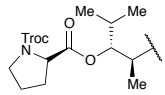
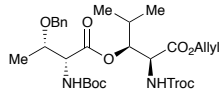
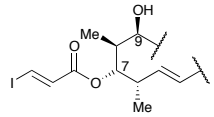
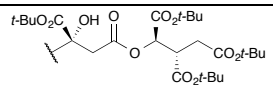
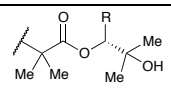
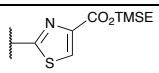
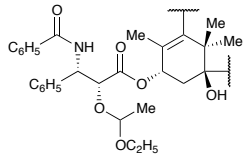
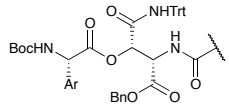
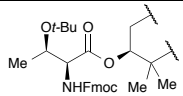
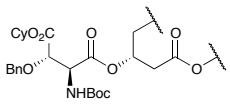
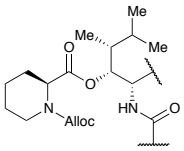
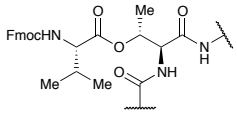
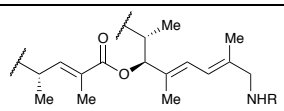
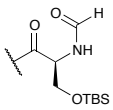
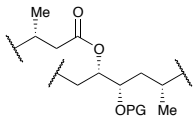
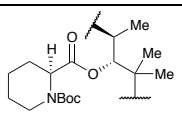
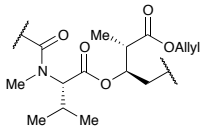
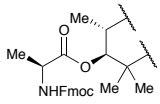
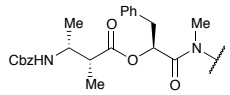
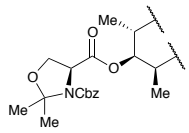
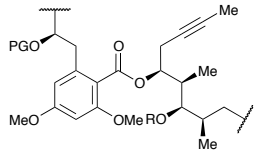
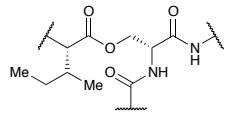
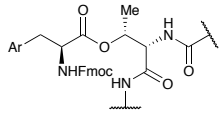
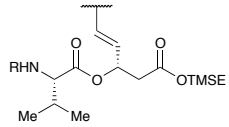
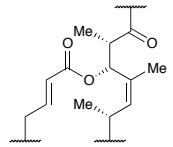
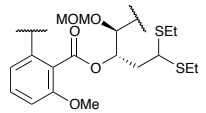
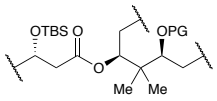
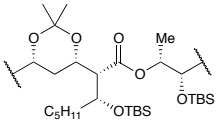
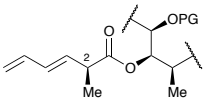
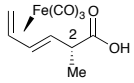
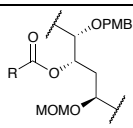
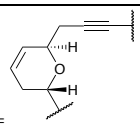
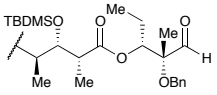
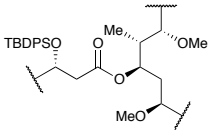
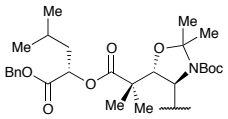
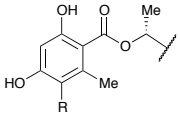
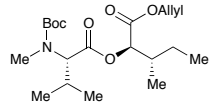
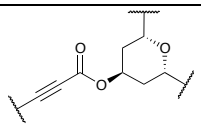
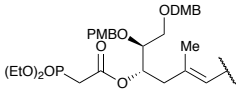
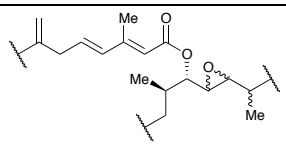
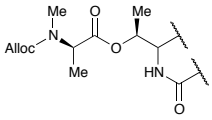
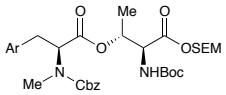
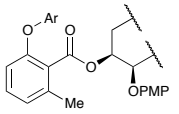
Table S1. Collection of complex ester couplings in total synthesis.

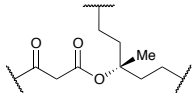
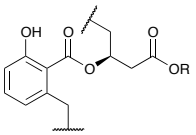
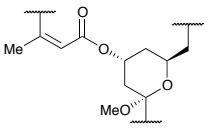
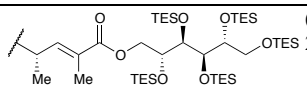
Entry	Substructure	Natural Product	Procedure[a]	Yield	Comment
1		**Virginiamycin M2** 1996[182]	DCC, DMAP (cat.) 0 °C to rt, 10 h	92%	
2		**A83586C** 1997[183] **Azinothricin** and **Kettapeptin** 2009[184]	DCC, DMAP[b] 0 °C to rt	83–88%	5–10% epimerization at the α-carbon of the threonine-unit
3		**Elaiophylin** (macrocyclic core) 1997[185]	DCC, DMAP, –20 °C, 16 h then Ti(O*i*-Pr)$_4$, 20 °C, 16 h[b]	44% (2 steps)	esterification followed by equilibration (C9-OH less hindered than C7-OH) esterification under kinetic conditions: C9:C7 ester = 94:6 after equilibration: C9:C7 ester = 31:69 *Unsuccessful*: • C9-OH Bz-potected: esterification failed under a variety of conditions, presumably due to steric congestion
4		**Citrafungin A** 2007 and 2008[129]	DCC (6.5 equiv.), DMAP•HCl (9.8 equiv.), ROH (2 equiv.) rt, 4 h	50%	
5		**Lyngbyabellin A** 2001[127,186]	 R = DCC, DMAP (cat.), CSA (cat.) rt, 19 h	64%	Keck procedure
		Lyngbyabellin B 2002[186]	R = CO_2Allyl TCBC, TEA, DMAP rt to 60 °C, 13 h	66%	*Unsuccessful*: • Keck conditions, which have successfully been employed for a related coupling in the synthesis of Lyngbyabellin A (*vide supra*)
6		**Taxol** 1988[21]	ROH (6 equiv.), DPC (6 equiv.), DMAP (2 equiv.) 73 °C, 100 h	80%[c]	Modification of Kim's esterification[22] *Unsuccessful*: • various ester coupling conditions that are usually successful for hindered substrates (not specified in the paper) • Kim's esterification (unmodified)
7		**Ramoplanin A2** 2003[104]	acid (2 equiv.), EDC (3 equiv.), DMAP (0.3 equiv.) 0 °C, 1 h	87%	diastereomeric ratio 9:1 *Unsuccessful:* • mixed anhydrides • Mitsunobu • acyl fluoride • Yamaguchi • Corey-Nicolaou • EDC or DCC without DMAP • higher temperature (25 °C) • longer reaction time • more DMAP (0.5–2 equiv.) lower conversion, lower *dr* or *β*-elimination
8		**Viequeamide A** 2013[187] coupling junction: [L-Thr – (2*S*)-Dhoya] (See also entry 33)	acid (5 equiv.), EDC (10 equiv.), DMAP (10 equiv.) rt, o/n	81%	*Unsuccessful:* • acid-Cl/DMAP/DIPEA *Low yields:* • DCC/PPY • TCBC/DMAP/DIPEA • EDC/DMAP (3 equiv. each)

