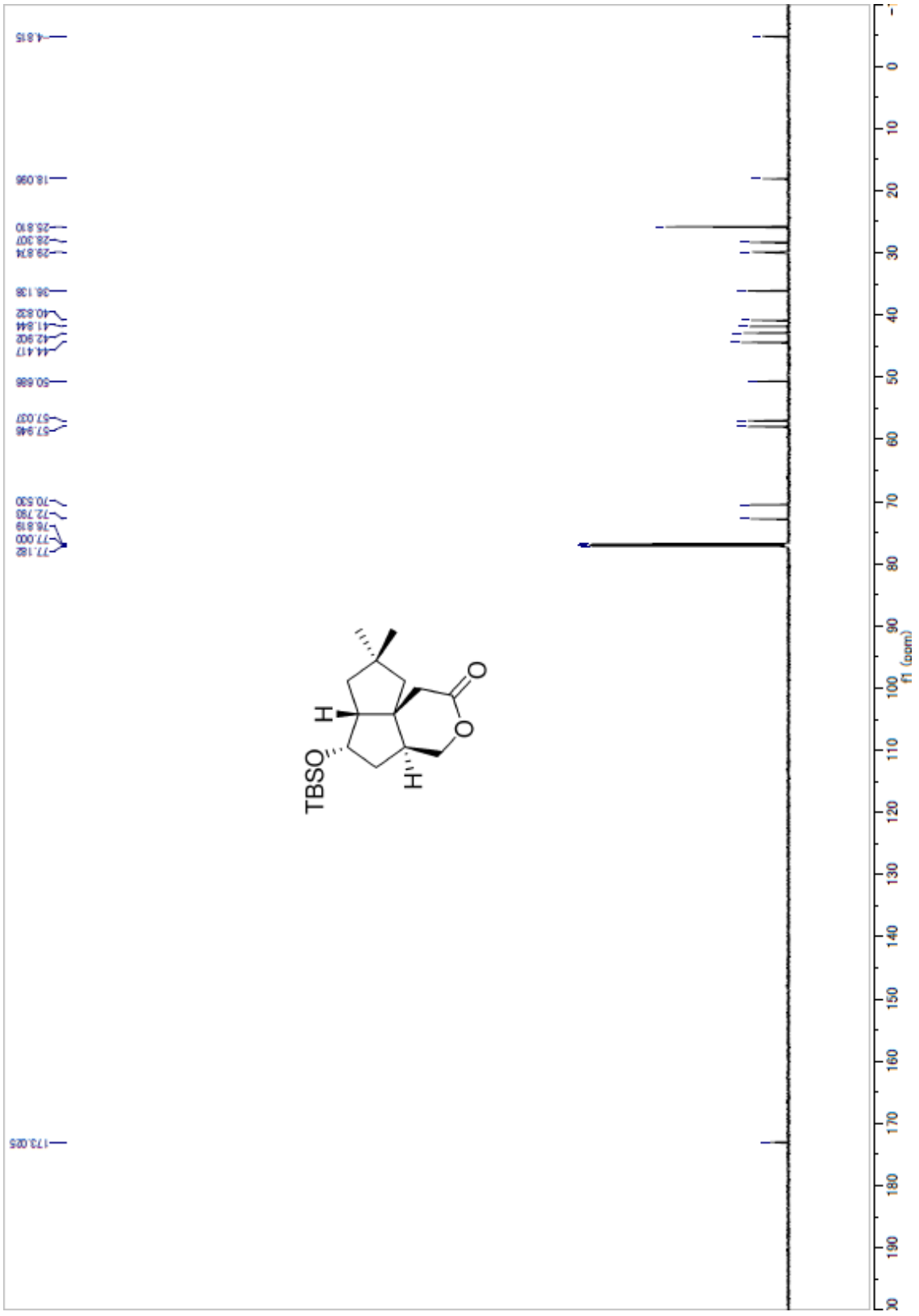

TBSO
H
H
MeO
O
O
f1 (ppm)

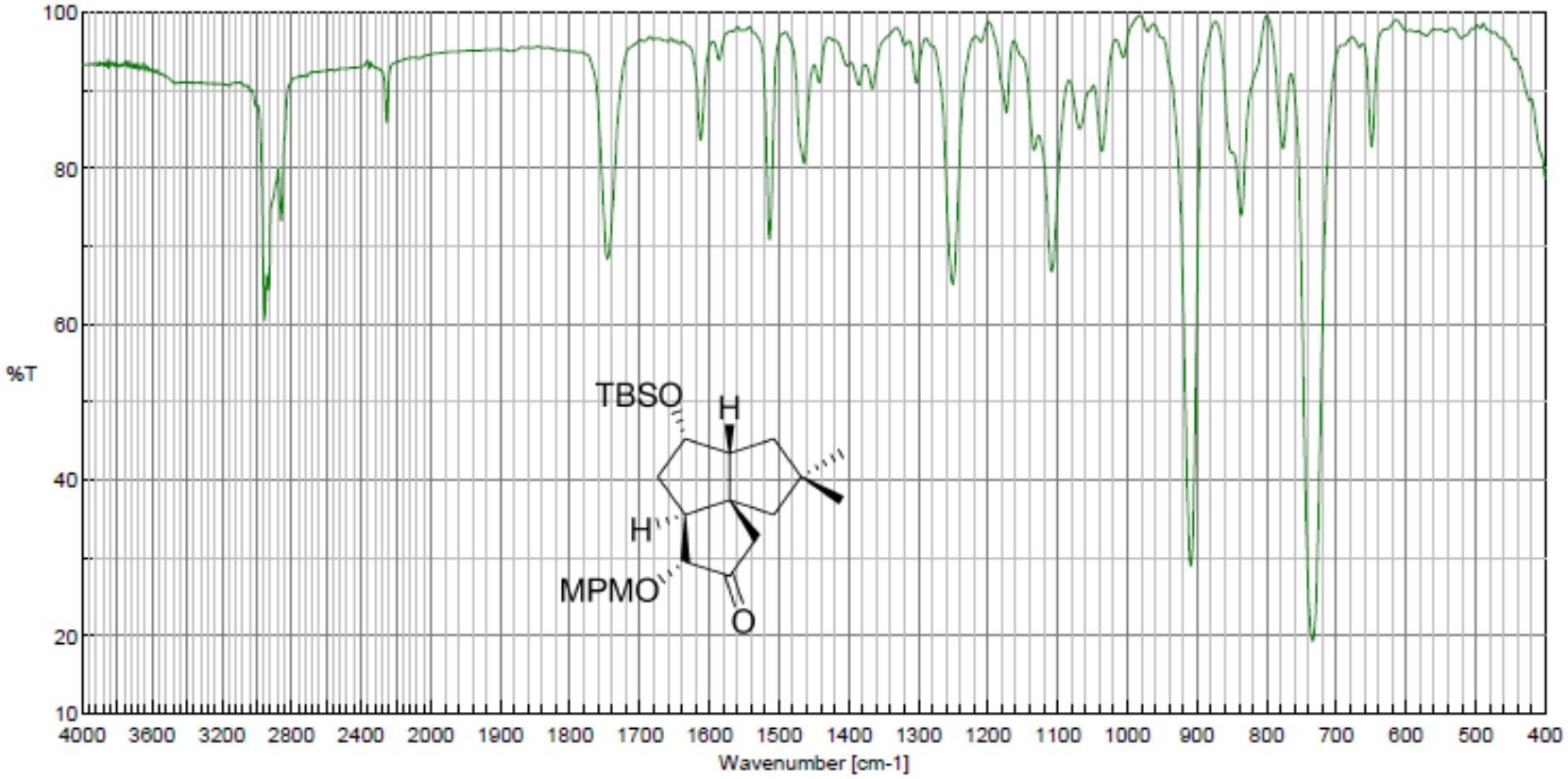

4.841
4.787
18.092
25.837
29.034
30.085
37.011
40.685
41.769
43.036
48.692
50.115
56.300
56.719
56.958
72.576
76.819
77.000
77.182
106.896
171.618
TBSO
H
H
MeO
O
O
f1 (ppm)



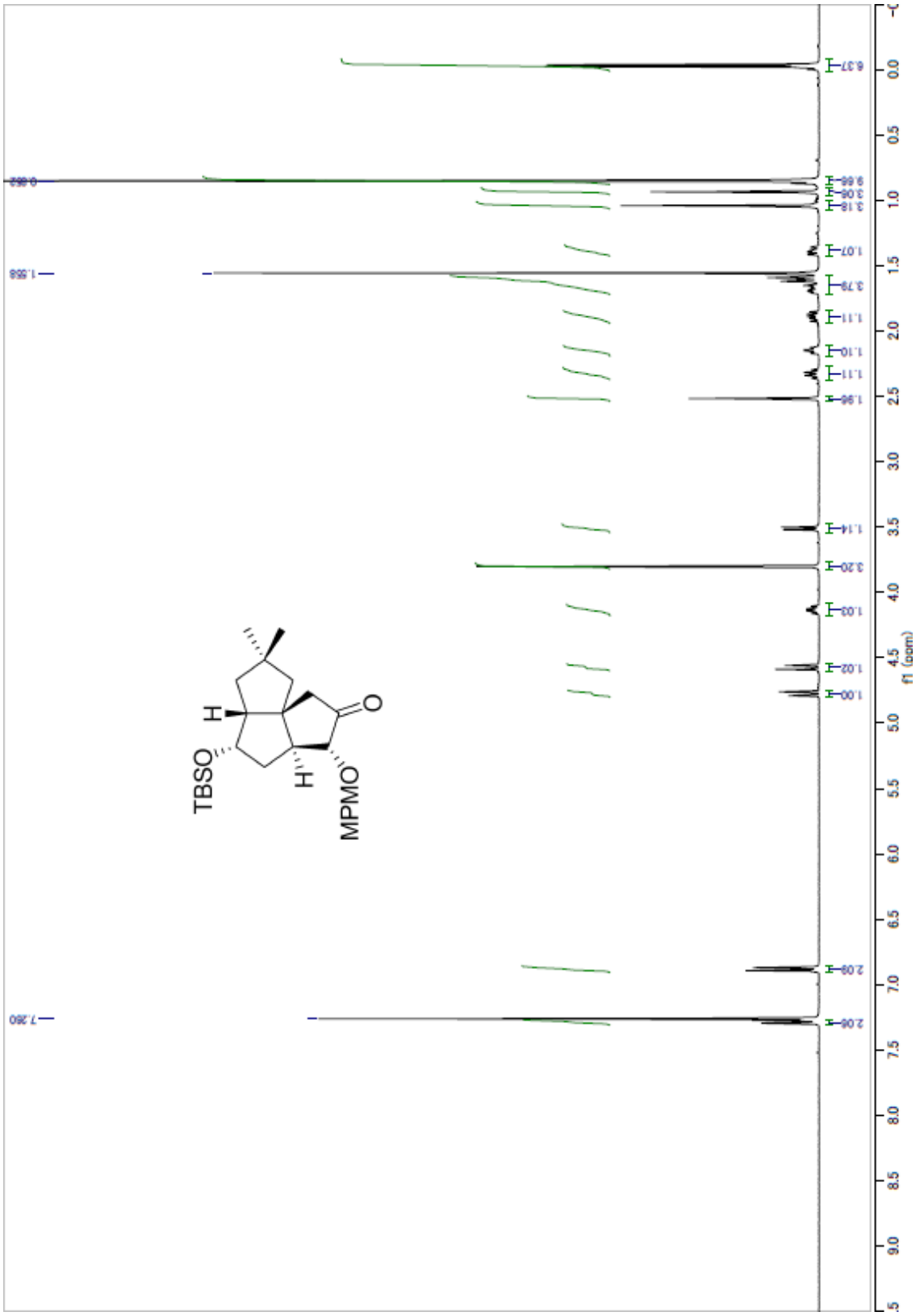
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

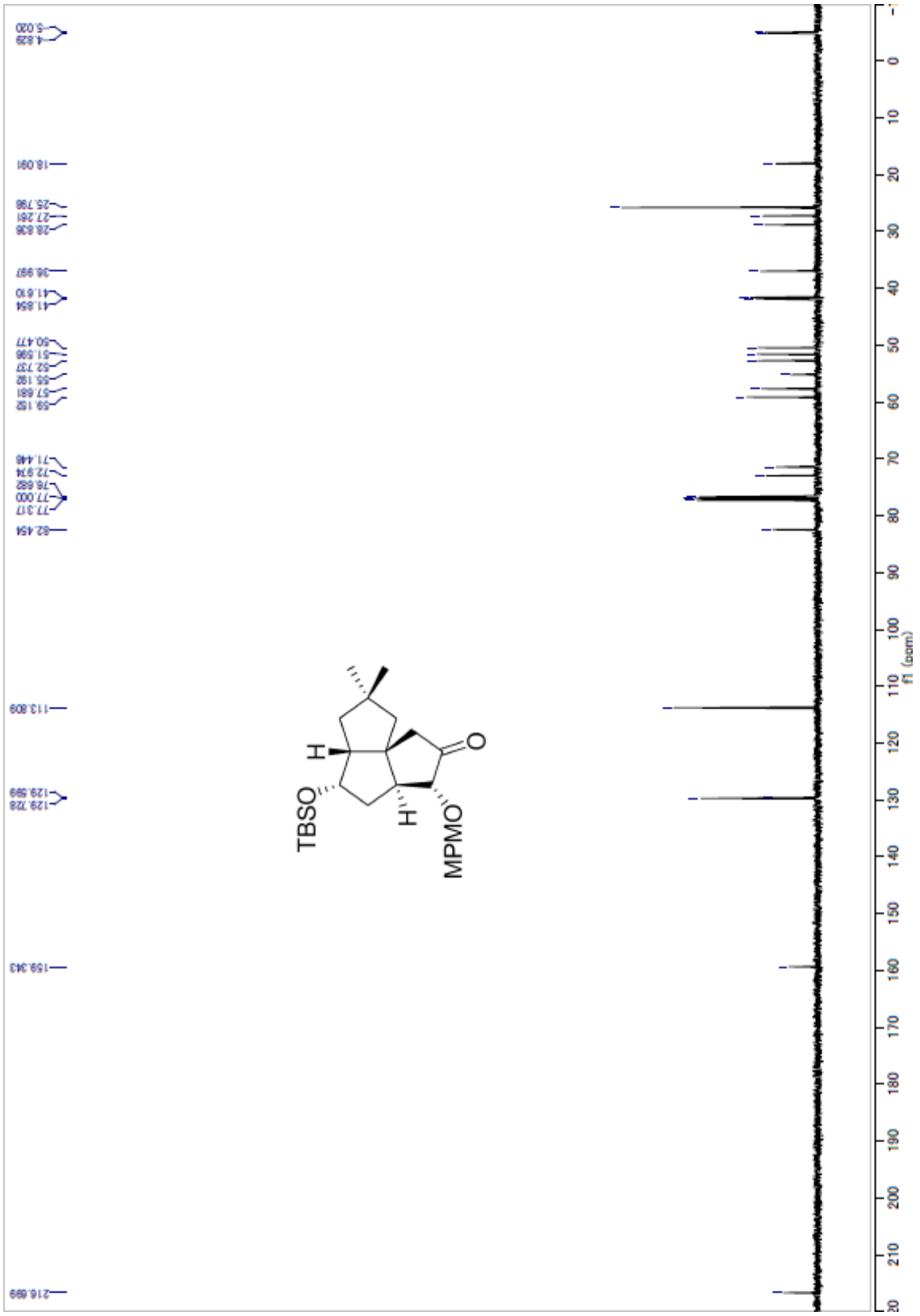

TBSO
H
H
O
O
f1 (ppm)

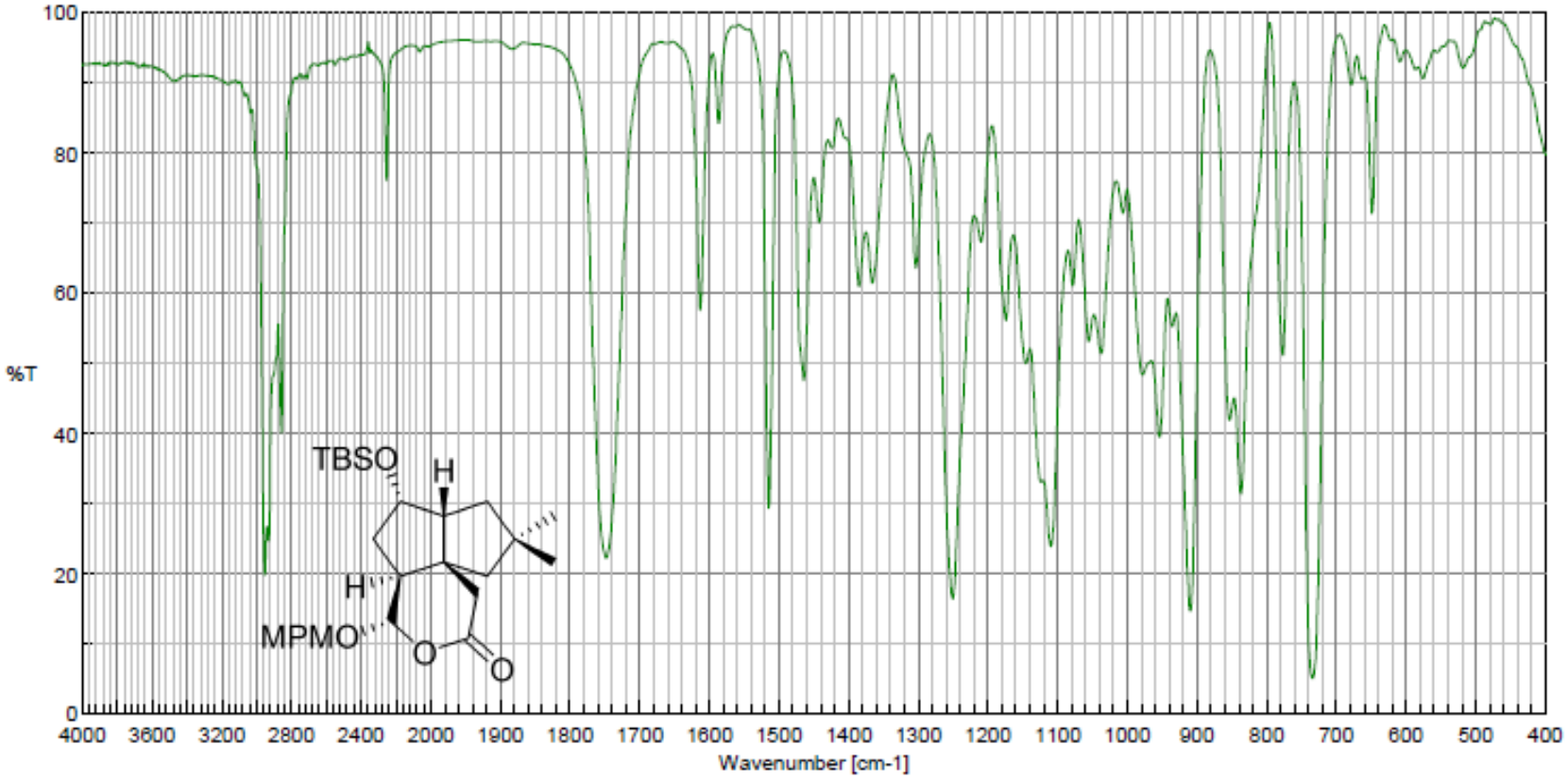

-4.815
18.096
25.810
28.307
29.874
36.138
40.832
41.844
42.902
44.417
50.686
57.027
57.946
70.530
72.790
76.819
77.000
77.182
173.025
TBSO
H
H
O
O
f1 (ppm)



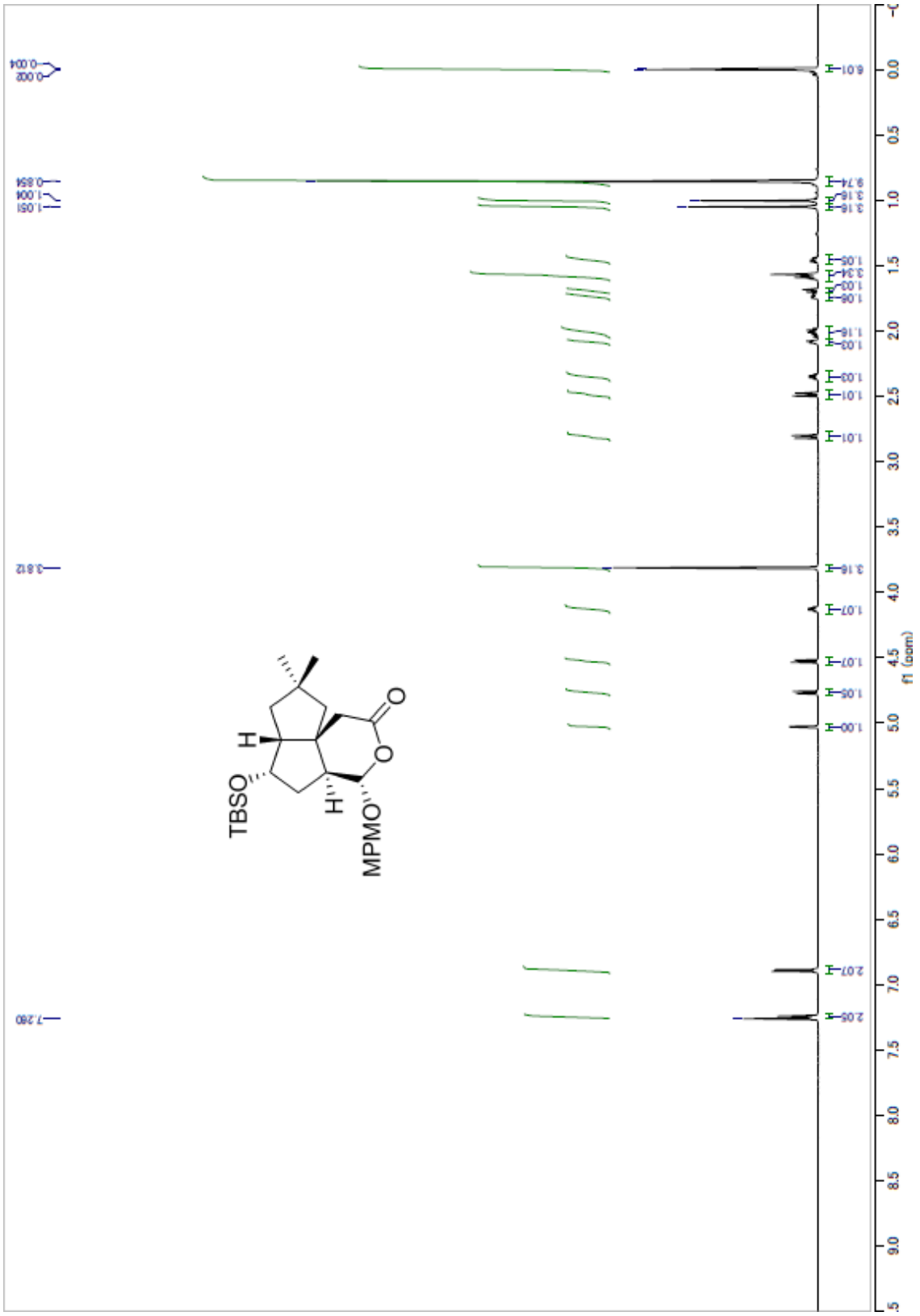
[コメント情報]
試料名 A15
コメント
測定者
所属
会社 新潟大学 理学部

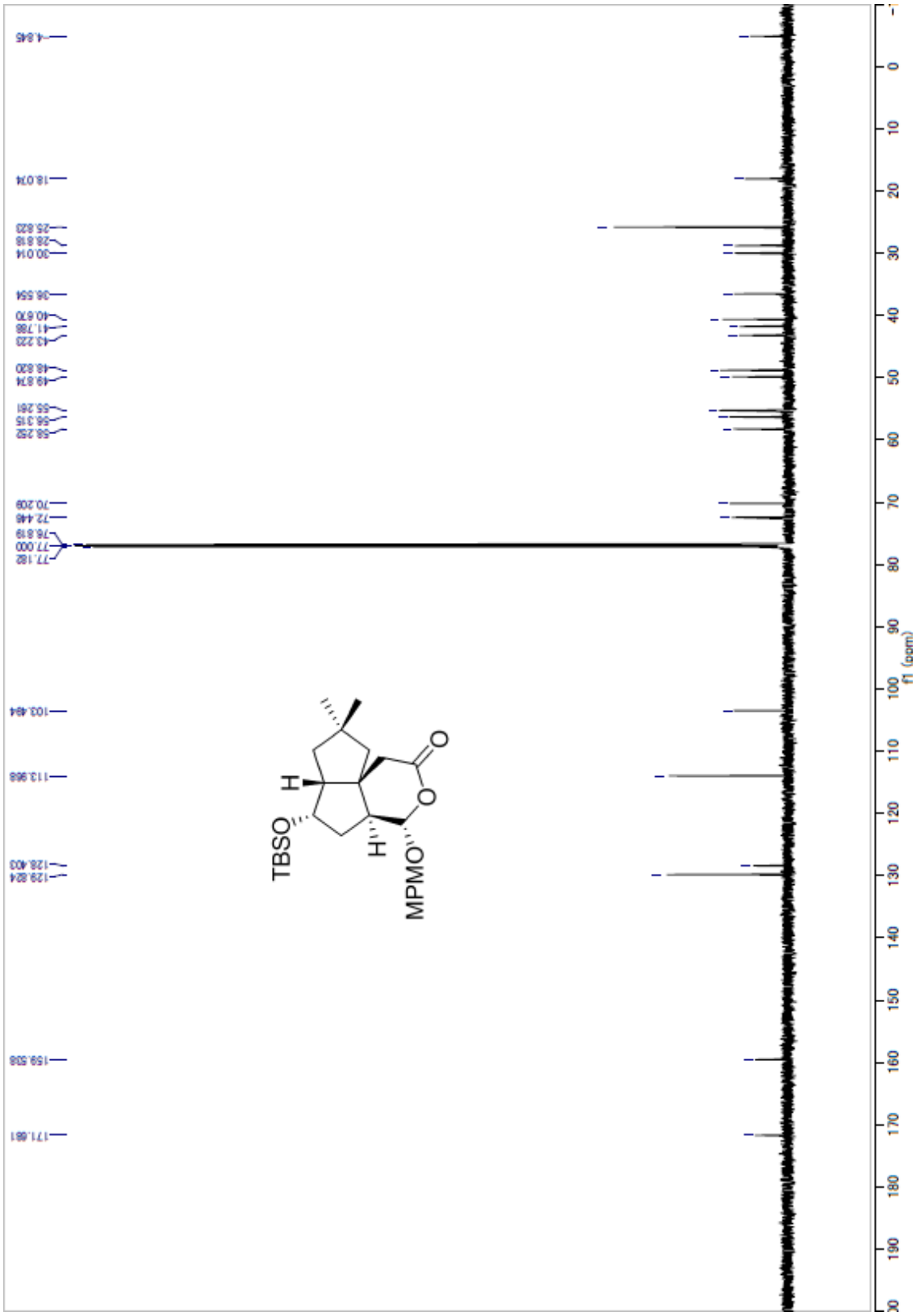

TBSO
H
H
MPMO
O
f1 (ppm)

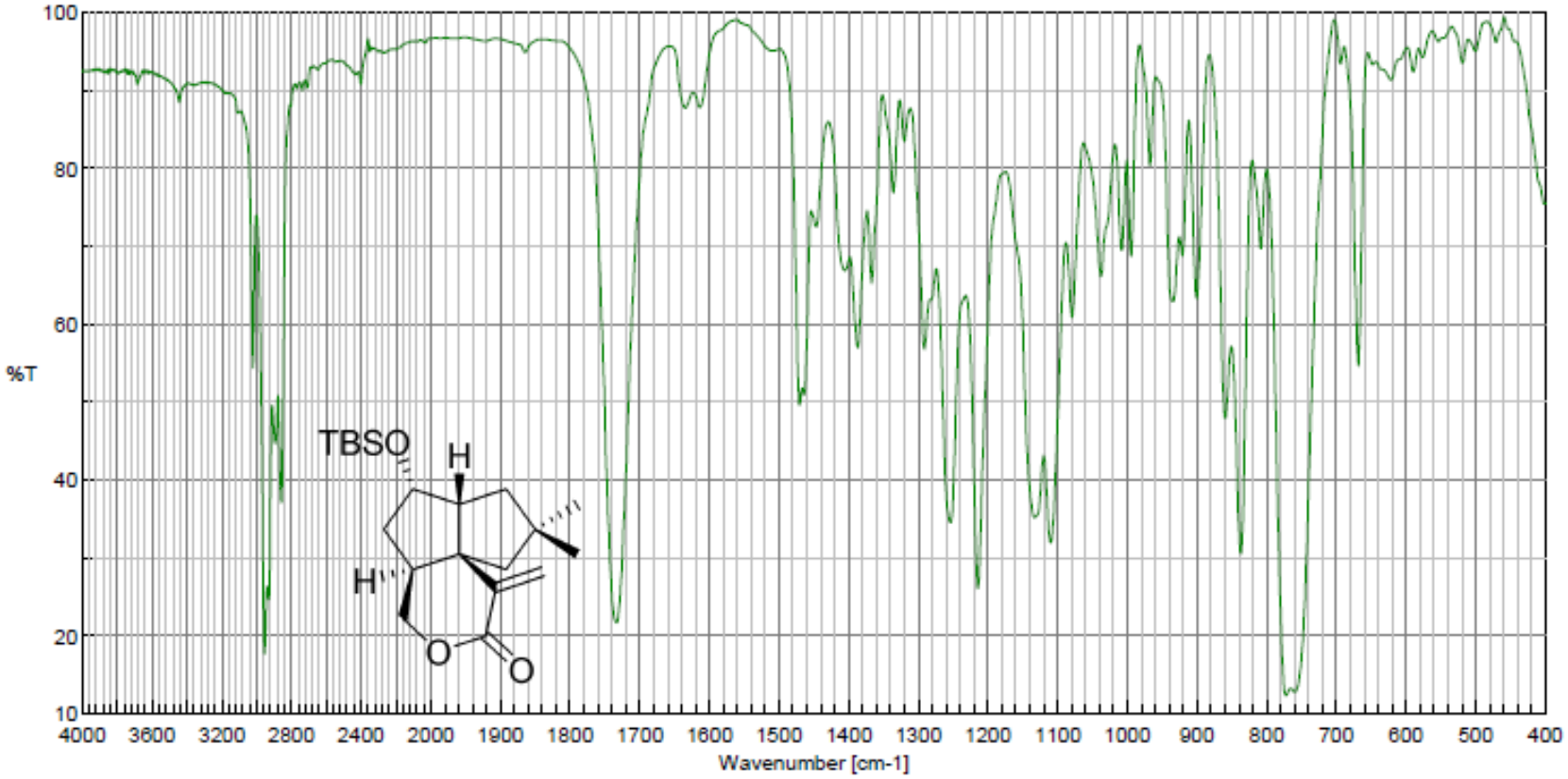

TBSO
H
H
O
MPMO
f1 (ppm)



