

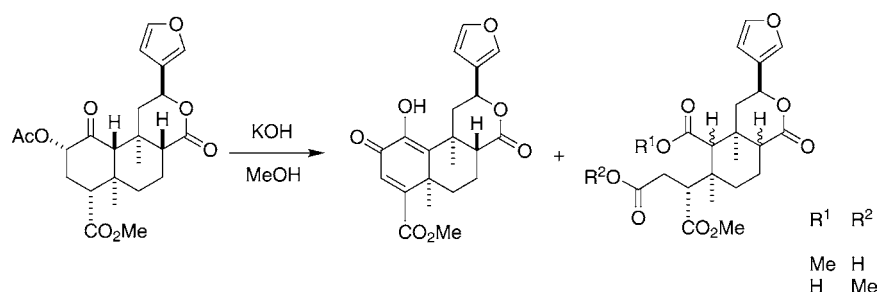
Autoxidation of Salvinorin A under Basic Conditions

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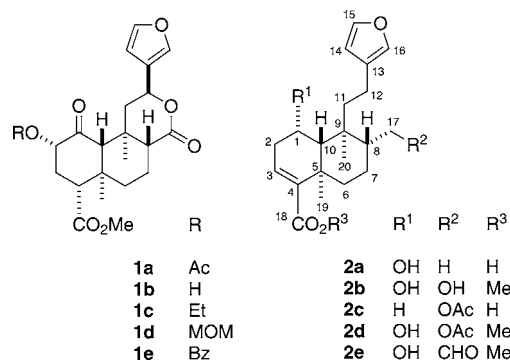


Treatment of salvinorin A (**1a**) with KOH in MeOH gave the enedione **3**, for which the dienone structure **7** was recently proposed. Also isolated, after methylation, were the secotriesters **4a–c**. A mechanism for this unusual series of autoxidations is proposed. Surprisingly, **4a** showed weak affinity at the κ -opioid receptor. Divinatorins A–C (**2a–c**) showed no affinity at opioid receptors. Attempted reduction of **3** to a novel salvinorin diol (**9d**) was unsuccessful, but careful deacetylation of salvinorin C (**9a**) provided a viable route to this compound. A general method for identifying salvinorin 8-epimers by TLC is also presented.

Introduction

Salvinorin A (**1a**)¹ is a neoclerodane diterpenoid isolated from the Mexican medicinal plant *Salvia divinorum*. Compound **1a** is an agonist at the κ -opioid receptor (KOR)² and is the most potent naturally occurring hallucinogen known.³ As a result, both the compound and the plant itself have been prohibited in some countries and several US states. Compound **1a** has also attracted growing scientific interest, being the only non-nitrogenous KOR agonist known, with no apparent structural similarity to other ligands. This anomaly has inspired several groups to study the structure–activity relationships of **1a**.^{4–11}

We recently showed that the ketone and lactone are not involved in activation of the KOR by **1a**, while the



methyl ester and furan ring are.¹⁰ Consistent with this, recent work has confirmed that steric hindrance around

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(1) Ortega, A.; Blount, J. F.; Manchand, P. S. *J. Chem. Soc., Perkin Trans. 1* **1982**, 2505–2508.

(2) Roth, B. L.; Baner, K.; Westkaemper, R.; Siebert, D.; Rice, K. C.; Steinberg, S.; Ernsberger, P.; Rothman, R. B. *Proc. Natl. Acad. Sci. U.S.A.* **2002**, *99*, 11934–11939.

(3) Siebert, D. J. *J. Ethnopharmacol.* **1994**, *43*, 53–56.

(4) Béguin, C.; Richards, M. R.; Wang, Y.; Chen, Y.; Liu-Chen, L.-Y.; Ma, Z.; Lee, D. Y.; Carlezon, W. A.; Cohen, B. M. *Bioorg. Med. Chem. Lett.* **2005**, *15*, 2761–2765.

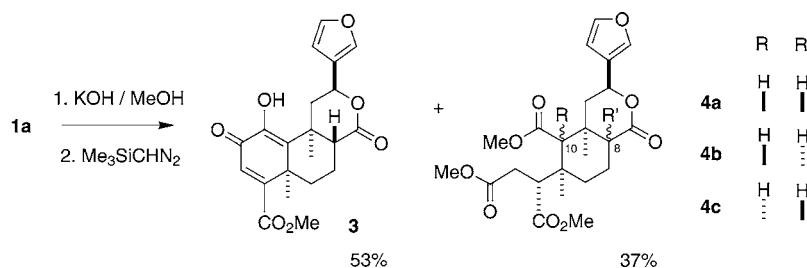
(5) Chavkin, C.; Sud, S.; Jin, W.; Stewart, J.; Zjawiony, J. K.; Siebert, D. J.; Toth, B. A.; Hufeisen, S. J.; Roth, B. L. *J. Pharmacol. Exp. Ther.* **2004**, *308*, 1197–1203.

(6) Harding, W. W.; Tidgewell, K.; Byrd, N.; Cobb, H.; Dersch, C. M.; Butelman, E. R.; Rothman, R. B.; Prisinzano, T. E. *J. Med. Chem.* **2005**, *48*, 4765–4771.

(7) Lee, D. Y.; Ma, Z.; Liu-Chen, L.-Y.; Wang, Y.; Chen, Y.; Carlezon, W. A.; Cohen, B. *Bioorg. Med. Chem.* **2005**, *13*, 5635–5639.

(8) Lee, D. Y.; Karnati, V. V.; He, M.; Liu-Chen, L.-Y.; Kondareti, L.; Ma, Z.; Wang, Y.; Chen, Y.; Béguin, C.; Carlezon, W. A.; Cohen, B. *Bioorg. Med. Chem. Lett.* **2005**, *15*, 3744–3747.

SCHEME 1



the furan ring¹² or the C-18 ester⁹ greatly reduce binding affinity. Most work, however, has been devoted to modification of the acetoxy function. More hindered esters show greatly reduced affinity at the KOR.^{4–6,8} The deacetyl compound salvinorin B (**1b**)¹³ also shows little⁸ or no⁵ affinity. Nonetheless, the acyloxy group is not essential for activity. Some notable examples are the ethyl ether **1c**,⁴ which displays comparable affinity at the KOR to **1a**, and even more remarkably the methoxy-methyl ether **1d**,⁸ which exhibits substantially increased (sub-nanomolar) affinity and potency. Another surprise is the benzoate **1e**,⁶ which is a potent μ -opioid receptor agonist. Some of these compounds also exhibit antagonist activity.^{10,12} Complementing this work, site-directed mutagenesis suggests that **1a** and analogues activate the KOR via different residues than conventional ligands.¹¹ That such a small body of work should generate so many noteworthy results establishes **1a** as a valuable lead for the study of opioid receptors and for the development of new ligands.

Results and Discussion

For the purposes of our derivative work, we needed to cleave the methyl ester. While searching for a suitable method, we treated **1a** with 1 M KOH in MeOH. To our surprise, the major product, found in the neutral fraction, was enedione **3** (Scheme 1). The ¹H spectrum showed two new singlets at δ 6.91 and 6.99 ppm. The peak at 6.91 showed no COSY or HMQC cross-peak and exchanged with D₂O. Such strongly deshielded exchangeable peaks are typical of cyclic α -diones, whose enol tautomers are stabilized by internal H-bonds.¹⁴ Consistent with this, the compound exhibited strong IR absorptions at 3373 and 1651 cm⁻¹ (OH and enol C=C). The structure was further elucidated by analysis of the HMBC spectrum. The quaternary C-10 peak, located unambiguously by its correlations to the H-19 and 20 methyls, showed a correlation to the enolic proton, placing the enol at C-1 and the ketone at C-2. The vinylic H-3 peak showed the

expected correlations to C-1, -4, -5, and -18 (see Figure 1). UV absorptions at 215, 249, and 324 nm confirmed

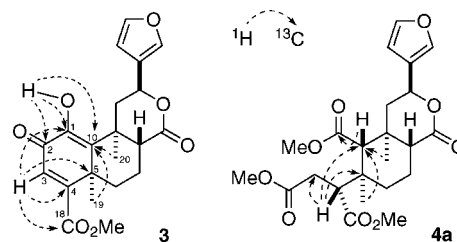


FIGURE 1. Key HMBC correlations of **3** and **4a**.