9		**Plusbacin A_3**[188] (2007)	EDC, DMAP (cat.) –15 °C to rt, 12 h	84%	EDC added in 5 portions over 1 h
10		**Pipecolidepsin A** 2013[109]	solid phase acid (15 equiv.), DIC (15 equiv.), DMAP (0.5 equiv.), CH_2Cl_2/DMF 9:1 45 °C, 2.3 h	98%	11% epimerization *Unsuccessful:* • MSNT/NMI • acyl fluoride/DIPEA *Lower yield*: • less equivalents of DIC • rt
11		**Symplocamide A** 2010[189]	solid phase acid (10 equiv.), DIC (10 equiv.), DMAP (1 equiv.), CH_2Cl_2/DMF 9:1 rt, 4 x 2 h	92%	
12	 R = 	**Iejimalides** 2011[190,124]	A: EDC (2 equiv.), DMAP (2 equiv.), DMAP•HCl (2.1 equiv.), high vacuum, Ar (g), then acid (1.3 equiv.), ROH, rt, 48 h (sealed flask under Ar (g) in the dark)[190]	78%[d]	*Unsuccessful*:[190] • Yamaguchi/Yonemitsu (*note*: Yonemitsu successful for R = Boc[191,192]) • Mukaiyama's salt • DCC/DMAP • EDC/DMAP • EDC/DMAP/$Sc(OTf)_3$ *Low to moderate yield*:[190] • Keck (DCC (1 equiv.), DMAP (cat.), DMAP•HCl (cat.)): DCC-urea byproduct difficult to separate • EDC (1 equiv.), DMAP (cat.), DMAP•HCl (cat.): low yield (20%) • As procedure A, but alcohol : acid = 1:1 instead of 1.3:1 (60%)
			B: acid, EDC, PPY (cat.), 0 °C to rt 10 min then conc. under a stream of argon, addition of ROH rt, 18 h[124]	82%	reaction has to be monitored closely, conditions have to be scrupulously met
13		**Iriomoteolide-3a** 2009[112,193]	EDC, PPY, rt (PG = TBS)[b,112] *Alternatively*: TCBC, TEA, DMAP, rt, 36 h (PG = MOM)[193]	72%[112] 93%[182]	
14		**506BD** 1991[114]	DIC (5 equiv.), PPY (3 equiv.), acid (4 equiv.) –20 °C, 20 h	92%	
15		**Veraguamide A** 2012[194]	EDC 0 °C to rt[b]	55%	*Unsuccessful:* • DCC/PPY • Yamaguchi • oxalyl chloride/DMAP
16		**Halipeptin A** 2005[132]	acid-Cl, DMAP (cat.), DIPEA –15 °C[b]	95%[d]	*Unsuccessful:* • Yamaguchi • other activated esters • higher temp (0 °C): racemization • more DMAP (1 equiv.): racemization • higher temp (0 °C) and less DMAP (0.2 equiv.): low conversion

17		**Grassypeptolide** 2010[195]	acid-Cl, DMAP (cat.), NMM 0 °C to rt[b]	90%	*Unsuccessful:* • EDC/DMAP • DCC/DMAP • Mukaiyama's reagent
18		**LL15G256γ** 2008[196]	acid, $(COCl)_2$, DMF/CH_2Cl_2, then ROH, TEA, DMAP, CH_2Cl_2	85%	Garner's protective protocol for serine was crucial for the coupling *Unsuccessful*: • Coupling of diprotected serine (TBS and CBz or Fmoc) under Keck and Yamaguchi conditions led to racemization and low yields
19	 R = TBS, PG = TBDPS[138] R = H, PG = TIPS[137]	**Cruentaren A** 2007[137,138]	2,4,6-trifluoro-1,3,5-triazene (5 equiv.), pyridine (1.1 equiv.), CH_2Cl_2 –25 °C, 10 min then sodium salt of the alcohol (1.1 equiv.), THF rt, 1 h	91% (2 steps)	*Unsuccessful*: • Mitsunobu • Yamaguchi • Trost esterification • carbodiimide based reagents • acid chloride (lactone formation) • activated esters and thioesters • PySSPy/PPh_3, AgBF • di-2-thienyl carbonate (2-DTC), $Hf(OTf)_2$, DMAP • PG = MOM or TCA (lactone formation) *Modest yields*: • Mukaiyama's reagent • sodium salt of the alcohol/ imidazolide derivative of the acid, 0 °C to rt, 3 d (65%) (for R = H and PG = TIPS)
20		**MA026** 2013[143]	acid (1.15 equiv.), HBTU (4 equiv.), HOBt (4 equiv.), NMM (5 equiv.), CH_2Cl_2/DMF 4:1 rt, 48 h	40% (71% brsm)	*Unsuccessful:* • EDC • mixed anhydrides • Yamaguchi • Mukaiyama • Shiina`s protocol *Low conversion*: • EDC/HOBt/NMM
21		**Daptomycin** 2013[144]	acid (2.2 equiv.), PyBOP (4 equiv), DIPEA (4 equiv), rt, 12 h	87%	*Unsuccessful:* • coupling of the unnatural amino acid kynurenine
22		**FK228** 2008[152]	R = Fmoc-D-Val-D-Cys(Tr)-Dhb-: MSNT, *N*-Me-imidazole 0 °C, 5 h to rt, 100 min	34%	For R = Fmoc-D-Val-D-Cys(Tr)-Dhb-: • prolonged reaction time resulted in epimerization • 42% unreacted alcohol
			R = Fmoc: DCC, DMAP (cat.) 0 °C, 3 h	85%	
23		**(+)-Migrastatin** 2003,[161] 2004[162] and 2007[197]	acid (3 eqiv.), TCBC (3 equiv.), DIPEA (2.8 equiv.), rt, 3 h then ROH, pyridine (4 equiv.) rt, 24 h	66–74%	*Unsuccessful*: • acid chloride/DMAP, pyridine or AgCN • EDC or DCC • Mukaiyama's reagent • Keck coupling decomposition of SM or partial isomerisation to the *β*,*γ*-unsaturated ester
24		**Oximidines I and II** 2003[198]	TCBC, TEA, CH_2Cl_2, rt, 3 h then ROH, DMAP, PhMe, 90 °C, 16 h	38%	

25		**Rhizopodin** 2012[199,200] and 2013[201,202,203]	TCBC, TEA, DMAP[b,201]	63–96%	PG = TBS or TES
26		**Filipin III** 1999[204]	TCBC, TEA, THF, rt, 16 h then ROH, DMAP, PhMe, rt, 2 h	70%	*Unsuccessful*: • DCC/DMAP • BOP/DMAP *Low yield*: • PyBroP (30% yield)
27		**Amphidinolide E** 2007[205]	$(CO)_3$Fe-complexed dienoic acid (see below), TCBC, TEA, DMAP 0 °C, 1 h to rt, 1 h  followed by oxidative decomplexation of the $(CO)_3$Fe unit (96%)	94%	*Note*: inversion at C2 of the acid component! *Unsuccessful*: • excess amounts of acid and various coupling reagents • Yonemitsu modification of the Yamaguchi reaction • mild peptide coupling conditions (EDC•methiodide (EDC•MeI)/ DMAP, PyBrOP/DIPEA, DCC/HOBt), • Otera's transesterification catalyst • tributyltin ether of the alcohol/acyl fluoride • lithium alkoxide/acyl fluoride • Kita's conditions isomerization to the fully conjugated species
28		**(-)-Laulimalide** 2012[170e,171]	 R = TCBC, DIPEA, DMAP (Yonemitsu modification)[b]	18% .	*Unsuccessful*: • Steglich and related protocols • acyl chloride or acyl fluoride • Ghosez reagent[48f,g] (allene formation) • Kita's conditions *Low yields/only traces of product*: • transesterification from methyl ester in presence of Otera`s catalyst (13%) • Shiina mixed anhydride
			$R = CH_2PO(OCH_2CF_3)_2$ acid (2.3 equiv.), TCBC (2.9 equiv.), DIPEA (4.6 equiv.), THF, rt, 10 min then DMAP (6.9 equiv.), C_6H_6 rt, 2 h	99%	presumably via a more reactive ketene intermediate from phosphonoacetic acid
29		**Methynolide** 1986[206]	TCBC, TEA, DMAP rt, 20 h[b]	58%	*Unsuccessful*: • DCC/DMAP: 70% yield but impurities difficult to remove • other esterification reagents (not specified)
30		**Mycalolide B** 2010[207]	MNBA, TEA, DMAP rt[b]	55%	
31		**Kitastatin** and **Respirantin** 2014[208]	MNBA, DMAP, TEA rt, 40 h	93%	
32		**Pochonin C**[179,180] and **Radicicol**[180] 2004 (R = H)	P(*m*ClPh)$_3$, DIAD 23 °C, 3 h	84%	*Lower yield*: • 2-OH group protected (Mitsunobu or carbodiimide conditions) • different strategy for R = Cl (Pochonin A[49(b)]): persilylation of the benzoic acid