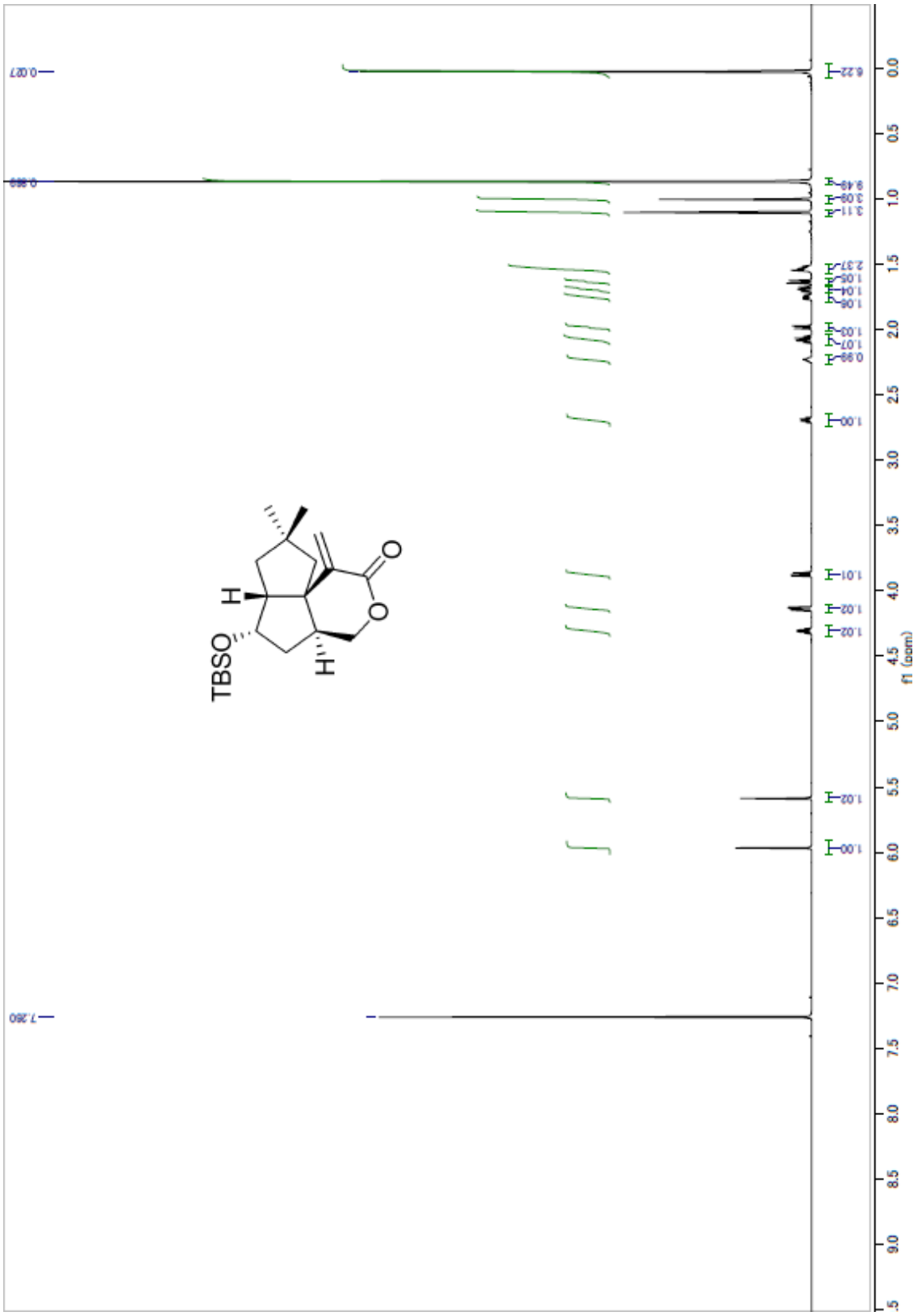
[コメント情報]
試料名 A15
コメント
測定者
所属
会社 新潟大学 理学部

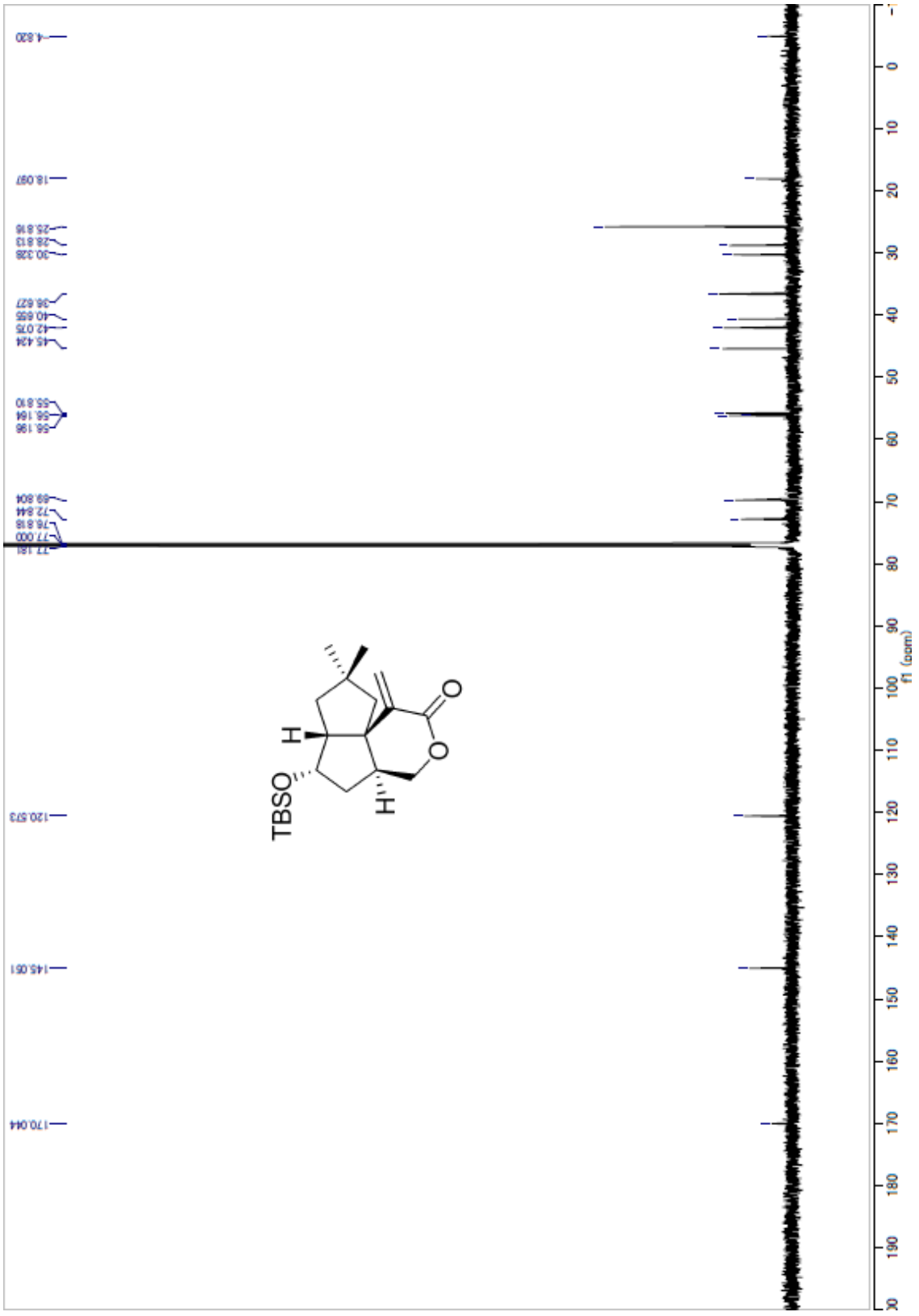

TBSO
H
H
O
O
MPMO
f1 (ppm)

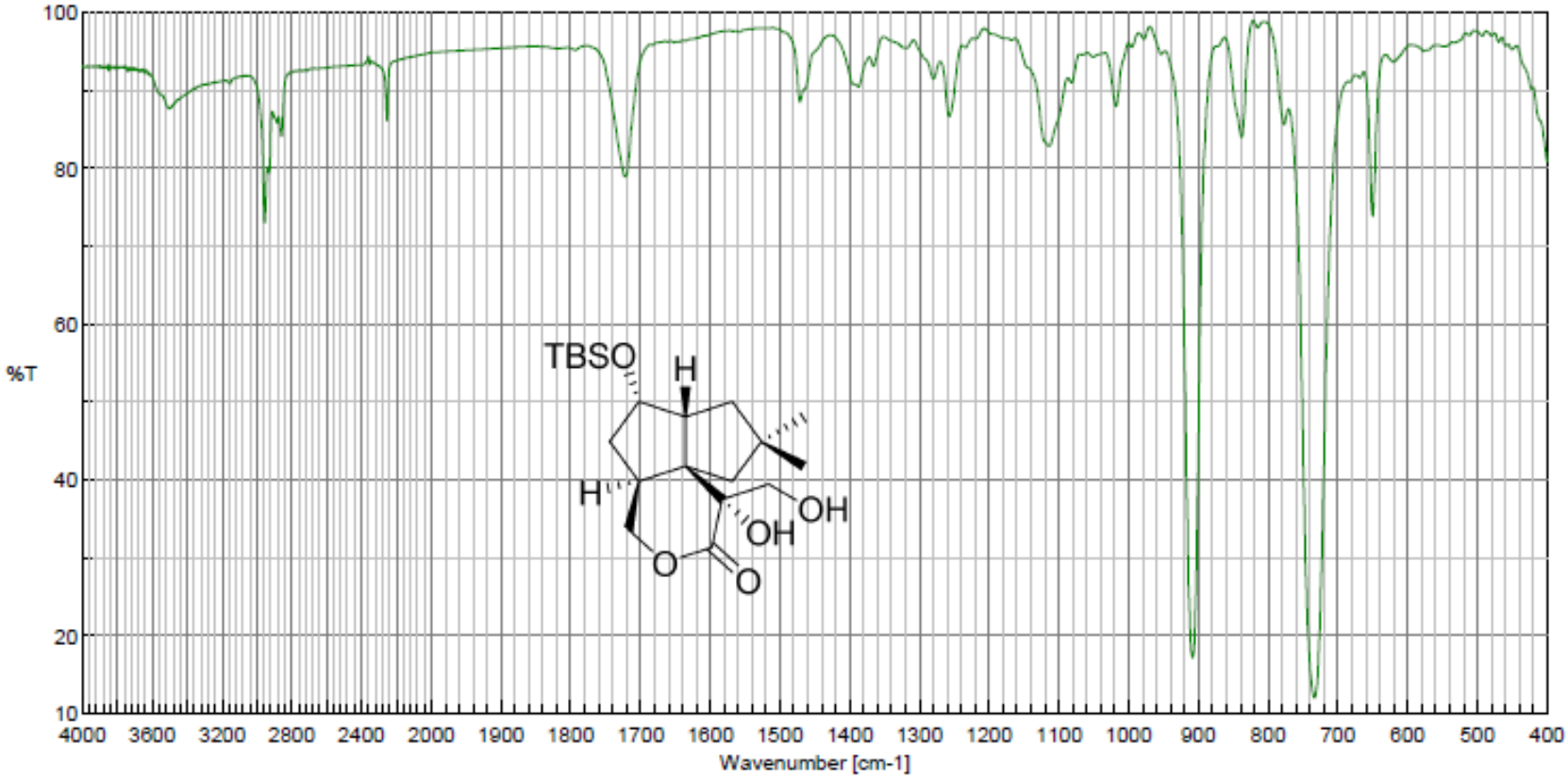

-4.845
18.074
25.820
26.818
30.014
36.554
40.670
41.788
43.220
49.874
55.261
56.315
58.252
70.209
72.446
76.819
77.000
77.182
103.464
113.968
128.403
129.824
159.526
171.661
TBSO
H
H
O
O
MPMO
f1 (ppm)



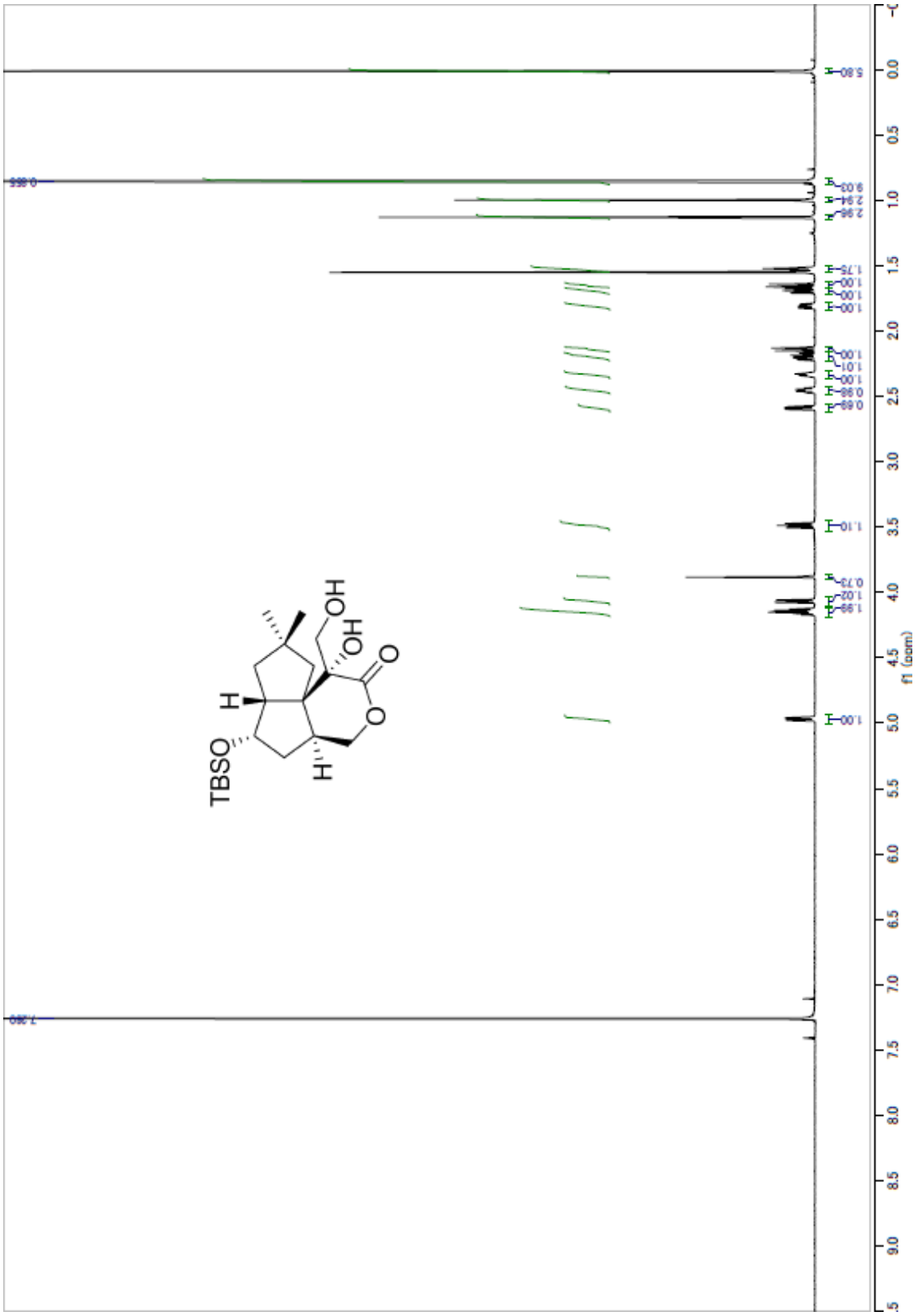
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

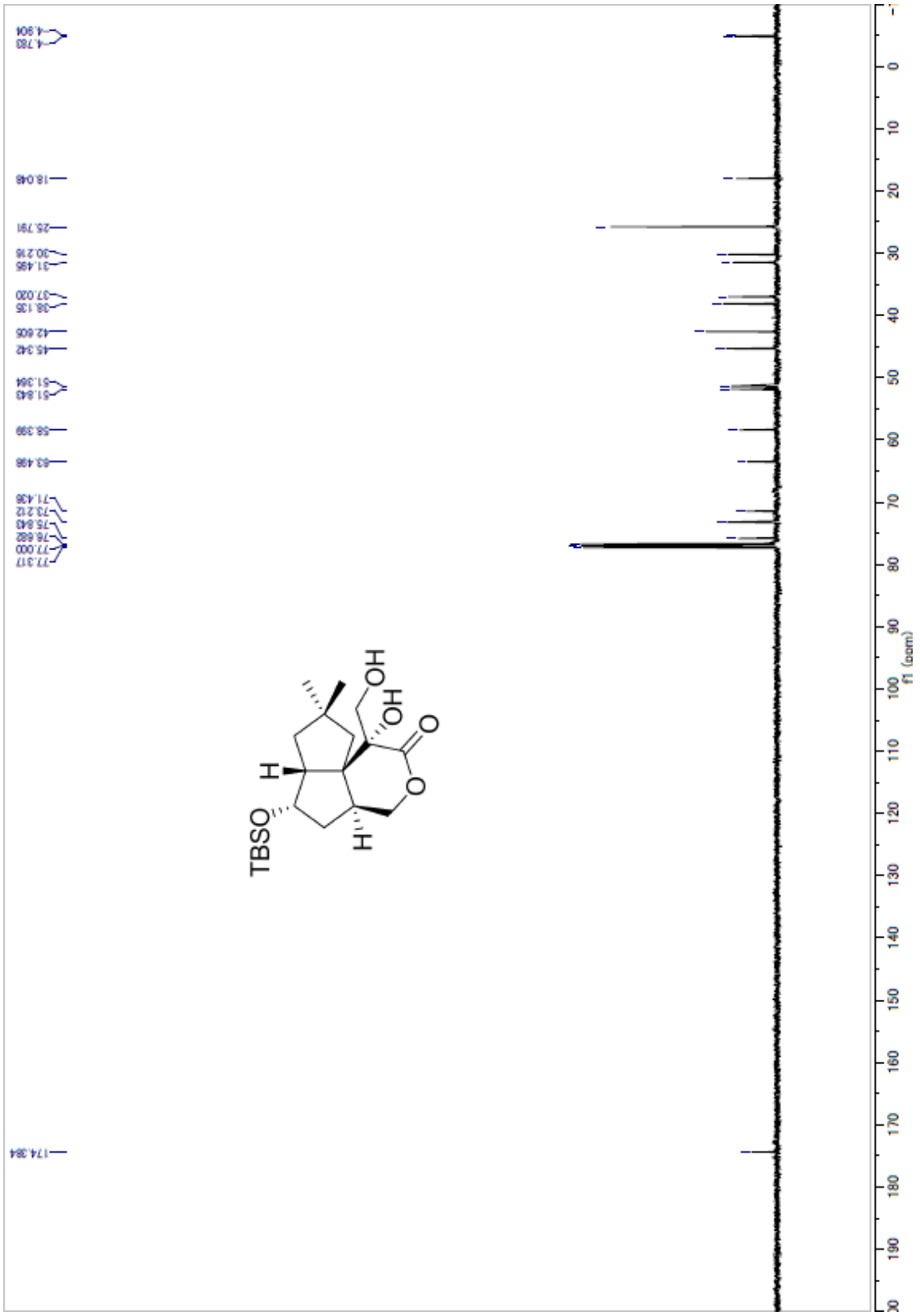

TBSO
H
H
O
O
f1 (ppm)

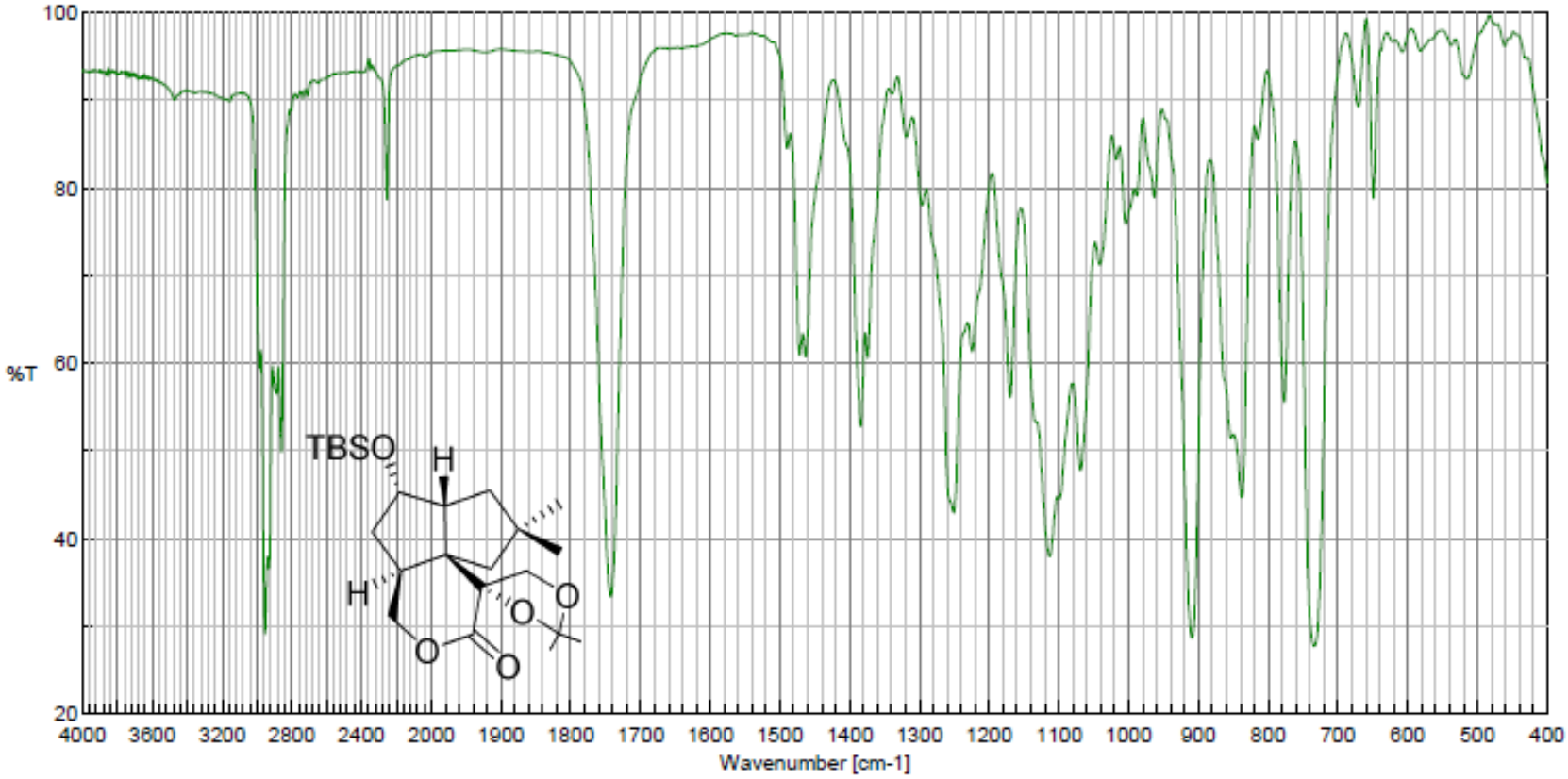

4.820
18.097
25.816
28.813
30.328
36.627
40.655
42.075
45.424
55.810
56.184
56.196
69.804
72.844
76.818
77.000
77.181
120.573
145.061
170.044
TBSO
H
H
O
O
f1 (ppm)



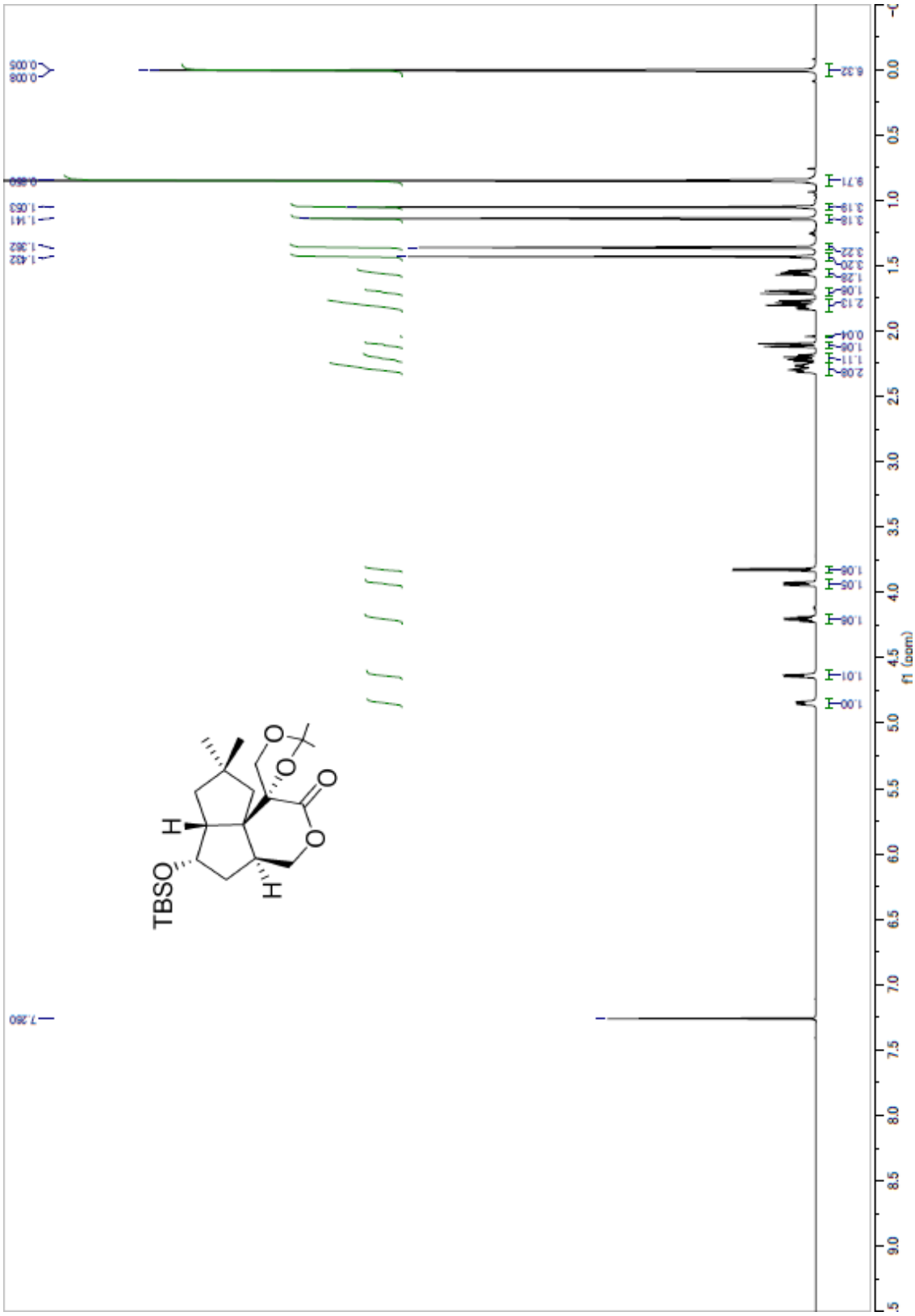
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

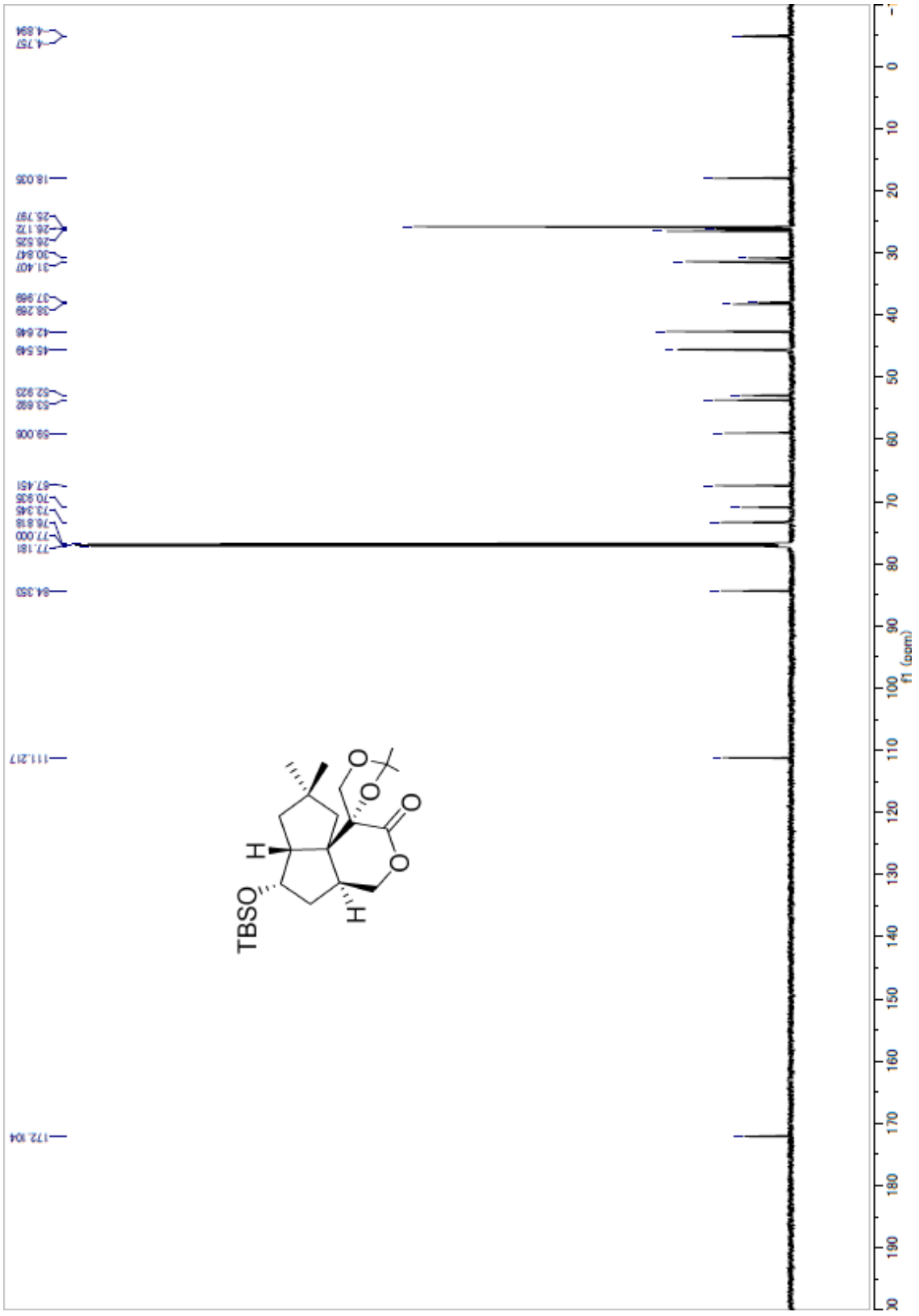

TBSO
H
OH
OH
O
O
H
f1 (ppm)