an extended π system (compare **9a**:¹⁵ 208 nm). HRESIMS confirmed the molecular formula. The remainder of the structure, unchanged from the salvinorins, was fully elucidated and assigned by NMR experiments (DEPT, COSY, HMQC, HMBC, and NOE). The H-12 coupling constants were closer to those of 8-*epi*-**1a**¹⁰ than of **1a**, suggesting that epimerization at C-8 may have occurred (as is typical for salvinorins and analogues under basic conditions).¹⁰ However, the β configuration of H-8 was evidenced by a diaxial coupling constant (9.7 Hz); in addition, irradiation of H-12 gave an NOE enhancement of H-20. The structure of **3** thus established is remarkably similar to the recently isolated salvinorin G (**6**).⁷

The base-soluble fraction was difficult to analyze, smearing on TLC and giving a poorly resolved ¹H NMR spectrum. Surprisingly, at least eight peaks were apparent in the methoxy region. After methylation with Me₃-SiCHN₂,¹⁶ TLC showed only a single spot. ¹H NMR analysis, however, revealed three major compounds, which were separated with difficulty by HPLC. Baseline resolution was not achieved, necessitating repeated re-purification and poor recoveries. The major product was identified as 1,2-secotriester **4a** based on extensive NMR experiments. The H-10 singlet showed an HMBC correlation to the new C-1 ester carbonyl (Figure 1). H-4 showed correlations to C-3, -5, and -10 and formed an isolated spin system with the two deshielded H-3 peaks. This confirmed the location of the new methyl esters at C-1 and -2, although the three esters were not sufficiently resolved in the 2D spectra to allow individual assignment. The remaining NMR data was very similar to that of **1a**. The chemical shift and coupling constants of H-12 were nearly identical to those of **1a**, confirming the configuration at C-8. HRESIMS confirmed the molecular formula. The second major product was identified as the

(9) Lee, D. Y.; He, M.; Kondaveti, L.; Liu-Chen, L. Y.; Ma, Z.; Wang, Y.; Chen, Y.; Li, J. G.; Béguin, C.; Carlezon, W. A.; Cohen, B. *Bioorg. Med. Chem. Lett.* **2005**, *15*, 4169–4173.

(10) Munro, T. A.; Rizzacasa, M. A.; Roth, B. L.; Toth, B. A.; Yan, F. *J. Med. Chem.* **2005**, *48*, 345–348.

(11) Yan, F.; Mosier, P. D.; Westkaemper, R. B.; Stewart, J.; Zjawiony, J. K.; Vortherms, T. A.; Sheffler, D. J.; Roth, B. L. *Biochemistry* **2005**, *44*, 8643–8651.

(12) Harding, W. W.; Tidgewell, K.; Schmidt, M.; Shah, K.; Dersch, C. M.; Snyder, J.; Parrish, D.; Deschamps, J. R.; Rothman, R. B.; Prisinzano, T. E. *Org. Lett.* **2005**, *7*, 3017–3020.

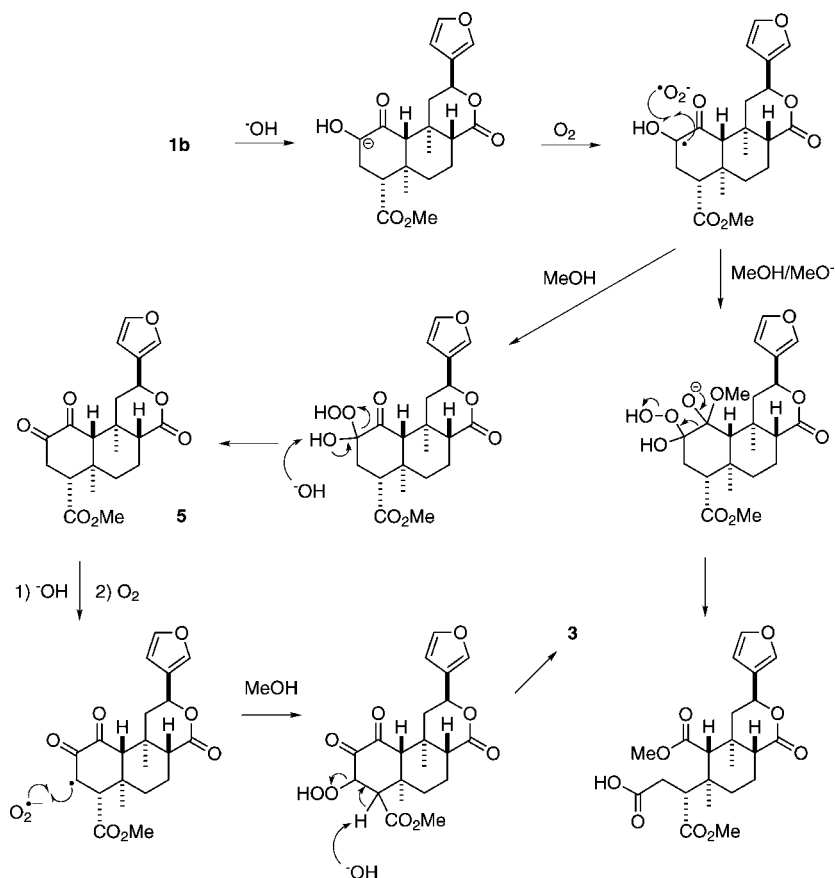
(13) Valdés, L. J. J.; Butler, W. M.; Hatfield, G. M.; Paul, A. G.; Koreeda, M. *J. Org. Chem.* **1984**, *49*, 4716–4720.

(14) Silverstein, R. M.; Webster, F. X.; Kiemle, D. *Spectrometric Identification of Organic Compounds*, 7th ed.; Wiley: New York, 2005; p 153.

(15) Valdés, L. J. J.; Chang, H. M.; Visger, D. C.; Koreeda, M. *Org. Lett.* **2001**, *3*, 3935–3937.

(16) Presser, A.; Huefner, A. *Monatsh. Chem.* **2004**, *135*, 1015–1022.

SCHEME 2. Proposed Mechanism of the Autoxidation



8-epimer **4b** on the basis of the shifts and coupling constants of H-8 and -12 (nearly identical to those of 8-*epi*-**1a**).¹⁰ Assignment of the remaining data was straightforward. 2D NMR showed the same correlations as **4a**; HRESIMS again confirmed the molecular formula. Interestingly, although **4a** and **4b** cospotted by TLC, they gave different colors with vanillin/ H_2SO_4 in EtOH. After development with a heat gun and several minutes' cooling, **4a** gave a pink/purple color, while **4b** appeared blue. Similar colors were observed for salvinorins A–E and several derivatives. In all pairs other than **4a/4b**, the 8-epimer gave a higher R_f in Et₂O or EtOAc/petroleum ether. Given the tendency for salvinorins to epimerize at C-8 under basic conditions, this information should prove useful for future derivative work.

The third (minor) compound decomposed in CDCl_3 before characterization was completed, but was tentatively assigned as **4c**. HRESIMS established that the compound was also an isomer of **4a**, and the appearance of the same couplings in the COSY spectrum suggested another stereoisomer. The coupling constants of H-8 and -12 established that the C-ring configurations matched those of **4a**. Indeed, all of the coupling constants determined were close to those in **4a**, whereas many chemical shifts showed large changes. This implied a change in the electronic environment of the coupling protons, without a change in their configuration. The most plausible candidate structure was therefore the 10-epimer **4c**, since H-10 is not coupled. Placing a large substituent in an axial configuration would be expected to affect the conformation of both remaining rings and, hence, the chemical shifts around those rings. By con-

trast, inversion at C-4 would not be expected to dramatically alter the conformations of the rings but would be expected to alter the coupling constants with the H-3 protons. These couplings were scarcely changed, while the chemical shifts of H-4, -7, -8, -10, -11, and -12 (but not H-3) were dramatically altered. Thus, **4c** is the more plausible structure. The particularly large change at H-4, shifted downfield by 0.83 ppm, might be due to falling within the deshielding region of the C-1 carbonyl. Interestingly, Brown found that when **1a** was refluxed with KCN in CD_3OD , deuterium exchange occurred at H-2, -8, and -10 but not H-4.¹⁷ In the absence of NOE data, however, the proposed structure **4c** must remain tentative.