					derivative, followed by conversion to the acid chloride and esterification with the alcohol a) TBSCl, DIPEA, b) $(COCl)_2$, DMF/CH_2Cl_2 c) ROH, TEA (29% over 3 steps) *Poor selectivity*: • classical Mitsunobu conditions: alkylation of the *para*-phenol
33		**Viequeamide A** 2013[187] coupling junction: [*N*-Me-L-Val – (2*R*,3*S*)-HMPA] (See also entry 8)	acid (3 equiv.), DEAD (3 equiv.), PPh_3 (4.5 equiv.) 0 °C to rt, 14 h	91%	
34		**Leucascandrolide A** 2003[176c-d]	acid (4.5 equiv.), DEAD (3.3 equiv.), PPh_3 (20 equiv.), THF/PhMe = 1.5:1, 0 °C to 20 °C, 14 h	90%	From C5 equatorial alcohol *Unsuccessful:* from C5 axial alcohol: • various activated acid derivatives, • acid chloride
35		**(+)-Zampanolide** and **(+)-Dactylolide** 2002[91]	acid (15 equiv.), PPh_3 (6.5 equiv.), DEAD (7 equiv.) rt, o/n	99%	*Note:* complete retention of configuration! Saturation of the reaction medium with acid, PPh_3 and DEAD necessary to achieve full conversion of the starting material *Unsuccessful*: • standard Mitsunobu protocol (premixing alcohol and acid followed by addition of PPh_3 and DEAD) • more DEAD and PPh_3 • prolonged reaction times • reversed order of reagent addition *Incomplete consumption of the alcohol:* • heating to 40–50 °C: elimination side product
36		**Amphidinolide A** (different stereoisomers) 2002[209], 2004[210], 2005[211] and 2006[212]	$[RuCl_2(p\text{-cymene})]_2$ (cat.), HCCOEt, PhMe, rt, 2 h ROH, CSA (cat.), $ClCH_2CH_2Cl$ rt, 2 h[209]	42–66%	*Unsuccessful*: • Keck or Mitsunobu: complex mixtures[212] • any other esterification which employed basic conditions: extensive isomerisation of the triene[209]
37		**Callipeltin B** 2006[213]	solid phase acid (4 equiv.), MSNT (4 equiv.), *N*-Me-imidazole (8 equiv.), rt, 5 min then ROH (resin bound), N_2, rt, 2.5 h	quant.	
38		**Didemnins A, B, C** 1990[214] and **Tamandarin A** 1999[215]	isoprenyl chloroformate, TEA, DMAP (cat.), 0 °C, 1 h *Alternatively*: TCBC, TEA, THF, rt, 1 h then ROH, DMAP, C_6H_5, rt, 4 h	87% 81%	Castro`s esterification procedure[216] *Unsuccessful*: • carbodiimides: poor yields after long reaction times (48 h)
39		**Aspercyclide C** 2005[217]	*N*-methyl-2-chloropyridinium iodide, TEA, MeCN, reflux[b]	82%	

40		**Lyngbyaloside B macrocycle** 2013[96]	ROH (1.2 equiv.), PhMe, reflux, 12 h azeotropic removal of EtOH	77%	transesterification from ethylester and tertiary alcohol via an acyl ketene intermediate (thermolysis of the ethylester) *Lower yield:* • equimolar amounts of alcohol and acid component (68%)
41		**Lobatamide C**[1] 2002[218]	R = H: ROH (1 eqiv.), NBu_4OH, MeOH, rt, 20 min, azeotropic removal of water, then cyanomethylester of the acid component (1 equiv.), Na_2CO_3, DMF/2-butanone 80 °C, 2 h	43%[f]	*Unsuccessful*: • for R = Et: base catalyzed fragment couplings: elimination side reactions
42		**Latrunculin B, C, and M** 2007[219]	ROH, Tf_2O (1.4 equiv.), pyridine (2.3 equiv.), CH_2Cl_2 –20 °C, 1 h then Na salt of the acid (3.5 equiv.), [15]crown-5, THF rt, o/n	58% (2 steps)	small amounts of an elimination product as byproduct *Unsuccessful*: • Mitsunobu esterification
43		**(+)-TMC-151C** 2011[220]	Piv_2O, TEA, CH_2Cl_2, 0 °C, 14 h then ROH, DMAP, PhMe, rt, 2 days	60% (2 steps)	

a: information concerning the stoichiometry is only given, when one of the coupling partners was used in a > 3-fold excess or if strict demands on the stoichiometry were reported; b: no detailed information provided; c: based on 50% conversion. 60% yield at 85% conversion; d: 2 steps, starting from the methylester of the acid; e: based on 90% conversion of the alcohol; f: after deprotection of a DEIPS group

References

[1] W. Mabey and T. Mill, *J. Phys. Chem. Ref. Data,* 1978, **7**, 383-415.

[2] A. Parenty, X. Moreau, G. Niel and J. M. Campagne, *Chem. Rev.* 2013, **113**, PR1–PR40.

[3] For a comprehensive ressource on ester coupling methods, see: J. Otera and J. Nishikido in *Esterification: Methods, Reactions, and Applications*, Wiley-VCH: Weinheim, 2nd edn., 2010.

[4] M. A Fischbach and C. T. Walsh, *Chem. Rev.*, 2006, **106**, 3468–3496.

[5] C. T. Walsh and M. A. Fischbach, *J. Am. Chem. Soc.*, 2010, **132**, 2469–2493.

[6] E. S. Sattely, M. A. Fischbach and C. T. Walsh, *Nat. Prod. Rep.*, 2008, **25**, 757–793.

[7] T. A. Keating, D. E. Ehmann, R. M. Kohli, C. G. Marshall, J. W. Trauger and C. T. Walsh, *Chembiochem*, 2001, **2**, 99–107.

[8] L. Du and L. Lou, *Nat. Prod. Rep.*, 2010, **27**, 255–278.

[9] K. Bloudoff, D. Rodionov and T. M. Schmeing, *J. Mol. Biol.*, 2013, **425**, 3137–3150.

[10] T. Stachelhaus, H. D. Mootz, V. Bergendahl and M. A. Marahiel, *J. Biol. Chem.*, 1998, **273**, 22773–22781.

[11] C. Olano, C. Méndez and J. A. Salas, *Nat. Prod. Rep.*, 2010, **27**, 571-616.

[12] P. Heikinheimo, A. Goldman, C. Jeffries and D. L. Ollis, *Structure*, 1999, **7**, R141–R146.

[13] D. C. Cantu, Y. Chen and P. J. Reilly, *Protein Sci.*, 2010, **19**, 1281–1295.

[14] S. C. Tsai, L. J. Miercke, J. Krucinski, R. Gokhale, J. C. Chen, P. G. Foster, D. E. Cane, C. Khosla and R. M. Stroud, *Proc. Natl. Acad. Sci. U. S. A.*, 2001, **98**, 14808–14813.

[15] A. Schneider and M. A. Marahiel, *Arch. Microbiol.*, 1998, **169**, 404–410

[16] R. Whicher, S. Dutta, D. A. Hansen, W. A. Hale, J. A. Chemler, A. M. Dosey, A. R. H. Narayan, K. Håkansson, D. H. Sherman, J. L. Smith and G. Skiniotis, *Nature*, 2014, **510**, 560–564.

[17] S. Dutta, J. R. Whicher, D. A. Hansen, W. A. Hale, J. A. Chemler, G. R. Congdon, A. R. H. Narayan, K. Håkansson, D. H. Sherman, J. L. Smith and G. Skiniotis, *Nature*, 2014, **510**, 512–517.

[18] Y. Xu, R. D. Kersten, S.-J. Nam, L. Lu, A. M. Al-Suwailem, H. Zheng, W. Fenical, P. C. Dorrestein, B. S. Moore and P.-Y. Qian, *J. Am. Chem. Soc.*, 2012, **134**, 8625–8632.

[19] A. V. Ramaswamy, C. M. Sorrels and W. H. Gerwick, *J. Nat. Prod.* 2007, **70**, 1977-1986.

[20] K. C. Nicolaou, W.-M. Dai and R. K. Guy, *Angew. Chem. Int. Ed. Engl.* 1994, **33**, 15-44.

[21] J.-N. Denis, A. E. Greene, D. Guenard, F. Gueritte-Voegelein, L. Mangatal and P. Potier, *J. Am. Chem. Soc.* 1988, **110**, 5917-5919.

[22] S. Kim, J. I. Lee and Y. K. Ko, *Tetrahedron Lett.*,1984, **25**, 4943–4946.