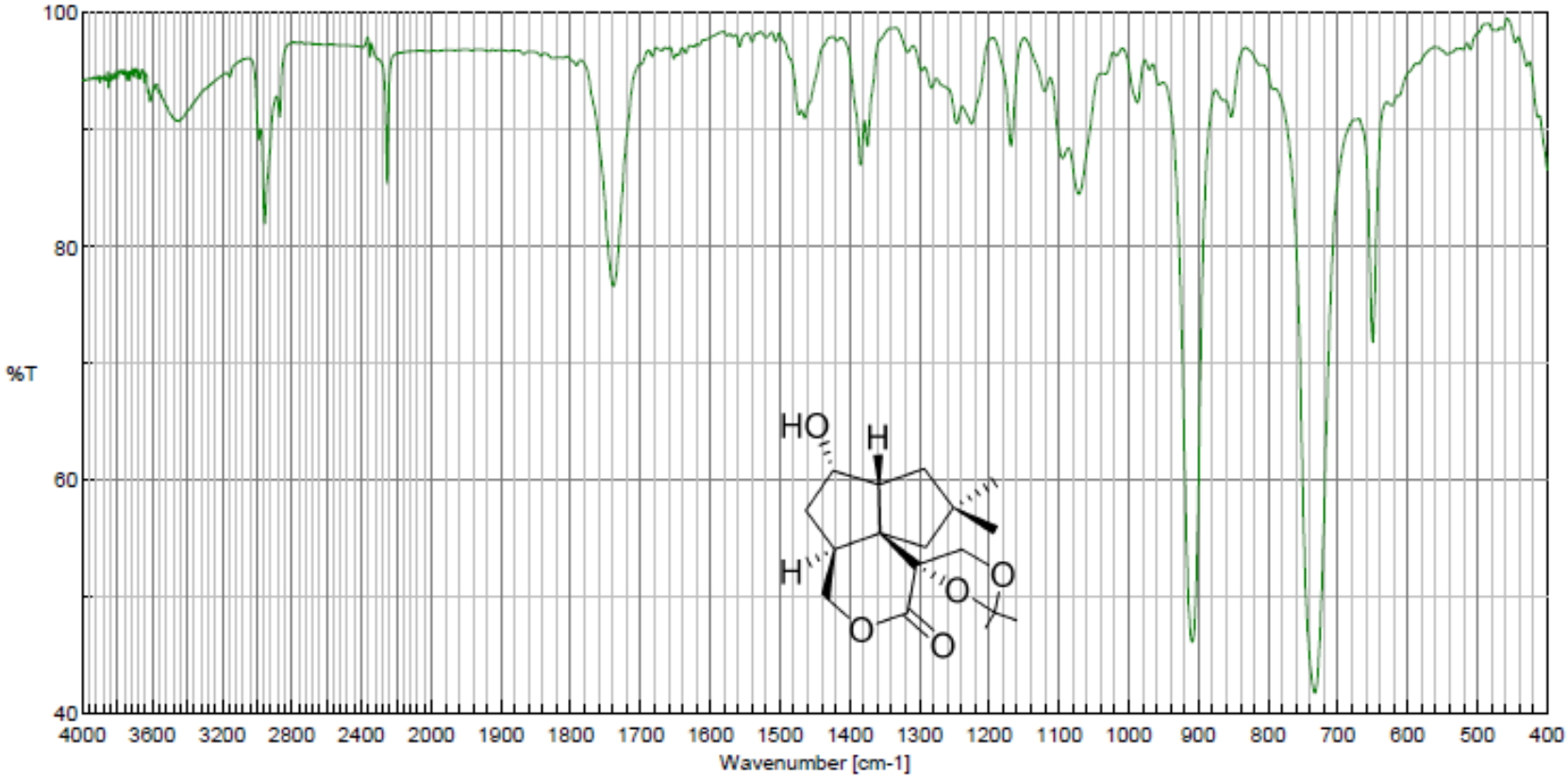

174.384
77.317
77.000
76.682
75.843
73.212
71.436
63.496
58.399
51.843
51.384
45.342
42.605
38.135
37.020
30.216
25.791
18.048
4.780
4.904
TBSO
H
H
OH
O
O
f1 (ppm)



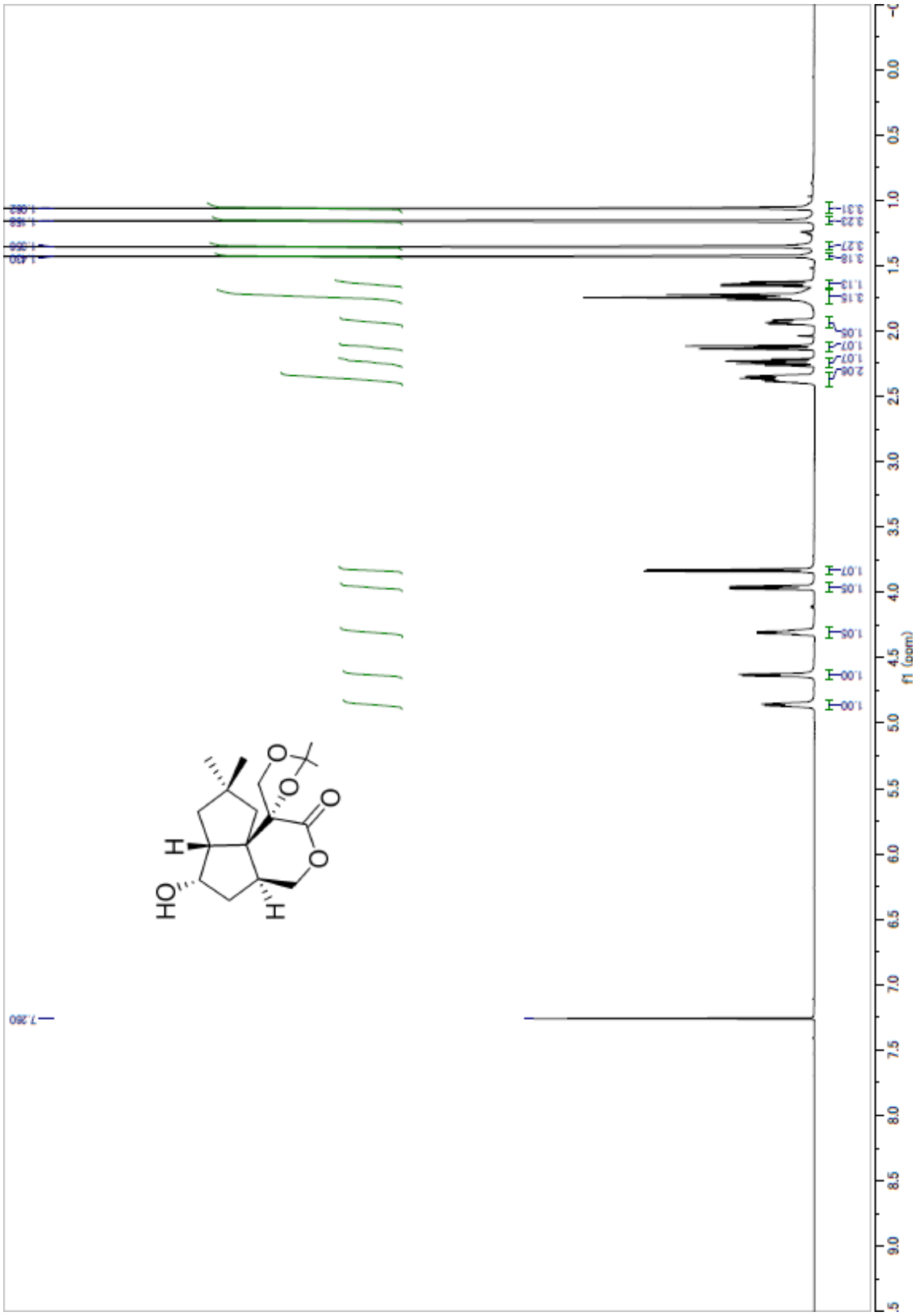
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

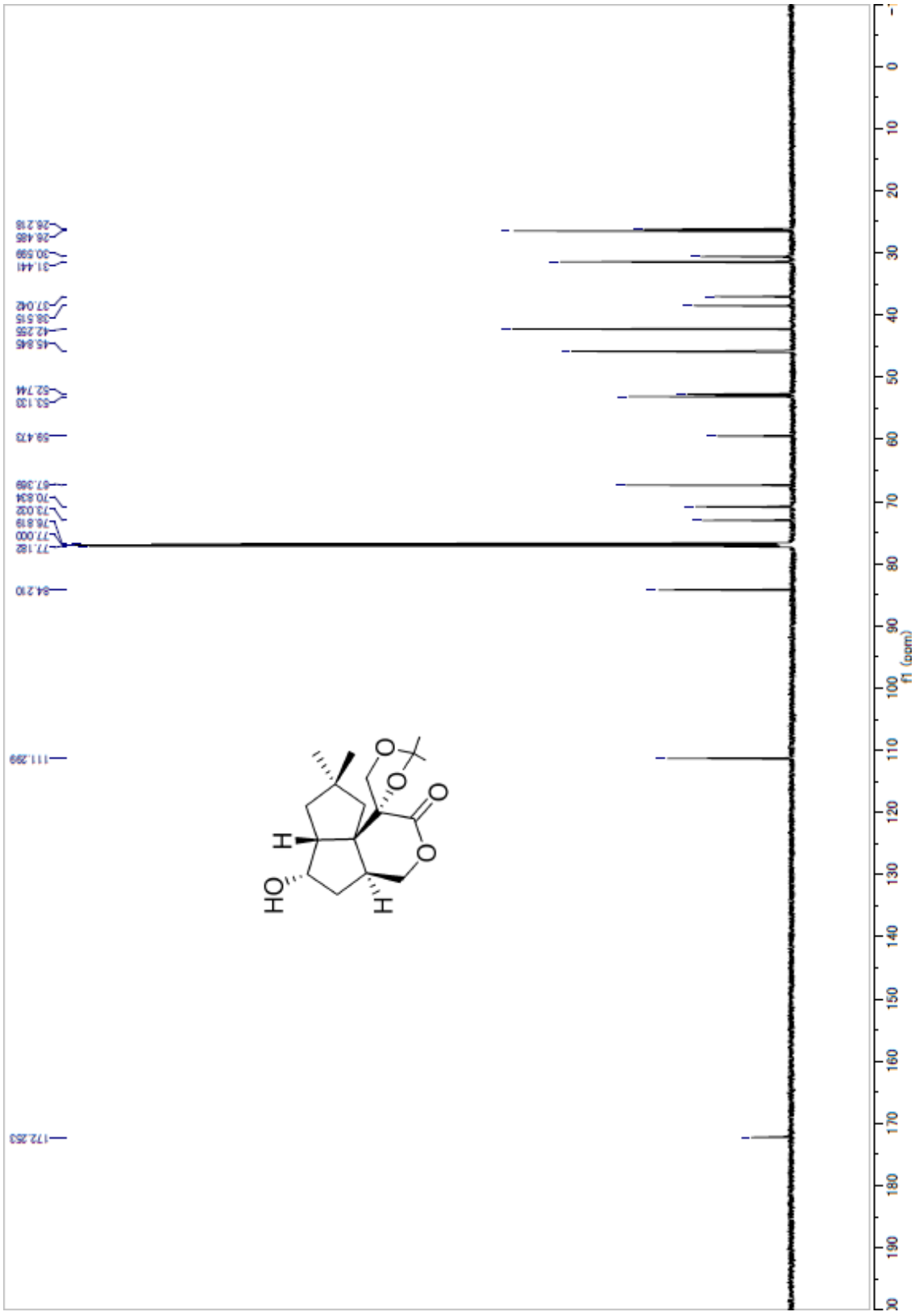

TBSO
H
H
O
O
O
O
f1 (ppm)

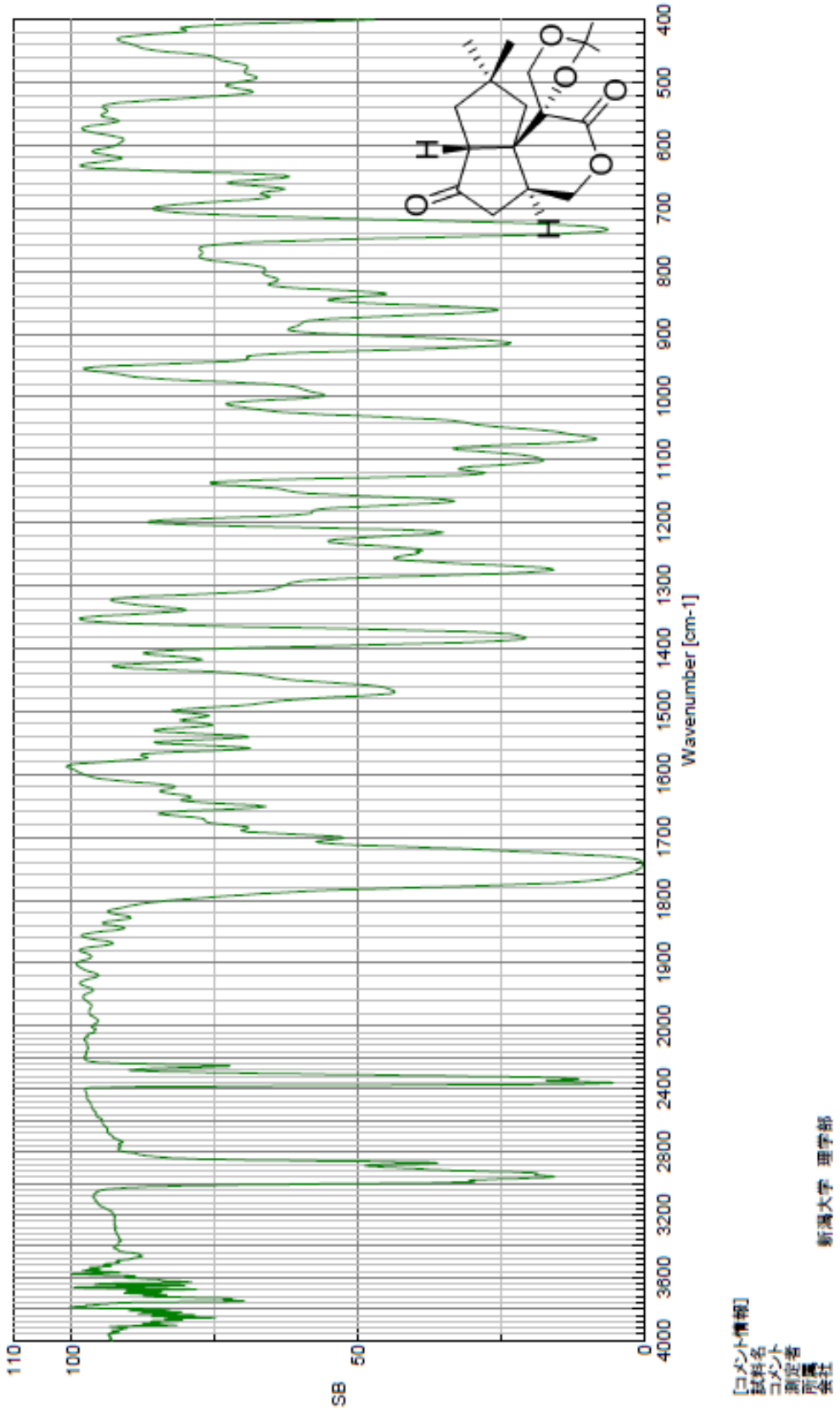

4.894
4.757
18.026
25.797
26.172
26.525
30.847
31.407
37.969
38.289
42.646
45.549
52.923
53.692
59.006
87.451
70.926
73.346
76.818
77.000
77.181
84.350
111.217
172.104
f1 (ppm)
TBSO
H
H
O
O
O
O

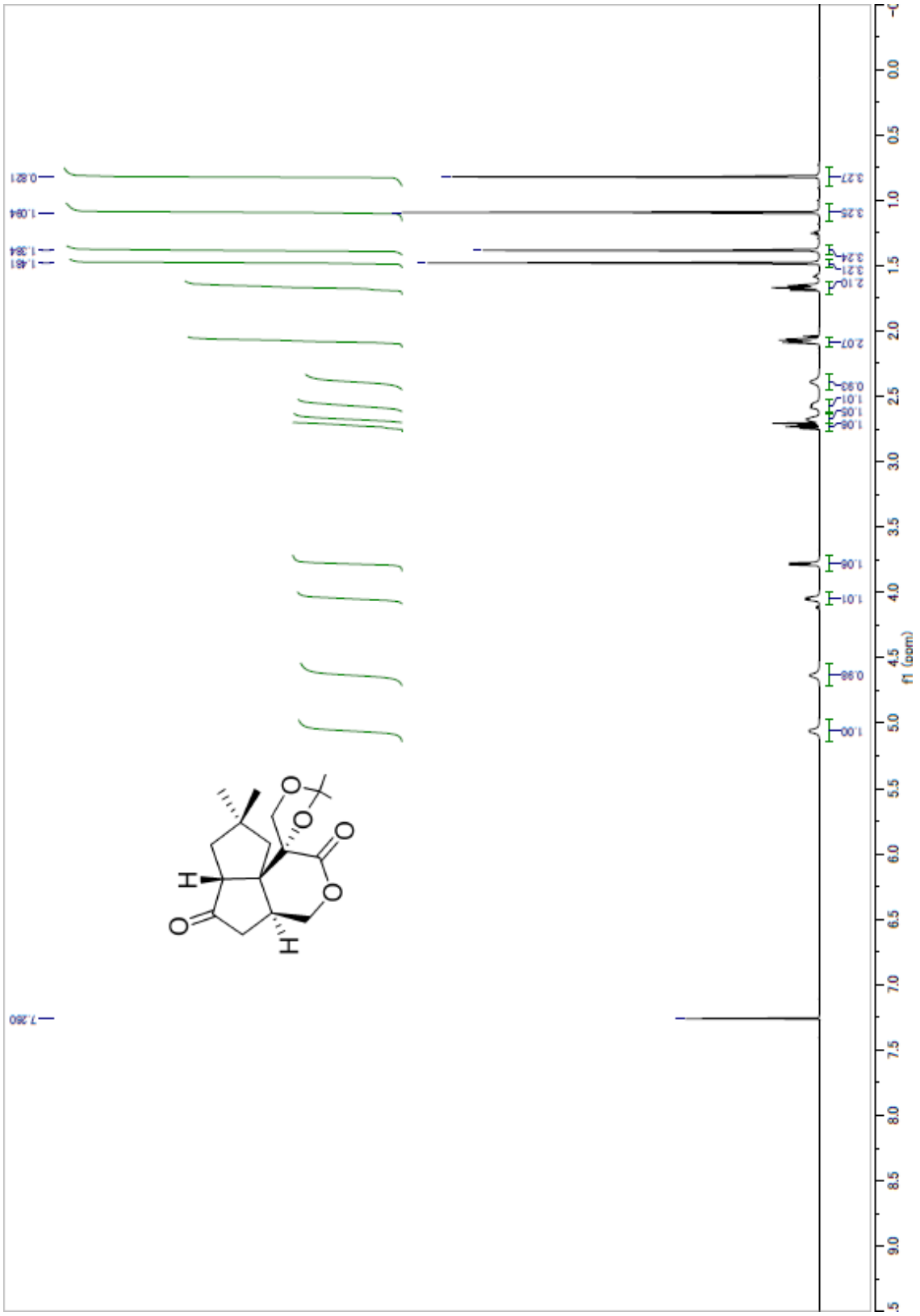


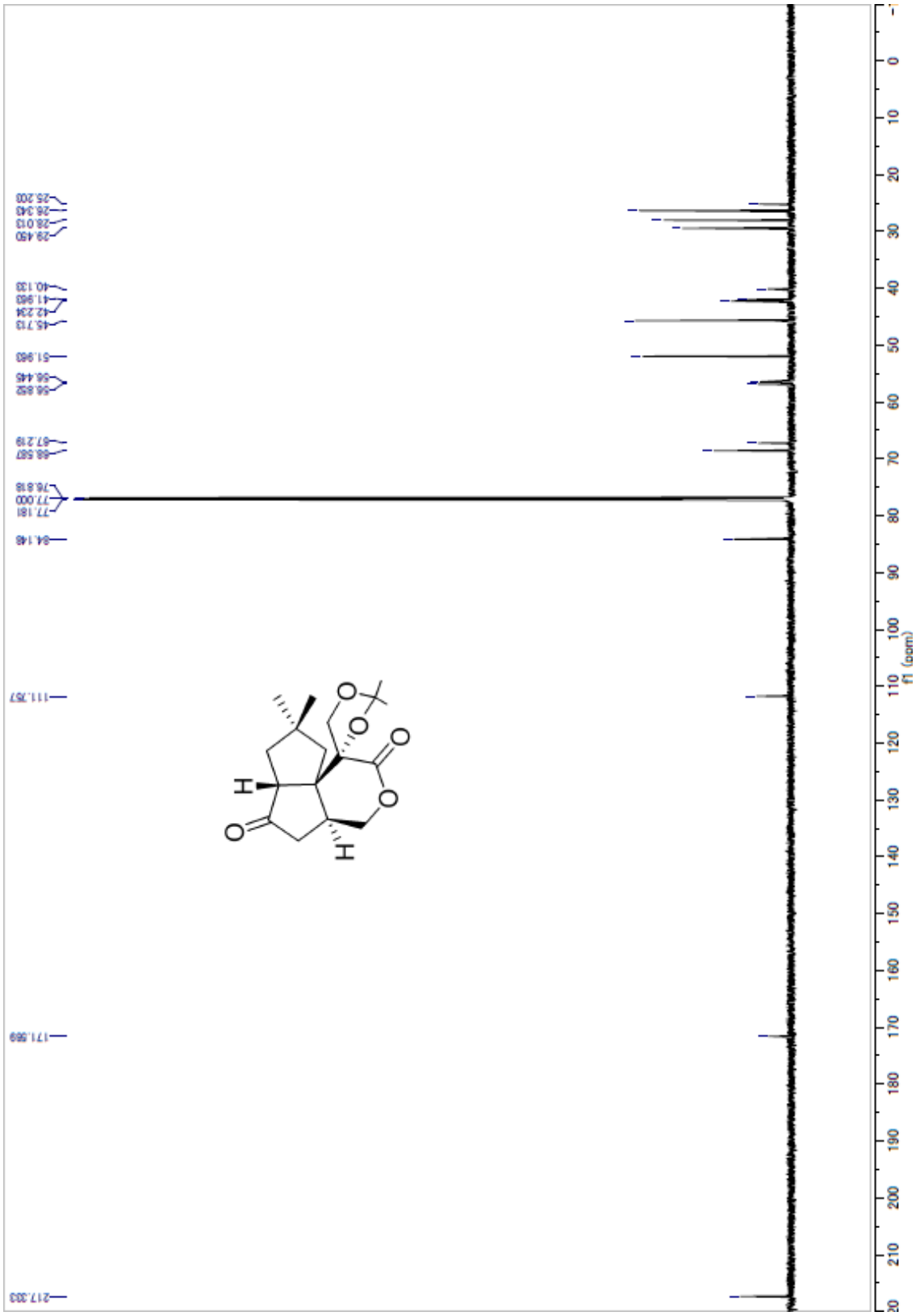
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

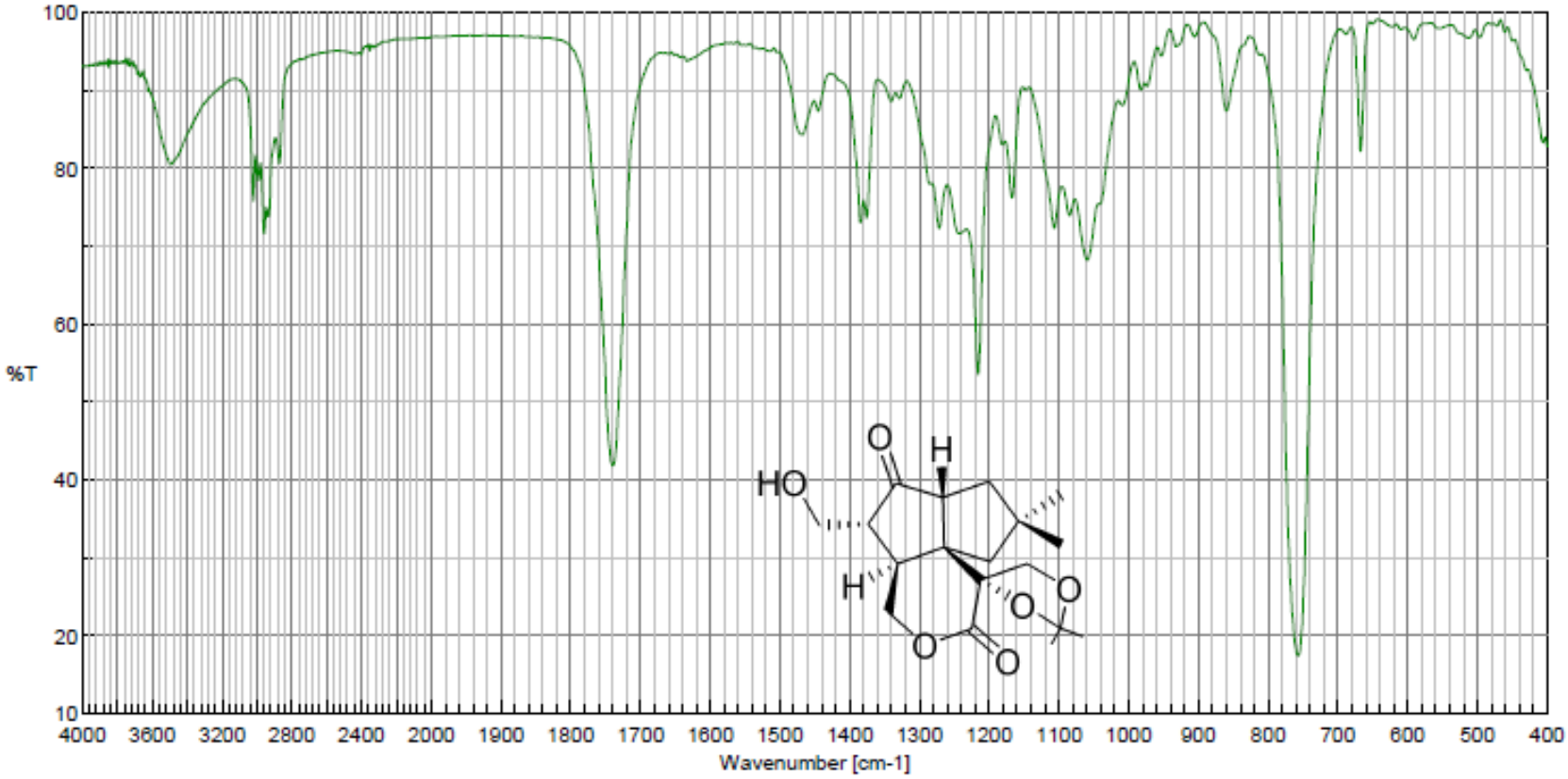

HO
H
H
O
O
O
O
f1 (ppm)


26.218
26.486
30.599
31.441
37.042
38.515
42.255
45.845
52.744
53.120
59.470
67.089
70.834
73.032
76.819
77.000
77.182
84.210
111.299
172.253
HO
H
H
O
O
O
O
f1 (ppm)

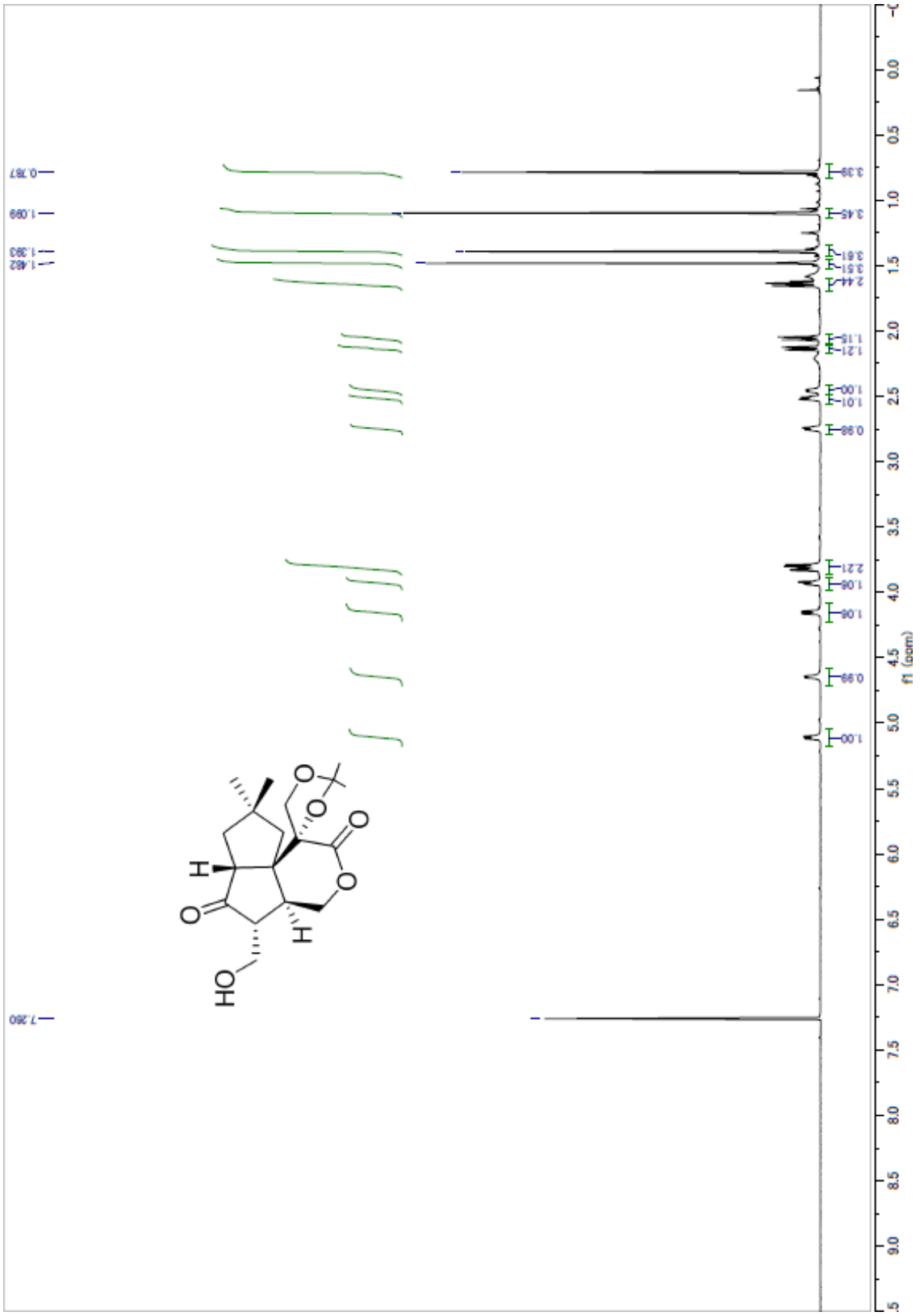

110
100
50
0
%T
4000
3600
3200
2800
2400
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
Wavenumber [cm-1]
[コメント情報]
試料名
コメント
測定者
所属
会社
新潟大学　理学部