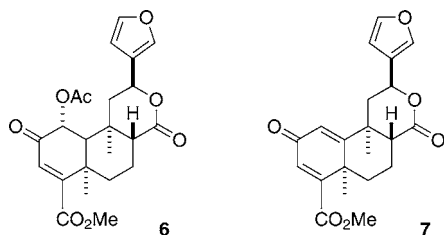
Our results conflict with recently published reports. Tidgewell et al.¹⁸ reported that heating **1a** with NaOH in MeOH caused cleavage of the methyl ester and opening of the lactone, without giving further detail. Since lactone hydrolysis would be reversed upon neutralization, we interpret this as methanolysis. Presumably, ester cleavage was inferred from the formation of a base-soluble fraction, and lactone methanolysis from the methoxy peaks in the ^1H NMR spectrum. As shown above, however, the acidic fraction and its methoxy peaks result from cleavage of the α -hydroxy ketone. Refluxing

(17) Brown, L. The Stereocontrolled Synthesis of Optically Active Vitamin E Side Chains. II. Benzoyl Triflate and its Application in the Determination of the Absolute Configuration of Divinorin A and B, and Terrecyclic Acid. Ph.D. Thesis, University of Michigan, Ann Arbor, MI, 1984; pp 82, 91.

(18) Tidgewell, K.; Harding, W. W.; Schmidt, M.; Holden, K. G.; Murry, D. J.; Prisinzano, T. E. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 5099–5102.

the 1-hydroxy derivative **8a**¹³ in KOH/MeOH for 30 min resulted only in epimerization at C-8, confirming that neither ester cleavage nor methanolysis occur under these conditions. More recently, Lee et al. treated **1a** with Ba(OH)₂ in MeOH. The ¹H and ¹³C NMR data of the product are nearly identical to **3**, apart from the omission of the multiplet at δ 1.77–1.67.⁸ On the basis of NMR analysis, they propose the dienone structure **7**, which is not consistent with the additional data presented here. Specifically, HRMS shows no molecular ion corresponding to C₂₁H₂₂O₆ (**7**), but a prominent peak corresponding to C₂₁H₂₂O₇ (**3**). Further, the singlet at 6.91 cannot be attached to C-1, since it exchanges with D₂O, has no HMQC cross-peak, and lacks the expected HMBC correlations to C-3, -5, and -9. A corresponding methine peak is also absent from the DEPT spectra. Moreover, deoxygenation would not be expected under these conditions.

By contrast, autoxidation of α -hydroxy ketones (acylols or α -ketols) to α -diones (diosphenols) under basic conditions is well-established.^{19–21} The reaction consumes 1 equiv of O₂, generating H₂O₂.²¹ While the autoxidation of unsubstituted ketones requires stronger bases such as *t*-BuOK, α -hydroxy ketones are more readily enolized, and the reaction proceeds with KOH.²⁰ A proposed mechanism, via saturated dione **5**, is shown in Scheme 2 (the initial deacetylation to **1b** is not shown). Dehydrogenation of **5** to form **3** is more unusual. While there have been several reports of dehydrogenation of 1,4-diones in alcoholic KOH,²² we have not located such a reaction involving a 4-ketoester. However, α -diones are much more readily enolized than unsubstituted ketones; in the case of **3**, no trace of the 1-keto tautomer was detectable by NMR. It is therefore plausible that **5** should be extremely reactive, and it is not surprising that this compound was not isolated. Consistent with this, Brown's attempts to prepare **5** via PCC oxidation of **1b** gave no isolable product.¹⁷ The alternate pathway, bond cleavage to give the secodiesters, has numerous precedents.^{20,23} We have based our proposed mechanism on the generally accepted formation of hydroperoxide intermediates,²⁰ although this mechanism has been disputed.²³ Tautomerization of the enolate or radical will give the regioisomeric diester, which along with epimerization at C-8 and -10 explains the numerous methoxy peaks in the ¹H NMR spectrum of the crude product.



The yield and selectivity of autoxidations of this type are subject to strong solvent effects.²⁰ We therefore

performed the reaction in EtOH, *i*-PrOH, and *t*-BuOH. The resulting neutral and acidic fractions were noticeably more complex. In each case, **3** was contaminated by inseparable impurities (presumably including the 8-epimer); the original selection of MeOH thus proved fortuitous. The reaction proceeded with only traces of oxygen, even when performed under N₂ in MeOH pre-saturated with N₂. This is again typical.^{20,23} Nonetheless, we found the reaction faster and more consistent when the solution was saturated with O₂. Another useful refinement was the use of dilute KOH rather than NaHCO₃ to extract the extremely hydrophobic diesters during work-up.

The new compounds **3** and **4a** were screened for binding affinity at cloned opioid receptors *in vitro*, as previously described.¹⁰ Compound **3** was inactive at the KOR ($K_i > 10 \mu\text{M}$), as Lee et al. reported for **7**.⁸ Surprisingly, **4a** showed weak affinity at the KOR ($K_i = 2.9 \pm 0.4 \mu\text{M}$). Both compounds were inactive at δ and μ subtypes. The result for **4a** provides further evidence that the 2-acyloxy function in **1a** is not essential for binding, but that modifying this function usually reduces affinity. In light of these findings, we also screened divinorins A–C (**2a–c**),²⁴ which we had previously isolated from *S. divinorum*. These compounds showed no affinity at κ , δ , or μ subtypes ($K_i > 10 \mu\text{M}$). Lee et al. also found **2c** to be inactive at the KOR.⁷ Intriguingly, however, the recently isolated divinorin D (**2d**)⁷ showed weak affinity ($K_i = 230 \text{ nM}$ vs 1.0 nM for **1a**). Thus, either of the A or C rings can be cleaved without total loss of affinity. Apart from this greater conformational freedom, **2d** not only lacks the 2-acetoxy function but also possesses a 1 α -hydroxy group, which drastically reduces activity in analogues of **1a**.¹⁰ The structure–activity relationships of this compound are thus markedly different from those of **1a**. Given that its deacetyl analogues **2b** and **2e**⁷ are inactive, perhaps the 17-acetoxy function substitutes for the furan ring in binding. However, **2c**, which also possesses this function, is inactive. Further exploration of this productive region of chemical space is clearly warranted.

Given the unexpected installation of the 3,4 double bond in **3**, we thought the compound might provide a route to diol **9d**. This would then give access to salvinorins C (**9a**),¹⁵ D (**9b**), and E (**9c**),²⁵ which occur in *S. divinorum* in much lower levels than **1a**. However, NaBH₄ in EtOH/CH₂Cl₂ resulted in conjugate addition and epimerization, giving the known 8-*epi*-diol **8b**¹⁵ in low yield (Scheme 3). Attempted reduction with NaBH₄–CeCl₃ in MeOH²⁶ (with or without sonication)²⁷ was also unsuccessful, giving a complex mixture whose unstable major components retained the characteristic enedione peaks at δ 6.8 and 7.0 ppm (these products cospotted with the starting material, making the reaction difficult to follow, but gave a darker purple with vanillin). Enolized α -diones form complexes with a variety of metal salts such as FeCl₃;²⁸ it appears likely that such an enolic

(19) Caton, M. P. L.; Darnbrough, G.; Parker, T. *Tetrahedron Lett.* **1980**, 21, 1685–1686.

(20) Lack, R. E.; Ridley, A. B. *J. Chem. Soc., C* **1968**, 3017–3020.

(21) Weissberger, A.; Schwarze, W. *Liebigs Ann. Chem.* **1931**, 487, 53–61 and references therein.

(22) Dauben, W. G.; Boswell, G. A.; Templeton, W. *J. Org. Chem.* **1960**, 25, 1853–1855 and references therein.

(23) Slavikova, B.; Kasal, A.; Budesinsky, M. *Collect. Czech. Chem. Commun.* **1999**, 64, 1125–1134.

(24) Bigham, A. K.; Munro, T. A.; Rizzacasa, M. A.; Robins-Browne, R. M. *J. Nat. Prod.* **2003**, 66, 1242–1244.

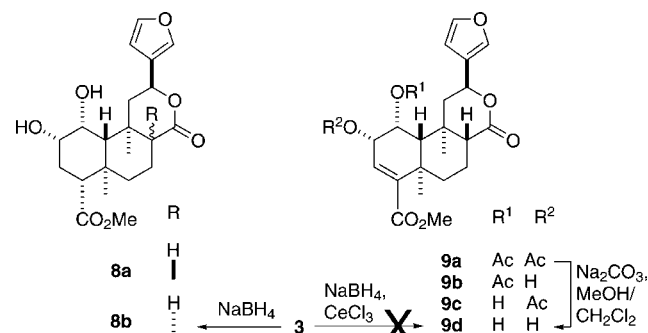
(25) Munro, T. A.; Rizzacasa, M. A. *J. Nat. Prod.* **2003**, 66, 703–705.