[23] R. A. Holton, H.-B. Kim, C. Somoza, F. Liang, R. J. Biediger, P. D. Boatman, M. Shindo, C. C. Smith, S. Kim, H. Nadizadeh, Y. Suzuki, C. Tao, P. Vu, S. Tang, P. Zhang, K. K. Murthi, L. N. Gentile and J. H. Liu, *J. Am. Chem. Soc.* 1994, **116**, 1599-1600

[24] I. Ojima, C. M. Sun, M. Zucco, Y. H. Park, O. Duclos, S. Kuduk, *Tetrahedron Lett.* 1993, **34**, 4149-4152.

[25] K. C. Nicolaou, Z. Yang, J. J. Liu, H. Ueno, P. G. Nantermet, R. K. Guy, C. F. Claiborne, J. Renaud, E. A. Couladouros, K. Paulvannan and E. J. Sorensen, *Nature*, 1994, **367**, 630-634.

[26] S. J. Danishefsky, J. J. Masters, W. B. Young, J. T. Link, L. B. Snyder, T. V. Magee, D. K. Jung, R. C. A. Isaacs, W. G. Bornmann, C. A. Alaimo, C. A. Coburn and M. J. Di Grandi, *J. Am. Chem. Soc.* 1996, **118**, 2843-2859.

[27] R. Croteau, R. E. B. Ketchum, R. M. Long, R. Kaspera and M. R. Wildung, *Phytochem. Rev.* 2006, **5**, 75-97

[28] G. E. Turfitt, *Biochem. J.*, 1948, **42**, 376–383.

[29] H. Leisch, K. Morley and P. C. K. Lau, *Chem. Rev.*, 2011, **111**, 4165–4222.

[30] G. de Gonzalo, M. D. Mihovilovic and M. W. Fraaije, *Chembiochem*, 2010, **11**, 2208–2231.

[31] Y. Schmidt, M. van der Voort, M. Crüsemann, J. Piel, M. Josten, H.-G. Sahl, H. Miess, J. M. Raaijmakers and H. Gross, *Chembiochem*, 2014, **15**, 259–266.

[32] Y. Hu, D. Dietrich, W. Xu, A. Patel, J. A. J. Thuss, J. Wang, W.-B. Yin, K. Qiao, K. N. Houk, J. C. Vederas and Y. Tang, *Nat. Chem. Biol.*, 2014, **10**, 552–554.

[33] C. A. Townsend, S. B. Christensen and S. G. Davis, *J. Am. Chem. Soc.*, 1982, **104**, 6154–6155.

[34] H. M. Dudek, M. J. Fink, A. V Shivange, A. Dennig, M. D. Mihovilovic, U. Schwaneberg and M. W. Fraaije, *Appl. Microbiol. Biotechnol.*, 2014, **98**, 4009–4020.

[35] N. M. Kamerbeek, D. B. Janssen, W. J. H. van Berkel and M. W. Fraaije, *Adv. Synth. Catal.*, 2003, **345**, 667–678.

[36] M. D. Mihovilovic, B. Müller and P. Stanetty, *Eur. J. Org. Chem.* 2002, 3711–3730.

[37] S. M. Roberts and P. W. H. Wan, *J. Mol. Catal. B Enzym.*, 1998, **4**, 111–136.

[38] J. Wright, T. Hu, J. L. McLachlan, J. Neddham and J. A. Walter, *J. Am. Chem. Soc.*, 1996, **7863**, 8757–8758.

[39] G. R. Macpherson, I. W. Burton, P. LeBlanc, J. A. Walter and J. L. C. Wright, *J. Org. Chem.*, 2003, **68**, 1659–1664.

[40] J. Jiang, C. N. Tetzlaff, S. Takamatsu, M. Iwatsuki, M. Komatsu, H. Ikeda and D. E. Cane, *Biochemistry*, 2009, **48**, 6431–6440.

[41] S. Li, H. Wang, Y. Li, J. Deng, C. Lu, Y. Shen and Y. Shen, *ChemBioChem*, 2014, **15**, 94–102.

[42] E. Malito, A. Alfieri, M. W. Fraaije and A. Mattevi, *Proc. Natl. Acad. Sci. U. S. A.*, 2004, **101**, 13157–13162.

[43] D. E. Torres Pazmiño, B.-J. Baas, D. B. Janssen and M. W. Fraaije, *Biochemistry*, 2008, **47**, 4082–4093.

[44] R. Criegee, *Justus Liebigs Ann. Chem.* 1947, **722**, 127–135.

[45] (a) E. J. Corey and K. C. Nicolaou, *J. Am. Chem. Soc.*, 1974, **96**, 5614-5616; (b) H. Gerlach, A. Thalman, *Helv. Chim. Acta.,* 1974, **57**, 293-294; (c) E. J. Corey and D. J. Brunelle, *Tetrahedron Lett.,* 1976, 3409-3412; (d) E. J. Corey, D. S. Clark, *Tetrahedron Lett.*, 1979, 2875-2878.

[46] For recent reviews on coupling reagents including the use of acid halides and BOP reagents, see: (a) S.-Y. Han and Y.-A. Kim, *Tetrahedron*, 2004, **60**, 2447-2467; (b) C. A. G. N. Montalbetti and V. Falque, *Tetrahedron*, 2005, **61**, 10827-10852.

[47] M. F. Antell, In *The Chemistry of Acyl Halides*; S. Patai, Ed.; Interscience: London, 1972; pp 35-68.

[48] (a) M. Zaoral and Z. Arnold, *Tetrahedron Lett.*, 1960, **1**, 9-12; (b) J. B. Lee, *J. Am. Chem. Soc.*, 1966, **88**, 3440-3441; (c) L. E. Barstow and V. J. Hruby, *J. Org. Chem.*, 1971, **36**, 1305-1306; (d) A. Wissner and C. V. Grudzinskas, *J. Org. Chem.*, 1978, **43**, 3972-3974; (e) K. Venkataraman and D. R. Wagle, *Tetrahedron Lett.*, 1979, **20**, 3037-3040; (f) A. Devos, J. Remion, A. M. Frisque-Hesbain, A. Colens and L. Ghosez, *J. Chem. Soc., Chem. Comm.*, 1979, 1180-1181; (g) B. Haveaux, A. Dekoker, M. Rens, A. R. Sidani, J. Toye and L. Ghosez, *Org. Synth.*, 1979, **59**, 26-34; (h) G. B. Villeneuve and T. H. Chan, *Tetrahedron Lett.*, 1997, **38**, 6489-6492; (i) D. O. Jang, D. J. Park and J. Kim, *Tetrahedron Lett.*, 1999, **40**, 5323-5326; (j) D. J. Hardee, L. Kovalchuke and T. H. Lambert, *J. Am. Chem. Soc.*, 2010, **132**, 5002-5003.

[49] (a) A. Fürstner and H. Weintritt, *J. Am. Chem. Soc.*, 1998, **120**, 2817-2825; (b) E. Moulin, S. Barluenga and N. Winssinger, *Org. Lett.*, 2005, **7**, 5637–5639.

[50] A. Oku, Y. Yamaura and T. Harada, *J. Org. Chem.*, 1986, **51**, 3732-3734.

[51] For examples, see: (a) S. Li, S. Liang, Z. Xu and T. Ye, *Synlett*, 2008, **4**, 569-574; (b) T. Conroy, J. T. Guo, R. G. Linington, N. H. Hunt and R. J. Payne, *Chem. Eur. J.*, 2011, **17**, 13544-13552.

[52] For examples, see: (a) H. Liu, Y. Liu, X. Xing, Z. Xu and T. Ye, *Chem. Commun.*, 2010, **46**, 7486-7488; (b) R. Beveridge and R. A. Batey, *Org. Lett.*, 2014, **16**, 2322-2325.

[53] L. A. Carpino, M. Beyermann, H. Wenschuh and M. Bienert, *Acc. Chem. Res.*, 1996, **29**, 268-274.

[54] M. Jedrzejczak, R. E. Motie, D. P. N. Satchell, R. S. Satchell and W. N. Wassef, *J. Chem. Soc., Perkin Trans. 2*, 1994, 1471-1479.

[55] B. Neises and W. Steglich, *Angew. Chem. Int. Ed. Engl.*, 1978, **17**, 522–524.