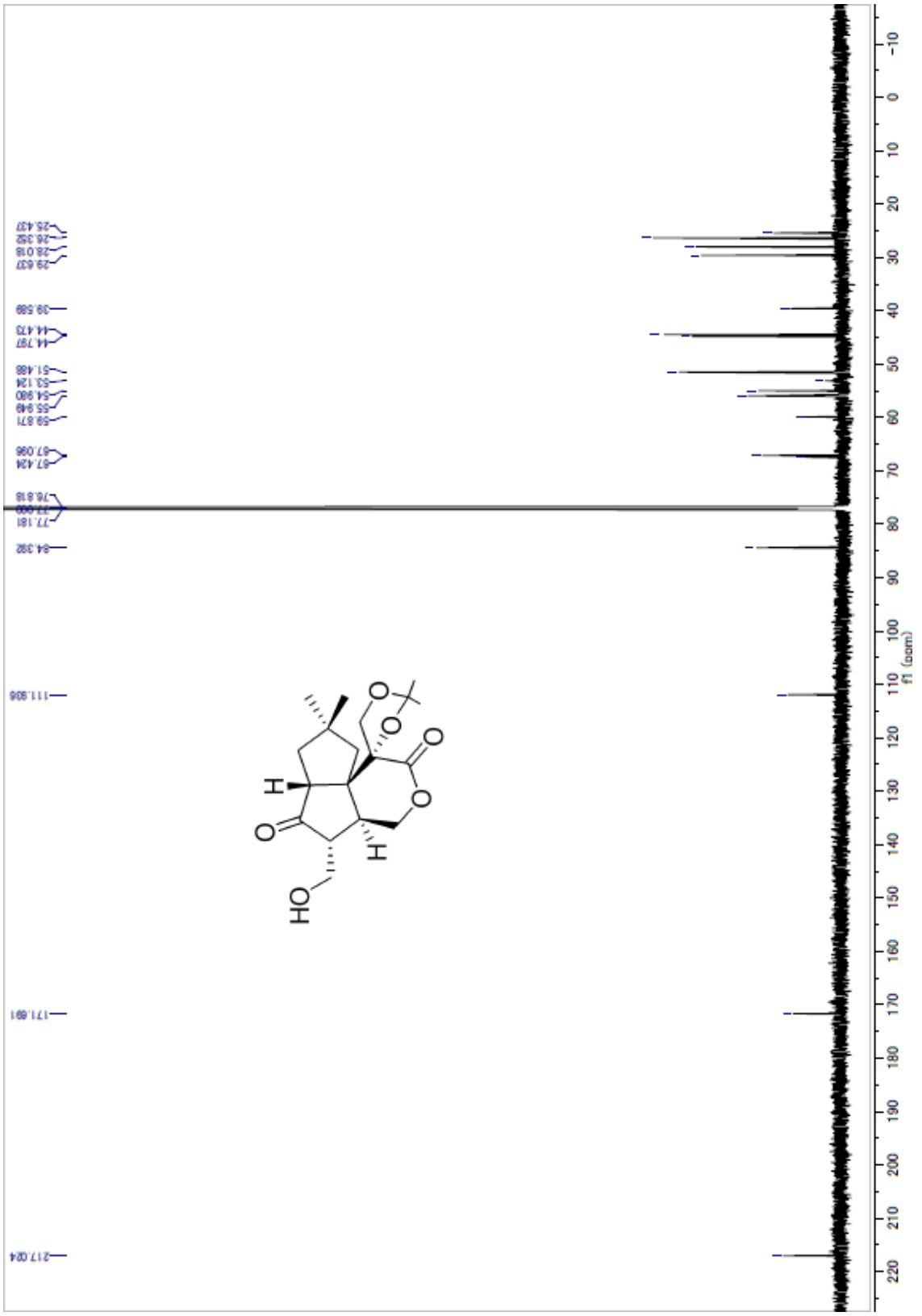

0.821
1.094
1.384
1.461
7.260
3.27
3.25
3.24
3.21
2.10
2.07
0.80
1.01
1.05
1.06
1.08
1.01
0.98
1.00
f1 (ppm)

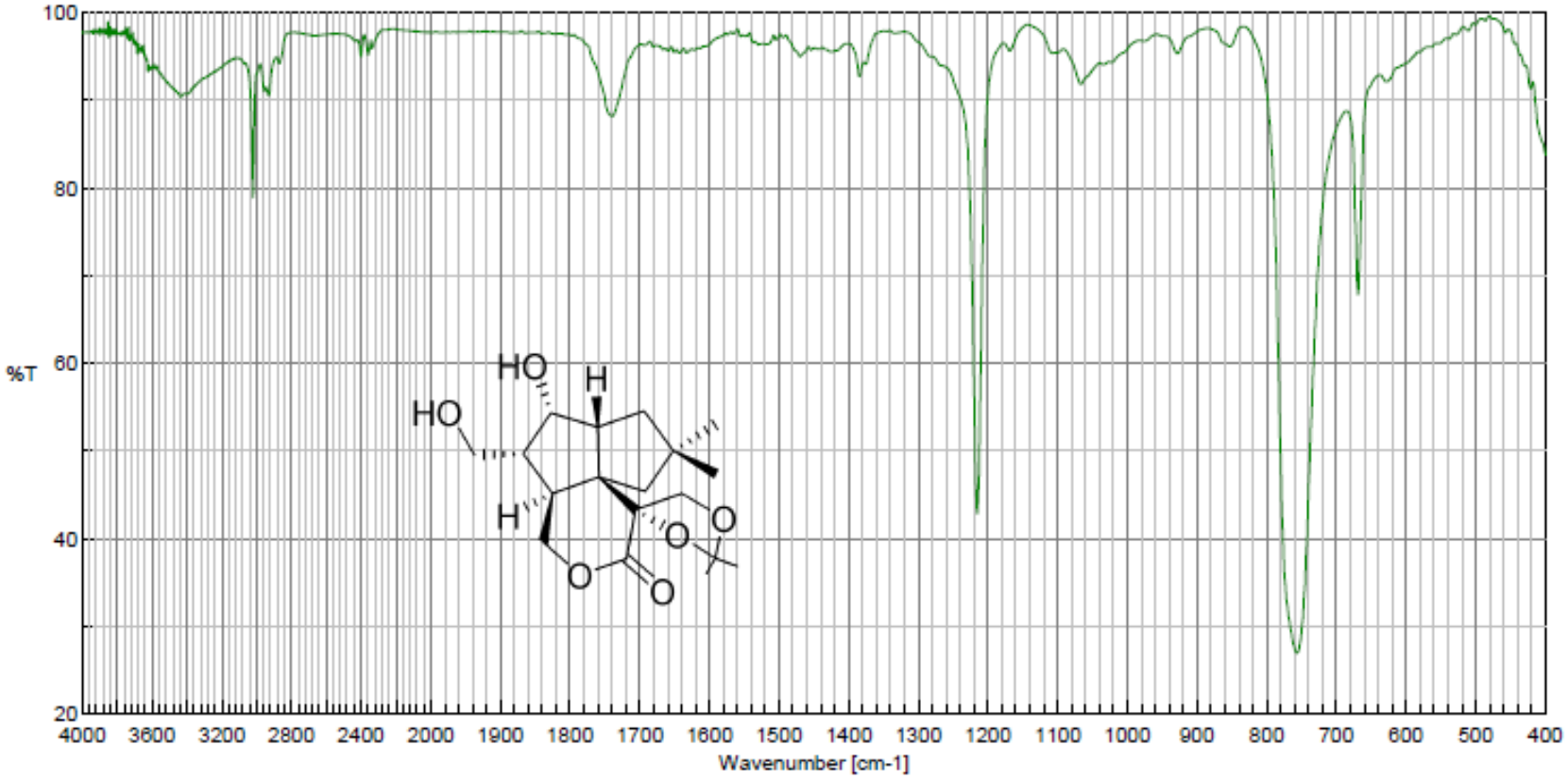

217.303
171.569
111.757
84.148
77.181
77.000
76.818
68.587
67.219
56.850
56.445
51.960
45.713
42.234
41.960
40.130
29.450
28.013
26.040
25.200
f1 (ppm)



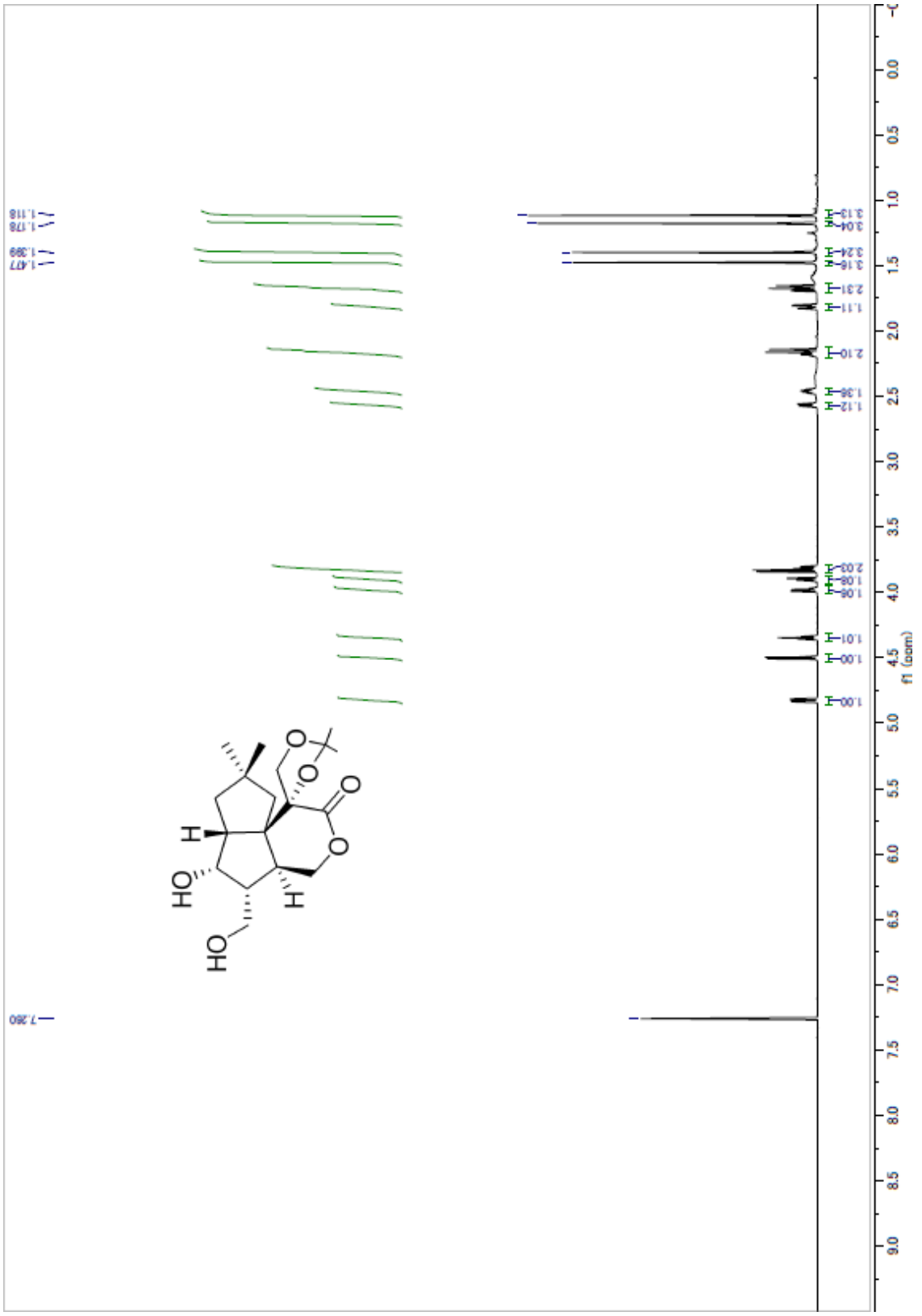
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

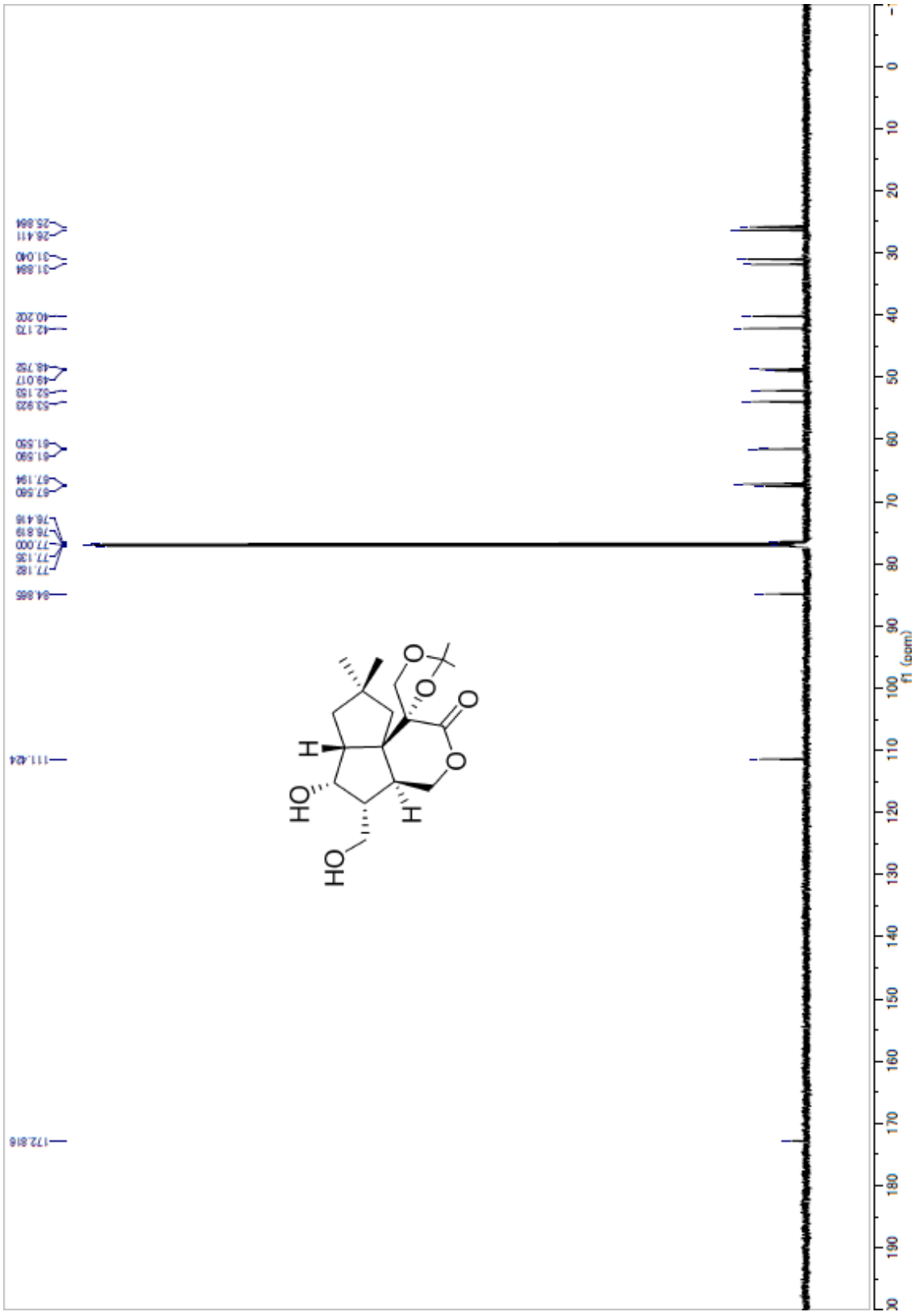

0.787
1.099
1.380
1.462
7.260
3.39
3.45
3.61
3.51
2.44
1.15
1.21
1.00
1.01
0.98
2.21
1.06
1.06
0.99
1.00
f1 (ppm)
H
O
O
O
O
O
H
HO

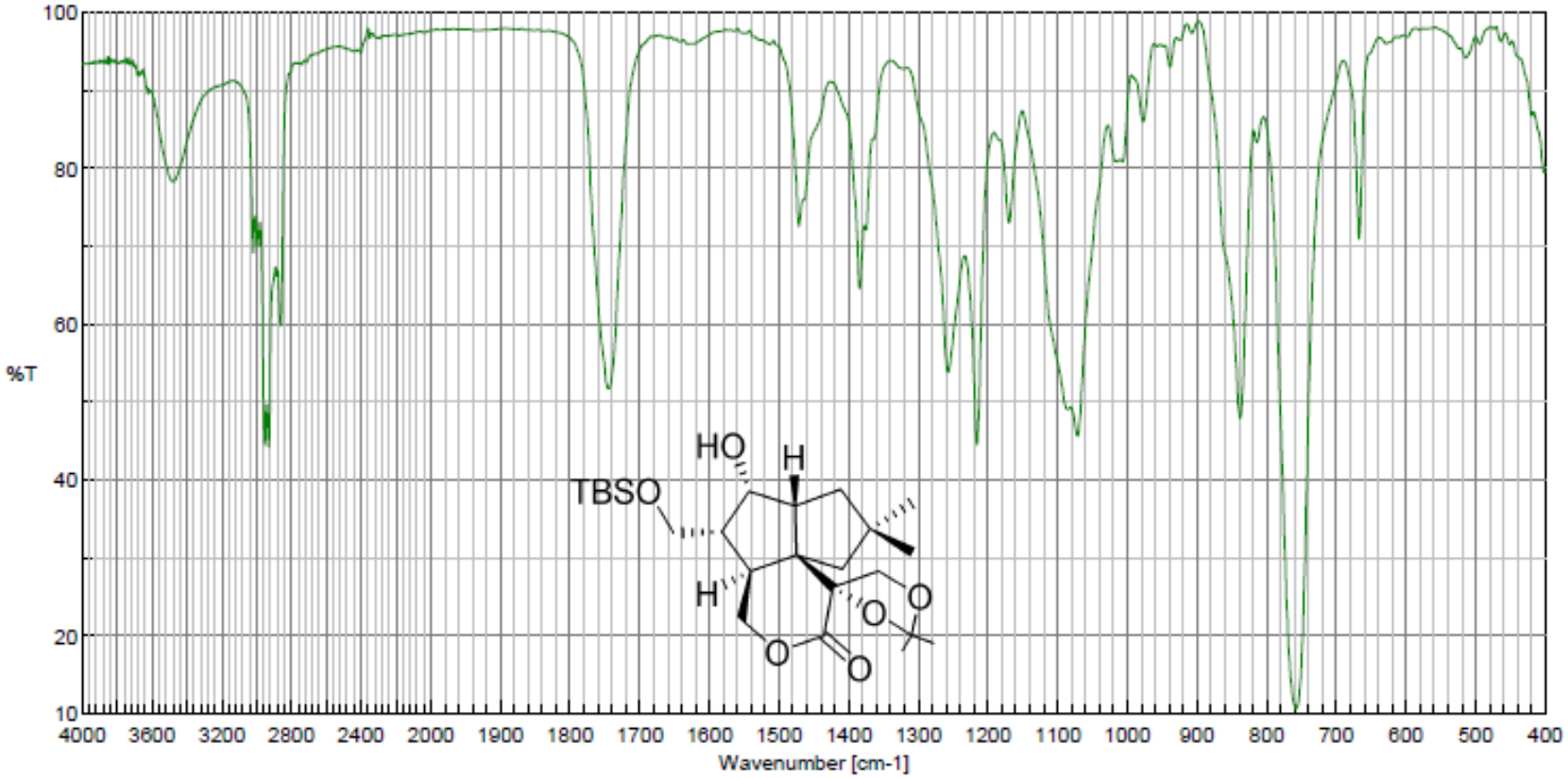

217.004
171.691
111.806
84.382
77.181
76.818
67.424
67.096
59.871
55.949
54.980
53.124
51.488
44.737
44.473
39.589
29.637
26.352
26.016
25.437
f1 (ppm)



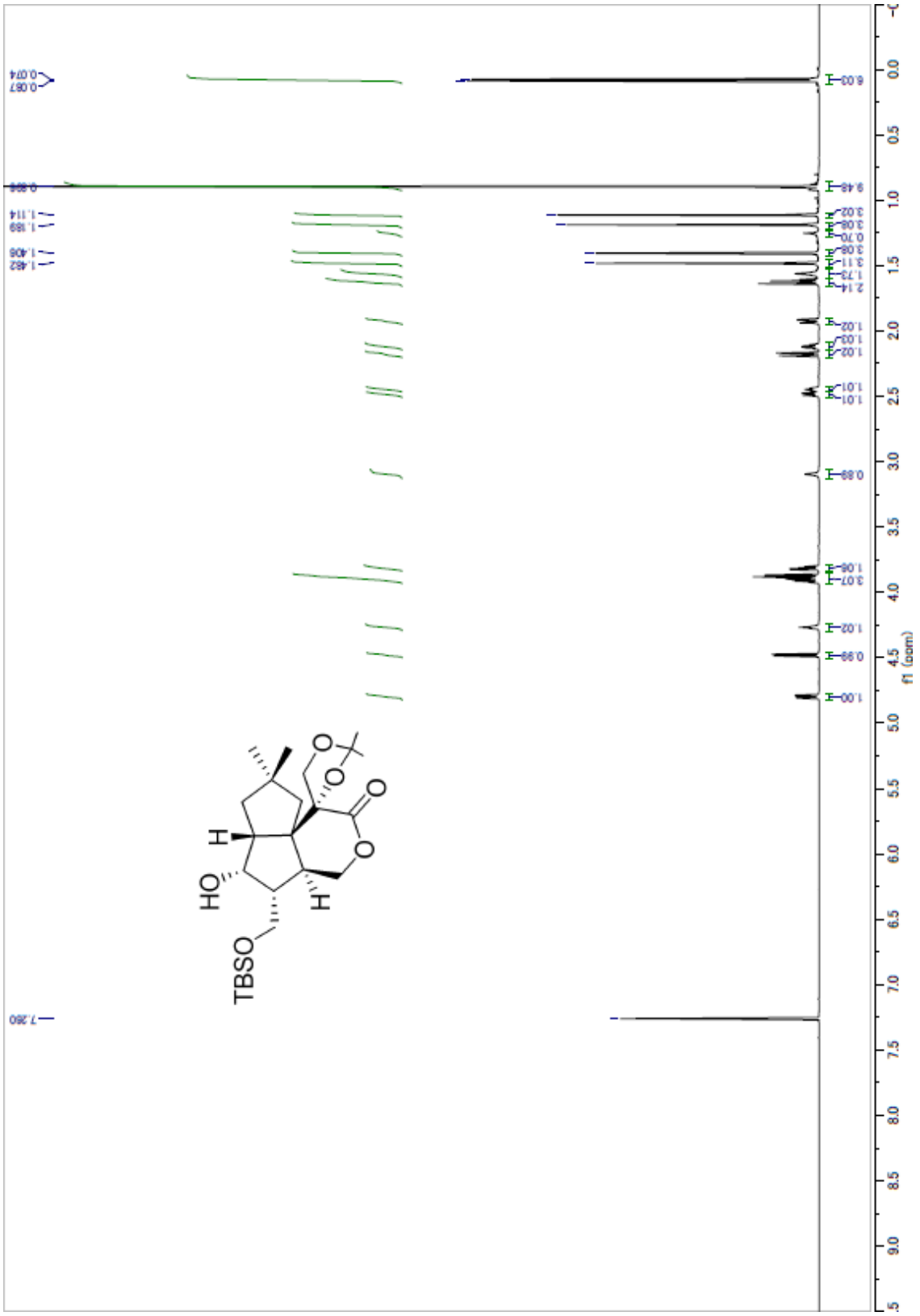
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

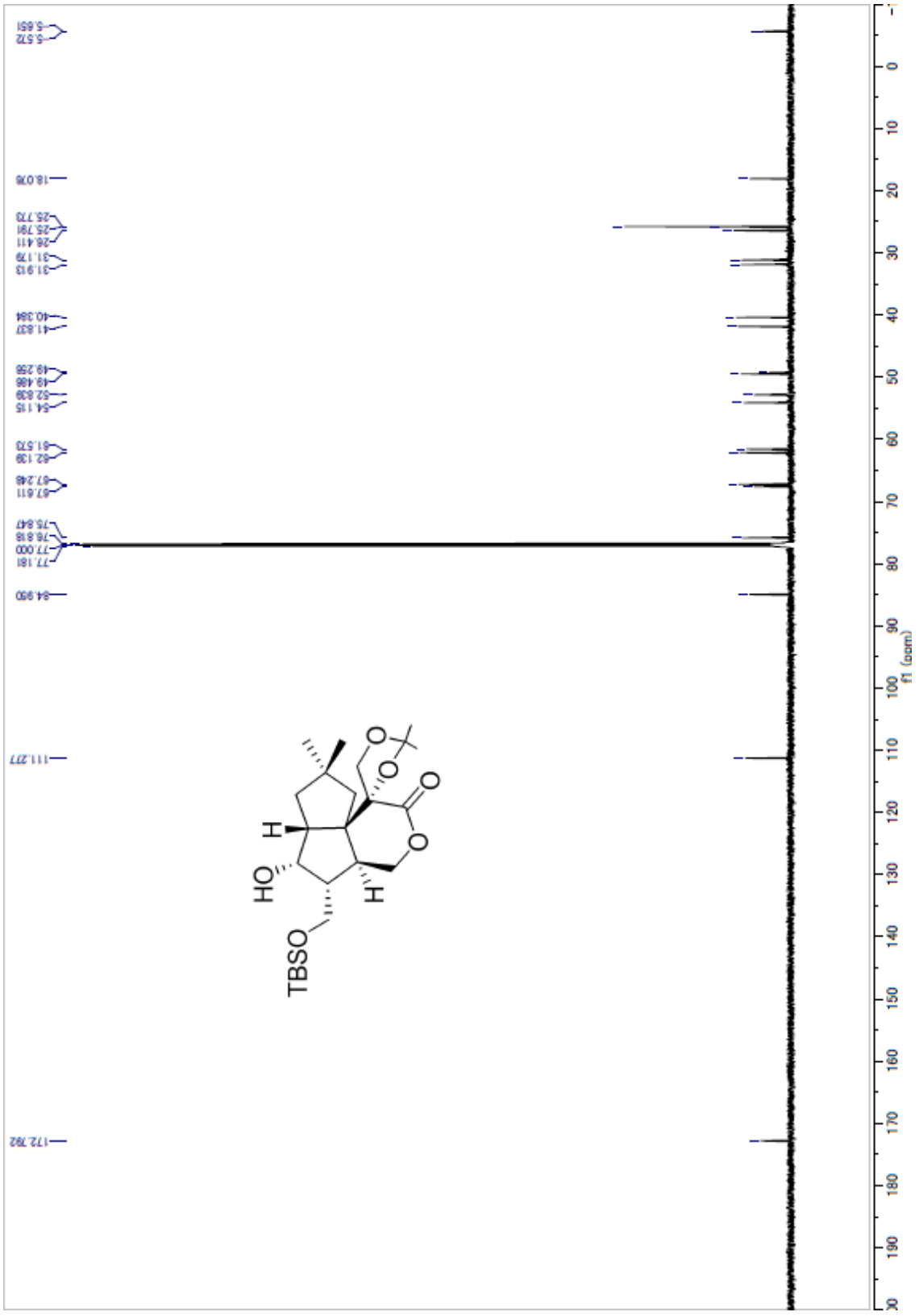

7.260
1.178
1.118
1.497
1.399
3.13
3.04
3.24
3.18
2.31
1.11
2.10
1.36
1.12
2.02
1.08
1.08
1.01
1.00
1.00
f1 (ppm)
H
HO
HO
H
O
O
O
O

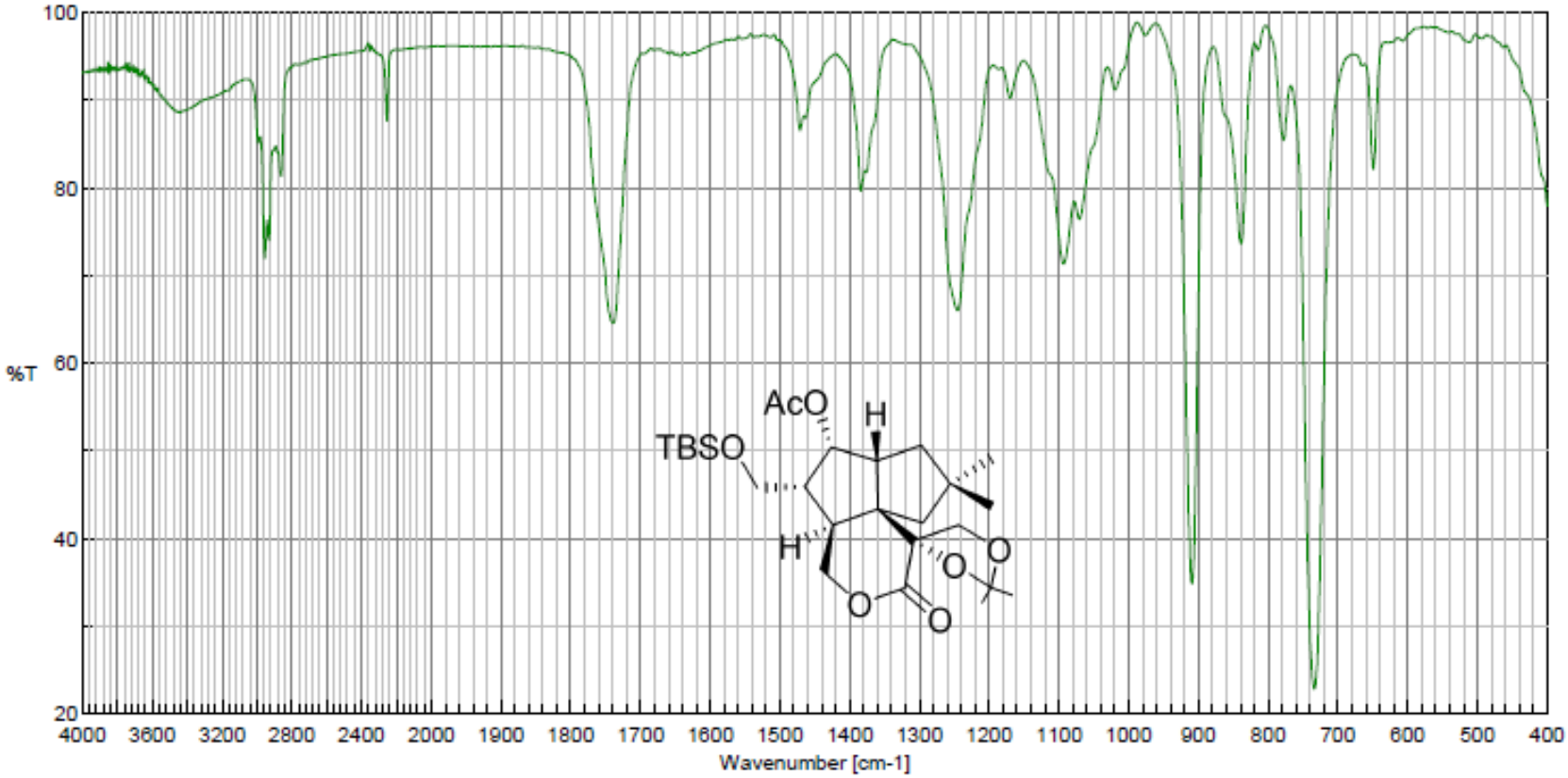

172.816
111.424
94.865
77.180
77.136
77.000
76.819
76.416
67.580
67.194
61.590
61.550
53.920
52.150
49.017
48.752
42.173
40.202
31.884
31.040
26.411
25.884
f1 (ppm)