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

(27) Marchand, A. P.; Reddy, G. M. *Org. Prep. Proced. Int.* **1990**, 22, 528–531.

(28) Zsakó, J.; László, T. *Rev. Roum. Chim.* **1981**, 26, 237–243.

SCHEME 3. Attempted Reductions of 3



complex forms in preference to the desired ketone–solvent– Ce^{3+} complex,²⁶ and the reaction therefore does not follow the desired course. The only successful precedent we located for this reduction involved nonenolizable enediones.²⁹ It might be possible to prevent this problem by protection of the enol, but attempted TES protection was unsuccessful.

As an alternative route, the target diol **9d** was prepared by deacetylation of **9a**. Tidgewell et al.'s now-standard conditions for **1a** (Na_2CO_3 in minimal MeOH)¹⁸ gave almost exclusively the 8-epimer, but we found this could be prevented by addition of CH_2Cl_2 , affording **9d** from **9a** or **9b** in up to 86% yield. Reacetylation under standard conditions progressed slowly through intermediate **9b** and **9c** to give **9a**. While no one has yet

isolated **9d** from *S. divinorum*, it may be that the compound occurs in the plant in very low levels. This would be expected if its formation were the rate-limiting step on the path to **9a–c**. Alternatively, current isolation procedures may give poor recoveries. Indeed, we found that like **1b**, the compound precipitates when loaded on silica gel in most solvent systems. Stripping the column with MeOH/ CH_2Cl_2 was required to achieve satisfactory recovery.

Conclusions

In summary, we have identified the actual products of the treatment of **1a** with hydroxide in MeOH, resolving recent conflicting reports. One of these products, **4a**, shows mild affinity at the KOR, further elucidating the structure–activity relationships of **1a**. Finally, interconversion of salvinorins C–E (**9a–c**) with the novel diol **9d** provides further confirmation of the structure of these compounds.

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Supporting Information Available: Experimental details, characterization data, ^1H NMR spectra, and IUPAC International Chemical Identifiers (InChIs) of compounds **3**, **4a–c**, **8b**, and **9d**. This material is available free of charge via the Internet at <http://pubs.acs.org>.

JO051813E

(29) Rubin, Y.; Knobler, C.; Diederich, F. *J. Am. Chem. Soc.* **1990**, *112*, 1607–1617.

Autoxidation of Salvinorin A under Basic Conditions

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Supporting Information

Compound	Experimental	¹ H NMR spectrum
3	S2	S6
4a	S3	S7
4b	S3	S8
4c	S4	S9
8b	S4	S10
9a	S4	
9d	S4	S11

General Experimental Methods. NMR peaks assignments were based on HMQC, HMBC and COSY data. Stereochemical assignments (α vs β) were based on coupling constants where possible (peaks whose stereochemistry could not be unambiguously assigned on this basis are listed as “a” and “b”). Radioligand binding assays were performed as previously detailed,¹ using cloned opioid receptors stably expressed in HEK 293 cells, with [³H]diprenorphine (50 Ci/mmol, PerkinElmer Inc) as radioligand for all subtypes. IUPAC International Chemical Identifiers (InChIs)² were created using winChI version 1.³

Autoxidation of 1a. Oxygen was bubbled through a solution of KOH in MeOH (1 M, 2 mL) for 5 min. This was then added to a solution of **1a** (31.7 mg, 73.3 μ mol) in minimal CH₂Cl₂ ($\approx$ 250 μ L), and oxygen bubbled through the resulting orange solution for 20 minutes, after which time TLC (Et₂O) showed no **1a** (R_f = 0.54) or **1b** (R_f = 0.42). 10% HCl was added dropwise until an opaque white colour persisted. The solution was diluted in 0.05 M NaOH and extracted into CH₂Cl₂. Drying (MgSO₄) and evaporation *in vacuo* gave enedione **3** as a resin (14.9 mg, 53%). The aqueous layer was acidified with 10% HCl until opaque white, then extracted into CH₂Cl₂, which was dried (MgSO₄) and filtered. MeOH (10 mL) and Me₃SiCHN₂ in Et₂O (2.0 M, 200 μ L) were added. The yellow solution was stirred for 30 min, then evaporated *in vacuo*. Flash column chromatography on silica gel (50% EtOAc/petrol) gave a mixture of the seco triesters **4a**, **4b** and **4c** (12.2 mg, 37%) which cospotted by TLC (R_f = 0.45). Repeated HPLC (36% EtOAc/petrol) on 5 μ m silica gave a compound which was tentatively assigned as **4c**. Further elution gave **4a**, followed by **4b**.

Deacetyl-1,10-didehydrosalvinorin G (**3**).

TLC (Et₂O): R_f = 0.69;

$[\alpha]_D^{14}$ +58 (c 0.7, CH₂Cl₂);

UV (CH₃CN): $\lambda_{\max}$ (log ϵ) 215 (4.30), 249 (3.77), 324 (3.57) nm;

FTIR (film): $\bar{\nu}_{\max}$ 3373, 3149, 2955, 1726, 1651, 1601, 1504, 1456, 1435, 1408, 1380, 1331, 1244, 1203, 1162, 1068, 1022, 911, 875, 793, 736, 703 cm⁻¹;

¹H NMR (400 MHz, CDCl₃): δ 7.48 (1H, br s, H-16), 7.41 (1H, t, J = 1.8 Hz, H-15), 6.99 (1H, s, H-3), 6.91 (1H, s, OH), 6.42 (1H, dd, J = 2.0, 0.9 Hz, H-14), 5.44 (1H, dd, J = 12.3, 2.9 Hz, H-12), 3.85 (3H, s, CO₂CH₃), 3.11 (1H, ddd, J = 14.8, 2.9, 1.2 Hz, H-11 α), 2.98 (1H, ddd, J = 9.7, 5.4, 1.2 Hz, H-8), 2.53 (1H, ddd, J = 14.1, 7.7, 6.3 Hz, H-6a), 2.24 (1H, dtd, J = 14.6, 7.4, 5.3 Hz, H-7 β), 2.02 (1H, dd, J = 15.0, 12.2 Hz, H-11 β), 1.98 (1H, dddd, J = 14.3, 9.7, 7.7, 6.4 Hz, H-7 α), 1.77-1.67 (1H, m, H-6b), 1.72 (3H, s, H-19), 1.67 (3H, s, H-20);

¹³C NMR (100 MHz, CDCl₃): δ 180.7 (C, C-2), 173.2 (C, C-17), 165.4 (C, C-18), 157.5 (C, C-4), 145.0 (C, C-1), 143.6 (CH, C-15), 140.0 (C, C-10), 139.6 (CH, C-16), 128.2 (CH, C-3), 124.5 (C, C-13), 108.4 (CH, C-14), 70.9 (CH, C-12), 52.6 (CH₃, CO₂CH₃), 44.9 (CH, C-8), 42.3 (C, C-5), 37.7 (C, C-9), 36.8 (CH₂, C-11), 30.3 (CH₃, C-19), 28.3 (CH₂, C-6), 24.4 (CH₃, C-20), 21.9 (CH₂, C-7);

HRESIMS [M + Na]⁺ m/z 409.1265 (calcd for C₂₁H₂₂O₇Na⁺, 409.1258).

1-Methoxy-2-*O*-methyl-2-oxo-1,2-secosalvinorin B (4a).