[56] A. El-Faham and F. Albericio, *Chem. Rev.*, 2011, **111**, 6557–6602.
[57] J. C. Sheehan, P. A. Cruickshank and G. L. Boshart, *J. Org. Chem.*, 1961, **26**, 2525–2528.
[58] S.-Y. Han and Y.-A. Kim, *Tetrahedron*, 2004, **60**, 2447–2467.
[59] L. Bourel-Bonnet, K. V Rao, M. T. Hamann and A. Ganesan, *J. Med. Chem.*, 2005, **48**, 1330–1335.
[60] O. Kuisle, E. Quiñoá and R. Riguera, *J. Org. Chem.*, 1999, **64**, 8063–8075.
[61] M. Stawikowski and P. Cudic, *Tetrahedron Lett.*, 2006, **47**, 8587–8590.
[62] Á. López-Maciá, J. C. Jiménez, M. Royo, E. Giralt and F. Albericio, *Tetrahedron Lett.*, 2000, **41**, 9765–9769.
[63] H. Seo and D. Lim, *J. Org. Chem.*, 2009, **74**, 906–909
[64] D. F. DeTar and R. Silverstein, *J. Am. Chem. Soc.*, 1966, **88**, 1020–1023.
[65] (a) A. F. Hegarty and M. T. McCormack, *J. Am. Chem. Soc.*, 1977, **99**, 2015–2016. (b) A. F. Hegarty, M. T. McCormack, K. Brady, G. Ferguson and P. J. Roberts, *J. Chem. Soc. Perkin Trans. 2*, 1980, 867–875. (c) K. Yamada, K. Kishikawa and S. Kohmoto, Chem. Lett., 1988, 17, 351–352.
[66] R. Shelkov, M. Nahmany and A. Melman, *Org. Biomol. Chem.*, 2004, **2**, 397–401.
[67] A. Williams and I. T. Ibrahim, *J. Am. Chem. Soc.*, 1981, **103**, 7090–7095.
[68] W. König and R. Geiger, *Chem. Ber.*, 1970, **103**, 788–798.
[69] J. Morales-Serna, A. Vera, E. Paleo, E. García-Ríos, R. Gaviño, G. García de la Mora and J. Cárdenas, *Synthesis (Stuttg).*, 2010, 4261–4267.
[70] L. A. Carpino, *J. Am. Chem. Soc.*, 1993, **115**, 4397–4398.
[71] Y. Xu and M. J. Miller, *J. Org. Chem.*, 1998, **63**, 4314–4322.
[72] J. Inanaga, K. Hirata, H. Saeki, T. Katsuki and M. Yamaguchi, *Bull. Chem. Soc. Jpn.*, 1979, **52**, 1989–1993.
[73] M. Hikota, Y. Sakurai, K. Horita and O. Yonemitsu, *Tetrahedron Lett.*, 1990, **31**, 6367–6370.
[74] I. Dhimitruka and J. SantaLucia, *Org. Lett.*, 2006, **8**, 47–50.
[75] K. Makino, N. Nakajima, S. Hashimoto and O. Yonemitsu, *Tetrahedron Lett.*, 1996, **37**, 9077–9080.
[76] K. Hung, P. W. R. Harris, A. M. Heapy and M. A. Brimble, *Org. Biomol. Chem.*, 2011, **9**, 236–242.
[77] Y. Okuno, S. Isomura, A. Nishibayashi, A. Hosoi, K. Fukuyama, M. Ohba and K. Takeda, *Synth. Commun.,* 2014, 1–7.
[78] (a) I. Shiina, R. Ibuka and M. Kubota, *Chem. Lett.*, 2002, 286−287; (b) I. Shiina, M. Kubota and R. Ibuka, *Tetrahedron Lett.*, 2002, **43**, 7535-7539; (c) I. Shiina, M. Kubota, H. Oshiumi and M. Hashizume, *J. Org. Chem.*, 2004, **69**, 1822–1830.
[79] O. Mitsunobu and M. Yamada, *Bull. Chem. Soc. Jpn.*, 1967, **40**, 2380–2382.
[80] K. Hagiya, N. Muramoto, T. Misaki and T. Sugimura, *Tetrahedron*, 2009, **65**, 6109–6114.
[81] M. E. Lanning and S. Fletcher, *Tetrahedron Lett.*, 2013, **54**, 4624–4628.
[82] J. Yang, L. Dai, X. Wang and Y. Chen, *Tetrahedron*, 2011, **67**, 1456–1462.
[83] N. Iranpoor, H. Firouzabadi and D. Khalili, *Org. Biomol. Chem.*, 2010, **8**, 4436–4443.
[84] K. C. K. Swamy, K. P. Kumar and N. N. B. Kumar, *J. Org. Chem.*, 2006, **71**, 1002–8.
[85] D. L. Hughes, R. A. Reamer, J. J. Bergan, and E. J. J. Grabowski, *J. Am. Chem. Soc.*, 1988, **110**, 6487–6491.
[86] C. Ahn, R. Correia and P. DeShong, *J. Org. Chem.*, 2002, **67**, 1751-1753.
[87] D. Camp and I. D. Jenkins, *J. Org. Chem.*, 1989, **54**, 3045–3049.
[88] D. Camp and I. D. Jenkins, *J. Org. Chem.*, 1989, **54**, 3049–3054.
[89] E. Grochowski, B. D. Hilton, R. J. Kupper and C. J. Michejda, *J. Am. Chem. Soc.*, 1982, **104**, 6876–6877.
[90] K. C. K. Swamy, N. N. B. Kumar, E. Balaraman and K. V. P. P. Kumar, *Chem. Rev.*, 2009, **109**, 2551–651.
[91] A. B. Smith, I. G. Safonov and R. M. Corbett, *J. Am. Chem. Soc.*, 2002, **124**, 11102–11113.
[92] (a) H. Staudinger, *Ber. Dtsch. Chem. Ges.,* 1905, **38**, 1735; (b) H. Staudinger, *Die Ketene*, F. Enke: Stuttgart, 1912.
[93] (a) N. T. M. Wilsmore and A. W. Stewart*, Nature*, 1907, **75**, 510; (b) N. T. M. Wilsmore, *J. Chem. Soc., Trans.*, 1907, **91**, 1938-1941.
[94] For some representative reviews, see: (a) W. Reichen, *Chem. Rev.*, 1978, **78**, 569-588; (b) S. Patai, *The Chemistry of Ketenes, Allenes and Related Compounds*, Wiley: New York, 1980; (c) H. R. Seikaly and T. T. Tidwell, *Tetrahedron*, 1986, **42**, 2587-2613; (d) T. T. Tidwell, *Acc. Chem. Res.*, 1990, **23**, 273-279; (e) C. Wentrup, W. Heilmayer and G. Kollenz, *Synthesis*, 1994, 1219-1248; (f) T. T. Tidwell, *Angew. Chem. Int. Ed.*, 2005, **44**, 5778-5785; (g) K. P. Reber, S. T. Tilley and E. J. Sorensen, *Chem. Soc. Rev.*, 2009, **38**, 3022-3034; (h) A. D. Allen and T. T. Tidwell, *Chem. Rev.*, 2013, **113**, 7287-7342.
[95] M. Sato, J. Sakaki, K. Takayama, S. Kobayashi, M. Suzuki and C. Kaneko, *Chem. Pharm. Bull.*, 1990, **38**, 94-98.
[96] J. S. Yadav, A. Haldar and T. Maity, *Eur. J. Org. Chem.*, 2013, **15**, 3076–3085.
[97] D. R. Williams, B. J. Myers and L. Mi, *Org. Lett.*, 2000, **2**, 945-948.
[98] B. M. Trost, J. L. Gunzner, O. Dirat and Y. H. Rhee, *J. Am. Chem. Soc.*, 2002, **124**, 10396-10415.
[99] A. E. Marrouni, R. Lebeuf, J. Gebauer, M. Heras, S. Arseniyadis and J. Cossy, *Org. Lett.*, 2012, **14**, 314-317.
[100] R. L. Funk, M. M. Abelman and K. M. Jellison, *Synlett*, 1989, 36-37.
[101] (a) R. M. Moslin and T. F. Jamison, *J. Am. Chem. Soc.*, 2006, **128**, 15106-15107; (b) R. M. Moslin and T. F. Jamison, *J. Org. Chem.*, 2007, **72**, 9736-9745.
[102] L. Liang, M. Ramaseshan and D. I. MaGee, *Tetrahedron*, 1993, **49**, 2159-2168.
[103] S. Walker, L. Chen, Y. Hu, Y. Rew, D. Shin and D. L. Boger, *Chem. Rev.*, 2005, **105**, 449–476.
[104] W. Jiang, J. Wanner, R. J. Lee, P.-Y. Bounaud and D. L. Boger, *J. Am. Chem. Soc.*, 2003, **125**, 1877–1887.
[105] W. Jiang, J. Wanner, R. J. Lee, P.-Y. Bounaud and D. L. Boger, *J. Am. Chem. Soc.*, 2002, **124**, 5288–5290.
[106] D. Shin, Y. Rew and D. L. Boger, *Proc. Natl. Acad. Sci. U. S. A.*, 2004, **101**, 11977–11979.
[107] M. Pelay-Gimeno, J. Tylla-Puche and F. Albericio, *Mar. Drugs*, 2013, **11**, 1693-1717.
[108] L. Coello, R. Fernandez, J. F. Reyes, A. Francesch and M. D. C. Cuevas, Anticancer pipecolidepsins from marine organisms. Int. Appl. Pat. WO 2010/070078 A1, 2010.
[109] M. Pelay-Gimeno, Y. Garcia-Ramos, M. J. Martin, J. Spengler, J. M. Molina-Guijarro, S. Munt, A. M. Francesch, C. Cuevas, J. Tulla-Puche and F. Albericio, *Nat. Commun.*, 2013, **4**, 2352.
[110] L. Coello, F. Reyes, M. J. Martin, C. Cuevas and R. Fernandez, *J. Nat. Prod.*, 2014, **77**, 298-303.
[111] K. Oguchi, M. Tsuda, R. Iwamoto, Y. Okamoto, J. Kobayashi, E. Fukushi, J. Kawabata, T. Ozawa, A. Masuda, Y. Kitaya and K. Omasa, *J. Org. Chem.*, 2008, **73**, 1567-1570.
[112] R. Cribiu, C. Jäger and C. Nevado, *Angew. Chem. Int. Ed.*, 2009, **48**, 8780-8783.
[113] L. M. Litvinenko and A. I. Kirichenko, *Dokl. Akad. Nauk SSSR, Ser. Khim.*, 1967, **176**, 97-100.
[114] W. Steglich and G. Höfle, *Angew. Chem. Int. Ed.*, 1969, **8**, 981.
[115] G. Höfle, W. Steglich and H. Vorbruggen, *Angew. Chem. Int. Ed.*, 1978, **17**, 569-583.
[116] (a) A. Einhorn and F. Hollandt, *Justus Liebigs Ann. Chemie*, 1898, **301**, 95-115; (b) A. Verley and F. Bçlsing, *Ber. Dtsch. Chem. Ges.*, 1901, **34**, 3354-3358.
[117] W. Steglich and G. Höfle, *Tetrahedron Lett.*, 1970, **11**, 4727-4730.
[118] (a) A. Hassner, L. R. Krepski and V. Alexanian, *Tetrahedron*, 1978, **34**, 2069-2076; (b) E. F. V. Scriven, *Chem. Soc. Rev.*, 1983, **12**, 129-161.
[119] M. R. Heinrich, H. S. Klisa, H. Mayr, W. Steglich and H. Zipse, *Angew. Chem. Int. Ed.*, 2003, **42**, 4826-4828.
[120] For reviews on 4-dialkylaminopyridines, see: (a) A. C. Spivey and S. Arseniyadis, *Angew. Chem. Int. Ed.*, 2004, **43**, 5436-5441; (b) N. De Rycke, F. Couty and O. R. P. David, *Chem. Eur. J.*, 2011, **17**, 12852-12871.