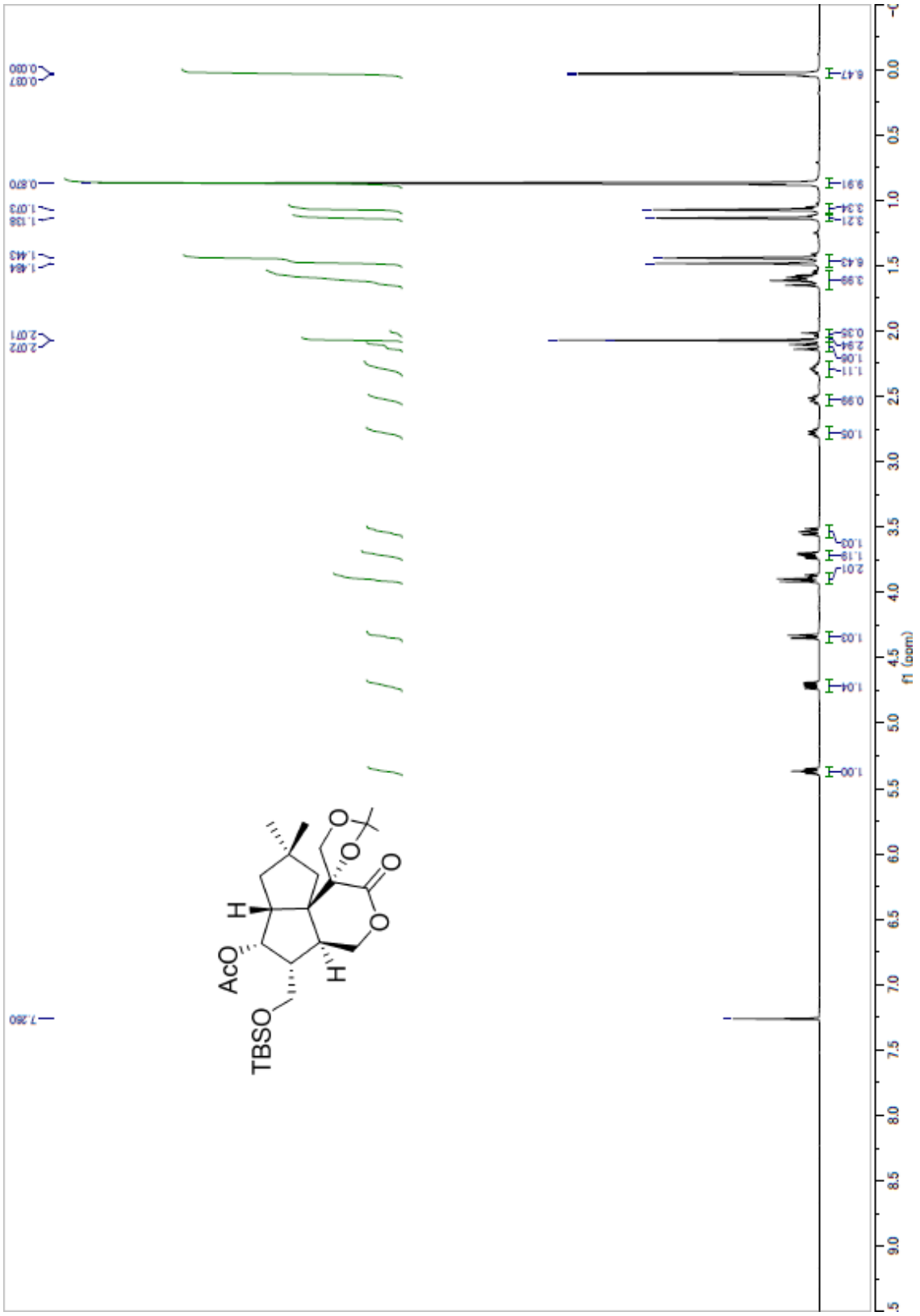
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

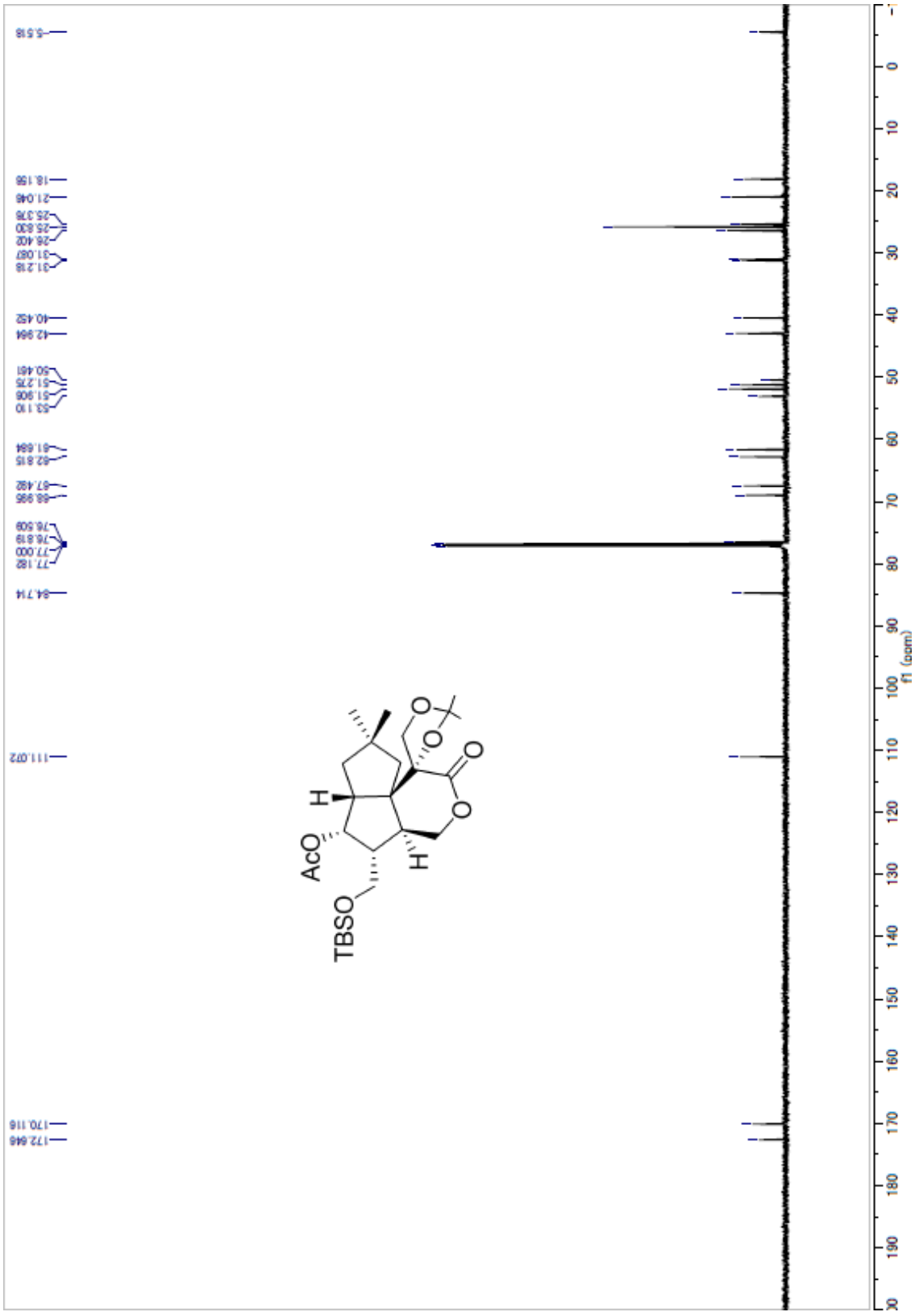

HO
H
H
O
O
O
O
TBSO
f1 (ppm)

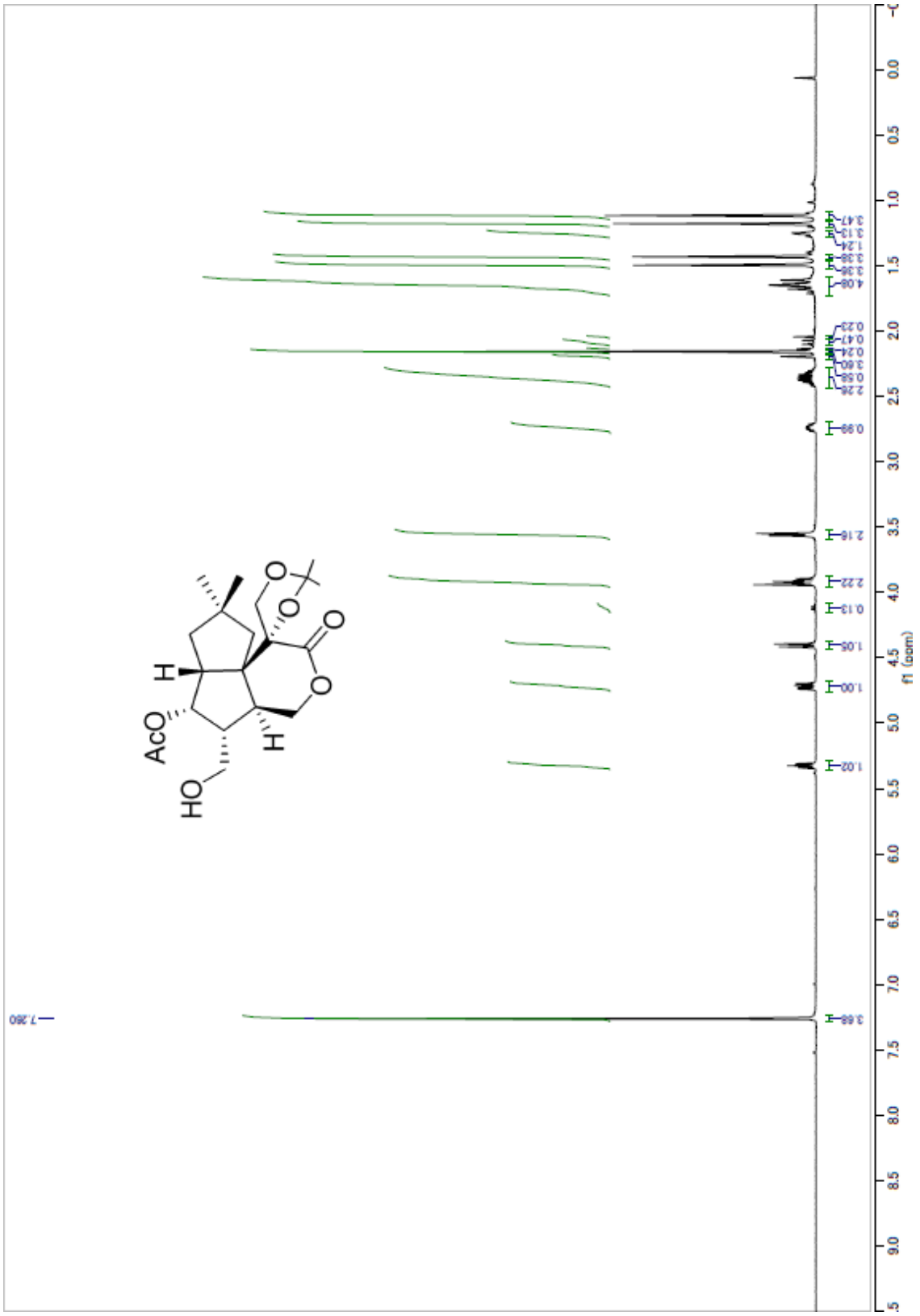

-5.572
-5.651
18.078
25.770
25.791
26.411
31.179
31.913
40.384
41.837
49.256
49.486
52.839
54.115
62.139
81.570
87.246
87.611
75.847
76.816
77.000
77.181
94.950
111.277
172.782
HO
H
H
O
O
O
TBSO
f1 (ppm)

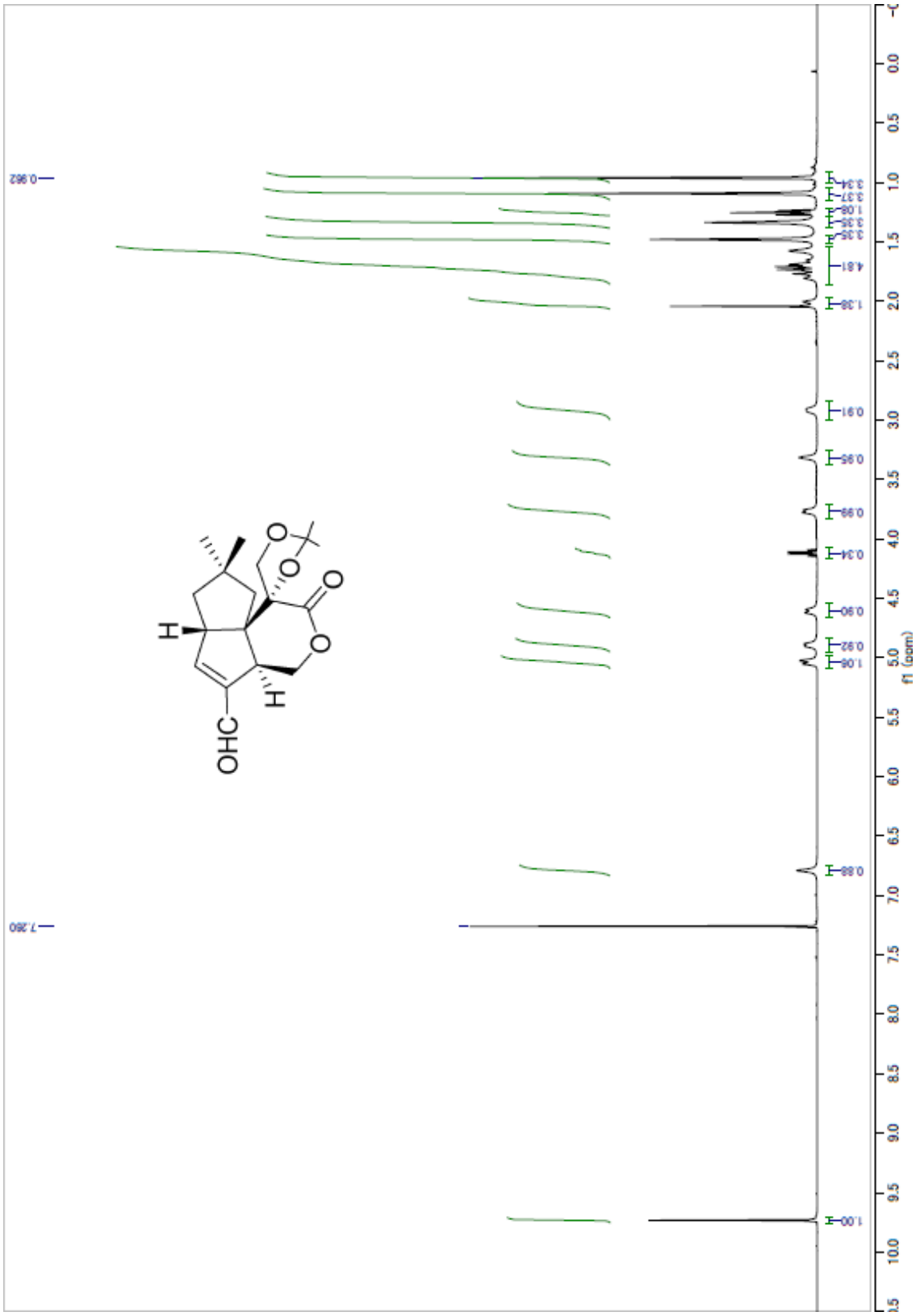


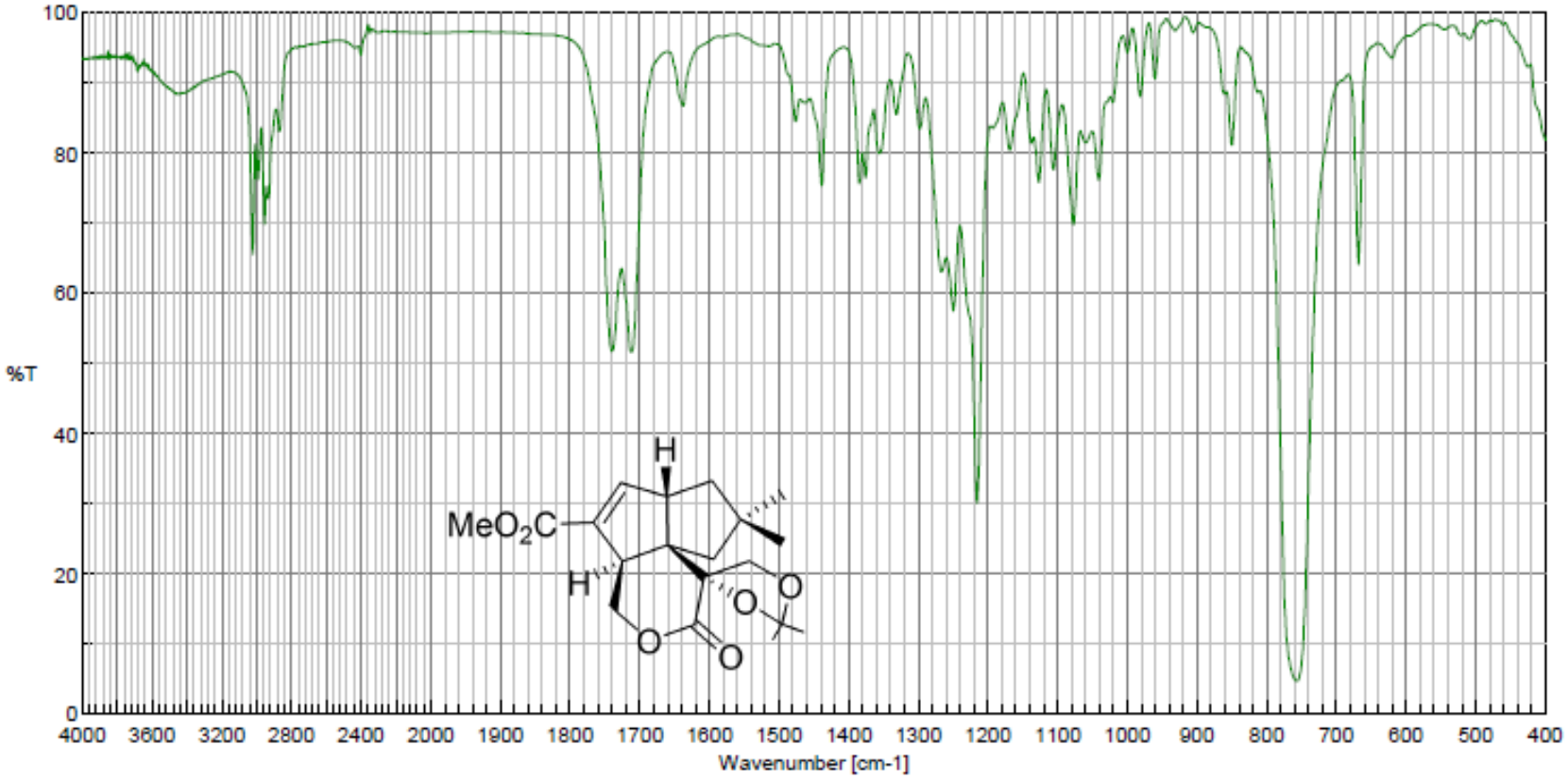
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部


AcO
H
H
TBSO
O
O
O
O
f1 (ppm)

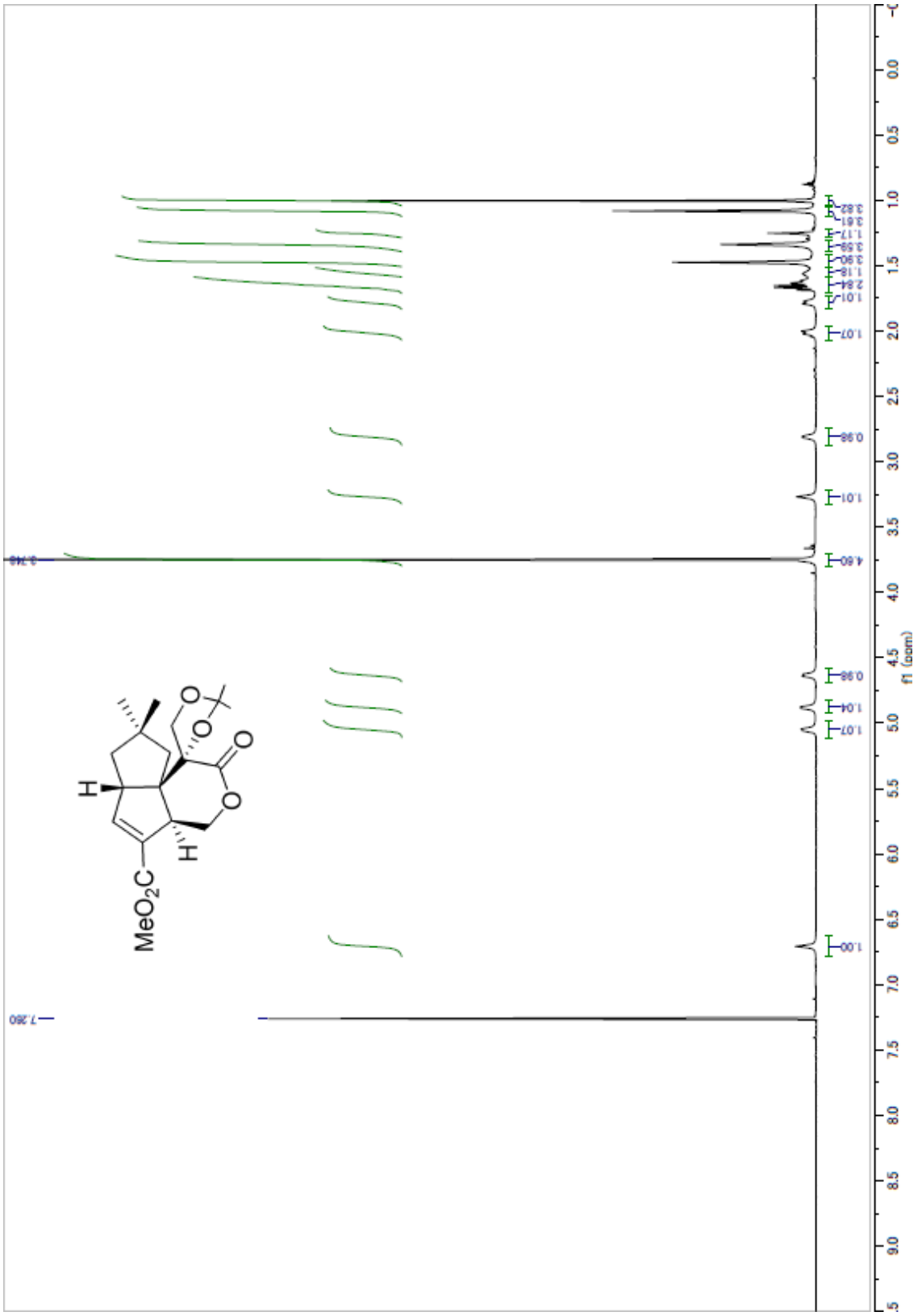

-5.518
18.156
21.046
25.378
25.830
26.402
31.087
31.218
40.452
42.984
50.481
51.275
51.906
53.110
61.684
62.815
87.482
88.986
76.509
76.819
77.000
77.182
84.714
111.072
170.116
172.846
AcO
H
TBSO
H
O
O
O
O
f1 (ppm)

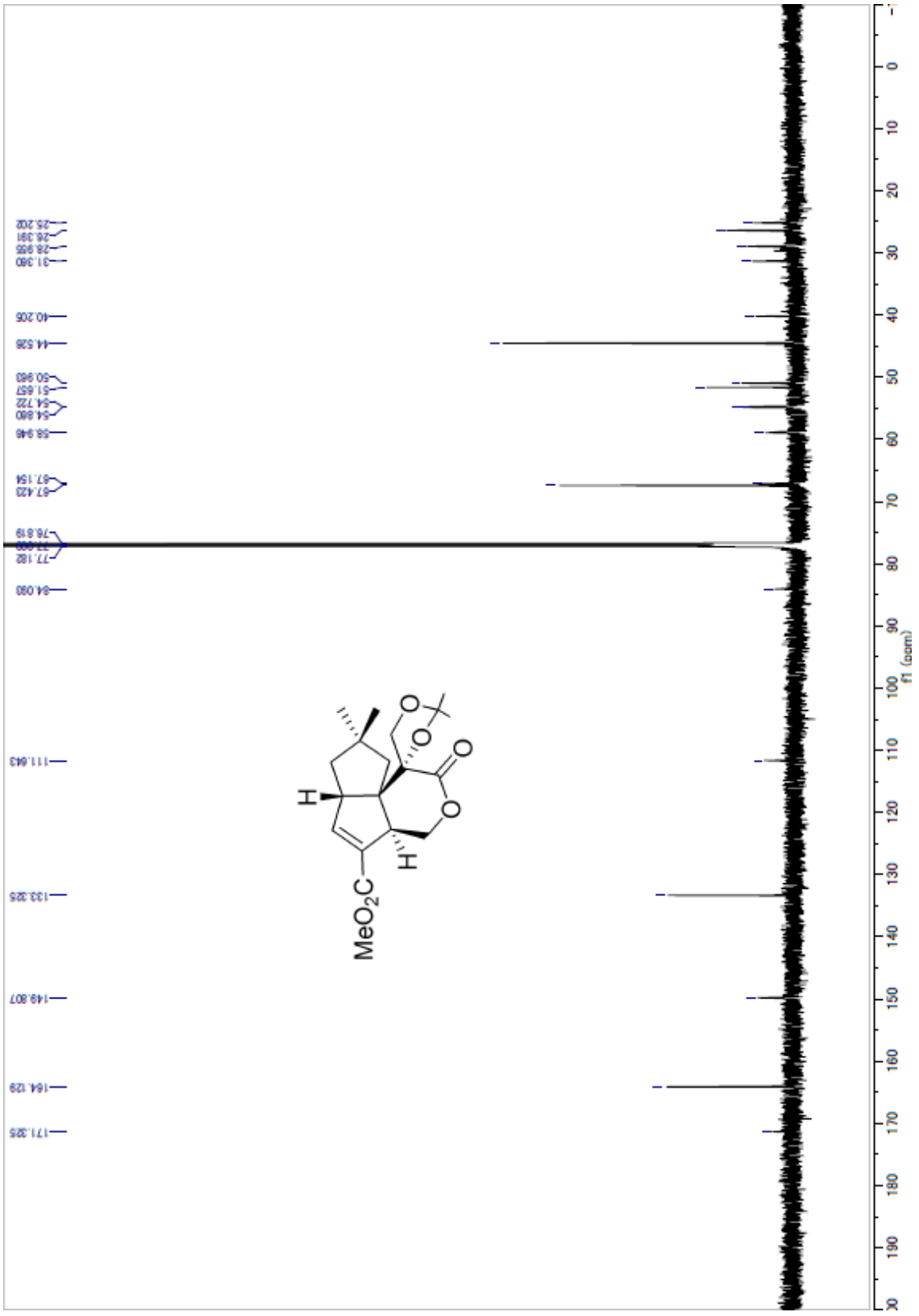

AcO
HO
H
H
O
O
O
O
f1 (ppm)