HPLC (36% EtOAc/ petrol): $t_R = 17.4$ min;

$[\alpha]_D^{24} +6$ (c 0.1, CH_2Cl_2);

FTIR (film): $\bar{\nu}_{\text{max}}$ 2953, 1732, 1506, 1436, 1393, 1373, 1261, 1226, 1202, 1163, 1137, 1079, 1025, 875, 792 cm^{-1} ;

^1H NMR (500 MHz, CDCl_3): δ 7.44 (1H, br s, H-16), 7.43 (1H, t, $J = 1.9$ Hz, H-15), 6.41 (1H, m, H-14), 5.46 (1H, dd, $J = 11.6, 5.4$ Hz, H-12), 3.69 (3H, s, CO_2CH_3), 3.68 (3H, s, CO_2CH_3), 3.65 (3H, s, CO_2CH_3), 2.82 (1H, dd, $J = 15.9, 11.8$ Hz, H-3a), 2.72 (1H, dd, $J = 11.8, 2.0$ Hz, H-4), 2.43 (1H, dd, $J = 15.9, 2.0$ Hz, H-3b), 2.25 (1H, s, H-10), 2.17-2.08 (2H, m, H-7 β , 8), 2.01 (1H, dd, $J = 13.7, 5.5$ Hz, H-11 α), 1.84 (1H, ddd, $J = 13.7, 12.0, 0.8$ Hz, H-11 β), 1.74-1.63 (2H, m, H-6a, 7 α), 1.52-1.48 (1H, m, H-6b), 1.38 (3H, s, H-19), 1.30 (3H, s, H-20);

^{13}C NMR (100 MHz, CDCl_3): δ 174.0 (C, C-2/18), 172.5 (C, C-2/18), 171.7 (C, C-1), 171.0 (C, C-17), 143.8 (CH, C-15), 139.6 (CH, C-16), 125.1 (C, C-13), 108.5 (CH, C-14), 71.6 (CH, C-12), 58.6 (CH, C-10), 52.0 (CH_3 , CO_2CH_3), 51.9 (CH, C-4), 51.7 (CH_3 , CO_2CH_3), 51.4 (CH_3 , CO_2CH_3), 50.5 (CH, C-8), 44.6 (CH_2 , C-11), 38.7 (C, C-5), 36.9 (C, C-9), 35.1 (CH_2 , C-6), 32.4 (CH_2 , C-3), 18.8 (CH_3 , C-19), 18.2 (CH_2 , C-7), 15.6 (CH_3 , C-20);

HRESIMS $[\text{M} + \text{Na}]^+$ m/z 473.1783 (calcd for $\text{C}_{23}\text{H}_{30}\text{O}_9\text{Na}^+$, 473.1782).

8-*epi*-1-Methoxy-2-*O*-methyl-2-oxo-1,2-secosalvinorin B (4b).

HPLC (36% EtOAc/petrol): $t_R = 18.3$ min;

$[\alpha]_D^{23} +4$ (c 0.4, CH_2Cl_2);

FTIR (film): $\bar{\nu}_{\text{max}}$ 2953, 1733, 1504, 1436, 1392, 1361, 1247, 1200, 1166, 1091, 1062, 1025, 998, 968, 909, 875, 849, 794, 735 cm^{-1} ;

^1H NMR (500 MHz, CDCl_3): δ 7.47 (1H, br s, H-16), 7.42 (1H, t, $J = 1.8$ Hz, H-15), 6.42 (1H, dd, $J = 1.8, 0.7$ Hz, H-14), 5.26 (1H, dd, $J = 12.0, 2.1$ Hz, H-12), 3.67 (3H, s, CO_2CH_3), 3.66 (3H, s, CO_2CH_3), 3.64 (3H, s, CO_2CH_3), 2.84 (1H, dd, $J = 15.9, 11.9$ Hz, H-3a), 2.76 (1H, dd, $J = 11.9, 1.6$ Hz, H-4), 2.53 (1H, dd, $J = 4.6, 2.8$, H-8), 2.39 (1H, dd, $J = 16.0, 1.8$ Hz, H-3b), 2.28 (1H, br s, H-10), 2.19-2.14 (1H, m, H-7 β), 2.02 (1H, dd, $J = 14.5, 11.9$ Hz, H-11 β), 1.94-1.86 (2H, m, H-6 β , 7 α), 1.80 (1H, dd, $J = 14.4, 2.1$ Hz, H-11 α), 1.48 (3H, s, H-20), 1.32-1.27 (1H, m, H-6 α), 1.29 (3H, s, H-19);

^{13}C NMR (125 MHz, CDCl_3): δ 173.8 (C, C-18), 173.2 (C, C-17), 172.6 (C, C-2), 172.2 (C, C-1), 143.7 (CH, C-15), 139.7 (CH, C-16), 123.6 (C, C-13), 108.4 (CH, C-14), 69.8 (CH, C-12), 57.8 (CH, C-10), 51.9 (CH_3 , CO_2CH_3), 51.7 (CH_3 , CO_2CH_3), 51.7 (CH, C-4), 51.5 (CH_3 , CO_2CH_3), 46.5 (CH_2 , C-11), 44.4 (CH, C-8), 38.5 (C, C-5), 35.8 (C, C-9), 32.2 (CH_2 , C-3), 31.6 (CH_2 , C-6), 25.1 (CH_3 , C-20), 18.2 (CH_3 , C-19), 18.2 (CH_2 , C-7);

HRESIMS $[\text{M} + \text{Na}]^+$ m/z 473.1780 (calcd for $\text{C}_{23}\text{H}_{30}\text{O}_9\text{Na}^+$, 473.1782).

10-*epi*-1-Methoxy-2-*O*-methyl-2-oxo-1,2-secosalvinorin B (4c).

HPLC (36% EtOAc/petrol): t_R = 17.0 min;

^1H NMR (400 MHz, CDCl_3): δ 7.46 (1H, br s, H-16), 7.42 (1H, t, J = 1.8 Hz, H-15), 6.42 (1H, dd, J = 1.9, 0.9 Hz, H-14), 5.19 (1H, dd, J = 11.7, 5.4 Hz, H-12), 3.72 (3H, s, CO_2CH_3), 3.67 (3H, s, CO_2CH_3), 3.65 (3H, s, CO_2CH_3), 3.55 (1H, dd, J = 12.3, 2.9 Hz, H-4), 2.80 (1H, dd, J = 16.6, 12.3 Hz, H-3a), 2.59 (1H, dd, J = 14.9, 5.5 Hz, H-11 α), 2.56 (1H, dd, J = 16.6, 2.9 Hz, H-3b), 2.53 (1H, br s, H-10), 2.39 (1H, dd, J = 12.6, 3.7 Hz, H-8), 1.94-1.83 (1H, m, H-7 α), 1.86 (1H, dd, J = 14.9, 11.8 Hz, H-11 β), 1.78 (1H, dq, J = 14.4, 3.8 Hz, H-7 β), 1.60-1.41 (2H, m, H-6 [obscured by H_2O]), 1.41 (3H, s, H-19), 1.20 (3H, s, H-20);

HRESIMS $[\text{M} + \text{Na}]^+$ m/z 473.1781 (calcd for $\text{C}_{23}\text{H}_{30}\text{O}_9\text{Na}^+$, 473.1782).

(4*R*,8*S*)-Dideacetyl-3,4-dihydrosalvinorin C (8b). Enedione **3** (41.3 mg, 107 μmol) and NaBH_4 (10 mg, 264 μmol) were dissolved in CH_2Cl_2 (500 μL), followed by EtOH (2 mL), and stirred under Ar at 40 °C. The initial orange colour faded to faint yellow within 1 h. After 4 h, TLC (Et_2O) showed no **3** (R_f = 0.69). The solution was cooled to 0 °C, and 0.5% $\text{H}_2\text{SO}_4/\text{MeOH}$ added dropwise until effervescence ceased. The solution was concentrated to $\approx$ 500 μL *in vacuo*, then partitioned between brine (acidified with 10% HCl) and CH_2Cl_2 . Drying (MgSO_4), evaporation *in vacuo* and flash column chromatography on silica gel (70-100% Et_2O /petrol) gave **8b** (15.7 mg, 37%);

TLC (Et_2O): R_f = 0.53;

^1H NMR (400 MHz, CDCl_3): δ 7.48 (1H, dt, J = 1.7, 0.9 Hz, H-16), 7.42 (1H, t, J = 1.7 Hz, H-15), 6.41 (1H, dd, J = 1.9, 0.9 Hz, H-14), 5.29 (1H, dd, J = 11.7, 1.5 Hz, H-12), 4.07 (1H, br s, H-1), 3.65 (3H, s, CO_2CH_3), 3.54 (1H, ddd, J = 11.1, 4.7, 3.2 Hz, H-2), 2.45 (1H, br d, J = 4.7 Hz, H-8), 2.23-2.10 (4H, m), 1.90 (1H, tdd, J = 14.4, 5.5, 4.0 Hz, H-7 α), 1.73-1.53 (m, obscured by H_2O & OH), 1.66 (3H, s, H-20), 1.32 (3H, s, H-19), 0.90 (1H, d, J = 1.6 Hz, H-10);

^1H NMR ($[\text{CD}_3]_2\text{CO}$) and ^{13}C NMR (CDCl_3) matched literature values.⁴

Salvinorin C (9a).