[121] S. Singh, G. Das, O. V. Singh and H. Han, *Org. Lett.*, 2007, **9**, 401-404.
[122] N. De Rycke, G. Berionni, F. Couty, H. Mayr, R. Goumont and O. R. P. David, *Org. Lett.*, 2011, **13**, 530-533.
[123] R. P. Wurz, *Chem. Rev.*, 2007, **107**, 5570-5595.
[124] J. Gagnepain, E. Moulin and A. Fürstner, *Chem. Eur. J.*, 2011, **17**, 6964-6972.
[125] P. K. Somers, T. J. Wandless and S. L. Schreiber, *J. Am. Chem. Soc.*, 1991, **113**, 8045-8056.
[126] E. P. Boden and G. E. Keck, *J. Org. Chem.*, 1985, **50**, 2394-2395.
[127] F. Yokokawa, H. Sameshima and T. Shioiri, *Tetrahedron Lett.*, 2001, **42**, 4171-4174.
[128] I. Paterson, S. J. Fink, L. Y. W. Lee, S. J. Atkinson and S. B. Blakey, *Org. Lett.*, 2013, **15**, 3118-3121.
[129] (a) M. F. A. Amer, K. Takahashi, J. Ishihara and S. Hatakeyama, *Heterocycles*, 2007, **72**, 181–185; (b) F. Calo, J. Richardson and A. G. M. Barrett, *J. Org. Chem.*, 2008, **73**, 9692–9697.
[130] A. Randazzo, G. Bifulco, C. Giannini, M. Bucci, C. Debitus, G. Cirino and L. Gomez-Paloma, *J. Am. Chem. Soc.*, 2001, **123**, 10870–10876.
[131] C. D. Monica, A. Randazzo, G. Bifulco, P. Cimino, M. Aquino, I. Izzo, F. De Riccardis and L. Gomez-Paloma, *Tetrahedron Lett.*, 2002, **43**, 5707-5710.
[132] S. Yu, X. Pan, X. Lin and D. Ma, *Angew. Chem. Int. Ed.*, 2005, **44**, 135-138.
[133] S. Yu, X. Pan and D. Ma, *Chem. Eur. J.*, 2006, **12**, 6572-6584.
[134] L. Jundt, H. Steinmetz, P. Luger, M. Weber, B. Kunze, H. Reichenbach and G. Hofle, *Eur. J. Org. Chem.*, 2006, 5036-5044.
[135] B. Kunze, H. Steinmetz, G. Höfle, M. Huss, H. Wieczorek and H. Reichenbach, *J. Antibiot.*, 2006, **59**, 664-668.
[136] B. Kunze, F. Sasse, H. Wieczorek and M. Huss, *FEBS Lett.*, 2007, **581**, 3523-3527.
[137] V. V. Vintonyak and M. E. Maier, *Angew. Chem. Int. Ed.*, 2007, **46**, 5209-5211.
[138] (a) A. Fürstner, M. Bindl and L. Jean, *Angew. Chem. Int. Ed.*, 2007, **46**, 9275-9278. (b) M. Bindl, L. Jean, J. Herrmann, R. Müller and A. Fürstner, *Chem. Eur. J.*, 2009, **15**, 12310–12319.
[139] V. V. Vintonyak and M. E. Maier, *Org. Lett.*, 2007, **9**, 655-658.
[140] T. Mukaiyama, M. Usui, E. Shimada and K. Saigo, *Chem. Lett.*, 1975, 1045-1048.
[141] B. M. Trost and J. D. Chisholm, *Org. Lett.*, 2002, **4**, 3743-3745.
[142] M. Ishima, T. Yoshida, T. Yamazaki, F. Sugawara, K. Hatta, M. Shimojoe and K. Masaki, PCT WO 02/062831, 2002.
[143] S. Shimura, M. Ishima, S. Nakajima, T. Fujii, N. Himeno, K. Ikeda, J. Izaguirre-Carbonell, H. Murata, T. Takeuchi, S. Kamisuki, T. Suzuki, K. Kuramochi, K. Watashi, S. Kobayashi and F. Sugawara, *J. Am. Chem. Soc.*, 2013, **135**, 18949-18956.
[144] H. Y. Lam, Y. Zhang, H. Liu, J. Xu, C. T. T. Wong, C. Xu and X. Li, *J. Am. Chem. Soc.*, 2013, **135**, 6272-6279.
[145] M. Debono, M. Barnhart, C. B. Carrell, J. A. Hoffmann, J. L. Occolowitz, B. J. Abbott, D. S. Fukuda, R. L. Hamill, K. Biemann and W. C. Herlihy, *J. Antibiot.* 1987, **40**, 761−777.
[146] R. H. Baltz, *Curr. Opin. Chem. Biol.*, 2009, **13**, 144-151.
[147] H. Ueda, H. Nakajima, Y. Hori, T. Fujita, M. Nishimura, T. Goto and M. Okuhara, *J. Antibiot.*, 1994, **47**, 301-310.
[148] R. Furumai, A. Matsuyama, N. Kobashi, K.-H. Lee, M. Nishiyama, H. Nakajima, A. Tanaka, Y. Komatsu, N. Nishino, M. Yoshida and S. Horinouchi, *Cancer Res.*, 2002, **62**, 4916-4921.
[149] M. H. Shah, P. Binkley, K. Chan, J. Xiao, D. Arbogast, M. Collamore, Y. Farra, D. Young and M. Grever, *Clin. Cancer Res.*, 2006, **12**, 3997-4003.
[150] K. W. Li, W. Xing and J. A. Simon, *J. Am. Chem. Soc.*, 1996, **118**, 7237-7238.
[151] T. J. Greshock, D. M. Johns, Y. Noguchi and R. M. Williams, *Org. Lett.*, 2008, **10**, 613-616.
[152] S. Wen, G. Packham and A. Ganesan, *J. Org. Chem.*, 2008, **73**, 9353-9361.
[153] (a) C. B. Reese, R. C. Titmas and L. Yau, *Tetrahedron Lett.*, 1978, **19**, 2727-2730; (b) S. S. Jones, B. Rayner, C. B. Reese, A. Ubasawa and M. Ubasawa, *Tetrahedron*, 1980, **36**, 3075-3085; (c) R. Frank, W. Heikens, G. Heisterberg-Moutsis and H. Blocker, *Nucleic Acids Res.*, 1983, **11**, 4365-4377;