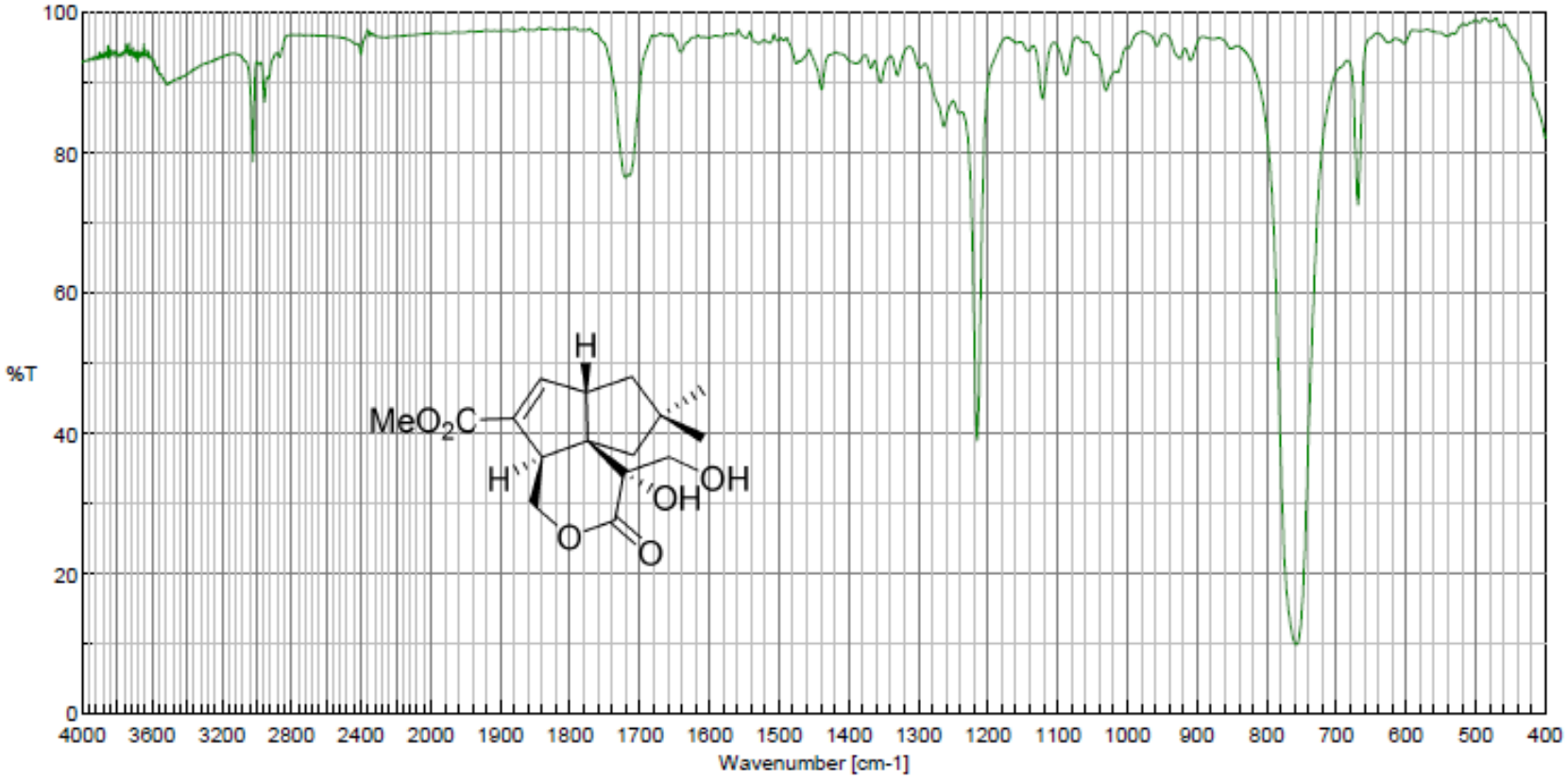

0.962
7.260
3.34
3.37
1.08
3.35
3.35
4.81
1.38
0.91
0.95
0.99
0.34
0.90
0.92
1.06
0.88
1.00
f1 (ppm)
H
O
O
O
O
H
OHC



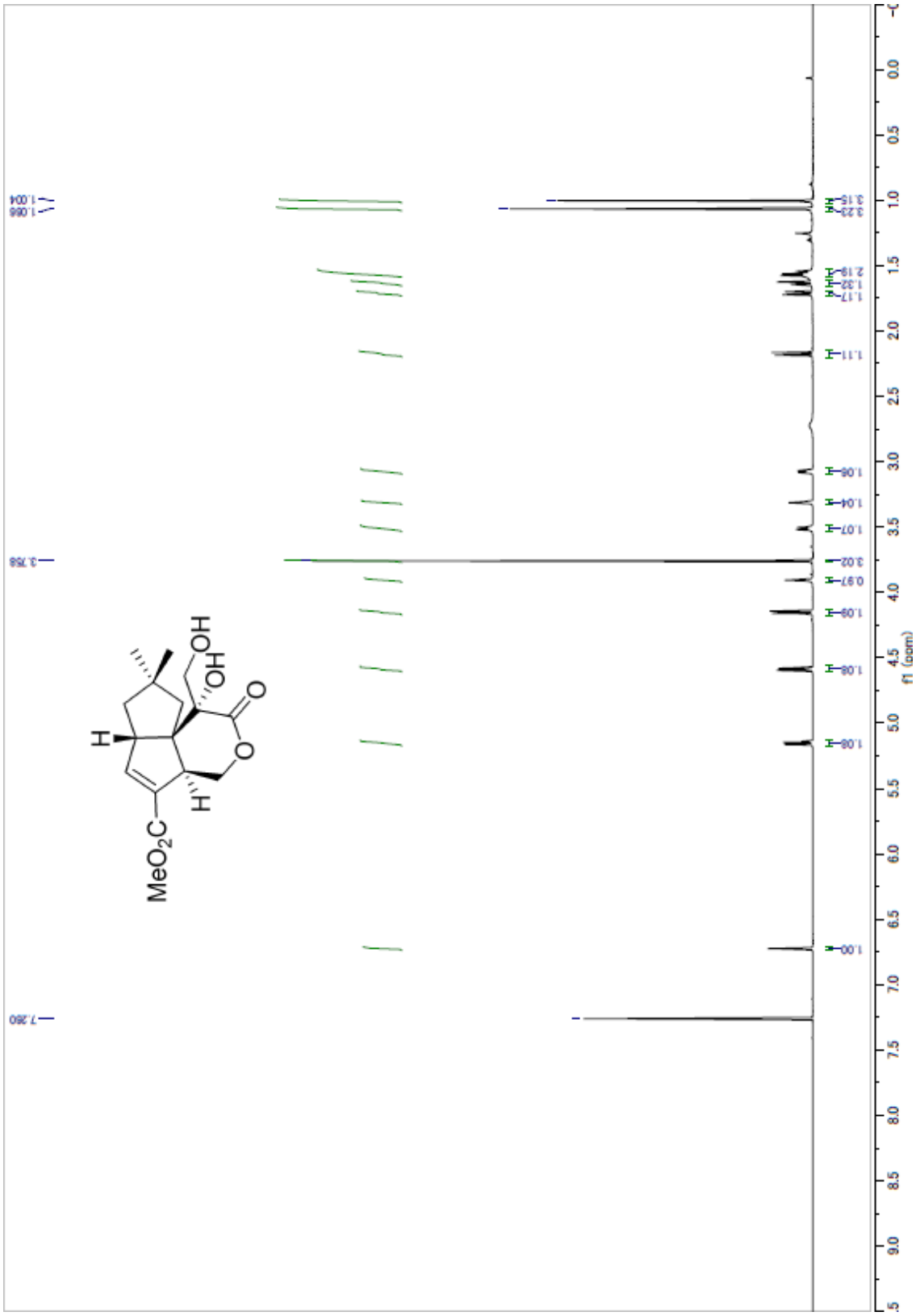
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

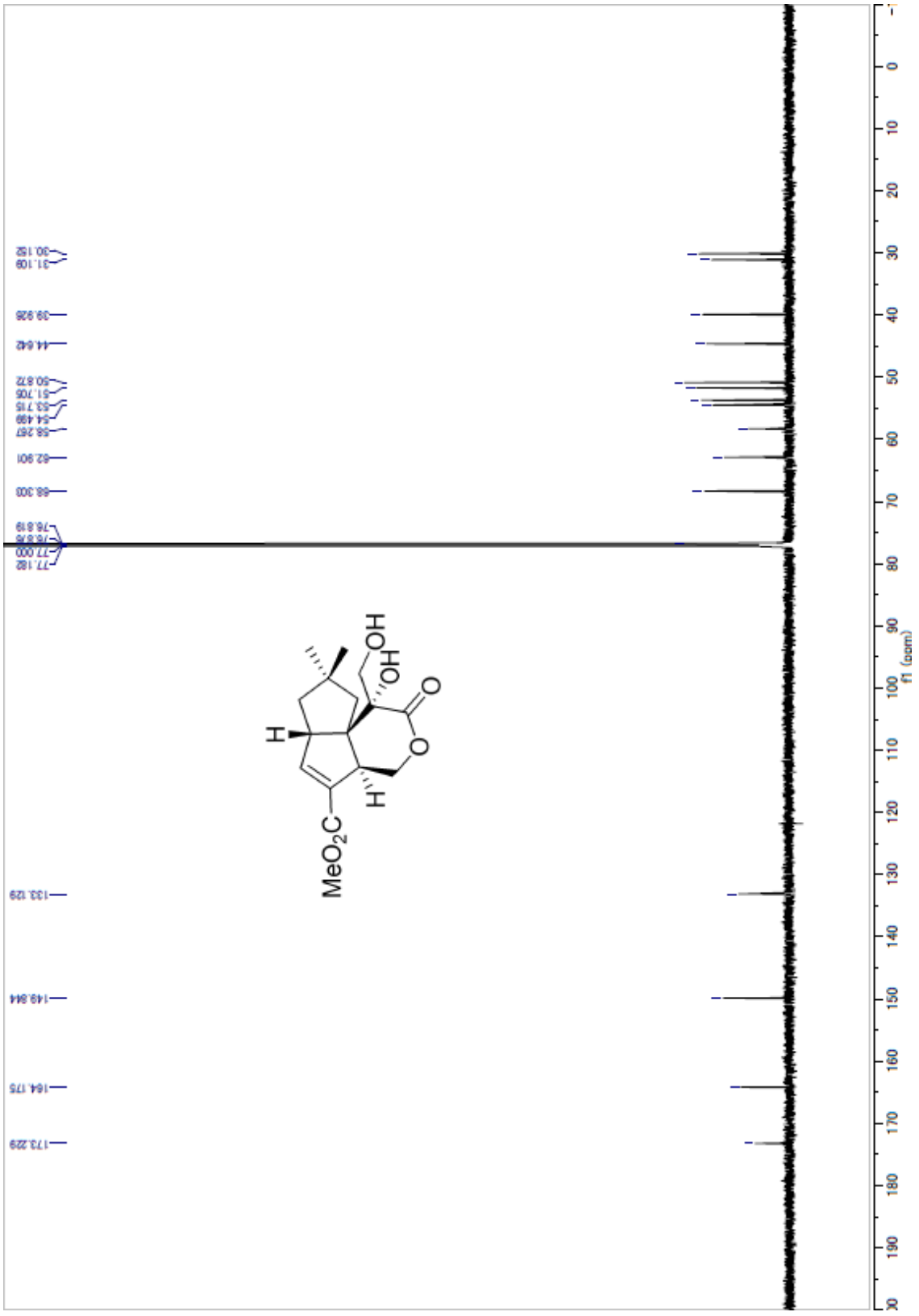

MeO2C
H
H
O
O
O
O
f1 (ppm)

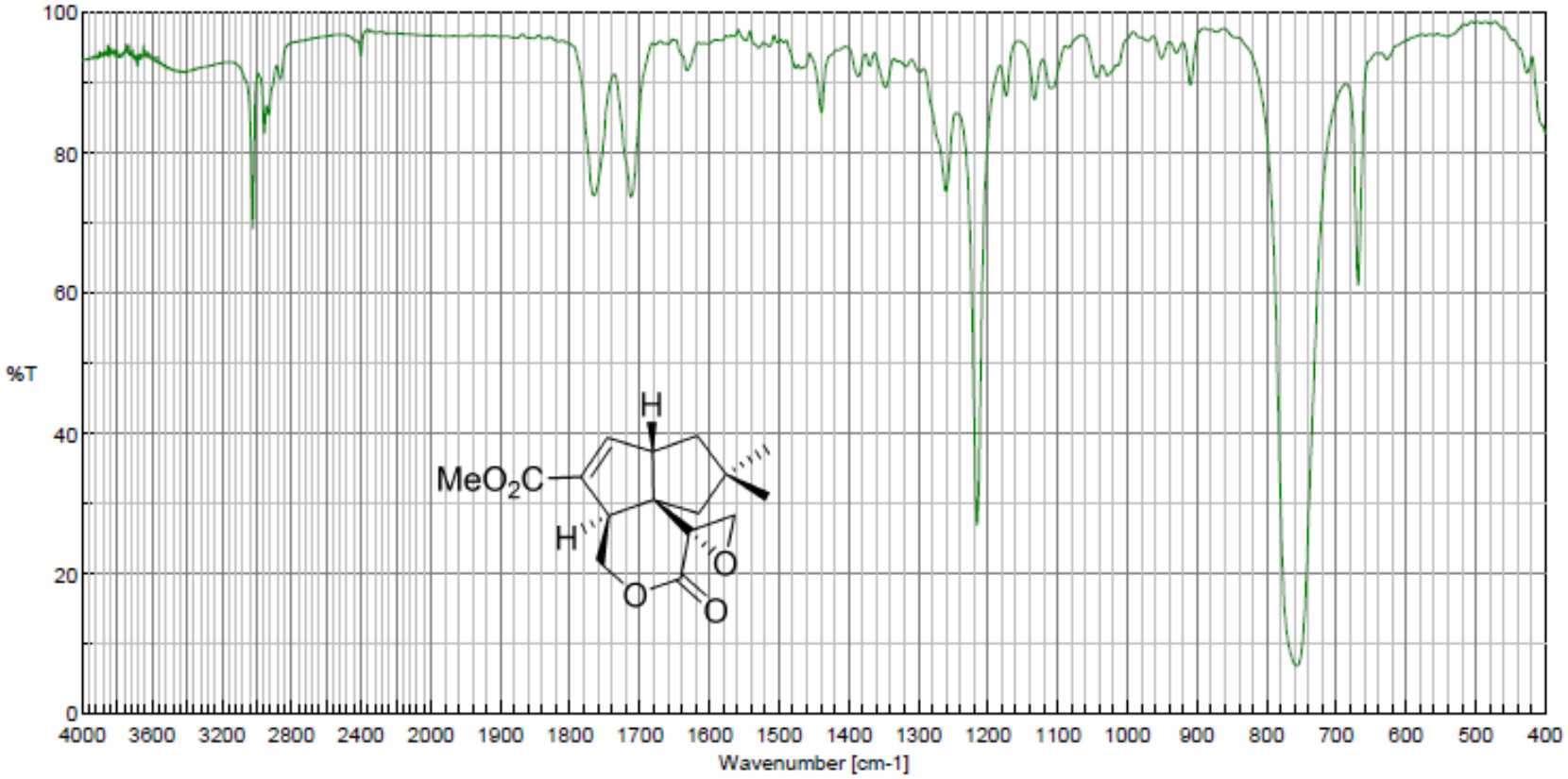

25.202
26.391
28.955
31.360
40.205
44.526
50.960
51.657
54.722
54.880
58.946
67.154
67.420
76.819
77.000
77.180
84.080
111.643
133.325
149.807
164.129
171.325
f1 (ppm)
MeO2C
H
H
O
O
O
O



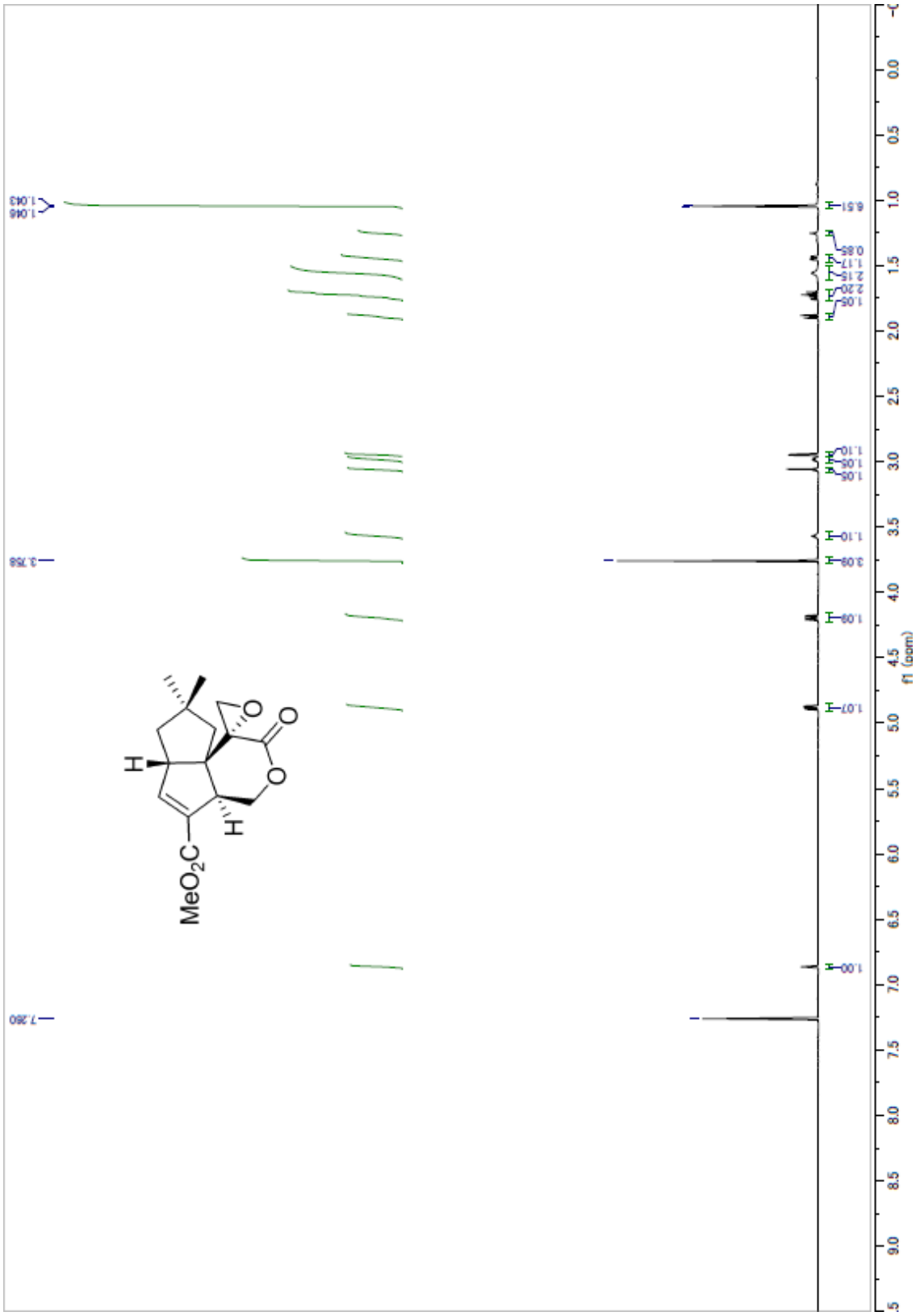
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

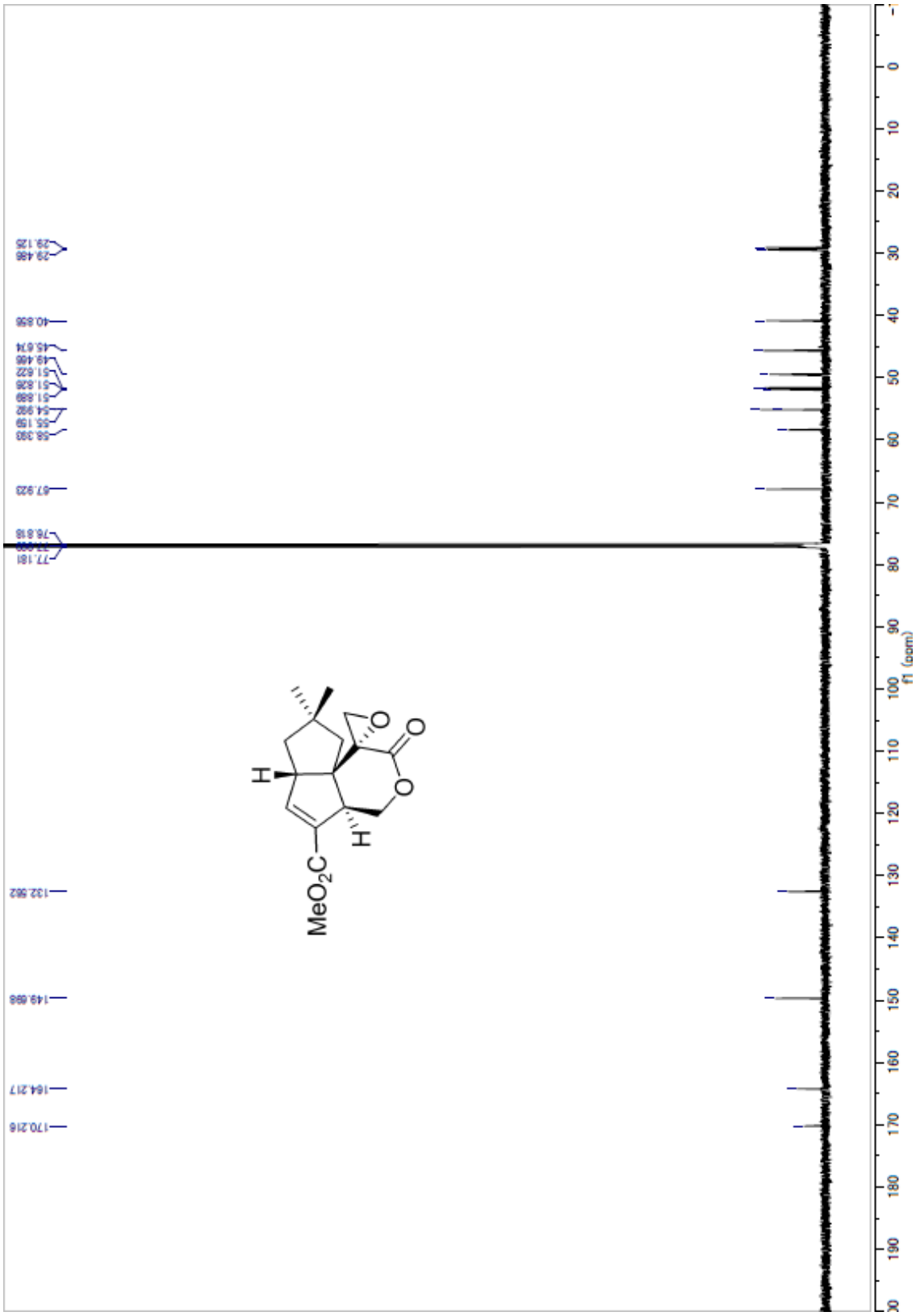

OH
OH
O
O
H
H
MeO2C
f1 (ppm)

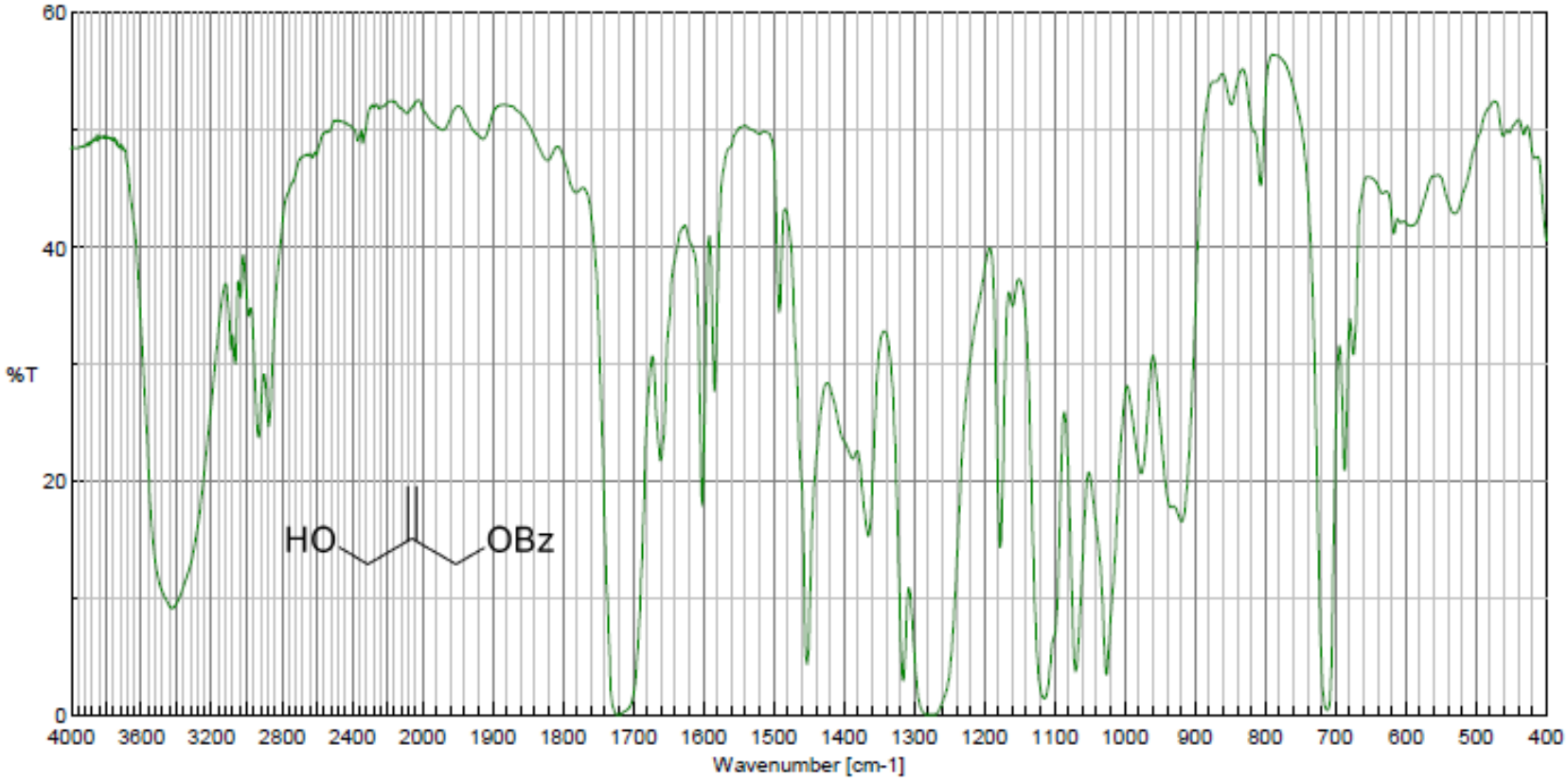

30.152
31.109
39.926
44.642
50.872
51.706
53.715
54.499
58.267
62.901
68.300
76.819
76.876
77.000
77.182
133.129
149.844
164.175
173.229
H
OH
OH
O
O
H
MeO2C
f1 (ppm)



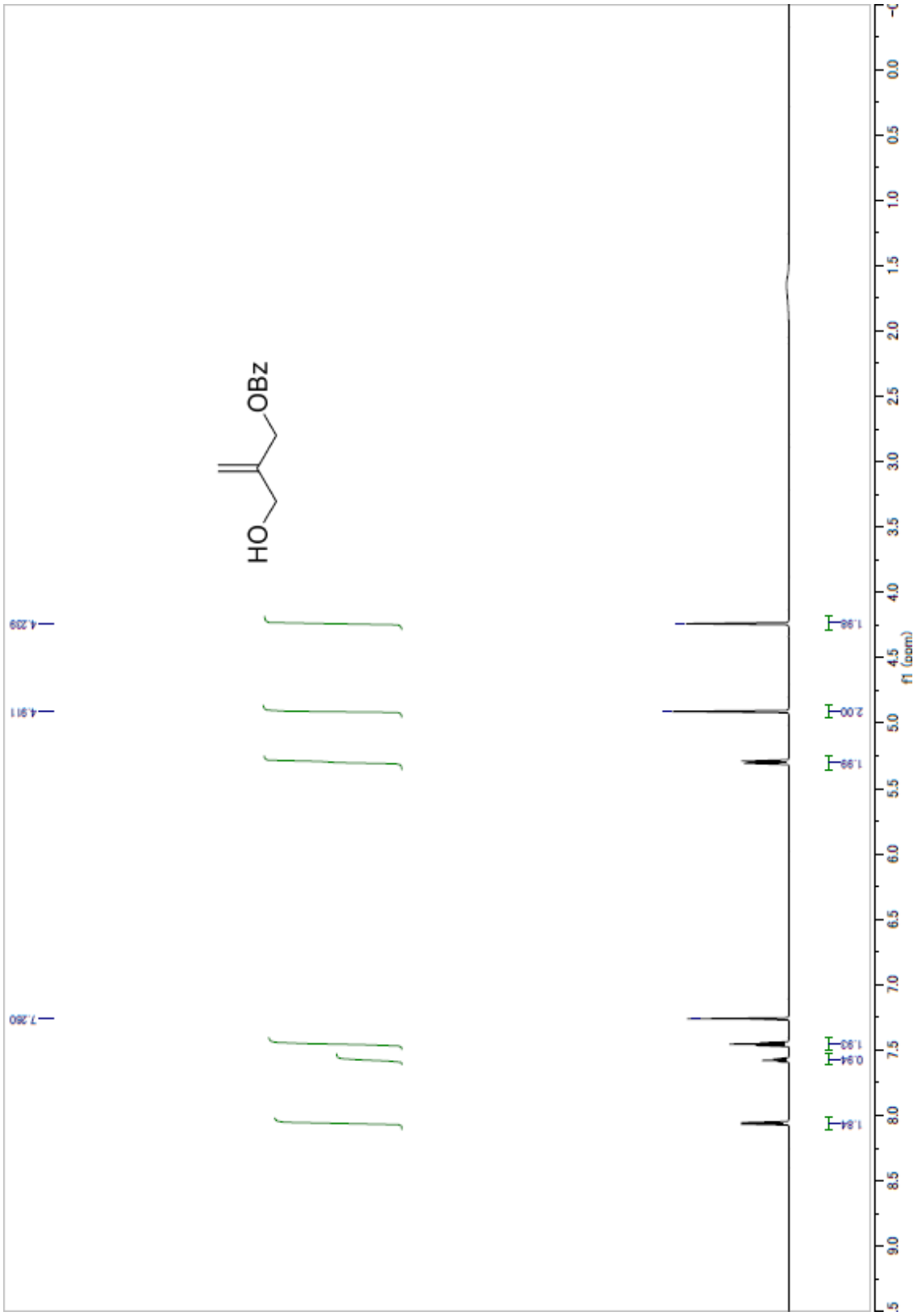
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