UV (CH_3CN): λ_{max} (log ε) 208 (4.10) nm.

^1H and ^{13}C NMR (CDCl_3) matched literature values.⁴

Dideacetylsalvinorin C (9d). To **9a** (5.8 mg, 12.2 μmol) and Na_2CO_3 (5.1 mg, 41.1 μmol) in CH_2Cl_2 (1 mL) was added MeOH (1 mL), and the solution stirred at rt for 2 h, when TLC (10% acetone/ CH_2Cl_2) showed considerable **9a** (R_f = 0.60). The solution was heated at 45 °C with a reflux condenser for a further 90 min, when TLC showed no **9a**. The solution was partitioned between brine (acidified with 10% HCl) and CH_2Cl_2 . Drying (MgSO_4), evaporation *in vacuo* and flash column chromatography on silica gel (33 - 50% EtOAc/petrol, then 25% MeOH/ CH_2Cl_2) gave **9d** as a resin (4.1 mg, 86%); TLC (10% acetone/ CH_2Cl_2): R_f = 0.18;

$[\alpha]_{\text{D}}^{18} +27$ (c 0.2, CH_2Cl_2);

FTIR (film): $\bar{\nu}_{\text{max}}$ 3456, 2951, 1714, 1504, 1435, 1379, 1314, 1229, 1177, 1144, 1075, 1049, 1027, 949, 875, 788, 736, 685 cm^{-1} ;

^1H NMR (400 MHz, CDCl_3): δ 7.43 (1H, m, H-16), 7.42 (1H, t, $J = 1.8$ Hz, H-15), 6.48 (1H, dd, $J = 2.5, 1.6$ Hz, H-4), 6.40 (1H, dd, $J = 1.9, 0.9$ Hz, H-14), 5.60 (1H, dd, $J = 11.1, 5.9$ Hz, H-12), 4.32 (1H, br d, $J = 5.1$ Hz, H-1), 4.28 (1H, dd, $J = 5.1, 2.4$ Hz, H-2), 3.73 (3H, s, CO_2CH_3), 2.49 (1H, dd, $J = 13.2, 6.0$ Hz, H-11 α), 2.50-2.45 (1H, m, H-6 α), 2.38 (1H, br d, $J = 2.1$ Hz, OH), 2.33 (1H, br d, $J = 5.9$ Hz, OH), 2.14-2.10 (1H, m, H-8), 2.09 (1H, dq, $J = 14.6, 3.6$ Hz, H-7 β), 1.82 (1H, dtd, $J = 15.0, 13.2, 3.3$ Hz, H-7 α), 1.70 (3H, s, H-19), 1.60 (1H, ddd, $J = 13.0, 11.1, 0.8$ Hz, H-11 β), 1.47 (3H, s, H-20), 1.22 (1H, d, $J = 1.0$ Hz, H-10), 1.16 (1H, tdd, $J = 13.3, 3.6, 0.9$ Hz, H-6 β);

^{13}C NMR (100 MHz, CDCl_3): δ 172.0 (C, C-17), 166.6 (C, C-18), 143.9 (CH, C-15), 142.2 (C, C-4), 139.3 (CH, C-16), 135.3 (CH, C-3), 125.8 (C, C-13), 108.4 (CH, C-14), 71.8 (CH, C-12), 69.6 (CH, C-2), 65.6 (CH, C-1), 54.1 (CH, C-10), 51.8 (CH, C-8), 51.7 (CH_3 , CO_2CH_3), 44.4 (CH_2 , C-11), 37.49 (C, C-5/9), 37.45 (C, C-5/9), 37.0 (CH_2 , C-6), 22.1 (CH_3 , C-19), 18.4 (CH_2 , C-7), 16.3 (CH_3 , C-20);

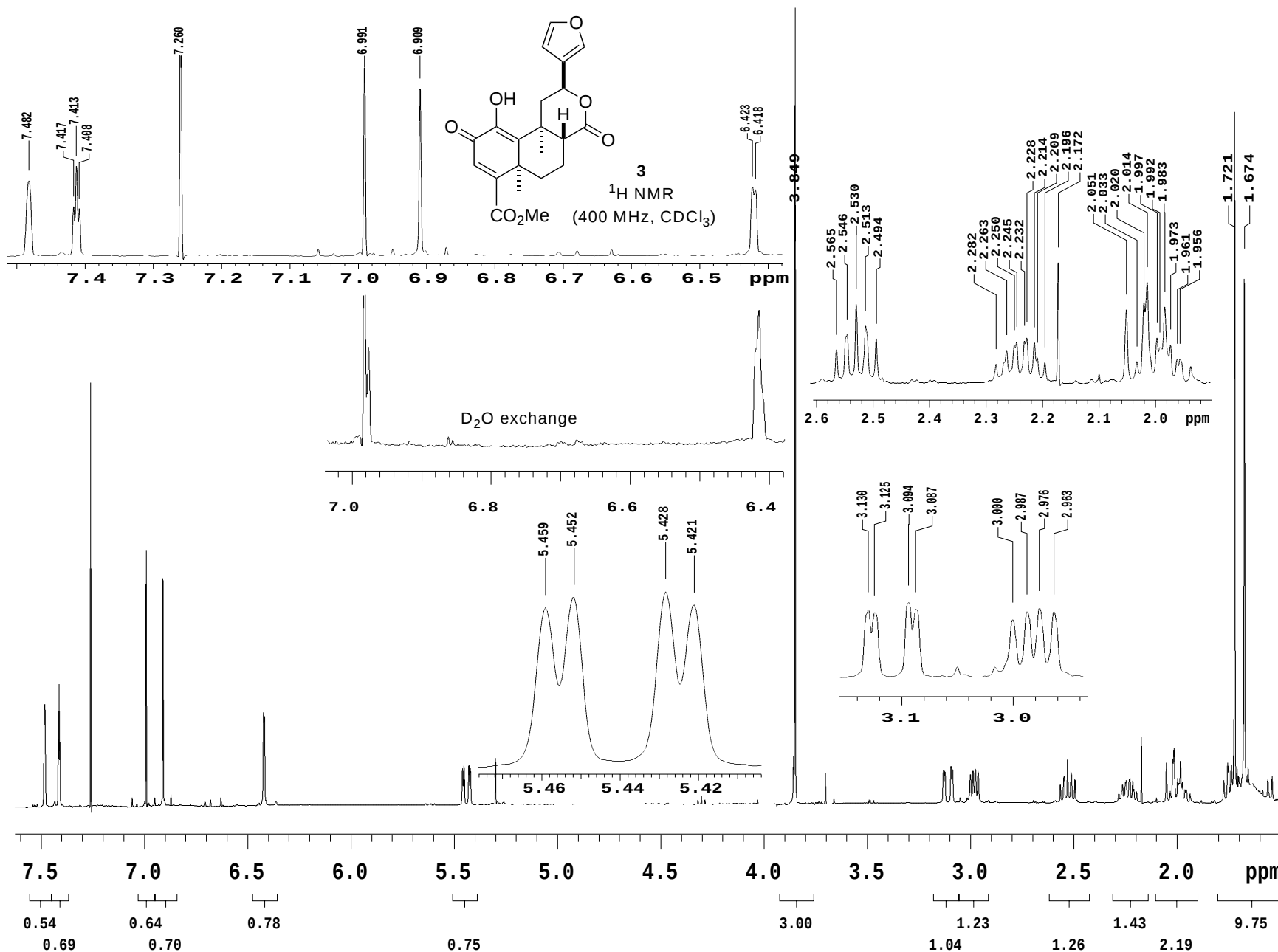
HRESIMS $[\text{M} + \text{Na}]^+$ m/z 413.1588 (calcd for $\text{C}_{21}\text{H}_{26}\text{O}_7\text{Na}^+$, 413.1571).