[154] (a) W. Bannwarth, *Chimia*, 1987, **41**, 302-317; (b) X. Jorba, F. Albericio, A. Grandas, W. Bannwarth and E. Giralt, *Tetrahedron Lett.*, 1990, **31**, 1915-1918.
[155] (a) R. Frank and R. Doring, *Tetrahedron*, 1988, **44**, 6031-6040; (b) B. Blankemeyer-Menge, M. Nimtz and R. Frank, *Tetrahedron Lett.*, 1990, **31**, 1701-1704.
[156] R. Petersen, J. F. Jensen and T. E. Nielsen, *Org. Prep. Proced. Int.*, 2014, **46**, 267-271.
[157] K. Nakae, Y. Yoshimoto, T. Sawa, Y. Homma, M. Hamada, T. Takeuchi and M. Imoto, *J. Antibiot.*, 2000, **53**, 1130-1136.
[158] E. J. Woo, C. M. Starks, J. R. Carney, R. Arslanian, L. Cadapan, S. Zavala and P. Licari, *J. Antibiot.*, 2002, **55**, 141-146.
[159] Y. Takemoto, K. Nakae, M. Kawatani, Y. Takahashi, H. Naganawa and M. Imoto, *J. Antibiot.*, 2001, **54**, 1104-1107.
[160] H. Nakamura, Y. Takahashi, H. Naganawa, K. Nakae, M. Imoto, M. Shiro, K. Matsumura, H. Watanabe and T. Kitahara, *J. Antibiot.*, 2002, **55**, 442-444.
[161] C. Gaul, J. Njardarson and S. J. Danishefsky, *J. Am. Chem. Soc.*, 2003, **125**, 6042-6043.
[162] C. Gaul, J. T. Njardarson, D. Shan, D. C. Dorn, K.-D. Wu, W. P. Tong, X.-Y. Huang, M. A. S. Moore and S. J. Danishefsky, *J. Am. Chem. Soc.*, 2004, **126**, 11326-11337.
[163] D. G. Corley, R. Herb, R. E. Moore, P. J. Scheuer and V. J. Paul, *J. Org. Chem.*, 1988, **53**, 3644-3646.
[164] E. Quinoa, Y. Kakou and P. Crews, *J. Org. Chem.*, 1988, **53**, 3642-3644.
[165] J.-i. Tanaka, T. Higa, G. Bernardinelli and C. W. Jefford, *Chem. Lett.*, 1996, **25**, 255-256.
[166] (a) S. L. Mooberry, G. Tien, A. H. Hernandez, A. Plubrukarn and B. S. Davidson, *Cancer Res.*, 1999, **59**, 653-660; (b) D. E. Pryor, A. O'Brate, G. Bilcer, J. F. Diaz, Y. Wang, Y. Wang, M. Kabaki, M. K. Jung, J. M. Andreu, A. K. Ghosh, P. Giannakakou and E. Hamel, *Biochemistry*, 2002, **41**, 9109-9115; (c) B. M. Gallagher, Jr., *Curr. Med. Chem.*, 2007, **14**, 2959-2967.
[167] C. W. Jefford, G. Bernardinelli, J. I. Tanaka and T. Higa, *Tetrahedron Lett.*, 1996, **37**, 159-162.
[168] A. K. Ghosh and Y. Wang, *J. Am. Chem. Soc.*, 2000, **122**, 11027-1028.
[169] For early total syntheses see: J. Mulzer and E. Ohler, *Chem. Rev.*, 2003, **103**, 3753-3786.
[170] (a) B. M. Gallagher, F. G. Fang, C. W. Johannes, M. Pesant, M. R. Tremblay, H. Zhao, K. Akasaka, X. Y. Li, J. Liu and B. A. Littlefield, *Bioorg. Med. Chem. Lett.*, 2004, **14**, 575-579; (b) J. Uenishi and M. Ohmi, *Angew. Chem. Int. Ed.*, 2005, **44**, 2756-2760; (c) A. Gollner, K-H. Altmann, J. Gertsch and J. Mulzer, *Chem. Eur. J.*, 2009, **15**, 5979-5997; (d) A. Gollner, K-H. Altmann, J. Gertsch and J. Mulzer, *Tetrahedron Lett.*, 2009, **50**, 5790-5792; (e) B. M. Trost, D. Amans, W. M. Seganish and C. K. Chung, *Chem. Eur. J.*, 2012, **18**, 2961-2971.
[171] B. M. Trost, W. M. Seganish, C. K. Chung and D. Amans, *Chem. Eur. J.*, 2012, **18**, 2948-2960.
[172] Y. Kita, H. Maeda, K. Omori, T. Okuno and Y. Tamura, *Synlett*, 1993, 273-274.
[173] (a) J. Otera, S. Ioka and H. Nozaki, *J. Org. Chem.*, 1989, **54**, 4013-4014; (b) J. Otera, N. Danoh and H. Nozaki, *J. Org. Chem.*, 1991, **56**, 5307-5311.
[174] M. D'Ambrosio, A. Guerriero, C. Debitus, and F. Pietra, *Helv. Chim. Acta*, 1996, **79**, 51-60.
[175] K. R. Hornberger, C. L. Hamblett, and J. L. Leighton, *J. Am. Chem. Soc.*, 2000, **122**, 12894-12895.
[176] (a) A. Fettes and E. M. Carreira, *Angew. Chem. Int. Ed.*, 2002, **41**, 4098-4101; (b) Y. Wang, J. Janjic, and S. A. Kozmin, *J. Am. Chem. Soc.*, 2002, **124**, 13670-13671; (c) I. Paterson and M. Tudge, *Angew. Chem. Int. Ed.*, 2003, **42**, 343-347; (d) I. Paterson and M. Tudge, *Tetrahedron*, 2003, **59**, 6833-6849; (e) M. T. Crimmins and P. Siliphaaivanh, *Org. Lett.*, 2003, **5**, 4641-4644; (f) A. Fettes and E. M. Carreira, *J. Org. Chem.*, 2003, **68**, 9274-9283; (g) Q. Su and J. S. Panek, *Angew. Chem. Int. Ed.*, 2005, **44**, 1223-1225; (h) Y. Wang, J. Janjic and S. A. Kozmin, *Pure Appl. Chem.*,