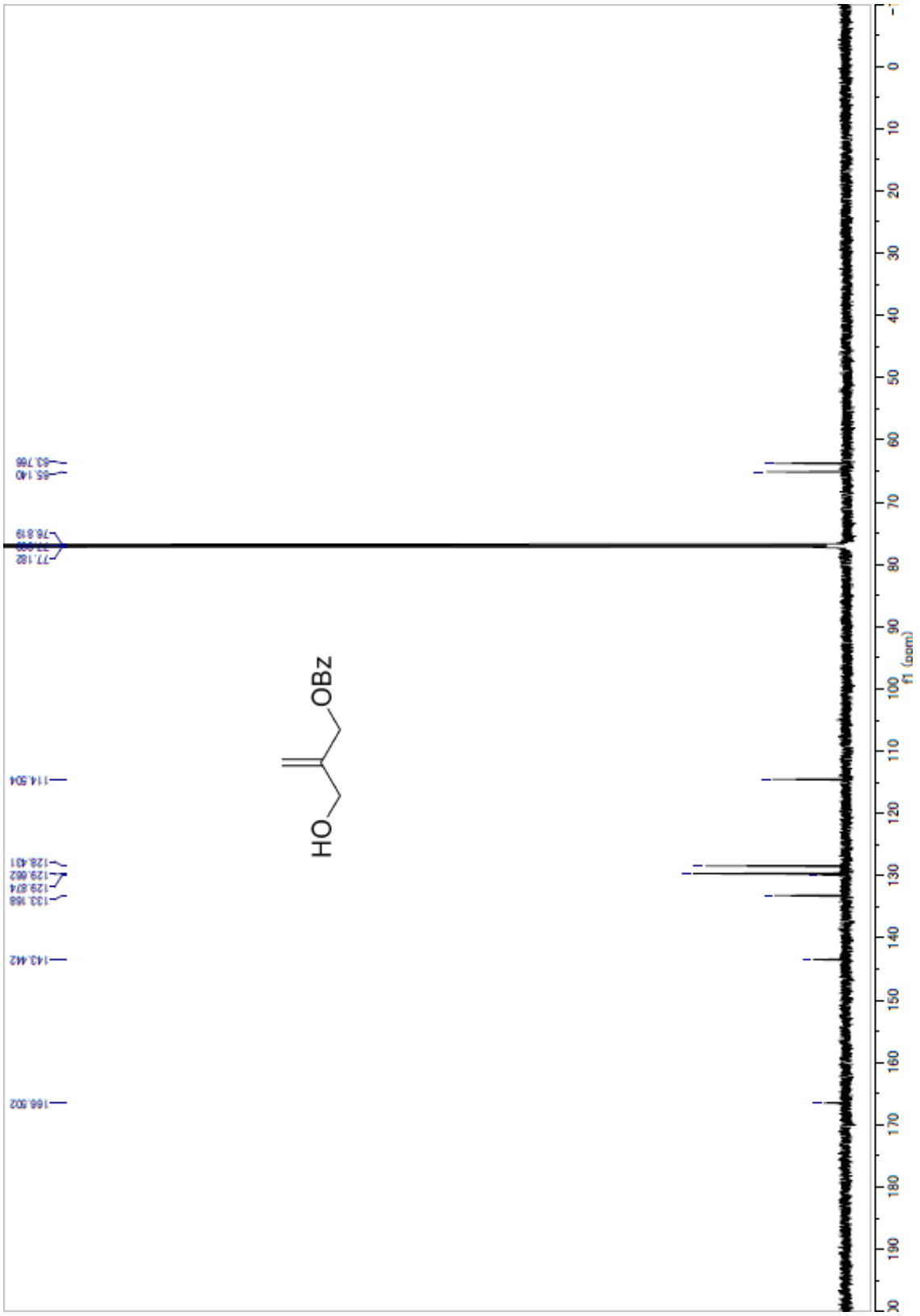

1.046
1.043
3.758
7.260
6.51
0.85
1.17
2.15
2.20
1.05
1.05
1.05
1.10
3.09
1.09
1.07
1.00
f1 (ppm)
MeO2C
H
H
O
O
O

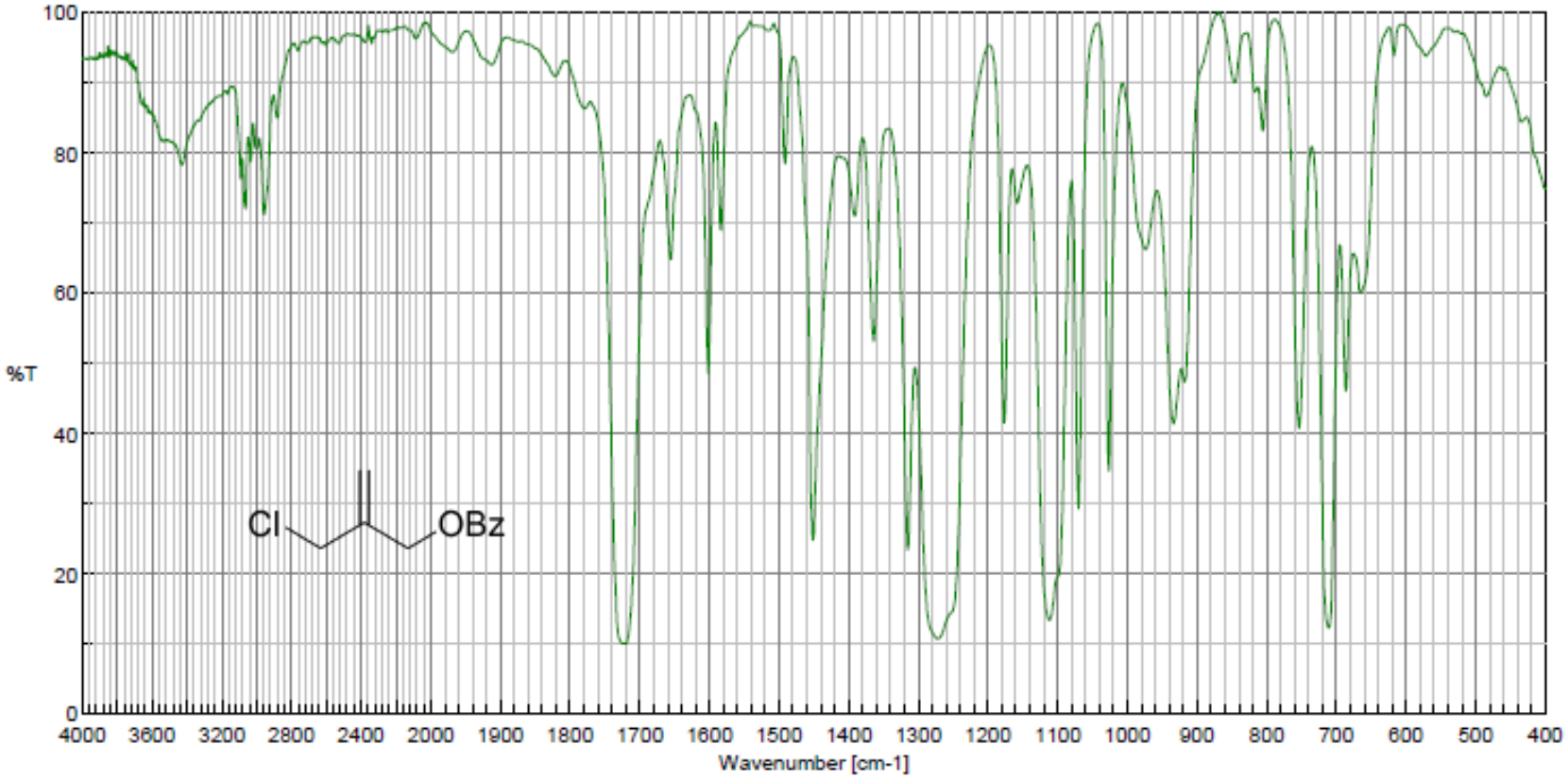

29.125
29.486
40.856
45.674
49.486
51.622
51.826
51.889
54.992
55.159
58.330
67.923
76.818
77.000
77.181
132.862
149.086
164.217
170.216
f1 (ppm)



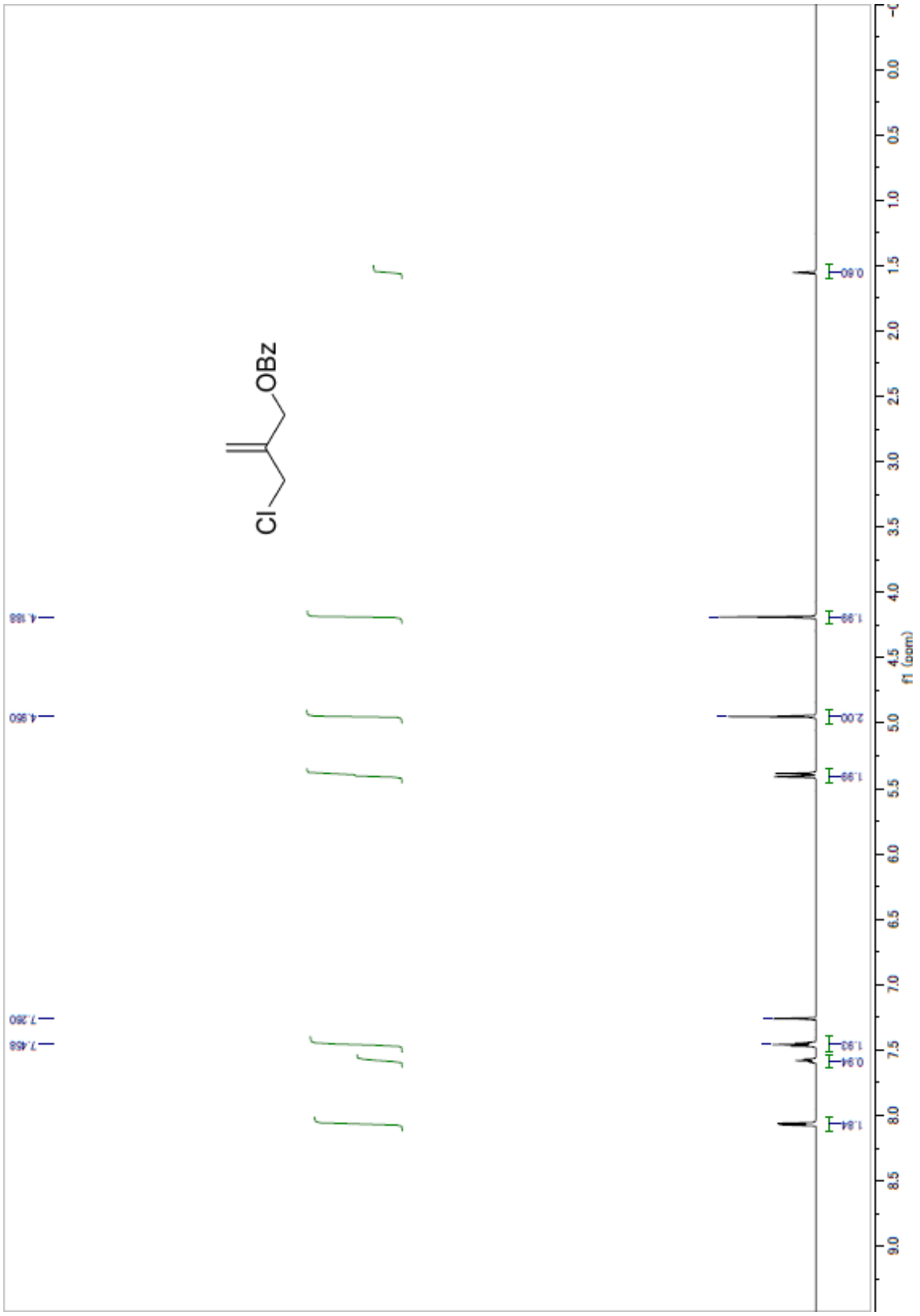
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

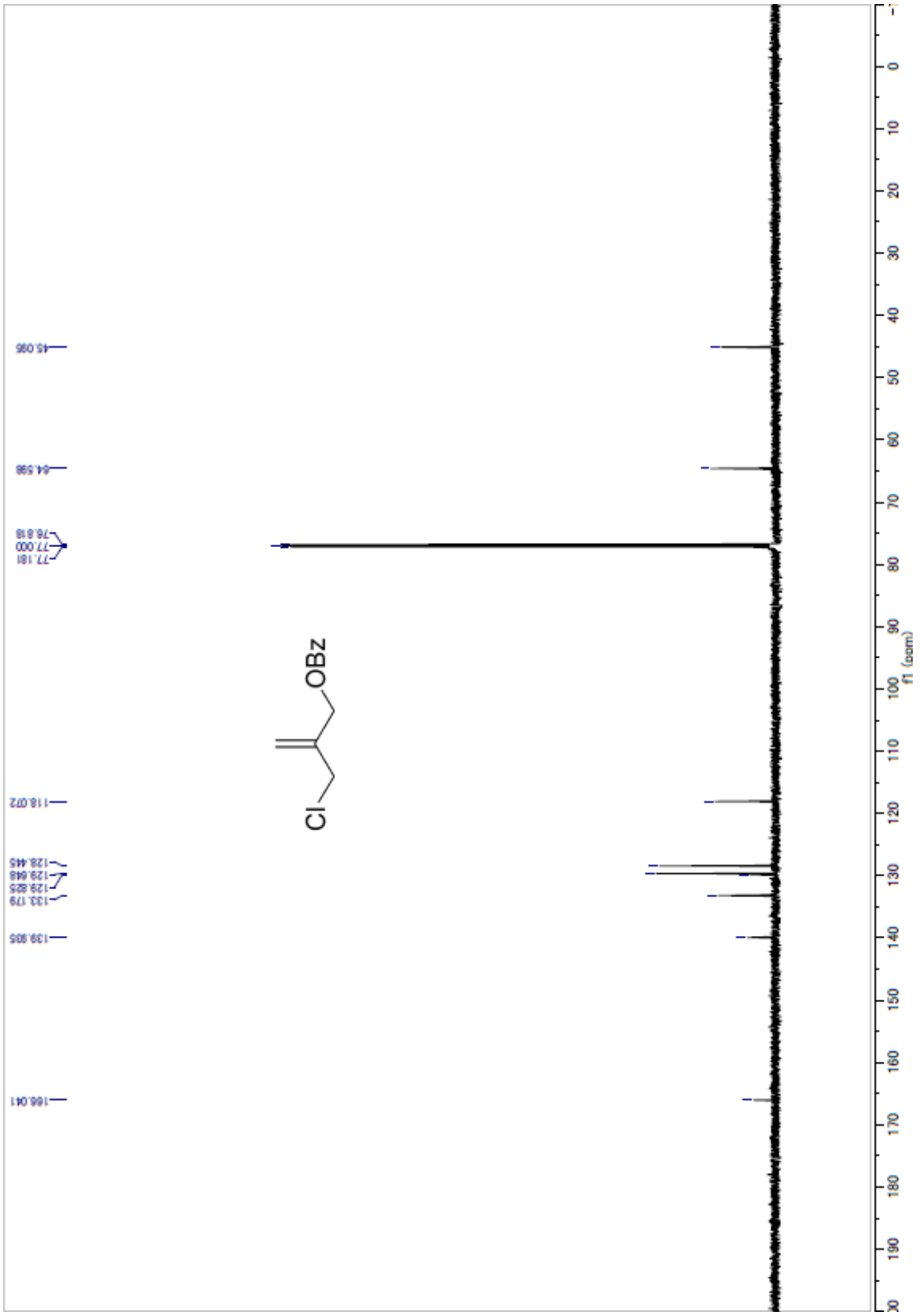

OBz
HO
4.209
4.911
7.260
1.98
2.00
1.99
1.93
0.94
1.84
f1 (ppm)

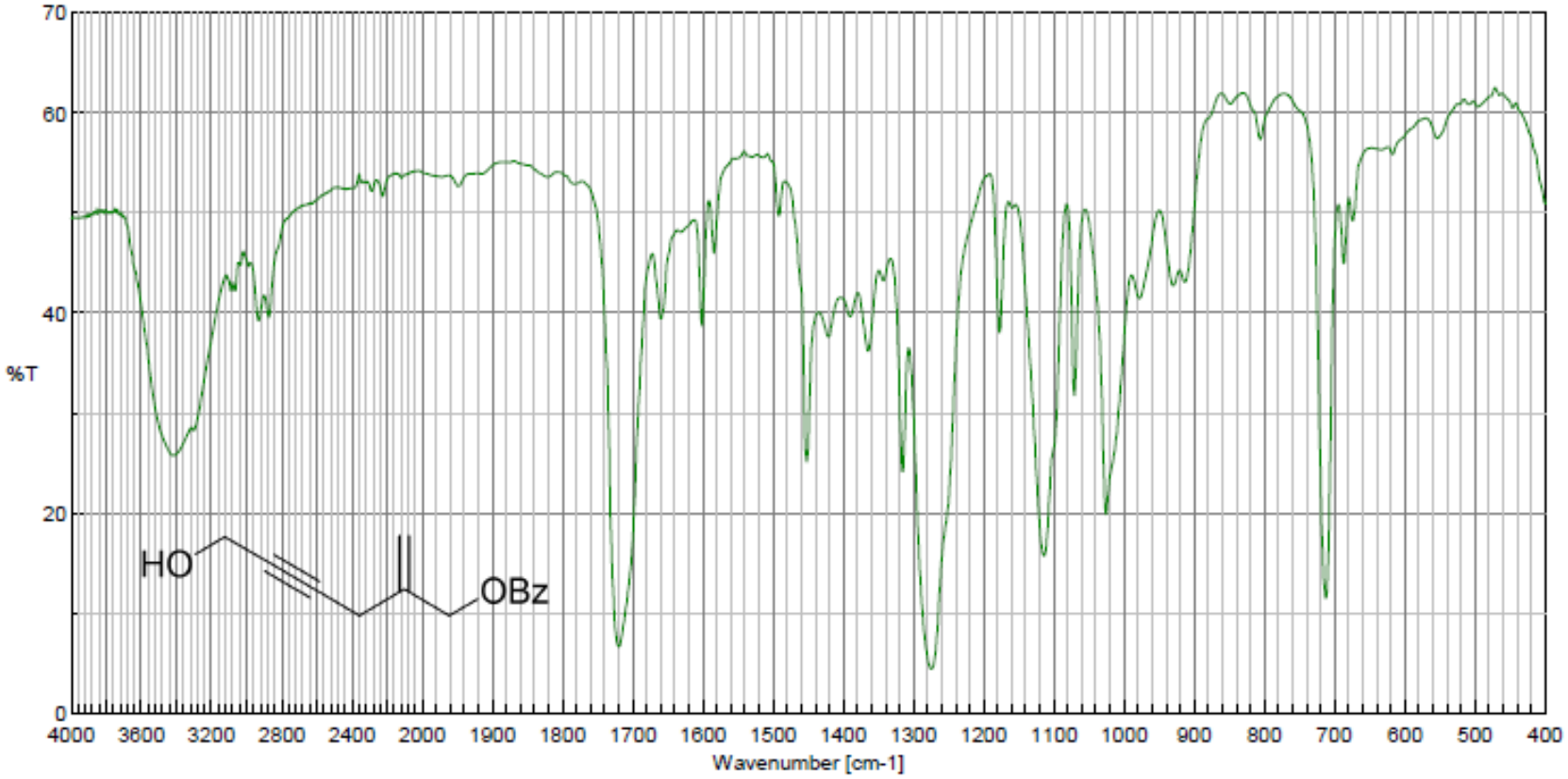

OBz
HO
166.502
143.442
133.169
129.874
129.662
128.431
114.504
77.180
76.819
65.140
63.766
f1 (ppm)



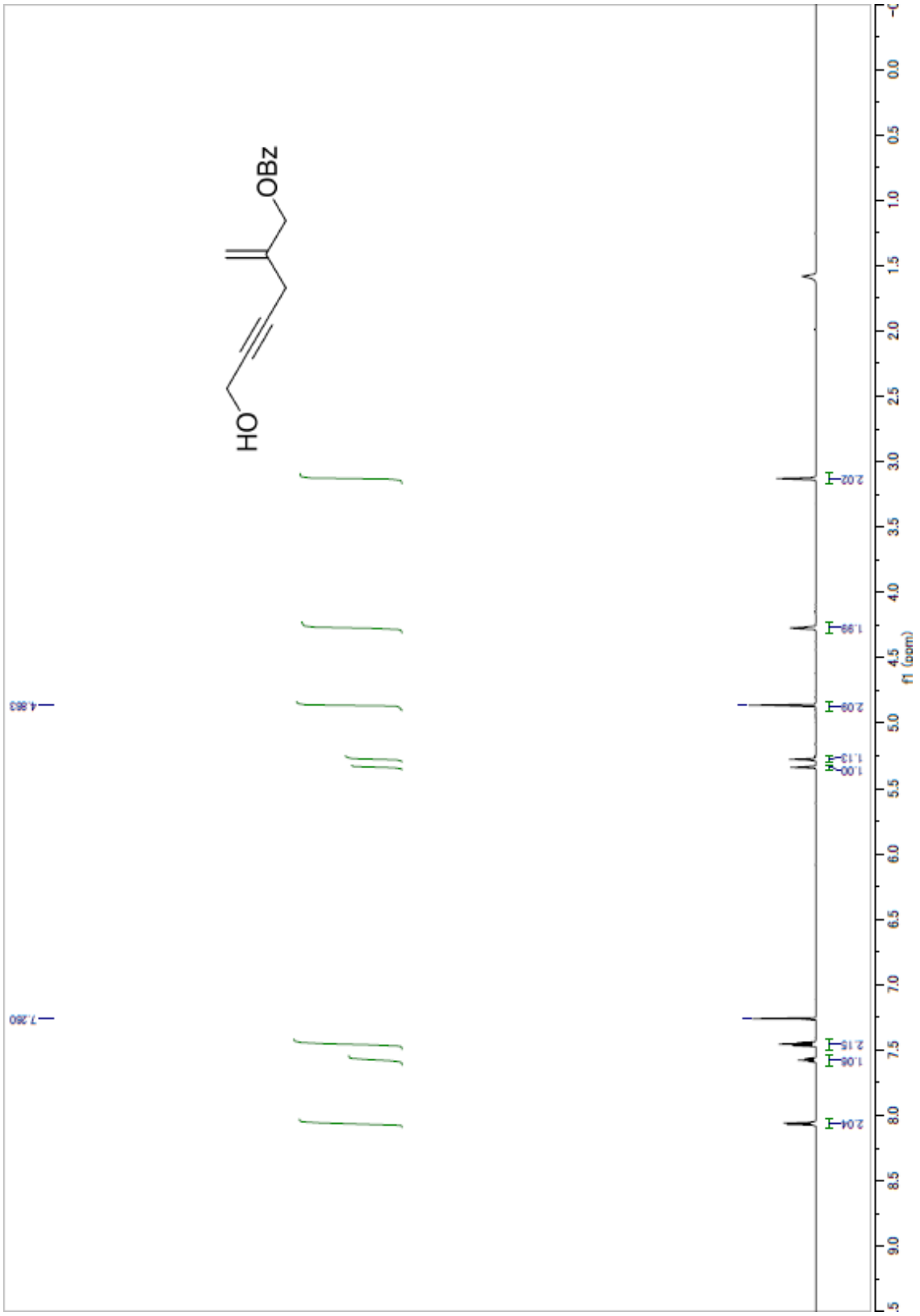
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

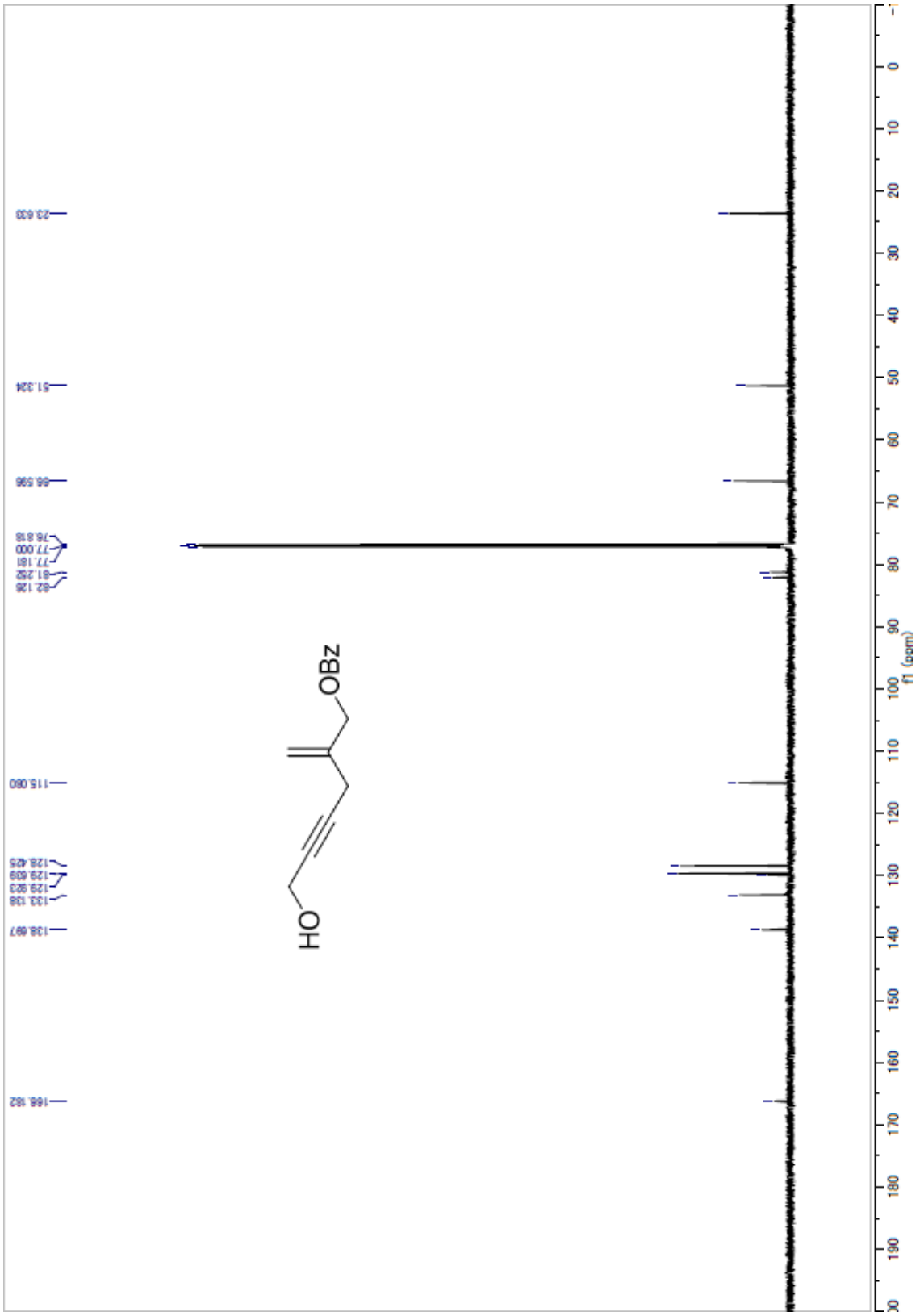

OBz
Cl
4.188
4.950
7.260
7.458
0.60
1.99
2.00
1.99
1.93
0.94
1.84
f1 (ppm)

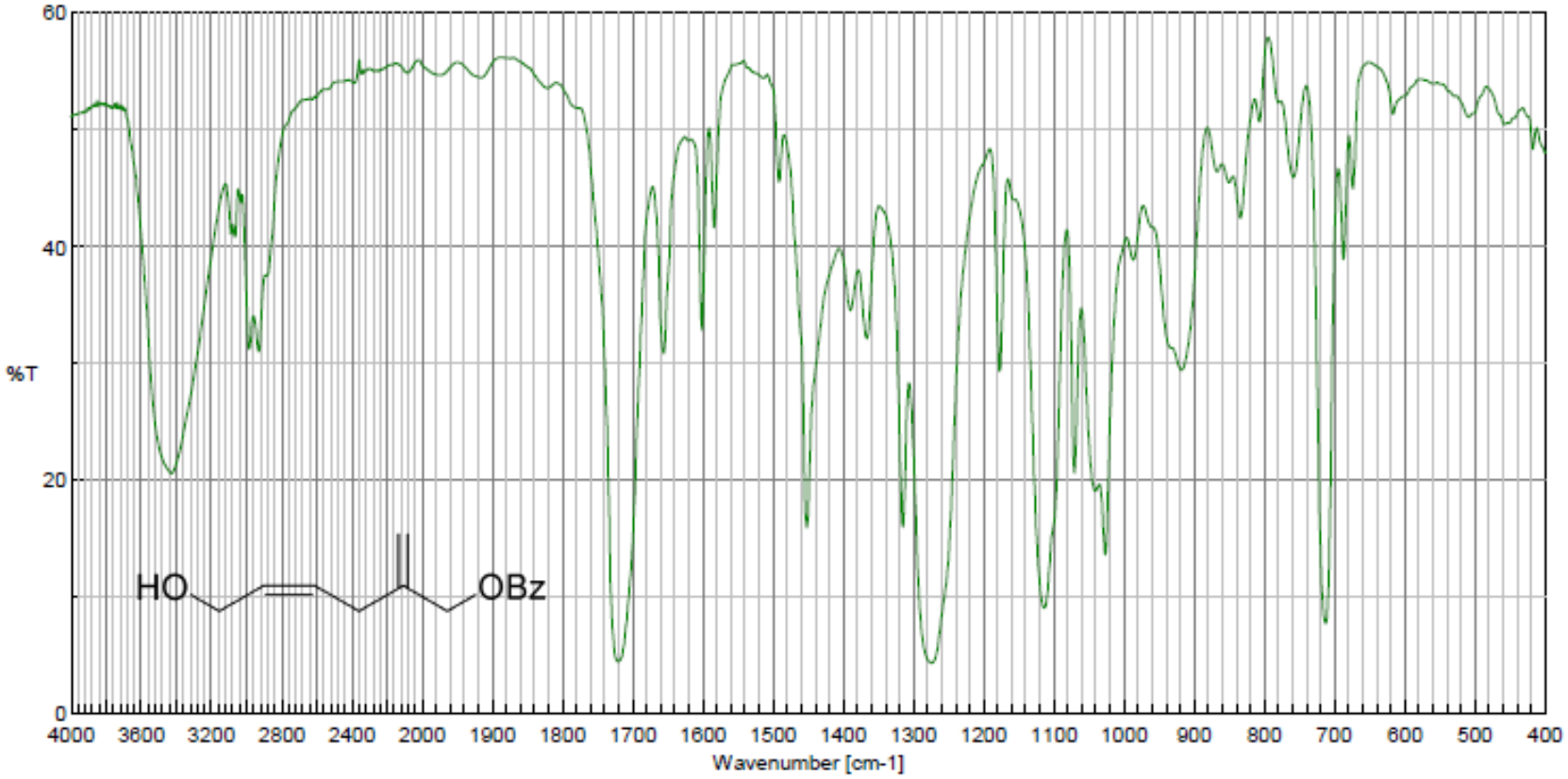

OBz
Cl
f1 (ppm)