References

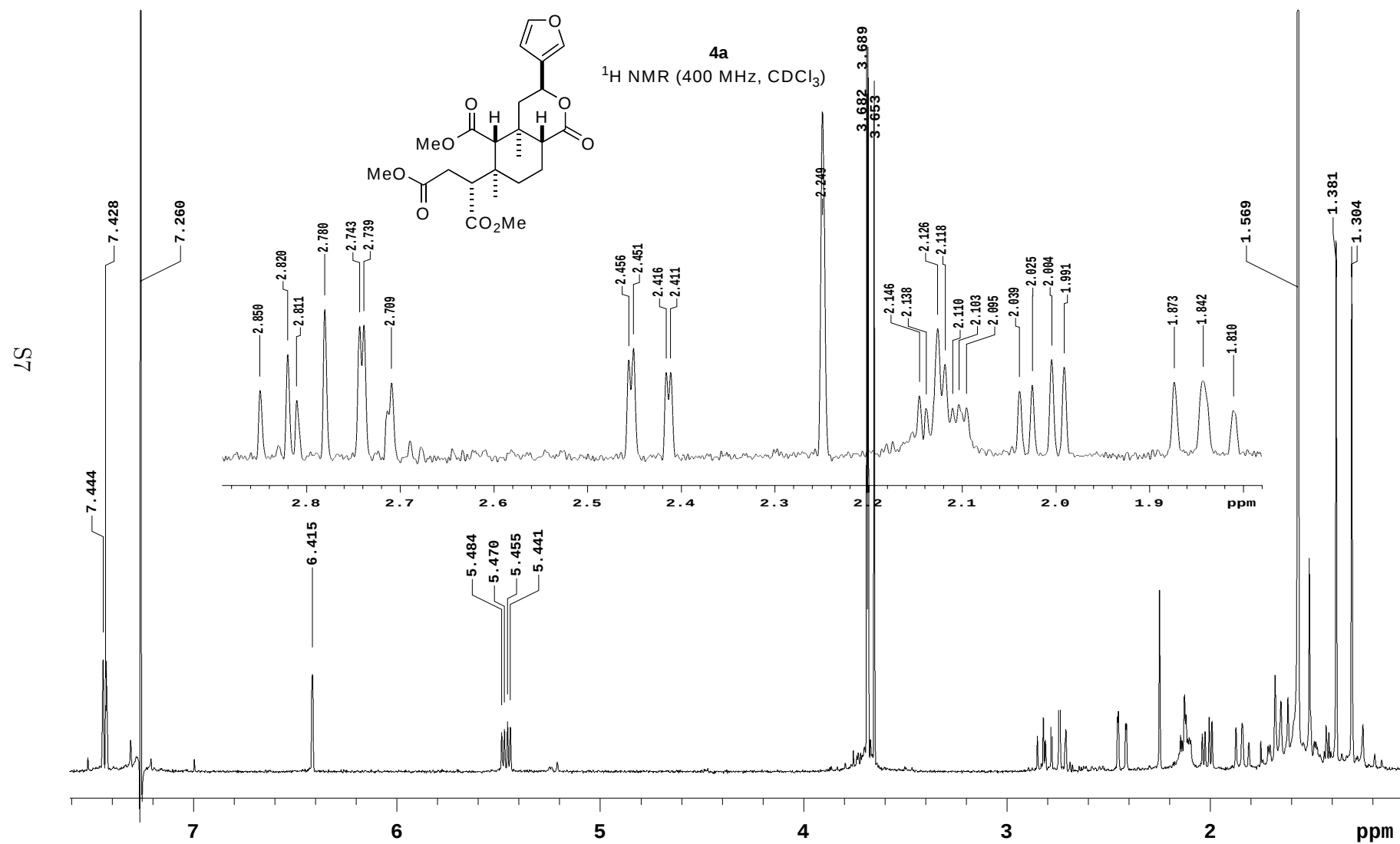
- [1] Munro, T. A.; Rizzacasa, M. A.; Roth, B. L.; Toth, B. A.; Yan, F. *J. Med. Chem.* **2005**, 48, 345-348.
- [2] Rovner, S. L. *Chem. Eng. News* **2005**, 83, 39-40.
- [3] <http://www.iupac.org/inchi> (accessed Sept. 2005).
- [4] Valdés, L. J. J.; Chang, H. M.; Visger, D. C.; Koreeda, M. *Org. Lett.* **2001**, 3, 3935-3937.

InChI=1/C21H22O7/c1-20-6-4-12-19(25)28-15(11-5-7-27-10-11)9-21(12,2)17(20)16(23)14(22)8-13(20)18(24)26-3/h5,7-8,10,12,15,23H,4,6,9H2,1-3H3/t12-,15-,20-,21-/m0/s1