2005, **77**, 1161-1169; (i) L. J. Van Orden, B. D. Patterson and S. D. Rychnovsky, *J. Org. Chem.*, 2007, **72**, 5784-5793.
[177] V. Hellwig, A. Mayer-Bartschmid, H. Mueller, G. Greif, G. Kleymann, W. Zitzmann, H.-V. Tichy and M. Stadler, *J. Nat. Prod.*, 2003, **66**, 829-837.
[178] S. M. Roe, C. Prodromou, R. O'Brien, J. E. Ladbury, P.W. Piper and L. H. Pearl, *J. Med. Chem.*, 1999, **42**, 260-266.
[179] S. Barluenga, P. Lopez, E. Moulin and N. Winssinger, *Angew. Chem. Int. Ed.*, 2004, **43**, 3467-3470.
[180] S. Barluenga, E. Moulin, P. Lopez and N. Winssinger, *Chem. Eur. J.*, 2005, **11**, 4935-4952.
[181] D. L. Hughes, R. A. Reamer, J. J. Bergan and E. J. J. Grabowski, *J. Am. Chem. Soc.*, 1988, **110**, 6487-6491.
[182] R. H. Schlessinger and Y.-J. Li, *J. Am. Chem. Soc.* 1996, **118**, 3301–3302.
[183] K. J. Hale and J. Cai, *Chem. Commun.*, 1997, **23**, 2319–2320.
[184] K. J. Hale, S. Manaviazar, J. H. George, M. A. Walters, and S. M. Dalby, *Org. Lett.*, 2009, **11**, 733–736.
[185] I. Paterson and J. Man, *Tetrahedron Lett.*, 1997, **38**, 695–698.
[186] F. Yokokawa, H. Sameshima, D. Katagiri, T. Aoyama, and T. Shioiri, *Tetrahedron*, 2002, **58**, 9445–9458.
[187] D. Wang, S. Song, Y. Tian, Y. Xu, Z. Miao, and A. Zhang, *J. Nat. Prod.*, 2013, **76**, 974–978.
[188] A. Wohlrab, R. Lamer and M. S. VanNieuwenzhe, *J. Am. Chem. Soc.* 2007, **129**, 4175-4177
[189] S. C. Stolze, M. Meltzer, M. Ehrmann and M. Kaiser, *Chem. Commun.* 2010, **46**, 8857–8859.
[190] Q. Chen, D. Schweitzer, J. Kane, V. J. Davisson and P. Helquist, *J. Org. Chem*., 2011, **76**, 5157–5169.
[191] A. Fürstner, C. Nevado, M. Waser, M. Tremblay, C. Chevrier, F. Teplý, C. Aïssa, E. Moulin and O. Müller, *J. Am. Chem. Soc.*, 2007, **129**, 9150–9161.
[192] A. Fürstner, C. Aïssa, C. Chevrier, F. Teplý, C. Nevado and M. Tremblay, *Angew. Chem. Int. Ed.*, 2006, **45**, 5832–5837.
[193] C. R. Reddy, G. Dharmapuri and N. N. Rao, *Org. Lett.*, 2009, **11**, 5730–5733.
[194] D. Wang, X. Jia and A. Zhang, *Org. Biomol. Chem.* 2012, **10**, 7027–7030.
[195] H. Liu, Y. Liu, X. Xing, Z. Xu and T. Ye, *Chem. Commun.*, 2010, **46**, 7486–7488.
[196] S. Li, S. Liang, Z. Xu and T. Ye, *Synlett*, 2008, **4**, 569–574.
[197] S. Reymond and J. Cossy, *Tetrahedron* 2007, **63**, 5918–5929.
[198] T. Haack, S. Kurtkaya, J. P. Snyder and G. I. Georg, *Org. Lett.*, 2003, **5**, 5019–5022.
[199] M. Dieckmann, S. Rudolph, S. Dreisigacker and D. Menche, *J. Org. Chem*., 2012, **77**, 10782−10788.
[200] M. Dieckmann, M. Kretschmer, P. Li, S. Rudolph, D. Herkommer and D. Menche, *Angew. Chem. Int. Ed.*, 2012, **51**, 5667–5670.
[201] M. Kretschmer, M. Dieckmann, P. Li, S. Rudolph, D. Herkommer, J. Troendlin and D. Menche, *Chem. Eur. J.*, 2013, **19**, 15993–16018.
[202] L. Song, J. Liu, H. Gui, C. Hui, J. Zhou, Y. Guo, P. Zhang, Z. Xu and T. Ye, *Chem. Asian J.*, 2013, **8**, 2955–2959.
[203] S. M. Dalby, J. Goodwin-Tindall and I. Paterson, *Angew. Chem. Int. Ed.*, 2013, 52, 6517–6521.
[204] T. I. Richardson and S. D. Rychnovsky, *Tetrahedron*, 1999, **55**, 8977–8996.
[205] P. Va and W. R. Roush, *Tetrahedron*, 2007, **63**, 5768–5796.
[206] T. Tanaka, Y. Oikawa, T. Hamada and O. Yonemitsu, *Tetrahedron Lett.*, 1986, **27**, 3647–3650.
[207] M. Kita, H. Watanabe, T. Ishitsuka, Y. Mogi and H. Kigoshi, *Tetrahedron Lett.*, 2010, **51**, 4882–4885.
[208] R. E. Beveridge and R. A. Batey, *Org. Lett.*, 2014, **16**, 2322–2325.
[209] B. M. Trost, J. D. Chisholm, S. T. Wrobleski and M. Jung, *J. Am. Chem. Soc*., 2002, **124**, 12420–12421.
[210] B. M. Trost and P. E. Harrington, *J. Am. Chem. Soc*., 2004, **126**, 5028–5029.
[211] B. M. Trost, P. E. Harrington, J. D. Chisholm and S. T. Wrobleski, *J. Am. Chem. Soc.,* 2005, **127**, 13598–13610
[212] H. Ishiyama, Y. Nakamura and J. Kobayashi, *Tetrahedron*, 2006, **62**, 166–170.
[213] R. Krishnamoorthy, L. D. Vazquez-Serrano, J. A. Turk, J. A. Kowalski, A. G. Benson, N. T. Breaux and M. A. Lipton, *J. Am. Chem. Soc*., 2006, **128**, 15392–15393.
[214] W.-R. Li, W. R. Ewing, B. D. Harris and M. M. Joullié, *J. Am. Chem. Soc.*, 1990, **112**, 7659–7672.
[215] B. Liang, P. Portonovo, M. D. Vera, D. Xiao and M. M. Joullié, *Org. Lett.*, 1999, **1**, 1319–1322.
[216] P. Jouin, B. Castro, C. Zeggaf, A. Pantaloni, J.P. Senet, S. Lecolier and G. Sennyey, *Tetrahedron Lett.*, 1987, **28**, 1661–1664.
[217] A. Fürstner and C. Müller, *Chem. Commun.*, 2005, **44**, 5583–5585.
[218] R. Shen, C. T. Lin and J. A. Porco, Jr., *J. Am. Chem.. Soc.*, 2002, **124**, 5650–5651.
[219] A. Fürstner, D. De Souza, L. Turet, M. D. B. Fenster, L. Parra-Rapado, C. Wirtz, R. Mynott and C. W. Lehmann, *Chem. Eur. J.*, 2007, **13**, 115–134.
[220] R. Matsui, K. Seto, Y. Sato, T. Suzuki, A. Nakazaki and S. Kobayashi, *Angew. Chem. Int. Ed.*, 2011, **50**, 680–683.
[221] K. G. M. Kou, D. N. Le and V. M. Dong, *J. Am. Chem. Soc.*, 2014, **136**, 9471-9476.
[222] N. A. Vermeulen, J. H. Delcamp and M. C. White, *J. Am. Chem. Soc.*, 2010, **132**, 11323-11328.
[223] (a) K. J. Fraunhoffer, N. Prabagaran, L. E. Sirois and M. C. White, *J. Am. Chem. Soc.*, 2006, **128**, 9032-9033; (b) E. M. Stang and M. C. White, *Nat. Chem.*, 2009, **1**, 547-551; (c) E. M. Stang and M. C. White, *Angew. Chem. Int. Ed.*, 2011, **50**, 2094-2097.
[224] Y. Bai, D. C. Davis and M. Dai, *Angew. Chem. Int. Ed.*, 2014, **53**, 6519-6522.
[225] H. Fuwa, A. Saito, S. Naito, K. Konoki, M. Yotsu-Yamashita and M. Sasaki, *Chem. Eur. J.*, 2009, **15**, 12807-12818.
[226] Manuscript under preparation.
[227] T. B. Poulsen, *Chem. Commun.*, 2011, **47**, 12837-12839.
[228] (a) J. S. Davies, *J. Peptide Sci.*, 2003, **9**, 471-501; (b) M. Stawikowski and P. Cudic, *Methods Mol. Biol.*, 2007, **386**, 321-339.