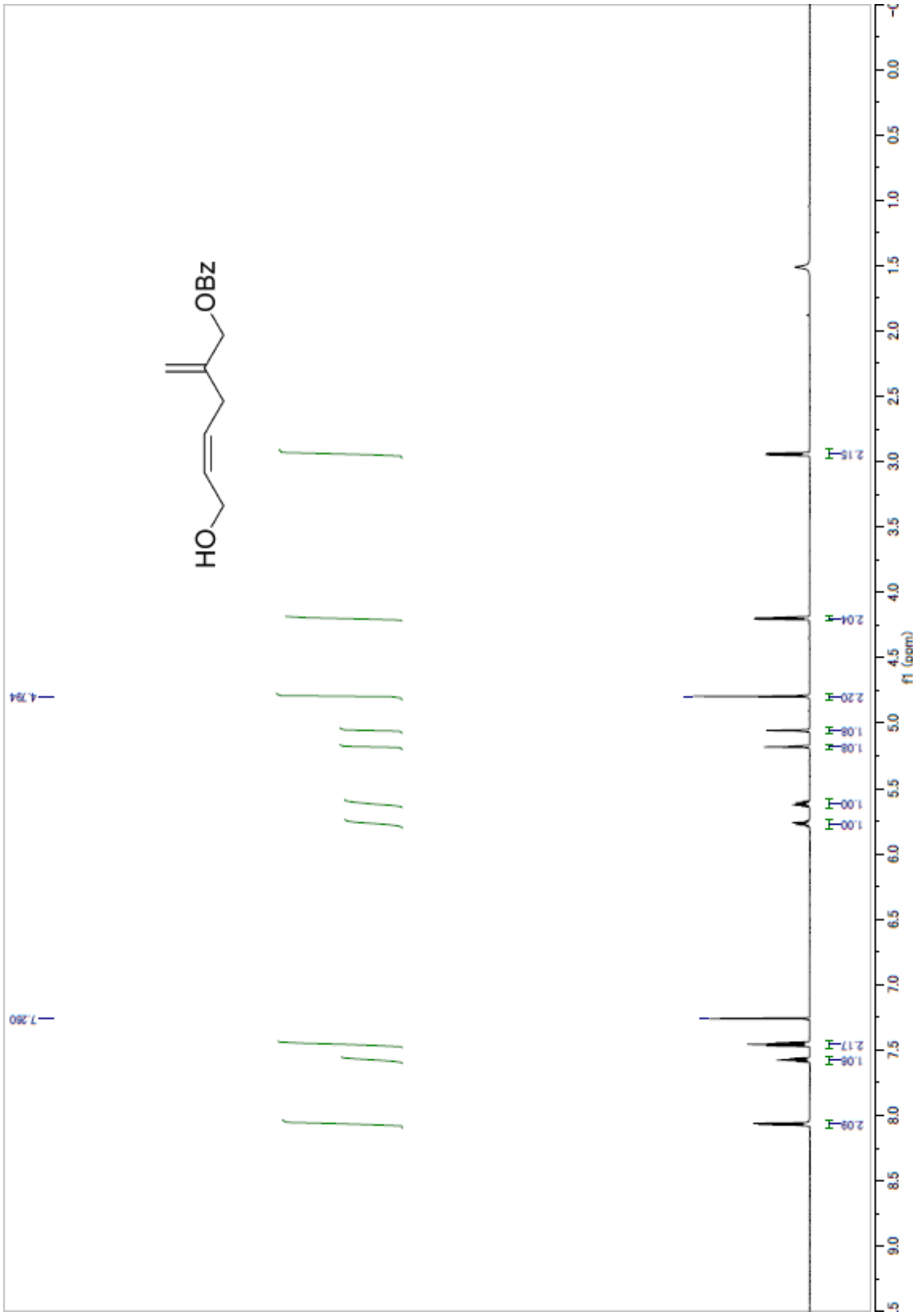
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

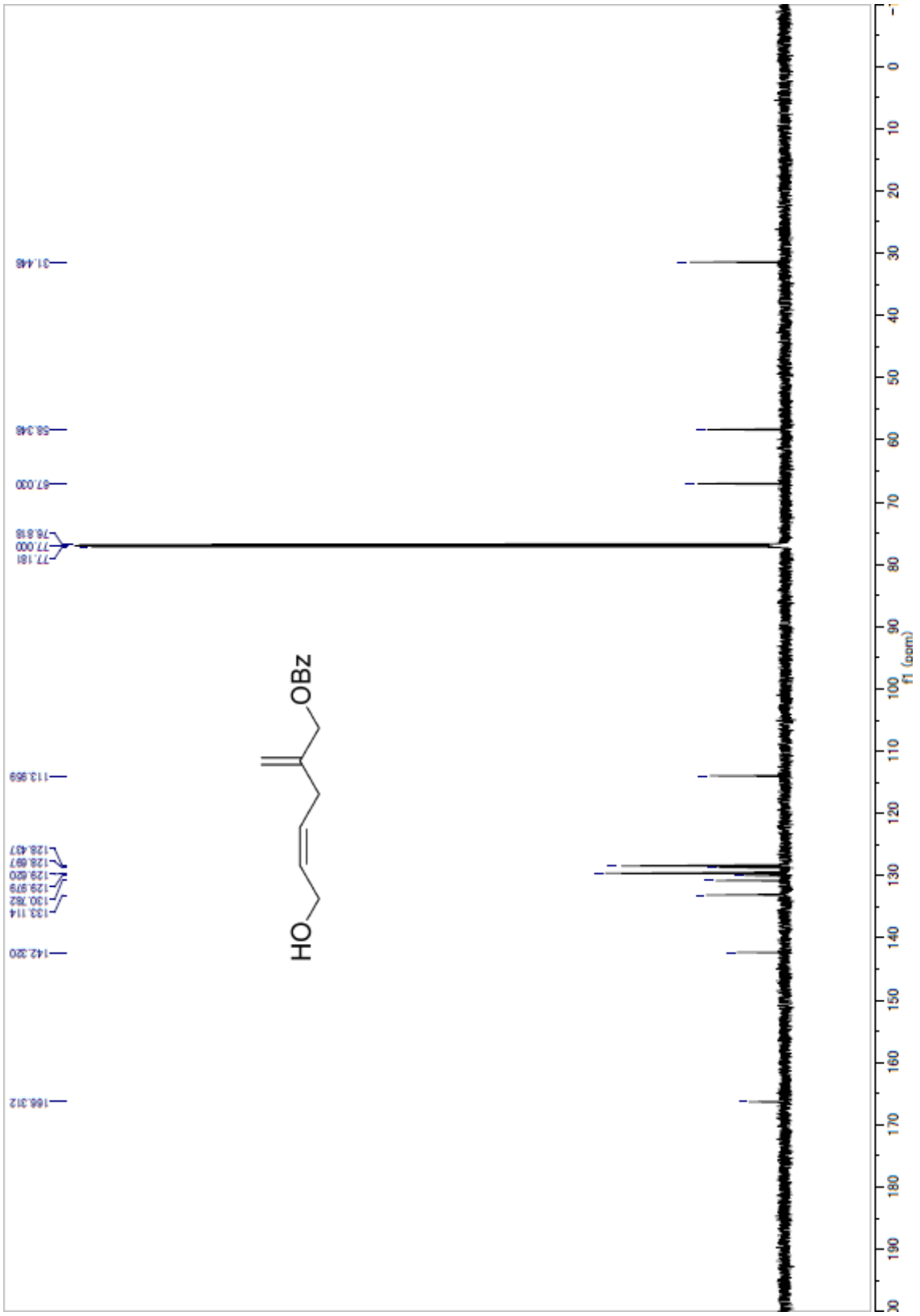

OBz
HO
7.260
4.863
2.02
1.99
2.09
1.00
1.13
2.15
1.06
2.04
f1 (ppm)

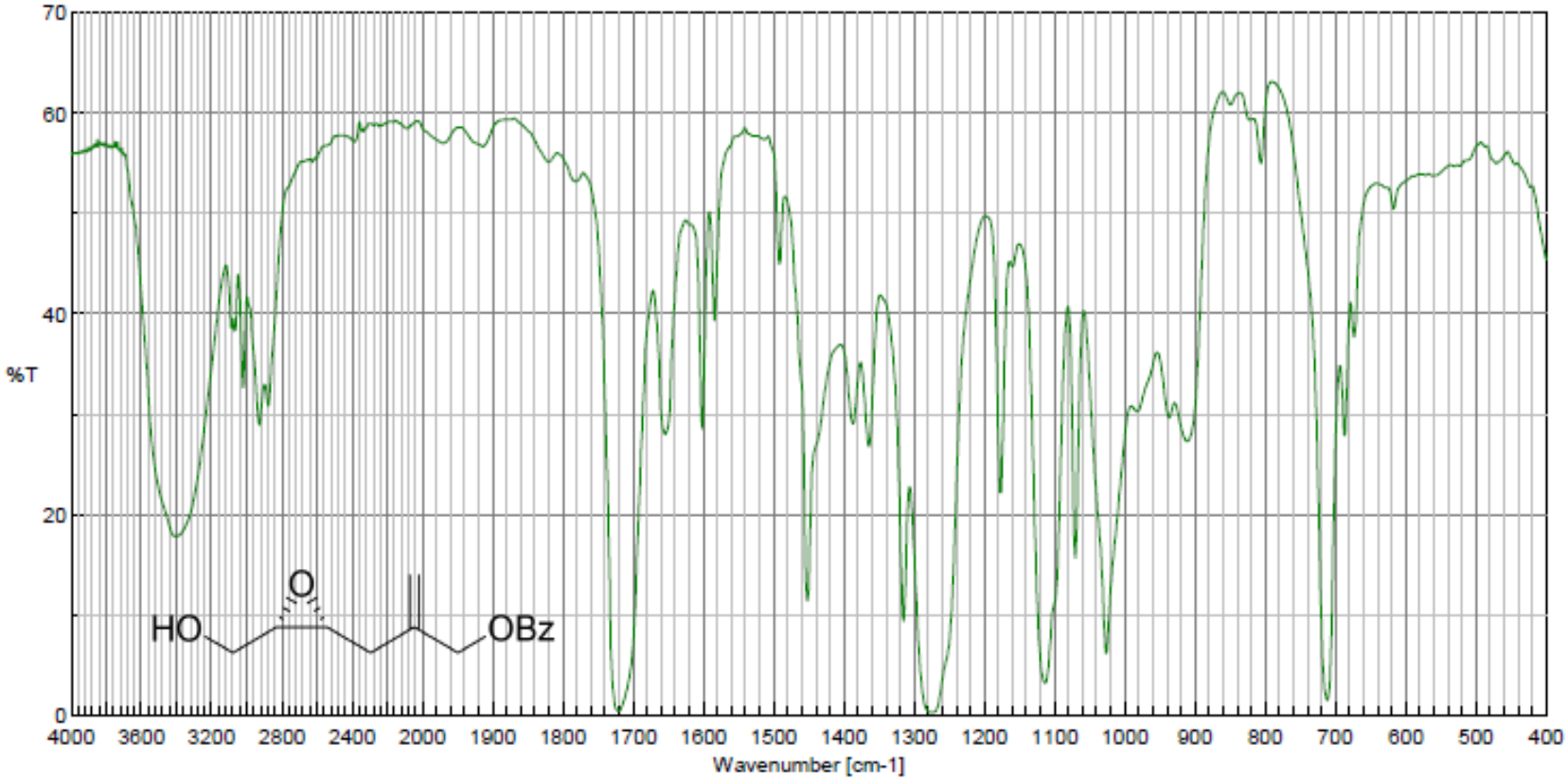

OBz
HO
f1 (ppm)



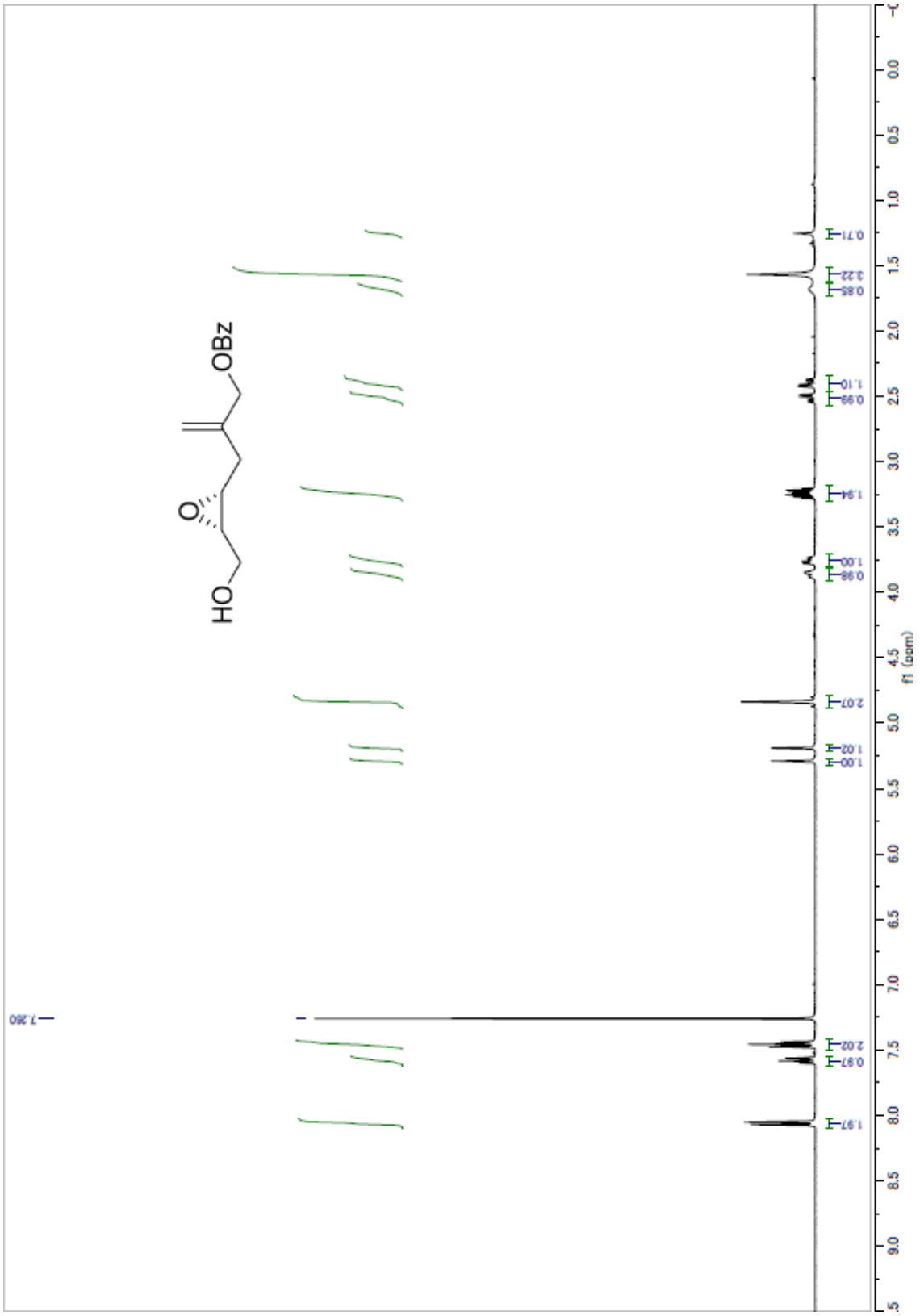
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

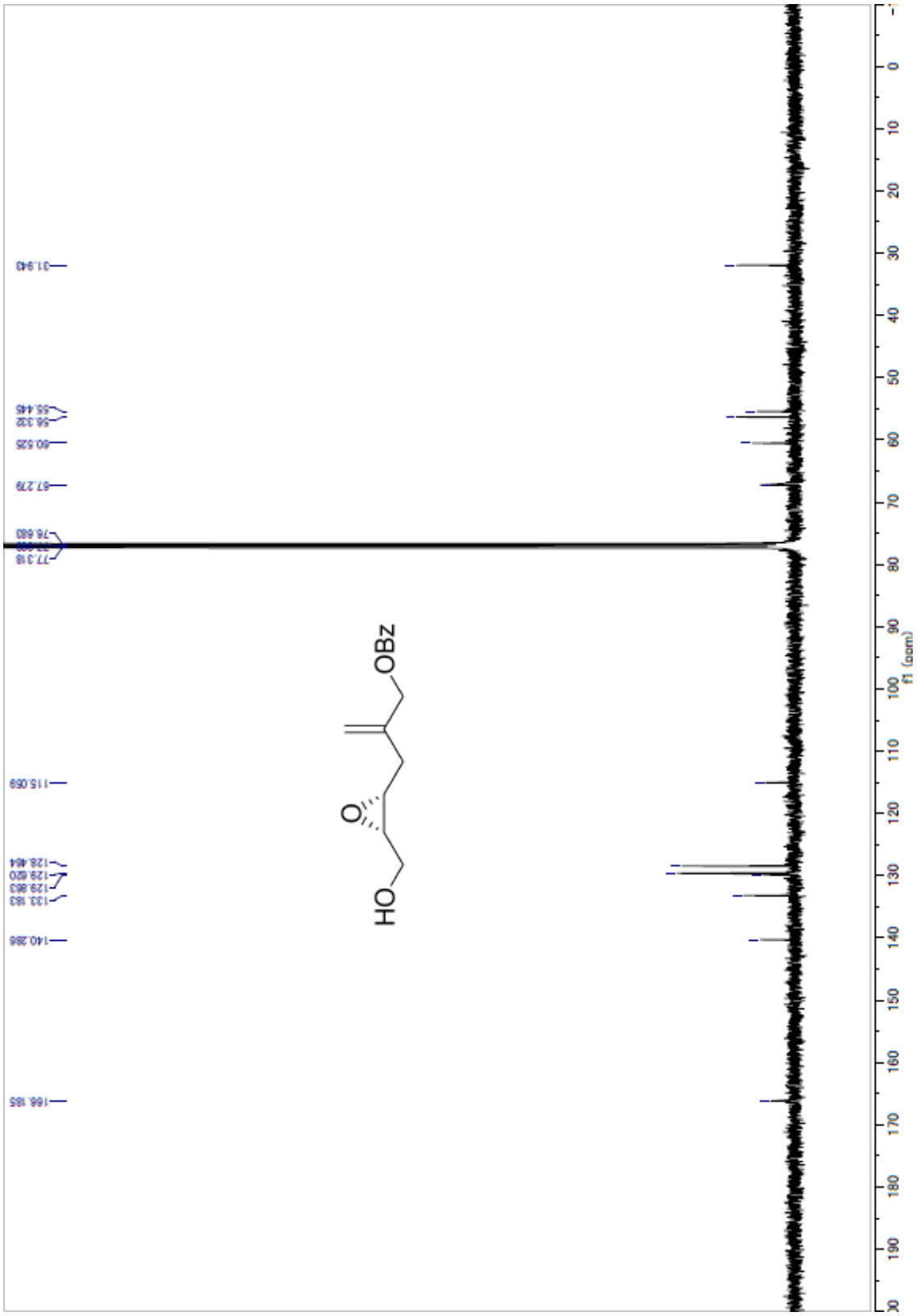

OBz
HO
7.260
4.794
2.15
2.04
2.20
1.08
1.08
1.00
1.00
2.17
1.06
2.09
f1 (ppm)

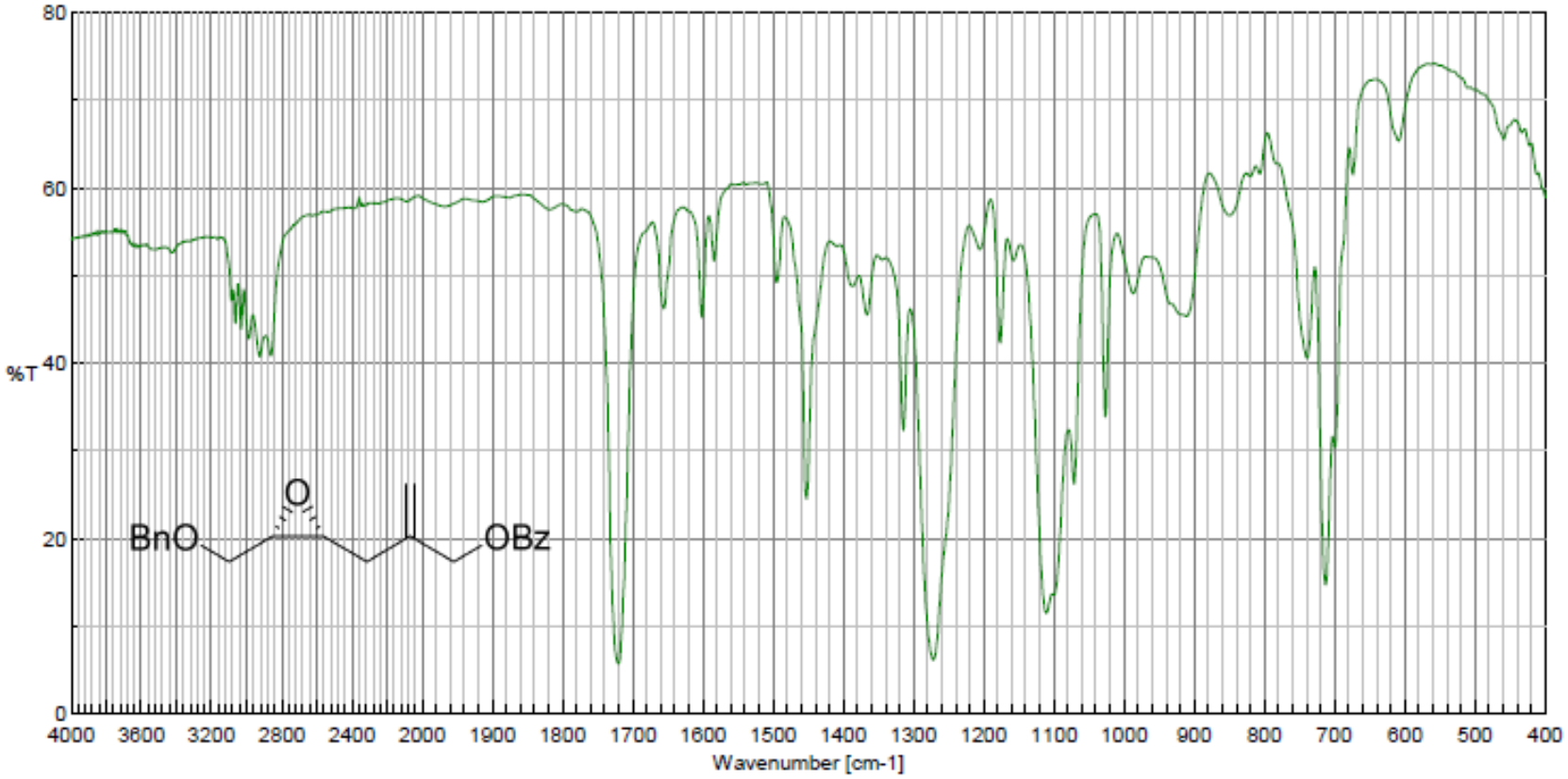

OBz
HO
31.446
58.346
67.000
76.818
77.000
77.181
113.869
128.437
128.697
129.820
129.979
130.782
133.114
142.320
166.312
f1 (ppm)



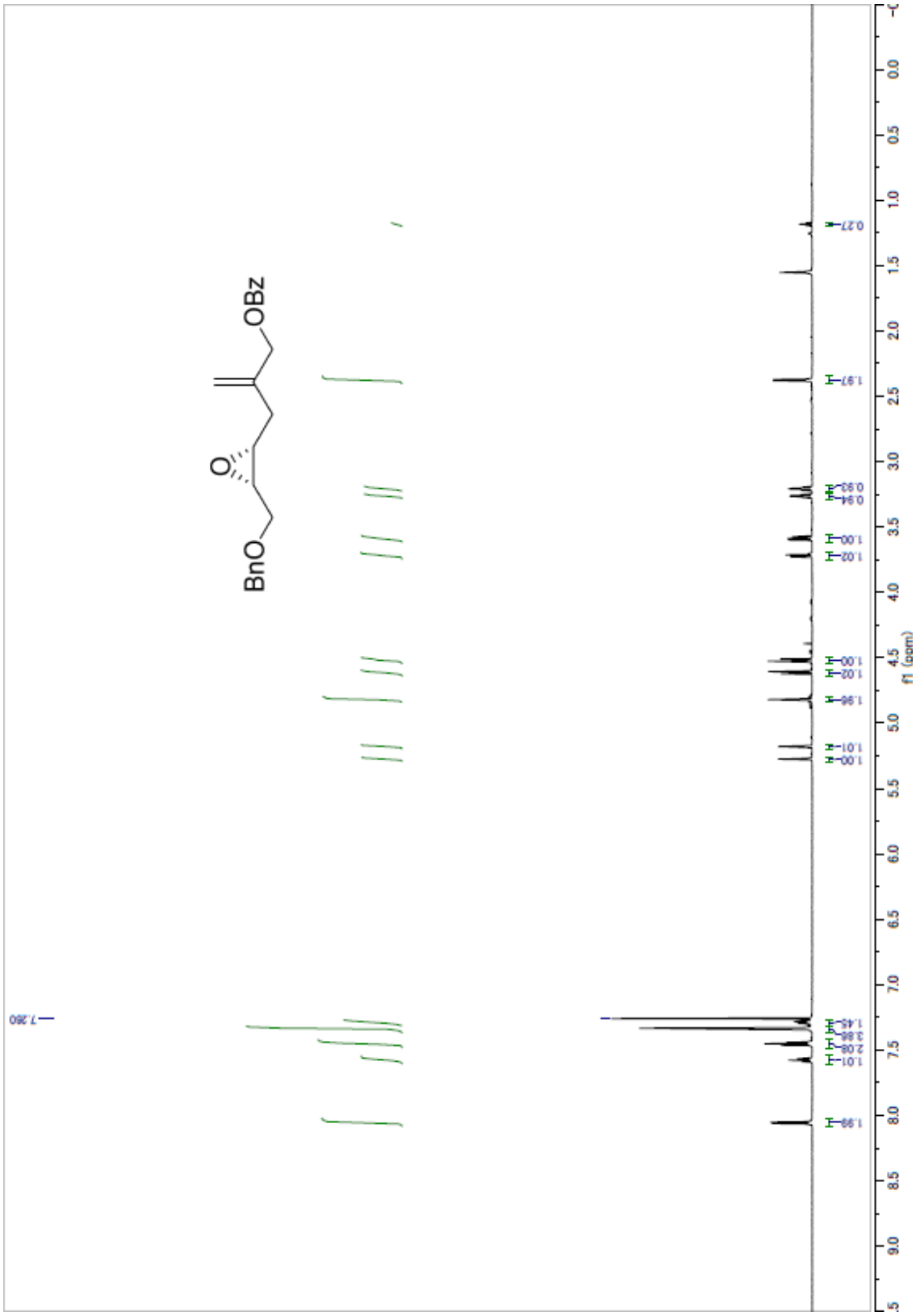
[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部

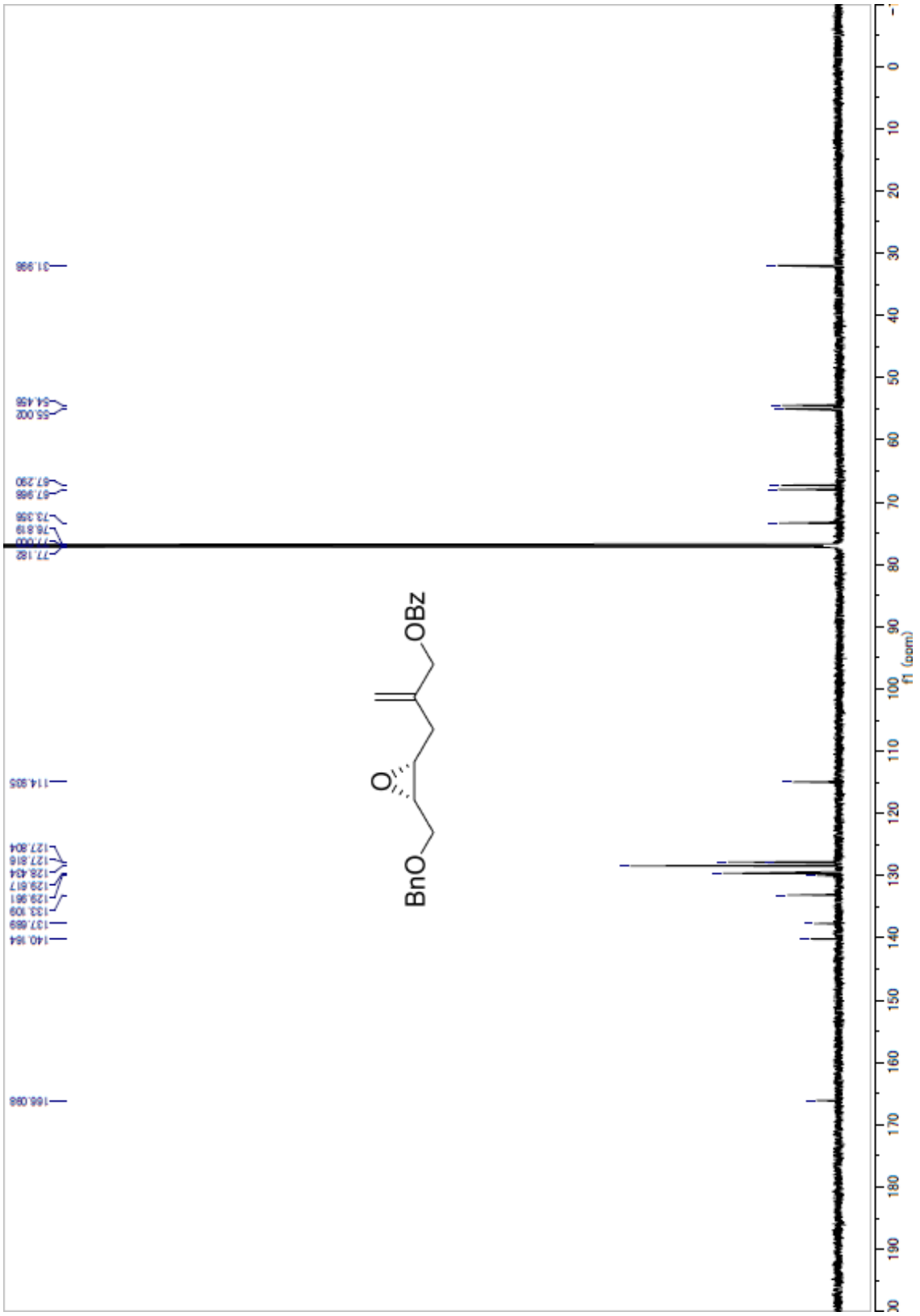

OBz
O
HO
7.260
1.97
2.02
0.97
1.00
1.02
2.07
0.98
1.00
1.94
0.99
1.10
0.85
3.22
0.71
f1 (ppm)


OBz
O
HO
31.940
55.445
56.332
60.525
67.279
76.680
77.018
115.069
128.464
129.820
129.863
133.183
140.286
166.185
f1 (ppm)



[コメント情報]
試料名
コメント
測定者
所属
会社　　新潟大学　理学部


OBz
O
BnO
7.260
0.27
1.97
0.94
0.90
1.00
1.02
1.00
1.02
1.96
1.00
1.01
1.45
3.86
2.08
1.01
1.99
f1 (ppm)


OBz
O
BnO
f1 (ppm)