9S

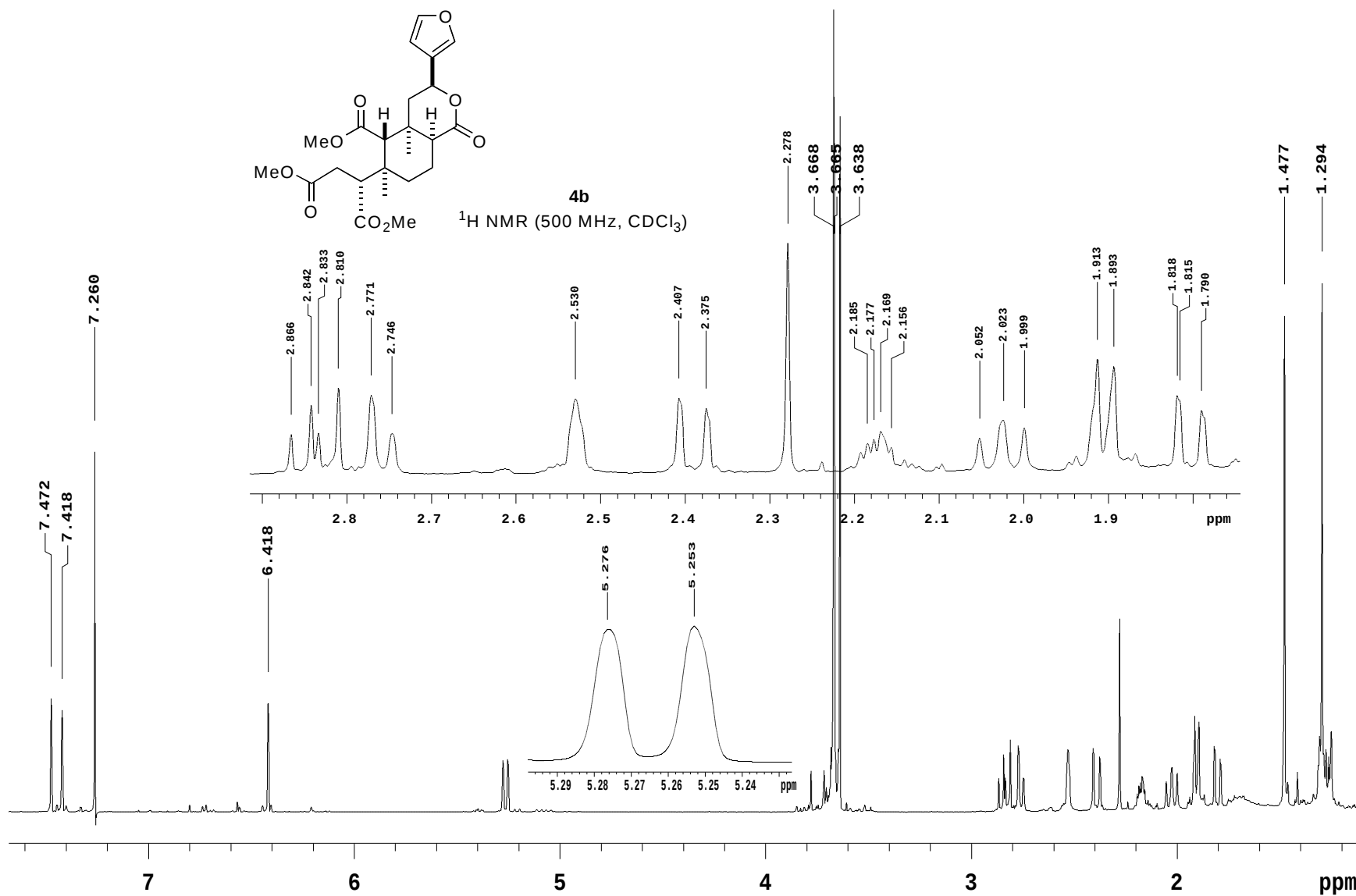


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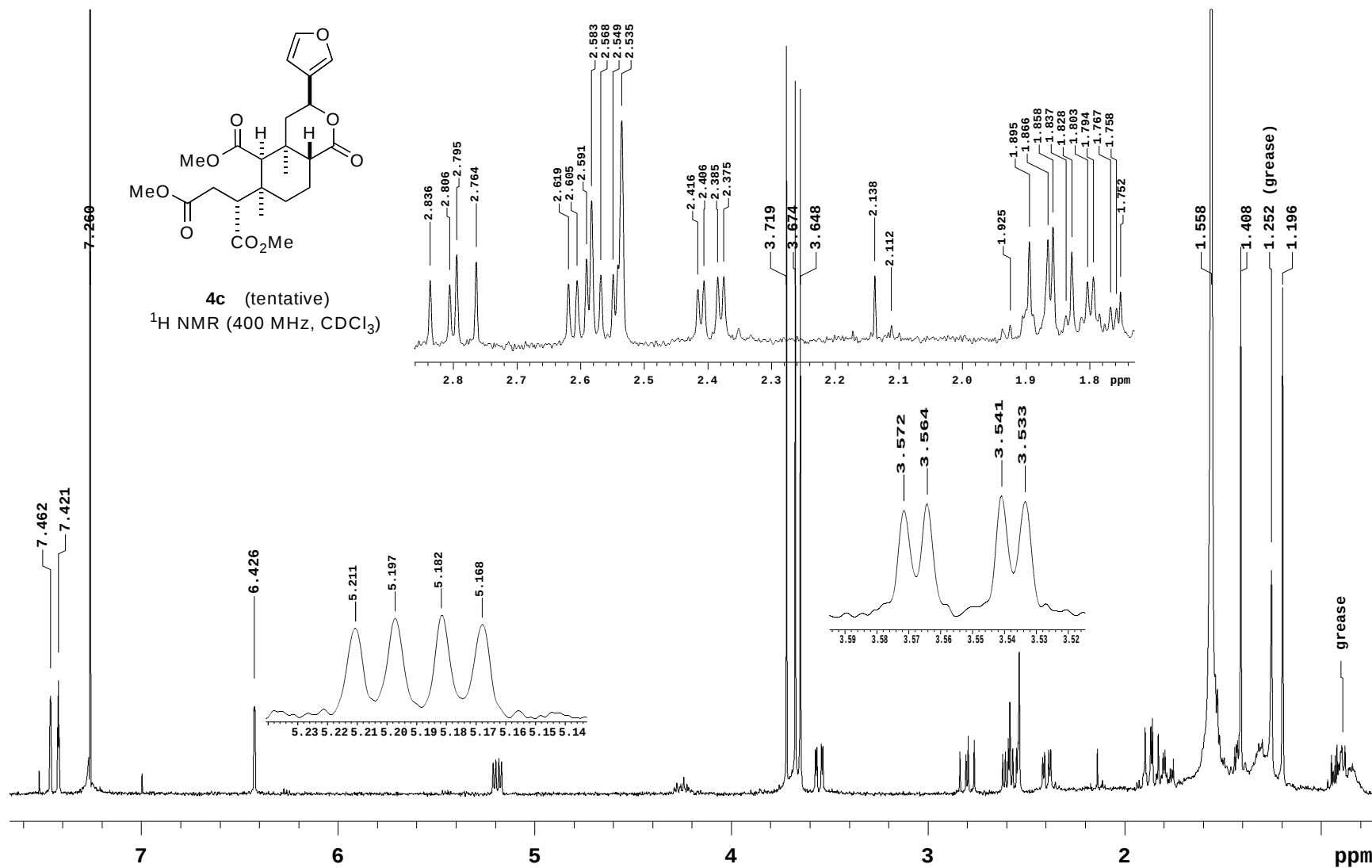
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85

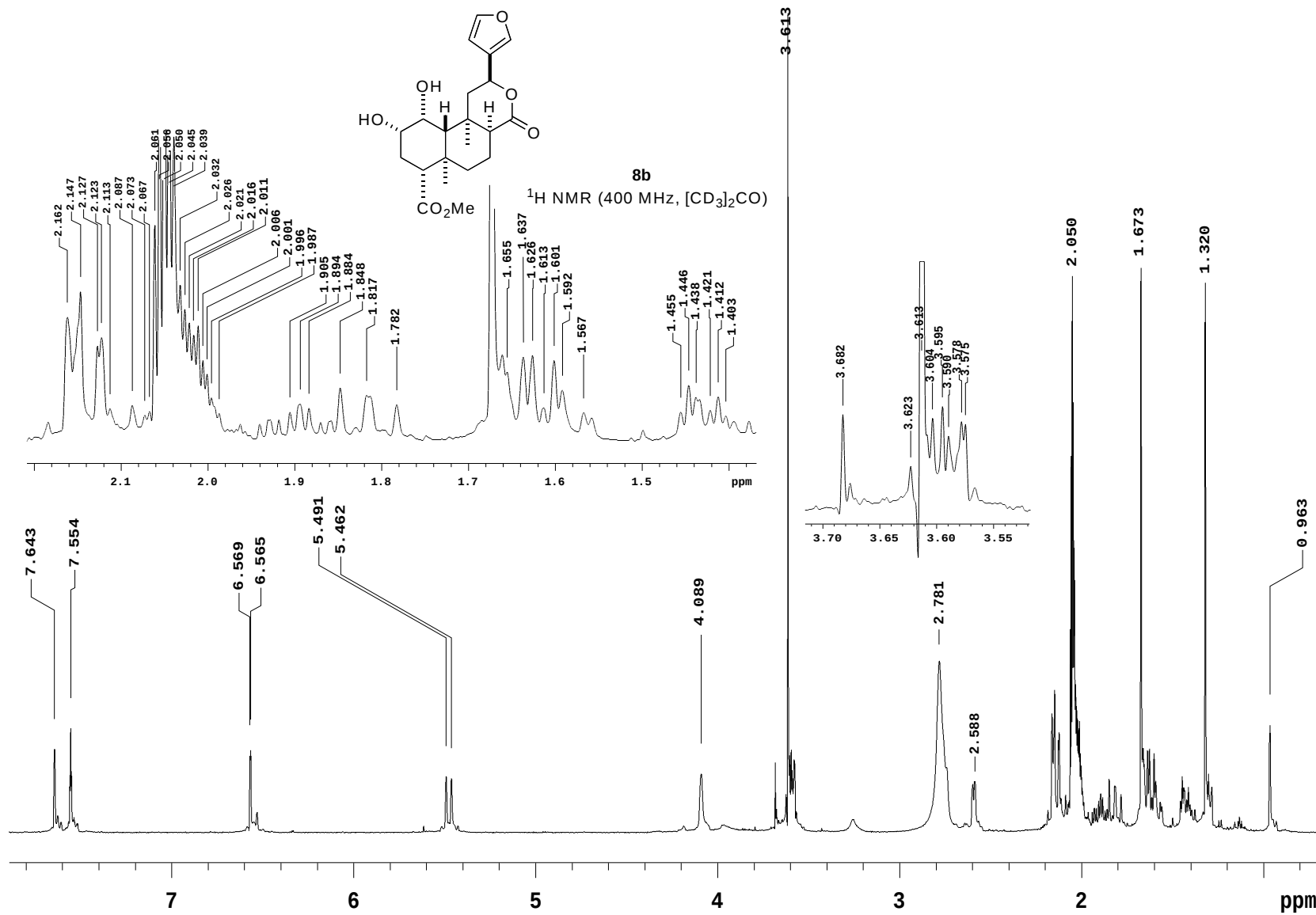


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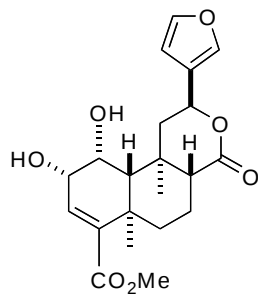
6S



InChI=1/C21H28O7/c1-20-6-4-12-19(25)28-15(11-5-7-27-10-11)9-21(12,2)17(20)16(23)14(22)8-13(20)18(24)26-3/h5,7,10,12-17,22-23H,4,6,8-9H2,1-3H3/t12-,13+,14+,15+,16+,17+,20+,21+/m1/s1



InChI=1/C21H26O7/c1-20-6-4-12-19(25)28-15(11-5-7-27-10-11)9-21(12,2)17(20)16(23)14(22)8-13(20)18(24)26-3/h5,7-8,10,12,14-17,22-23H,4,6,9H2,1-3H3/t12-,14-,15-,16-,17-,20-,21-/m0/s1



9d

^1H NMR (400 MHz, CDCl_3)

T1S

